From:	Cousins, Autumn EAO:EX
To:	Milne, Andrew EAO:EX; Parks, Chris EAO:EX
Subject:	FW: Avalanche Risk Zoning Report
Date:	Saturday, April 18, 2015 12:28:34 AM

Please discuss with me prior to sending to anyone.

Sent from my Windows Phone

From: Lorimer, Mike TRAN:EX
Sent: 2015-04-17 4:20 PM
To: Craven, Paul EAO:EX
Cc: Cousins, Autumn EAO:EX; Lorimer, Mike TRAN:EX
Subject: FW: Avalanche Risk Zoning Report

Good Morning Paul,

As per your request below, we have assessed the Dynamic avalanche report with regards to whether or not the report is consistent with what we would typically accept for review as part of a land use permit or authorization. I appreciate that your staff may have discussed aspects of this review with our Headquarters Manager Snow Avalanche Program, Mike Boissoneault, in the last few days. This response incorporates feedback from Mike and other staff members in the Ministry to respond to the questions in the scope of your original request.

The assessment methods described in the report are consistent with the methods used in other avalanche zoning assessments MOTI has accepted from engineering consultants who specialize in assessing avalanche risks. Furthermore, the approach to the preparation of this report would meet our Provincial Approving Officer (PAO) requirements for consideration in land use approvals.

Avalanche Risk Zoning reports must be prepared by a Qualified Professional and a Professional Engineer with expertise in the field of avalanche risk zone analysis. The inclusion and recommendation of conditions that would facilitate the safe development in these areas is consistent with reports we would receive from Qualified Professionals in this field.

MOTI has adopted the criteria set out by the Canadian Avalanche Association (CAA) for evaluation of avalanche risk zones completed by Qualified Professionals. These standards have also been adopted by most Regional Districts in BC and many jurisdictions throughout Canada for more than a decade. This report appears to utilize this criteria. The report identifies the required red/blue/white avalanche risk zones

Red Zone – no development
Blue Zone – minimal with restrictions on inhabited buildings, potential for further investigation
White Zone – No risk – no restrictions

With regards to some areas that the EAO may wish to follow-up on with the developer, I offer the following:

s.13

s.13

The report also recommends three conditions for operation of the Day Lodge in the Blue Zone. I understand from discussions with Autumn Cousins in your office that these conditions are likely part of the enforcement process should a determination of non-compliance be the result. If this is the case, I would suggest the following items for follow-up with the developer.

s.13

I hope that this is enough to help your office in moving through the review process for this file.
Thank you,

Mike Lorimer

Regional Director - Southern Interior Region

From: Craven, Paul EAO:EX
Sent: Thursday, April 2, 2015 10:23 AM
To: Lorimer, Mike TRAN:EX
Cc: Cousins, Autumn EAO:EX
Subject: Avalanche Risk Zoning Report

Mike,

I am writing to you to ask for the Ministry of Transportation and Infrastructure's assistance with our review of the attached ***Snow Avalanche Risk Zoning for a Day Lodge and Service Building for the Jumbo Glacier Resort*** prepared by Dynamic Avalanche Consulting Ltd.

Given your Ministry's role in seeking similar reports, we are looking for any advice on whether the report is consistent with what your Ministry would normally expect and accept.

In particular, we would appreciate any advice on questions or clarifications, if any, we way wish to ask the author. One area to focus on is the report's recommendation related to the use of the daylodge subject to three conditions.

We will be using this report to determine whether the construction of these buildings is in compliance with a condition in the environmental assessment certificate. For clarity, we do not require your Ministry to opine on the compliance status in your response.

We would appreciate it if you could review the report and get back to us early next week, if possible.

Many thanks,

Paul

From:	Cousins, Autumn EAO:EX
To:	Milne, Andrew EAO:EX
Cc:	Pizarro, Kirsten EAO:EX
Subject:	TRIM: FW: Avalanche Risk Zoning Report
Date:	Tuesday, April 7, 2015 7:30:38 AM

From: Lorimer, Mike TRAN:EX
Sent: Thursday, April 2, 2015 1:19 PM
To: Craven, Paul EAO:EX
Cc: Cousins, Autumn EAO:EX
Subject: RE: Avalanche Risk Zoning Report

Thanks Paul,

We would be happy to assist. I have sent this to my operational for review.

Mike Lorimer
Regional Director - Southern Interior Region

From: Craven, Paul EAO:EX
Sent: Thursday, April 2, 2015 10:23 AM
To: Lorimer, Mike TRAN:EX
Cc: Cousins, Autumn EAO:EX
Subject: Avalanche Risk Zoning Report

Mike,

I am writing to you to ask for the Ministry of Transportation and Infrastructure's assistance with our review of the attached ***Snow Avalanche Risk Zoning for a Day Lodge and Service Building for the Jumbo Glacier Resort*** prepared by Dynamic Avalanche Consulting Ltd.

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We would appreciate it if you could review the report and get back to us early next week, if possible.

Many thanks,

Paul

From: Cousins, Autumn EAO:EX
To: Lorimer, Mike TRAN:EX
Subject: TRIM: RE: time sensitive...better?
Date: Thursday, April 23, 2015 3:18:00 PM

Thanks very much.

From: Lorimer, Mike TRAN:EX
Sent: Thursday, April 23, 2015 2:47 PM
To: Cousins, Autumn EAO:EX
Subject: RE: time sensitive...better?
s.13

Mike Lorimer
Regional Director - Southern Interior Region

From: Cousins, Autumn EAO:EX
Sent: Thursday, April 23, 2015 2:46 PM
To: Lorimer, Mike TRAN:EX
Subject: time sensitive...better?
Importance: High

Changed language is yellow. Any chance you can review in an hour or so? Sorry again for tight timelines.

Environmental Assessment Office (EAO) Compliance and Enforcement (C&E) interprets condition 36 to mean that commercial and residential structures must not be located in a zone that has an avalanche return period up to and including a 'once-in-200-to-300 year return period hazard area' as defined in the material developed during the EA. In 2002, the Canadian Avalanche Association developed Guidelines for Avalanche Risk Determination and Mapping (CAA Guidelines 2002) that includes zoning that aligns with the 'avalanche hazard area' in the EA material. When considering the EA condition requirements in terms of the three zones in the CAA Guidelines 2002, EAO C&E interprets condition 36 to mean that commercial and residential structures must not be located in a blue or red zone as determined by a qualified professional.

JUMBO GLACIER RESORT

SNOW AVALANCHE RISK ZONING FOR A DAY LODGE AND SERVICE BUILDING

Prepared for:
Glacier Resorts Ltd.

c/o
Pheidias Project Management Corp.
660 – 1188 West Georgia Street
Vancouver, BC V6G 2T3

Prepared by:
Dynamic Avalanche Consulting Ltd.
Box 2845
Suite 201, 103 2nd St. E.
Revelstoke, BC V0E 2S0
250.837.4466

DYNAMIC
AVALANCHE CONSULTING LTD.

March 19, 2015

Contents

1.0 Introduction

This report presents the results of an avalanche risk assessment and risk zoning for a Day Lodge and Service Building at the Jumbo Glacier Resort, located approximately 45 km west of Invermere, BC (Figure 1).

General recommendations are provided for management of avalanche risk in this area based on the risk zoning and the locations of the facilities.

This work was completed by Dynamic Avalanche Consulting Ltd. (DAC) on behalf of Pheidias Project Management Corp. (Pheidias), who is providing resort development services to Glacier Resorts Ltd. The work presented in this report is intended for the exclusive use of Pheidias and Glacier Resorts Ltd. (GRL).

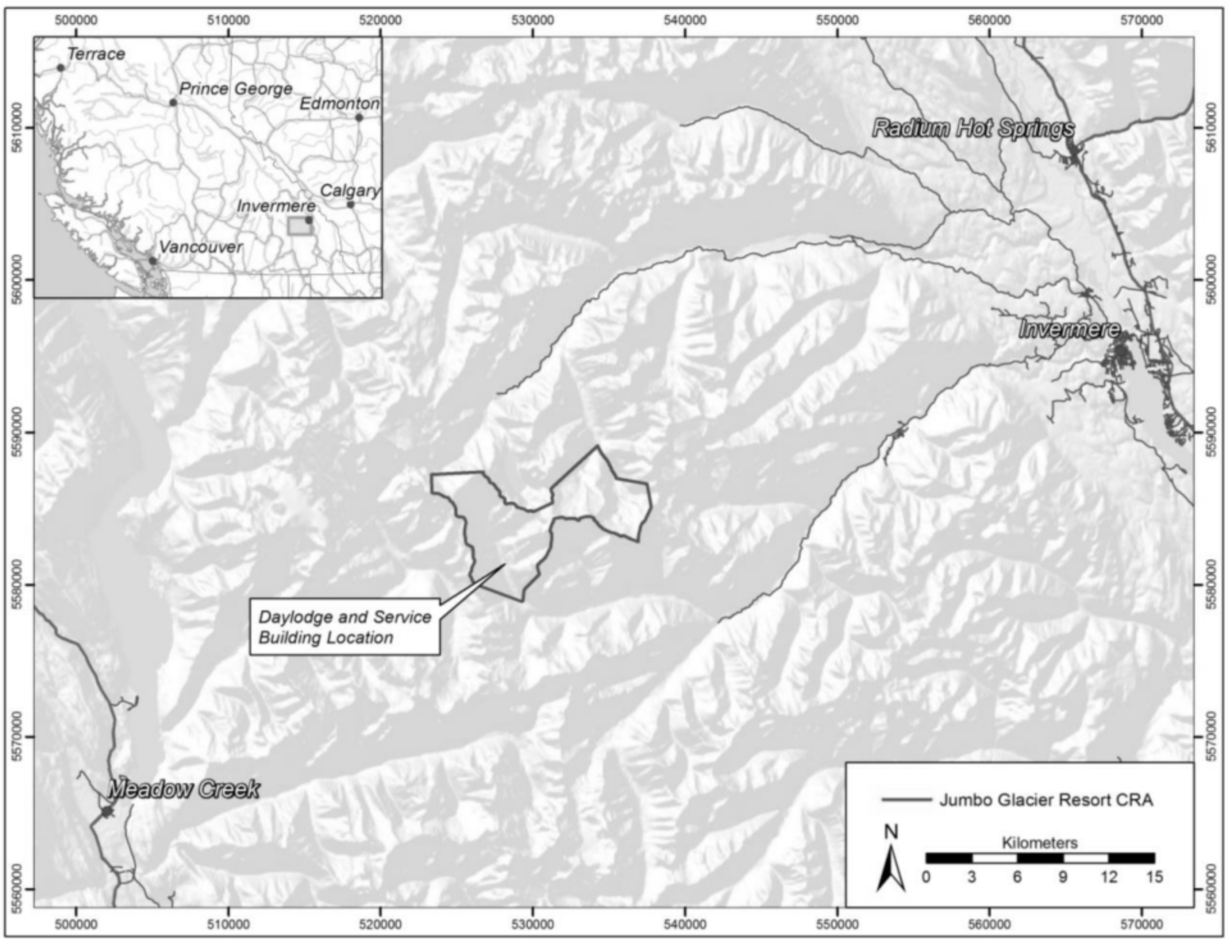


Figure 1. Location map for the Jumbo Glacier Resort.

1.1 Objectives

Mr. Peter Schaerer, snow avalanche expert and engineer, provided Oberti Resort Design (Oberti) a report (Schaerer, 2014) that assessed whether snow avalanches at the planned resort village in the Jumbo Valley could affect: (a) the residential areas; and (b) the Day Lodge north of the resort village.

The British Columbia Environmental Assessment Office (EOA) reviewed the Schaerer (2014) report and requested that an engineering avalanche risk evaluation, including a zoning plan, be completed for the Day Lodge and Service Building locations.

Following on the content of these two documents, the objectives of the current report are to:

1) Complete a snow avalanche risk assessment and risk zoning map for the Day Lodge and Service Building locations;
2) Summarize and provide guidance on applicable avalanche risk zoning guidelines in relation to the Day Lodge and Service Building locations; and
3) Provide conceptual recommendations for avalanche risk mitigation options, including but not limited to development restrictions, explosive avalanche control, operational avalanche safety programs and/or permanent avalanche defense structures.

1.2 Uncertainty

Avalanches are complex natural phenomena and there is considerable uncertainty in the estimates of frequency and magnitude and potential snow avalanche effects to the facilities described in this report.

Under extremely unstable snow conditions, avalanches may be observed in terrain where they would otherwise not occur, such as forested areas or low-angle open slopes. New avalanche paths may also be formed by removal of forest cover from forest harvesting, pest infestation, wildfire, or from slope-mass movement processes such as avalanches, landslides, rockfall or debris flows.

To the extent possible, uncertainty has been reduced in estimates of magnitude, frequency, runout distance and impact pressure by combining and appropriately weighting results from the following methods: vegetation patterns and terrain characteristics observed during the field review; historical observations of avalanches provided by observers working in the area; historical aerial photographs and digital imagery available online; analysis of topographic data; snow supply and regional climate data; application of statistical and dynamic models of avalanche motion. Information provided by these methods was combined with experience and judgement to complete the assessment of avalanche risk and risk zoning.

2.0 Avalanche Characteristics and Risk Guidelines

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; and
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 downslope. This is often the case with wet, loose snow avalanches descending in snow covered gullies.

Loose snow avalanches are typically smaller and less destructive than slab avalanches, although wet loose snow avalanches can be large or small. Slab avalanches are typically more dangerous and result in the largest and longest running avalanche events.

Avalanches can be characterized as either dry or wet, depending on the water content of the snow. However, avalanches that begin at higher elevations in dry snow may become wet or moist while they flow to lower elevations. Wet avalanches tend to move slower and are more likely than dry avalanches to be deflected by terrain features such as gullies. Large, dry avalanches are likely to travel faster, deviate from traditional paths, and overrun terrain features. Because of their higher speed, dry avalanches are often used as the design avalanche event for planning and engineering purposes.

Large, dry avalanches that do not become wet or moist 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. On occasion these two layers may separate and flow independently. The dense core typically has a flow depth of 1-3 m while the powder component may reach heights of tens of metres. Avalanches may reach speeds of up to 60 m/s (200km/h). 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 an avalanche runs. The terrain located 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 Frequency and Magnitude

The 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 Frequency (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.

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

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 typically not damage a residential structure. A Size 3 avalanche may damage an unprotected residential structure. Size 4 and 5 avalanches will destroy unprotected residential structures. 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.

2.4 Avalanche Risk Guidelines

The *Guidelines for Snow Avalanche Risk Determination and Mapping in Canada* CAA, (2002) are the generally accepted guidelines for land development and operations located in avalanche terrain. The recommended zones for land-use planning of occupied structures 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/year 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. Conditions may include reinforced structures, construction of avalanche defences, and requirements for evacuation plans or a combination of these.
- ***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. 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 White Zone hazard line, the risk of such damage is considered acceptable.

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

3.0 Methods

The locations of the avalanche risk zones were determined using the following methods:

- Review of numerous reference materials, as listed below and in the References;
- Discussions with GRL project development personnel, including: Oberto Oberti, Tommaso Oberti and Grant Costello;
- Telephone interviews with Graham Holt, Rod Gibbons and Andrew Nelson, senior guides with RK Heliski;
- Telephone interview with Peter Schaerer, avalanche expert.
- Review of topographic map data, including 1:20,000 TRIM and 1:50,000 NTS topographic contours;
- Review of historical aerial photographs, as listed below;
- Review of Google Earth and Bing (dated 2005) satellite imagery;
- Analysis of regional snow course and weather station data;
- Review of snow climate data provided by RK Heliski;
- Avalanche modelling using Dynamic (PCM, PLK, LEM, DAN-W, AVAL-1D), and statistical (Alpha-Beta, and Runout Ratio) models of avalanche models.
- Field survey of the terrain and vegetation by helicopter and ski on December 30, 2014.

The following materials were used and referenced in preparation of this report:

- Alpentech Inc. 1990. Jumbo Valley Access Avalanche Map. Revised November 8, 1990.
- British Columbia Environmental Assessment Office (EAO), 2014. Letter sent via email to Oberto Oberti, Glacier Resorts Ltd. Dated December 11, 2014.
- Chris Stethem & Associates Ltd. (CSA) 1995. Jumbo Glacier Alpine Resort. Avalanche Hazard to Access Road. Letter dated November 30, 1995.
- CSA, 1997. Jumbo Glacier Alpine Resort. Avalanche Hazard to Access Road on North Side of Valley. Report dated May 18, 1997.
- CSA, 2003. Jumbo Glacier Resort; Avalanche Control at Skiout Trails. Letter dated March 20, 2003.
- Pheidias Project Management Corp., 2010. Jumbo Glacier Resort Master Plan.
- RK Heliski. 2014. Re: Extreme Avalanche Hazard at New Jumbo Glacier Resort (JGR) Day Lodge Building Site. Letter to BC Environmental Assessment Office, dated October 30, 2014.
- Schaerer, 2014. Snow Avalanche Hazards at Jumbo Glacier Resort. Report prepared for Oberti Resort Design. Dated November 26, 2014.
- Sierra Systems Group Inc. 2004. Report to Environmental Assessment Office Jumbo Valley Assessment. Report dated July 28, 2004.
- Numerous site photographs taken on the ground and in the air, provided by Oberto Oberti, Grant Costello and RK Heliski.

Digital data used for the basemap:

- Day Lodge and service building location provided by Pheidias Project Management Corp., received 12 December, 2014.
- Resort infrastructure (ski lifts, runs, subdivisions, roads, other building locations) provided by Pheidias Project Management Corp., received 5 January, 2015.

The following aerial photographs were reviewed during completion of this work:

- 1968: 30BC7099 #260-263
- 1975: 30BC7821 #221-222
- 1981: 15BC81118 #17-18
- 1985: 30BC85062 #121,126
- 1995: 15BCB95058 #72
- 1997: BCB97099 #191
- 2005: 30BCC05036 #22
- 2006: 30BCC06066 #192

4.0 Geography and Snow Climate

4.1 Physical Setting

Jumbo Glacier Resort is located in the Purcell Mountains, which is a sub-range of the Columbia Mountains of British Columbia. This area is characterized as a transitional snow climate (McClung and Schaerer, 2006), which exhibits characteristics of both Maritime and Continental snow climates, namely the heavier precipitation and deep snowpack depths associated with a Maritime climate and the outbreaks of cold, dry artic air common to a Continental snow climate. The terrain is very mountainous with peaks and ridges reaching well into alpine areas, with extensive glaciated terrain in the western portion of the Controlled Recreation Area (CRA).

Elevations range within the CRA from approximately 1700 m near the proposed Village at the southern end of the CRA up to 3437 m at the summit Jumbo Mountain.

Snow supply estimates are provided below to help estimate avalanche magnitude and frequency, as well as to estimate the duration of the avalanche season for use in operational planning. Snow supply estimates were derived from regional climate station data judged to be representative of the project area, supplemented with observational data provided by RK Heliski. This information may also be useful in estimating static snow loads on roofs and other structures, and for assessing seasonal snow removal requirements in development areas.

The predominant wind direction in the project area is from the southwest, which corresponds to the regional wind direction as storm systems originate in the Pacific Ocean. Typical wind patterns may scour snow from south and west facing terrain and deposit it on north, northeast and east facing terrain, in some areas producing large cornices and areas with deep snow. However, local winds can vary significantly depending on the orientation of the valleys and mountain terrain features. Outbreaks of cold, dry air from the Rocky Mountains to the east and north can result in reverse wind loading onto west, southwest and south facing terrain.

4.2 Climate Stations Used for Snow Climate Analyses

Data from seven representative climate stations with medium (10-15 years) to long (> 15 years) records were used to estimate snow supply in the project area (Table 3). Due to similar location and elevation, the two Toby Creek stations (27221 and 37205) were combined into a single data set to improve the length of record for this station.

The climate stations listed in Table 3 are owned and monitored by the River Forecast Centre (RFC), Environment Canada (EC), British Columbia Ministry of Transportation and Infrastructure (MOTI), and RK Heliski (RKH). These stations provide data for a representative range of elevations from valley bottom stations (e.g. Duncan Lake on the west slope of the Purcell Mountains) as well as higher elevation stations used for monitoring hydrology/runoff conditions (e.g. East Creek).

Data provided by RK Heliski is not based on a weather station observations, but rather direct field observations made by trained observers: certified ski and mountain guides. This data is obtained periodically and thus differs from the regular weather station data, but provided useful information for higher elevations in the project area.

It should be noted that the snow climate varies significantly through the project area, particularly between the heavy precipitation areas near the height of land (e.g. Jumbo Peak, Glacier Dome) and the eastern, relatively drier lower elevation areas towards Toby Creek. Orographic effects (i.e. increased precipitation) will be highest near the height of land, with decreasing precipitation to the east in the Columbia Valley. Precipitation also decreases with decreasing elevation.

Table 3. Summary of weather station analyses for annual maximum height of snow, HS (cm).

Station Name	Station ID	Owner	Elev. (m)	Years of Record	Mean Annual Maximum	Standard Deviation	HS_{Max}	HS_{10}	HS_{30}	HS_{50}
Rod's	n/a	RKH	2400	2005-2014 (10)	296	55	370	368	416	n/a
Rosie's	n/a	RKH	2350	2000-2014 (15)	248	43	320	305	343	n/a
East Creek	2D08P	RFC	2030	1981-2011 (30)	223	69	337	313	374	402
Bugaboo Creek Lodge	1171105	EC	1503	1981-1996 (36)	121	23	167	151	171	180
Toby Creek Combined	27221 37205	MOTI	1155	1981-2014 (34)	82	22	135	111	130	139
Duncan Lake	2D07A	RFC	662	1991-2014 (24)	54	21	101	81	100	108

4.3 Long Term Snow Height Estimates

Annual maximum height of snow (HS) data from weather stations listed in Table 3 were fit to a Gumbel (Extreme Value Type 1) distribution to determine theoretical annual maximum HS for 10, 30 and 50 year return periods (Table 3). Stations with less than 20 years of observations were not analysed for 50-year values.

Mean, 10-year (HS_{10}), 30-year (HS_{30}) and 50-year (HS_{50}) values are plotted by the station elevation in Figure 2. Linear regression method provides equations to estimate HS as a function of elevation, which is a commonly used method to relate observed precipitation to elevation (Smith and Barstad, 2004). The RKH data provide field-verified observations in the project area, which increases the confidence in this analysis.

Avalanche starting zones in the project area range in elevation from approximately 2000 m to over 3200 m. For higher elevation areas, snow supply estimates are more uncertain, as the higher stations are located between 2000 and 2450 m elevation, which better represent the lower elevation starting zones in the project area.

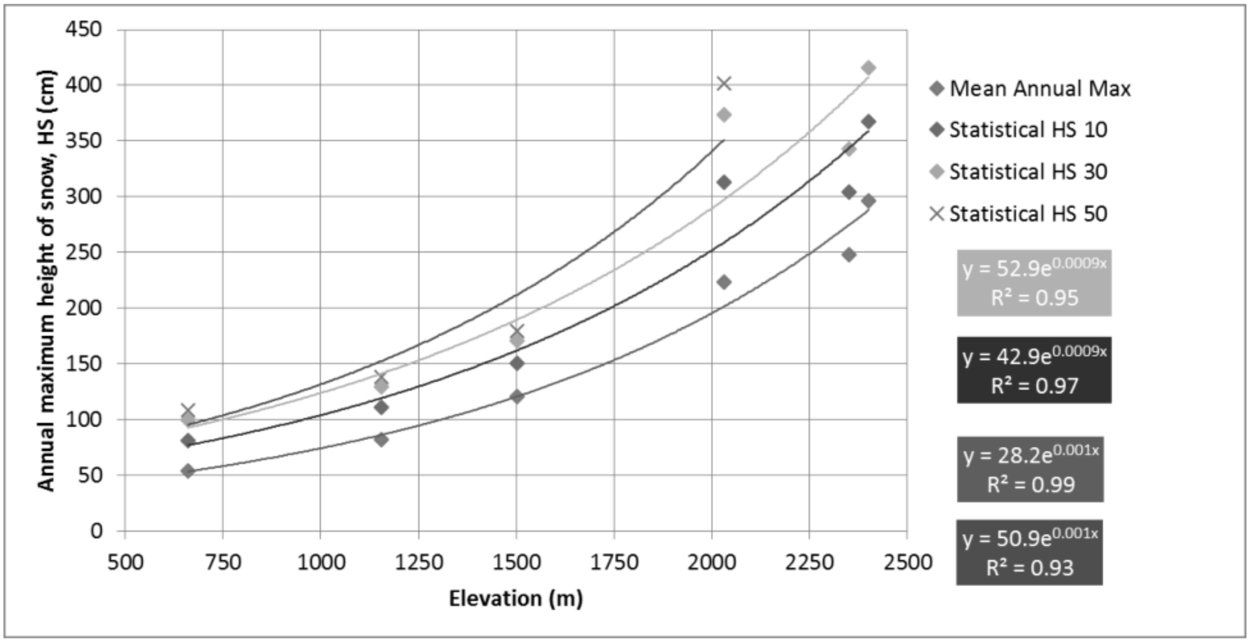


Figure 2 Linear regression showing the estimated Mean, 10-Year, 30-Year and 50-Year maximum annual snowpack height (HS) as a function of elevation for the Jumbo project area.

Table 3 and Figure 2 show lower elevation avalanche starting zones (near 2000 m) have a typical annual maximum snowpack on the order of 200 to 250 cm and maximum (30 to 50-year) winters produce snowpack heights on order of 300 to 400 cm.

Higher elevation starting zones in the project area, above 2500 m can be expected to have annual maximum snowpack heights greater than 300 cm, while maximum (30-50 year) winters in some areas can be expected to exceed 400-500 cm. Wind transporting and depositing snow can significantly increase snow heights in localized areas, sometimes by a factor of 2 to 3 times.

This analysis shows that all avalanche start zones in the project area receive sufficient snow supply to produce an avalanche hazard on an annual basis, and many steep avalanche prone areas will be capable of producing multiple avalanches per season.

4.4 Duration of the Avalanche Season

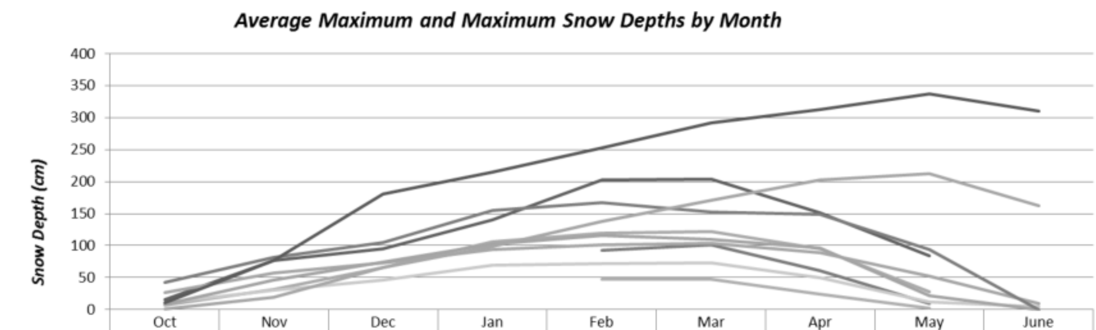
The average maximum and maximum observed snowpack height is plotted by month in order to estimate the duration of the avalanche season in the project area (Figure 3). Data from the Duncan Lake station is recorded between February and May; the rest of the stations start observations in October and continue through to the end of April through June.

Avalanche hazards exist when snow depths in avalanche starting zones exceeds threshold values. Typically threshold snowpack values for avalanche formation vary between 30 cm and 100 cm, depending on ground roughness. Rougher ground (e.g. talus slopes) requires a deeper snowpack for avalanche formation; smooth ground (e.g. grassy slopes or rock slabs) can require as little as 30 cm of snow to produce avalanches.

For alpine areas in the project area, threshold depth for avalanche formation is estimated to be 30 cm to 100 cm; for treeline and below treeline areas 75 cm to 100 cm is likely needed except where smooth rock or grassy slopes are present.

Based on the results shown in Figure 3, on average the avalanche season in the alpine can be expected to begin in November and extend into May. During maximum winters the avalanche season may extend into June at higher elevations.

Design (maximum) avalanches can occur at any point during the avalanche season, but on average could be expected to occur as early as January, after sufficient snow has accumulated in starting zones, through to April when large, spring (wet) avalanches can occur.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Duncan Lake Avg					47	47	24	2	
Duncan Lake Max					93	101	61	10	
Lardeau Avg	7	31	66	106	119	123	95	28	
Lardeau Max	16	77	96	140	203	203	152	84	
Toby Creek Avg	11	31	47	69	72	73	50	12	4
Toby Creek Max	26	57	73	93	102	104	89	53	10
Bugaboo Creek Avg	8	46	75	102	115	110	96	21	0
Bugaboo Creek Max	43	82	105	155	167	153	149	94	0
East Creek Avg	1	19	66	99	137	171	202	212	163
East Creek Max	10	77	180	215	253	292	313	337	310

Figure 3. Average and maximum snow depths plotted by month, illustrating the estimated duration of avalanche season in the Jumbo project area.

5.0 Avalanche Hazard Overview

5.1 Avalanche Path Description

5.1.1 Pink Panther (South Wolverine)

The Day Lodge and Service Building foundations are located adjacent to a large avalanche path known as South Wolverine in the Alpentech (1990) mapping, and is called the Pink Panther run by RK Heliski. The Pink Panther name convention is adopted for this report. A detailed risk assessment and avalanche risk zoning is presented for this path in the following sections.

The Pink Panther path starts immediately below a narrow ridge, with a starting zone between approximately 2400 m and 2700 m elevation. The starting zone consists of a large, east facing bowl, with a primary starting zone in the northern part of this bowl (upper right of Figure 4). This bowl is wind-loaded with snow due to its orientation to predominantly southwest winds. Slope inclines in the starting zone average 30-40º, with a steeper, rocky headwall in the southern part of the starting zone.

Figure 4. Pink Panther avalanche path. Day Lodge and Service Buildings are located in lower left of photo. Red dot shows the approximate location of the Day Lodge.

The track consists of unconfined terrain with an average incline of 25º. There are several distinct benches located in the track that serve to slow down avalanches, including a 350 m length of 16-21º terrain. The track includes two small, poorly defined streams, but neither are confined features and do not channelize avalanche flow.

The runout zone starts at the valley bottom at 1718 m, which is referred to as the Beta Point (β, where the incline first drops below 10º). This marks an abrupt transition where most avalanches will start to slow down. The β point is used as a reference point for avalanche runout distance measurement.

Large avalanches may continue approximately 210 m across the level valley to the toe of a slope just below a resource (mining and forestry) road. Historically, large avalanches have run up onto this slope into forested terrain; dense flow has reached the resource road, while powder flow periodically continues past the road.

The Pink Panther avalanche path has a vertical fall height of 990 m, overall path length of approximately 2250 m, and measures approximately between 350 m and 500 m wide. It is capable of producing a maximum Size 4 avalanche, and can be expected to produce numerous Size 2 to 3 avalanches each winter, most of which stop in the track above the valley bottom.

Vegetation within the main part of the avalanche path consists of shrubs, alters and scattered small conifers, typically 2-5 m in height. Ages of conifers vary within the track, but several in the central part of the track were observed to be approximately 40-50 years old. The path is bound by a distinct trim line (tree line marking a change in vegetation age class) on either side, with mature, old growth conifers approximately 100-150 years in age. A second trim line is located inside the mature tree boundary along the southern edge of the path; this tree stand is approximately 40-60 m wide. This forested area has regrown since it was removed by an avalanche sometime prior to 1968 (see Air Photo section below). This represents a major, destructive avalanche event in the 1950's or prior. Thus, the re-generating trees in this southern trimline are estimated to be approximately 60 years old, or older.

5.1.2 Karnak

The Karnak avalanche path is located on the east side of the valley, immediately north of the Pink Panther path. The two paths share overlapping runout zones in the valley bottom. The southern edge (trimline) of the Karnak path is located approximately 350 m north of the Day Lodge. The starting zone for this path is at approximately 2960 m in a well-confined alpine bowl below a steep rocky headwall.

Figure 5. Karnak avalanche path observed from Pink Panther path. Red dot shows the approximate location of the Day Lodge.

The Karnak path becomes very well confined in a gully that disperses onto a colluvial fan near 2240 m elevation. Below this elevation, part of the path is confined in a gully while the rest is on an open slope approximately 300-350 m wide. The lower track near 1760 m can turn toward the south on a natural deflection berm, while larger dense and powder flows will travel straight and across the valley.

RK Heli (2014) describes an explosive triggered Size 4 avalanche filmed in February 2013 that crossed the valley and climbed the slope within the Pink Panther path. The potential for this path both to cross the valley and to be deflected southwards towards the Day Lodge area was investigated and is discussed in the current report.

5.2 Field Investigation

On December 30, 2014 Alan Jones, P.Eng. and Greg Johnson, P.Eng. conducted a field investigation of terrain in select parts of the Jumbo Glacier Resort project area. An overview helicopter flight provided observations of the entire proposed CRA, including the Glacier Dome, Commander, Farnham, Upper Jumbo Creek, Day Lodge and Service Building, and Village development areas.

A ground survey was completed at the Day Lodge and Service Building area. Observations of the starting zone and track terrain and vegetation were made from a location within the Pink Panther (South Wolverine) path at approximately 2375 m to the valley bottom at 1718 m elevation.

A detailed topographic profile was completed from 1970 m elevation, within the lower part of the track to the valley bottom, and across to the east side of the valley at approximately 1750 m elevation. The profile was completed using clinometers, range finders and GPS instruments.

Detailed ground observations of terrain and vegetation were completed within the runout zone of the Pink Panther path, which focussed on areas close to the Day Lodge and Service Buildings. Where appropriate, vegetation age classes were observed, and visual evidence of dense and powder flow avalanche damage was noted.

5.3 Air Photo Analysis

Historical air photos were reviewed that show significant changes in the landscape during 1968 to 2014 (46 years). Figures 4a and 4b below compare the 1968 air photo to the most recent (2005) image, overlain with the Day Lodge and Service building locations. Important observations from these images include:

- A large swath of forest along the southern (bottom on photo) trimline of the 1968 photo was removed by an avalanche prior to 1968. Given that the vegetation had already partly re-vegetated in 1968, it is interpreted that this event may have occurred during the 1950’s. In 2005, this vegetation had grown in significantly, but the pre-1968 trimline can still be clearly observed and remains a potential avalanche area.

- The valley bottom where avalanches run out, including the eastern trimline near the road on the eastern side of the valley, has changed little during the period of 1968 to 2014. There was sparser forest cover present in the 1968 photos near the Day Lodge and Service Buildings, but overall there have been no major landscape/vegetation changing events in this part of the path between 1968 and 2014.

- The forest surrounding the Day Lodge regenerated significantly during 1968-2005. Evidence of large, logged stumps were observed in this area, showing that it had been selectively harvested prior to 1968. The distinct line of mature trees immediately north of the Day Lodge has not been significantly modified by avalanches in the 46 year period since 1968.

- Fallen logs near the Day Lodge can be observed on the 1968 photo, and are distributed in a random manner. If a large, destructive dense or powder avalanche had flowed through this area and knocked over trees, there would be evidence of fallen logs lying parallel to the avalanche flow (i.e. west to east). This implies that no major (i.e. destructive) avalanches had reached the Day Lodge site for a number of years prior to 1968, nor have any reached this location up to 2014 (verified by field observations).

- The area east of the resource road was harvested sometime between 1968 and 1981. This may have removed some long-term evidence of powder avalanches in this area. RK Heli has also completed glading of vegetation in this area to improve skiing. This activity removed lower branches on some trees, which was easily distinguished from damage produced by avalanches.

- A brown-toned swath of vegetation can be observed in the lower track in the 2005 image. This swath was produced by glading activity to improve the Pink Panther ski run (pers. comm., Andrew Nelson, RK Heliski), not by avalanches or terrain instability.

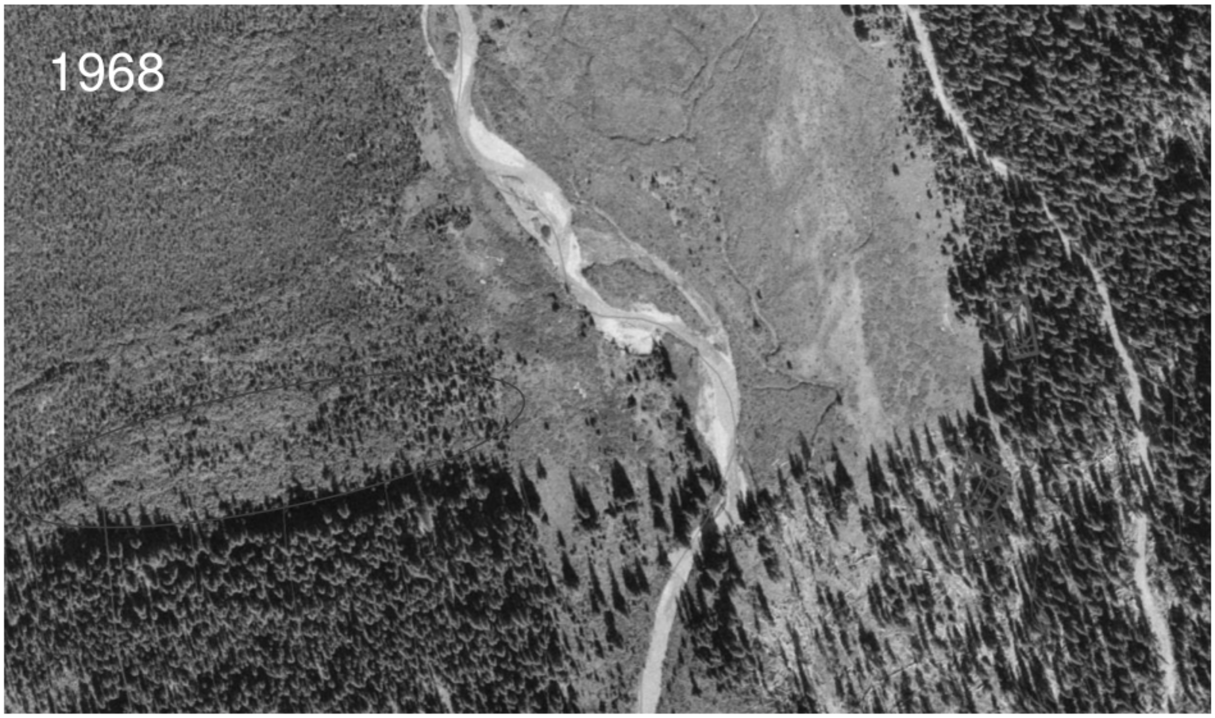


Figure 6a. Day Lodge and Service building overlain on the 1968 air photo. Red oval shows area where an avalanche removed forest cover, estimated to have occurred during the 1950's. Note selective logging and random orientation of deadfall in the vicinity of the Day Lodge.

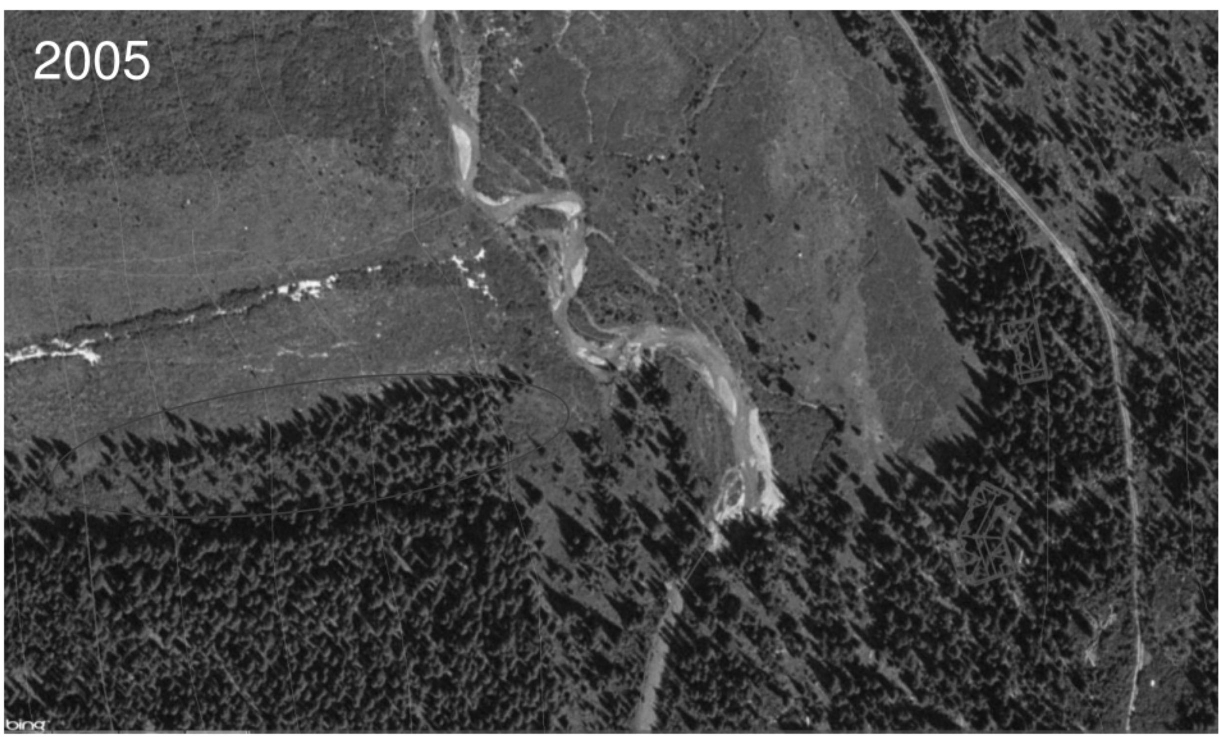


Figure 6b. Day Lodge and Service Building location overlain on the 2005 imagery. Red oval shows regenerated forest (trimline) from pre-1968 (estimated 1950's) avalanche event.

5.4 Historical Avalanches

5.4.1 Pink Panther

The historical evidence of avalanches within the Pink Panther path was assessed using a combination of field observations, air photos and interviews with RK Heli guide staff. Several key events are noted in Table 4. All of these events were assumed to be Size 4, as would any significant avalanche that reaches and crosses the valley bottom in this path.

Table 4. Historical avalanche events in the Pink Panther avalanche path.

Avalanche Event	Description
1950's (estimate)	Natural avalanche, removed forested strip of trees at southern edge of path, observed damage on 1968 photos, partially regrown.
January 16, 1996	Natural avalanche observed by RK Heli (Rod Gibbons, pers. comm.), deposited ~4 m snow on valley flats, debris reached ~50 m on opposite side of valley, snow on road, powder blast reached well up slope.
January 9, 2009	Explosive triggered avalanche, photographed (see RK Heli, 2014 for description), some light avalanche debris may have reached road (inconclusive), powder cloud reached up opposite side of valley, light powder may have reached or came close to Day Lodge location.

Based on discussions with RK Heliski, the 1996 avalanche event occurred during a significant avalanche cycle throughout the valley with many unusual events noted; this event may represent an approximately 30-year return period event (authors' opinion based on field evidence).

Both the 1996 and 2009 events crossed the valley bottom and put some debris on the road: significant debris in 1996 and potentially some light debris in 2009 (Andrew Nelson, RK Heliski, pers. comm.). Field evidence of the 1996 event was noted in vegetation at several locations.

No other notable events were reported by RK Heliski in the Pink Panther path during their working history in this area, which dates back to the early 1970's.

RK Heliski (Graham Holt, pers. comm.) estimates that the Pink Panther path runs full path (i.e. across the valley flats) on average every 4 years; powder avalanches travel approximately 200 m across the valley on average once every 3 years. Some of these may or may not have destructive potential by the time they reach the forest on the opposite side of the valley.

Based on these observations, avalanches with significant destructive potential (i.e. dense flow or fast moving, turbulent powder avalanches) are estimated to reach parts of the resource road on average every 15-20 years, which agrees with field observations of damage to vegetation.

5.4.2 Karnak

Detailed ground observations of avalanches were not completed within the Karnak path; however a combination of aerial and local observations combined with air photos, analyses and historical information provided sufficient information to assess if this path affects the Day Lodge.

RK Heli provided observations, including a video, of the February 2013 explosive-triggered avalanche in the Karnak path that crossed the valley and impacted forest in the Pink Panther path. Although this event caused significant damage to the forest, there is no evidence in this video, field evidence, air photos or terrain analysis to suggest this avalanche path can turn southwards and flow a significant distance down valley and affect the Day Lodge.

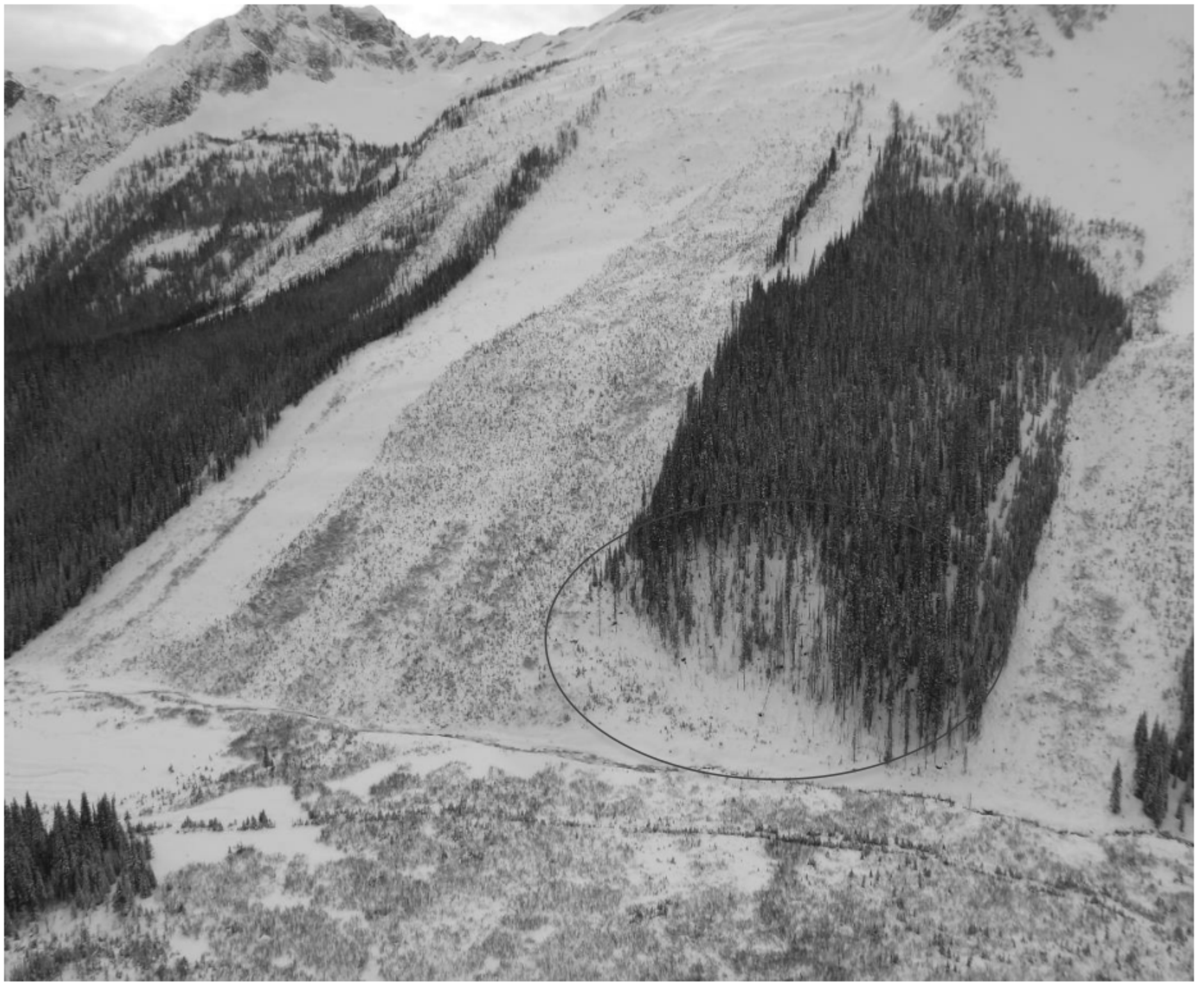


Figure 7. Destructive impacts to forest cover adjacent to the Pink Panther path caused by the cross-valley Size 4 explosive-triggered powder avalanche from the Karnak path in February 2013. Pink Panther path is located to the south (left) of red oval.

6.0 Avalanche Risk Assessment

6.1 Method for Determining the Location of Avalanche Risk Zones

Detailed analyses were completed for the Pink Panther path to determine potential avalanche frequency, runout distances and impact pressures in the runout zone. These parameters are required for determining the location of the Red, Blue and White Zones.

The process used to determine the location of avalanche risk zones was as follows:

1. **Avalanche profiles** were developed to model the trajectory of a design (100-year or greater) mixed (dense and powder) flow avalanche event.
   a. The primary profile (see profile in Appendix A) was assumed to flow down the centerline of the path and across the valley, which reaches the service road approximately 180 m north of the Day Lodge foundation. This profile was surveyed in the field.
   b. A second profile was assumed to turn southwards near the creek, where the avalanche first reaches the valley bottom (β-point), and flow along a curved path toward the Day Lodge.

2. **Runout-Return Period Fitting:** Return periods for identifiable avalanche events were determined along the centerline and Day Lodge profiles using a combination of field observations, historical avalanche observations, and air photo interpretation. These data points were used to develop a relationship between runout distance from the Beta Point and avalanche frequency (i.e. magnitude/frequency relationship).

3. **Velocity Modelling:** was completed for both dense and powder avalanche flow using dynamic avalanche models calibrated using a combination of methods: fitting to runout distances (as described in Point 2 above), damage to vegetation observed in the field, calculation of velocities using time stamps from the photograph sequence of the 2009 event, and use of empirical models (statistical runout and maximum velocity models). Dynamic models used for this assessment included: PCM, PLK, LEM, Aval-1D, and DAN-W. Statistical models included: Runout Ratio and Alpha-Beta models.

4. **Velocity Scaling**: Dense flow avalanches modelled using typical parameters generally did not reach the historical maximum runouts observed in the field. In order to accurately model avalanche flow to match field observations, model avalanche velocity profiles were developed by fitting a velocity curve to key locations in the profile (e.g. maximum velocity in the track, velocity at the β-point, velocity at the road, etc.). This provided a continuous range of velocity values as a function of return period (and runout distance), that could be scaled to model longer return period (e.g. 100 and 300 year) events.

5. **Impact pressures**: Design velocities for dense and powder flow were converted into equivalent impact pressures using standard average density values (300 $kg \cdot m^{-3}$ for dense and 10 $kg \cdot m^{-3}$ for powder flow) and impact pressure equations. Drag coefficients were assumed to be 2 for dense flow and 1 for powder flow. This provided a magnitude

(impact pressure) / frequency relationship that was then used with the CAA (2002) risk zone definitions to determine the locations of the Red, Blue and White Zones.

6. **Translation of risk zone boundaries laterally within the path**: Avalanche risk zone lines were determined along the centerline profile because this represents the most likely flow direction for an extreme avalanche event (i.e. straight across the valley). This profile was then translated to other trajectories starting at the Beta point, including one that gets deflected (e.g. by a previous deposit or by a separate dense flow pulse in an avalanche flow) and travels towards the Day Lodge. The lateral boundaries and risk zones were constrained by lateral boundaries (trimlines) observed in the field and on air photos, and by interpretations of confining terrain and vegetation.

For the Karnak Path, runout distance was determined using a combination of field observations, air photo analysis, dynamic modelling and topographic analysis. A path profile was assumed down the centerline of the path that crosses the valley and runs up the slope to the observed location of forest impacts (see profile in Appendix A).

Based on the Karnak path analyses, it was determined that avalanche flow cannot reach the DayLodge or Service Building location. Thus, a simpler modelling process was applied to the Karnak path that used statistical and dynamic models combined with field observations to determine the extreme runout position of the Karnak path. Air photos, field observations and topography were used to constrain the flow at the southern boundary, which is partly located within the Pink Panther path. The avalanche risk map includes the estimated historical avalanche path extent for the Karnak path, which corresponds approximately to a 100-year return period.

The resulting Red and Blue risk zones for the Pink Panther path overlap with the boundary for the Karnak path; however, the locations of the risk zones near the Day Lodge and Service Building are entirely determined by the Pink Panther path.

6.2 Avalanche Runout Estimates

6.2.1 Statistical Model Runout Estimates

The Alpha-Beta (McClung et al., 1989) and Runout Ratio (McClung and Mears, 1991) statistical models were used to estimate avalanche path runout distances. Both models use the reference β-point where the slopes incline decreases to approximately 10°. The β-point for the Pink Panther path is located at an elevation of 1718 m, where the valley floor is first reached. 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.

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 in this case is 0°. The Runout Ratio model estimates the 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.

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 Purcell and Rocky Mountains (McClung and Mears, 1991) and the Columbia Mountain models (Johnston et al., 2012).

Table 5a presents runout distance estimates for an extreme avalanche event in the Pink Panther path. For reference, the road on the east side of the valley is located at ΔX = 223 m. The Runout Ratio and Alpha-Beta models underestimate extreme runout distances for the Pink Panther path using P=0.5 (166-211 m) since the observed historical damage to vegetation from dense flow extends to near the road, which is at ΔX = 223 m. The more conservative P=0.85 m estimates represent unreasonably long runouts for this path since they are well beyond the road, which would require dense flow to continue running uphill for a long distance. These statistical models are meant to primarily represent dense flow, with limitations for paths with distinct run ups or large powder avalanche potential.

The results from the statistical runout models differed significantly from observations during the site investigation, air photo analysis, dynamic modelling and engineering judgement, and thus less emphasis was placed on these models compared to the other methods used.

Table 5a. Pink Panther: Statistical model runout distance estimates.

Statistical Model	Rockies	Columbias	Average
	ΔX (m)	ΔX (m)	ΔX (m)
RR- (P=0.5)	184	238	211
αβ (P=0.5)	160	172	166
RR (P=0.85)	362	449	406
αβ (P=0.85)	357	297	327

The statistical models estimates for Karnak using P=0.5 are more consistent between models and the different mountain ranges. An average of all four P=0.5 estimates is 290 m, which places the extreme runout on the opposite side of the valley near 1780 m elevation. This is close to the interpreted runout location of 1790 m elevation based on the field-observed damage from the 2013 avalanche event. Application of statistical models is limited by the run up of avalanches on the opposite side of the valley.

Table 5b. Karnak: Statistical model runout distance estimates.

Statistical Model	Rockies	Columbias	Average
	ΔX (m)	ΔX (m)	ΔX (m)
RR- (P=0.5)	239	310	275
αβ (P=0.5)	297	319	308
RR (P=0.85)	472	541	507
αβ (P=0.85)	661	550	606

6.2.2 Dynamic Model Runout Estimates

Avalanche runouts and velocities were estimated using five dynamic avalanche models, including PCM (Perla et al., 1982), PLK (Perla et al., 1984), LEM (McClung and Mears, 1995), Aval-1D (Gubler, 1994), and DAN-W (Hungr, 1995). 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, which was assessed by varying parameters within typical parameter ranges.

Table 6 presents runout distance (ΔX) and maximum velocity (V_{max}) estimates in the Pink Panther path for an extreme avalanche using the dynamic avalanche models. Assumptions for these models are provided in Appendix B.

The runout results for dense flow varied between 132 m and 238 m, which provides a wide range of runout estimates for this path. The average runout of the models of 185 m falls short of the observed field runout of 234 m. Maximum model speeds are more consistent, ranging between 33 m/s and 45 m/s, averaging 41 m/s. The higher maximum velocity of 45 m/s was used for subsequent analyses because it better fits with values estimated from the observed 2009 avalanche, and is more conservative.

Powder avalanche flow runout distances were provided by the Aval-1D, PCM and PLK models, averaging 289 m, which is consistent with the observed powder flow runout distance of 241 m. Maximum powder avalanche velocity for these models averaged 42 m/s.

Table 6. Pink Panther: Summary of dynamic model runout and maximum velocity estimates.

Dynamical Models	Dense Flow		Powder Flow	
	ΔX (m)	V_{max} (m/s)	ΔX (m)	V_{max} (m/s)
PCM	155	44.9	238	47.4
LEM	238	45.0*	n/a	n/a
PLK	205	36.1	274	45.3
DAN-W	132	37.7	n/a	n/a
AVAL-1D	194	40.3	356	32.0
Average Models	185	41	289	42
Max. Observed - Dense	234	n/a	n/a	n/a
Max. Observed - Powder	n/a	n/a	241	n/a

** V_{max} is assigned to LEM model from an empirical model (McClung & Mears, 1995).*

For the Karnak path, several models were used, but only the PLK model provided results that were consistent with field observations, and was thus the only model used. Modelling for dense flow provided a runout distance of 202 m, which is consistent with observed dense flow damage on the west side of the valley. The modelled powder flow runout distance was 298 m, which matches the field observed runout (i.e. damage to trees from 2013 event), and is consistent with the statistical model runout distance of 291 m.

6.2.3 Velocity Fitting to Return Period in Runout Zone

The statistical and dynamic models provided somewhat unsatisfactory results for avalanche runout in the Pink Panther path. In general, the models underestimated runout compared to the runouts observed in the field through vegetation damage. For the most part, dense flow models placed runouts in the middle of the valley (e.g. average ΔX = 185 m), while the observed damage to vegetation was another 49 m further, near ΔX = 234 m, which is upslope of the road. Model runout estimates for higher return periods (e.g. 100-300 years) should exceed the observed damage. Modelled powder avalanche runouts (ΔX = 289 m) exceeded the field observed runout (ΔX = 241 m), which represents reasonable model results.

In order to improve the model results, velocity squared (v^2) was scaled as a function of runout distance (and return period) to provide an improved model that could be extrapolated to higher return periods. Avalanche motion depends on v^2, which can be plotted to form a linear relationship with runout. A maximum velocity of 45 m/s was assumed at a point in the track, 35 m/s was assumed at the β-Point, 15 m/s was assumed at the road, dissipating to near zero near ΔX = 260 m, which is approximately 40 m upslope of the road.

Powder avalanche flow in the Pink Panther path was scaled similar to dense flow. A maximum velocity of 45 m/s was assumed in the track (same as dense flow), a slightly higher velocity of 37 m/s was assumed at the β-Point. Flow velocity dissipated to zero at a location consistent with field observations and observations from the 2009 avalanche photos.

Appendix C provides a summary of velocity fitting values used for both dense flow and power avalanche flow in the Pink Panther path.

Velocity fitting was not used for the Karnak path since the combination of statistical and dynamic avalanche models with field observations provided satisfactory results.

6.3 Avalanche Risk Zones

The objective of this report is to determine the location of Red, Blue and White risk zones according to the *Guidelines for Snow Avalanche Risk Determination and Mapping in Canada* (CAA, 2002). These guidelines are discussed in Section 2.0.

This report contains two maps that show avalanche risk to the project area:

1) Day Lodge and Service Building Overview Map, 14-0056-OBO-001
2) Day Lodge and Service Building Snow Avalanche Risk Map, 14-0056-OBO-002

The Overview Map provides an overview of avalanche boundaries in the Pink Panther avalanche path, including the entire path (starting zone, track and runout). The lower track and runout zone of the Karnak path is also shown. As previously noted, the Karnak and Pink Panther path runout zones overlap; emphasis was placed on determining the extents of the Pink Panther risk zones.

The Snow Avalanche Risk Map shows a detailed view of the Day Lodge and Service Building foundation locations, with delineation of the Red and Blue risk zones. The White Zone is considered a low risk avalanche area outside of the limits of the Red and Blue Zones; there may be potential for avalanches to reach this area, but with sufficiently long return period (> 300 years) <u>or</u> impact pressures less than 1 kPa and return period greater than 30 years.

The Red line, which indicates the boundary between the Red and Blue Zones, is located between 30 m and 50 m upslope (east) of the road. The distance is greater at the northern end of the path because the path runout zone is located at a similar level to the road and does not run up a steep slope to the road. Closer to where the Service Building is located, the road is located at a higher elevation than the valley bottom, which reduces the frequency with which dense flow can climb the slope.

The location of the Red line was determined based on potential dense avalanche flow, which has higher destructive potential than powder flow. Using the relationship between return period and impact pressure (I/I_0 / T/T_0), this line corresponds approximately to a dense flowing avalanche with a return period of 90 years and impact pressure of 9 kPa.

6.3.1 Service Building Avalanche Risk

The majority of the Service Building is located within the Red Zone (high risk); the remainder is located in the Blue Zone (moderate risk). Although there was no evidence of avalanche impacts to vegetation noted right at the site, either on the ground or on air photos, dense flow avalanche impacts to vegetation were noted within 10-15 m of the building site, and have reached the road in other parts of the runout zone.

The age of impacts near the Service Building was estimated to be older than 30 years, but was sufficiently frequent and of sufficiently high impact pressure to place this structure mostly within the Red Zone.

6.3.2 Day Lodge Avalanche Risk

The majority of the Day Lodge foundation is located in the Blue Zone, which represents moderate avalanche risk. The remainder is located in the White Zone (low risk). Potential avalanche risk to the Day Lodge exists only due to potential powder avalanche effects; there was no evidence to suggest potential for dense flow to reach this location.

The Red/Blue risk line is located approximately 25 m north of the Day Lodge; this location was determined as a function of potential dense flow avalanche impacts. The areas closest to the Day Lodge with evidence of dense flowing avalanche impacts are 80 m (near the Service Building) and 105 m (in the open meadow northwest of the Day Lodge) away. Dynamic avalanche modelling agreed with the field evidence in this regard: dense flow is very unlikely to reach the Day Lodge.

Powder avalanche impacts to vegetation were observed approximately 15 m north of the Day Lodge foundation in the form of a small, snapped tree stem, likely from the 1996 avalanche event (Figure 8). The force from this event was limited, indicating a relatively low impact pressure. However, mature (>100 years) forest the same distance away (Figure 9) to the northwest showed no evidence of avalanche impacts, indicating that the powder flow was light, laterally dispersed flow, and likely not a flow directed at the Day Lodge.

Figure 8. Power avalanche impact to a tree located 15 m north of the Day Lodge.

Figure 9. Day Lodge construction site. Area 1 indicates a mature forest immediately northwest of the site with no evidence of avalanche impacts. Area 2 indicates area with some powder avalanche impacts (see Figure 8). Red line shows main avalanche flow direction north of Day Lodge.

There was no evidence of dense flow or powder impacts noted at the Day Lodge site during the field investigation, on aerial photographs, or on photos of the site prior to construction. The only evidence of a powder avalanche reaching the Day Lodge was provided by RK Heli (2009) which shows a light powder flow travelling towards and possibly reaching the Day Lodge (Figure 10). Observation of vegetation at the site indicates that the 2009 event did not produce destructive powder effects to the Day Lodge site.

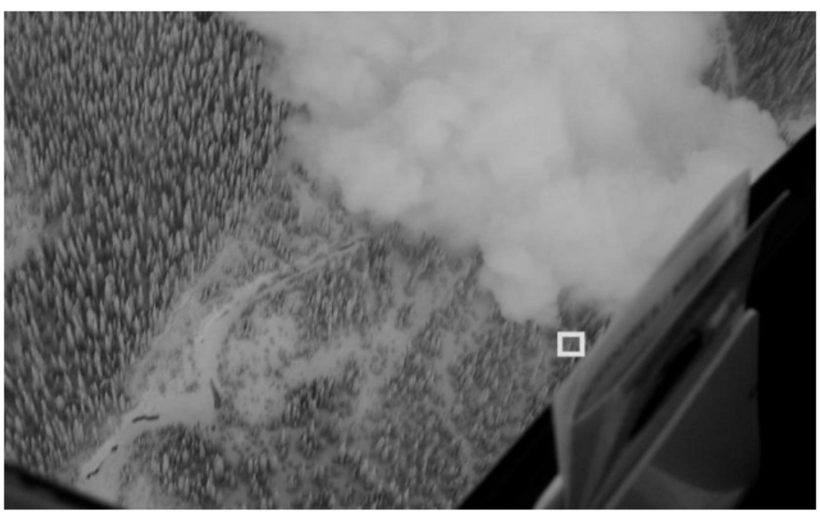


Figure 10. Powder flow during January 2009 explosive triggered avalanche in Pink Panther path. Day Lodge foundation location, as constructed in 2014 approximately indicated by yellow square. (Modified from RK Heli photo).

7.0 Avalanche Risk Discussion

The avalanche risk assessment in Section 6.0 determined that both the Day Lodge and Service building foundations are located in avalanche risk zones according to the CAA (2002) avalanche risk guidelines. This section provides additional discussion regarding avalanche risk zoning and recommended activities within these zones.

7.1 Service Building

The Service Building is mostly located within the Red Zone (high risk), for which the CAA (2002) guidelines recommend:

> *Construction of new buildings <u>not</u> normally permitted.*

This recommendation is intended to apply to occupied structures, either temporarily or permanently occupied.

Based on this guideline, if a structure is to be constructed at this location, it is recommended that it not be used or routinely accessed during the winter season (see Section 4.4 for duration). Seasonal (non-winter) usage of a building could be considered (e.g. seasonal storage), if permitted, which would meet the requirements of a non-occupied structure.

The return period for potentially destructive avalanches at this location is estimated to be in the range of 30-100 years, with an expected impact pressure range of approximately 10-40 kPa. These impact pressures are sufficient to destroy a wood-frame structure (Mears, 1992); thus structural reinforcement is recommended for a structure at this location. Other mitigation measures that could be considered include no windows or doors on the western edge of the building, and no prominent roof eaves that can be damaged by avalanche flow.

7.2 Day Lodge

The Day Lodge is located mostly within the Blue Zone (moderate risk), for which the CAA (2002) guidelines recommend:

> *Construction of new buildings, such as industrial plants and temporarily occupied structures, possibly permitted with specified conditions. Conditions may include structures reinforced for avalanche forces, construction of avalanche defences, and requirement for evacuation plans or a combination of these.*

Assuming the Day Lodge would be used only during limited (working) hours during the day, it may be considered a *temporarily occupied structure*. Based on the fact that dense flowing avalanches are not expected to affect this location, and only relatively low impact pressure powder avalanche effects need to be considered, use of this Day Lodge is recommended subject to the following conditions:

1) **Structural Reinforcement:** The building should be designed to withstand powder avalanche impact pressures of approximately 2 kPa (unfactored). This could be achieved by structural reinforcement where necessary (e.g. reinforced north and

northwest facing window panes) or other architectural means (e.g. orientation of design elements, shutters).

2) **Explosive Control**: Frequent explosive avalanche control should be conducted within the Pink Panther path to reduce avalanche hazard through the winter. This measure will also be required to protect ski terrain upslope of the Day Lodge. A highly reliable, all weather control system should be considered for starting zones in the Pink Panther path. Fixed exploder systems options should be evaluated (e.g. Gazex, O'BellX, Wyssen Tower, Avalanche Guard), which could be supplemented by hand charging and helicopter control, as needed.

3) **Evacuation Plan**: An evacuation plan should be developed for this building to reduce any potential residual risk to workers and the public both within and outside of the building. This could include short-term closures during periods of high avalanche hazard as well as complete evacuation of personnel and public from the Day Lodge and surrounding runout zone during explosive avalanche control.

Implementation of an avalanche safety plan, including an explosive control plan and an evacuation plan will require trained, experienced and licensed personnel (as per Schaerer, 2014).

Due to the large size of this avalanche path, construction of permanent structural mitigation measures is not recommended as an option. This includes snow retention net structures in the starting zone, deflection berms and stopping dams in the track or runout zone. These options are very expensive, difficult to construct due to access and environmental constraints, and would interfere with ski run development.

7.3 Structures at Ski Resorts within Avalanche Risk Zones

There are numerous ski resort facilities, including day lodges, currently located within avalanche risk zones within Canada, the US and throughout Europe. Most, if not all of these facilities in Canada and the US pre-date applicable avalanche risk zoning guidelines or standards, but some have been recently zoned.

Within Canada, the following ski resort day lodges are located in potential avalanche areas:

- Sunshine Village (Banff) day lodge and parking area. Expected to be in the Blue Zone, but risk zoning not completed. Several large avalanches have reached the parking area, impacted a ticket office and other infrastructure.
- Whitewater Ski Resort (Nelson). Powder avalanche(s) have reached the day lodge, potentially within the Blue Zone, but not zoned.
- Mount Norquay (Banff). The Tea House (now the Cliffhouse Bistro) was directly impacted by an avalanche in 1974, located in Red or Blue Zone, but not zoned.

Within the US, day lodges located within avalanche risk zones include:

- Alyeska Resort (Alaska) day lodge. Structurally reinforced building located in Blue Zone (zoned by Alan Jones, P.Eng.). Has been impacted in the past.
- Alpine Meadows (Tahoe, California) day lodge destroyed in 1982, rebuilt in the same location and not impacted since. Likely in the Red Zone, but not zoned.
- Jackson Hole Couloir Restaurant. Impacted by avalanche in 2008, likely in Red Zone.
- Alta, Utah. Multiple buildings in avalanche risk zone, Inter-Lodge travel restrictions (i.e. public remain and are protected within buildings) implemented during high avalanche periods and during avalanche control.

All of the areas listed above currently have active avalanche hazard management programs implemented by ski resort personnel (or highway personnel at Alta) to reduce avalanche risk to the public and workers. Control methods vary between areas, but include helicopter, artillery, avalauncher and hand charging in starting zones.

With the exception of Alta, explosive avalanche control is typically completed in these areas during the morning or end of day when there is no risk to the public (i.e. before or after the ski area opens). Alta is unique in that they require the public to remain inside buildings during explosive avalanche control, which is not recommended as an option for the Jumbo Glacier Resort Day Lodge.

The above discussion of other ski resort day lodges is meant to provide context to the proposed construction of the Jumbo Creek Day Lodge within an identified avalanche area. Development of ski resort facilities within avalanche risk areas is common in North America and Europe. Risk to structures is mitigated by a combination of structural protection and hazard reduction using explosive avalanche control methods. This may be considered acceptable for a temporarily occupied structure where the ski resort maintains full control over access to the building and can apply explosive control under strict safety protocols. This method is not considered acceptable for permanently occupied structures such as hotels and residences, since the authority usually has limited means to evacuate and control the public during unusual events.

8.0 Conclusion and Recommendations

The purpose of this report was to complete a snow avalanche risk assessment and risk zoning map for the recently constructed DayLodge and Service Building foundation locations at the Jumbo Glacier Resort. Guidance was provided regarding applicable avalanche risk zoning guidelines, and recommendations were provided for avalanche risk mitigation options.

The assessment reviewed potential avalanche risk from two avalanche paths: Pink Panther (South Wolverine) which is located immediately adjacent to the Day Lodge and Service Buildings, and the Karnak path which is approximately 350 m north of the Day Lodge. It was determined that Karnak does not affect the Day Lodge or Service Building locations.

The Pink Panther avalanche path was assessed in detail during a ground and aerial survey, and using a variety of methods, including: statistical and dynamic avalanche modelling, air photo interpretation, vegetation analysis, terrain/topographic analysis, and review of historical records.

There was no historical evidence of destructive avalanche effects observed at the Day Lodge foundation location. Powder avalanche flow (interpreted from 1996) produced damage to vegetation 15 m from the Day Lodge foundation; powder from the 2009 explosive triggered avalanche may have reached the Day Lodge with light powder flow, but destructive effects were not observed from this event. Dense flow avalanche impacts were observed 80 m from the Day Lodge, but there was no evidence to suggest that dense flow can reach the Day Lodge. The resulting avalanche risk zoning assessment places the Day Lodge mostly within the Blue Zone (moderate risk), with a small portion within the White Zone (low risk).

There was no evidence of avalanche impacts to vegetation at the Service Building site, but dense flow impacts were observed within 10-15 m of the building site. The resulting risk zoning places the majority of the Service Building the Red Zone (high risk); the remainder is located in the Blue Zone (moderate risk).

Based on this assessment, the following recommendations are provided:

1) If a structure is to be constructed at the Service Building location, it should not be used or routinely accessed during the winter season. Seasonal (non-winter) usage of a building could be considered (e.g. seasonal storage), if permitted.

2) Any structure constructed at the Service Building location should be structurally reinforced to withstand avalanche impact pressures of approximately 10-40 kPa. Doors and windows should face away from the avalanche flow direction (i.e. facing east), and prominent roof eaves should be avoided since they could be damaged by avalanches.

3) According to the CAA (2002) risk guidelines, the Day Lodge may be considered a temporarily occupied structure. Since dense flowing avalanches are not expected to affect this location and expected powder impact pressures are low, use of the Day Lodge site is recommended subject to three conditions:

a. **Structural reinforcement** for impact pressures of 2 kPa (unfactored).

b. **Explosive control** to reduce avalanche hazard, ideally with the installation of remote fixed exploders (e.g. Gazex, O'BellX, Wyssen Tower, Avalanche Guard)

c. **Evacuation plan** to reduce potential residual avalanche risk to workers and the public both within and outside of the building (i.e. short-term closures for high hazard and explosive control).

4) Protection of workers and the public in and around the Day Lodge will require implementation of an avalanche safety plan, which will include explosive avalanche control and an evacuation plan implemented by trained, experienced and licensed avalanche technicians.

9.0 Closure

This report was prepared for the exclusive use of Pheidias Project Management Corp., and Glacier Resorts Ltd. Any use which a third part 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 the undersigned at your convenience.

Dynamic Avalanche Consulting Ltd.

Prepared by:

Alan Jones, M.Sc., P.Eng.
CAA Professional Member

Chris Argue, Dipl.T.
CAA Professional Member

Reviewed by:

Greg Johnson, M.Sc., P.Eng.
CAA Professional Member
Association of Canadian Mountain Guides (ACMG)

References

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Appendix A: Avalanche Path Profiles

Jumbo - Pink Panther Straightline								
	Date:	20 February 2015				Observers:	AJ, GJ, CA	
Base Information:		TRIM Contours from DataBC WMS Field survey Dec 30, 2014.						
	Air Photos:	15BCB81122						
	Other Sources:	Google Earth						
Segment	**Elevation (m)**	**Horizontal Distance (m)**	**Width (m)**	**Slope Distance (m)**	**Vertical Distance (m)**	**Incline (deg)**	**Ground/Terrain Features & Comments**	**Alpha/Beta Points**
	2580		275				Upper start zone	
1		124		159	100	38.9		
	2480		460				Lower start zone	
2		106		122	60	29.5		
	2420		490					
3		142		154	60	22.9		
	2360		430					
4		74		84	40	28.4		
	2320		430					
5		146		158	60	22.3		
	2260		430					
6		89		98	40	24.2		
	2220		430					
7		175		202	100	29.7		
	2120		430					
8		52		66	40	37.6		
	2080		415					
9		62		74	40	32.8		
	2040		400					
10		134		147	60	24.1		
	1980		400					
11		40		42	12	16.5	Field profile starts here	
	1968.2		400				P.6	
12		159.2		170	60	20.5		
	1908.6		400				P. 7	
13		78.8		82	23	16.0		
	1886.0		400				P.8	
14		45.9		49	17	20.5		
	1868.9		400				P.9	
15		147.0		165	75	27.0		
	1794.0		400				P.11	
16		105.2		117	51	26.0		
	1742.7		420				P.12	
17		60.1		64	22	20.0		
	1720.8		450				P.13 Just above valley bottom	
18		13.7		14	3	11.5		
	1718		488				P.14 Beta Point	Beta
19		63.0		63	-1	-0.5		
	1718.5		490				P.15	
20		96.0		96	-1	-0.5		
	1719.4		490				P.16	
21		52.0		52	0	0.0		
	1719.4		490				P.17 Toe of slope, start of	
22		20.7		22	-8	-20.0		

Jumbo - Pink Panther Straightline								
Date:	20 February 2015					**Observers:**	AJ, GJ, CA	
Base Information:	TRIM Contours from DataBC WMS Field survey Dec 30, 2014.							
Air Photos:	15BCB81122							
Other Sources:	Google Earth							
Segment	**Elevation (m)**	**Horizontal Distance (m)**	**Width (m)**	**Slope Distance (m)**	**Vertical Distance (m)**	**Incline (deg)**	**Ground/Terrain Features & Comments**	**Alpha/Beta Points**
	1726.9		490				P.18 At road, 5 m wide	
23		5.0		5	0	0.0	Road	
	1726.9		490				P.19 at road cut slope	Alpha
24		27.1		31	-15	-29.0		
	1741.9		490					
25		93		100	-38	-22.3	Field profile ends here	
	1780		490					
26		80		89	-40	-26.6		
	1820		490					

Jumbo - Karnak (Lower Start Zone and Runup)								
Date:	13 March 2015				Observers:	CA, AJ		
Base Information:	TRIM Contours from DataBC WMS							
Air Photos:	15BCB81122							
Other Sources:	Google Earth							
Segment	**Elevation (m)**	**Horizontal Distance (m)**	**Width (m)**	**Slope Distance (m)**	**Vertical Distance (m)**	**Incline (deg)**	**Ground/Terrain Features & Comments**	**Alpha/Beta Points**
	2960		290				Top of main start zone	
1		68		91	60	41.4		
	2900		325					
2		37		54	40	47.2		
	2860		330					
3		85		104	60	35.2		
	2800		330				Bottom of main start zone	
4		56		69	40	35.5		
	2760		370					
5		200		233	120	31.0		
	2640		460					
6		194		239	140	35.8		
	2500		380				Start of main track, confined	
7		206		229	100	25.9		
	2400		240					
8		170		197	100	30.5		
	2300		330				Track is not confined below	
9		92		110	60	33.1		
	2240		330					
10		211		226	80	20.8		
	2160		320				Gully in lower track begins	
11		57		70	40	35.1	Wet flows channelled	
	2120		300					
12		155		184	100	32.8		
	2020		330					
13		241		261	100	22.5		
	1920		330					
14		184		194	60	18.1		
	1860		315					
15		225		246	100	24.0		
	1760		360				Top of runout, slight fan	
16		106		108	20	10.7		
	1740		400					Beta
17		135		136	20	8.4		
	1720		470					
18		18		18	0	0.0		
	1720		450				River	
19		49		53	-20	-22.2	Runup begins, dense flow	
	1740		450				Powder damage only above	Alpha
20		47		51	-20	-23.1	Signficant powder damage	
	1760		450					
21		41		46	-20	-26.0	Signficant powder damage	
	1780		450					
22		19		21	-10	-27.8	Signficant powder damage	

Jumbo - Karnak (Lower Start Zone and Runup)								
Date:	13 March 2015					**Observers:**	CA, AJ	
Base Information:	TRIM Contours from DataBC WMS							
Air Photos:	15BCB81122							
Other Sources:	Google Earth							
Segment	**Elevation (m)**	**Horizontal Distance (m)**	**Width (m)**	**Slope Distance (m)**	**Vertical Distance (m)**	**Incline (deg)**	**Ground/Terrain Features & Comments**	**Alpha/Beta Points**
	1790		450				End of powder damage	
23		95		107	-50	-27.8		
	1840		450				Segment for models only	

Appendix B: Summary of Assumptions for Models – Pink Panther Path

Dense Flow

PCM

	Start Zone	Track	Runout
μ	0.155	0.20-0.25	0.30
M/D	650 $m \cdot s^{-1}$	650 $m \cdot s^{-1}$	650 $m \cdot s^{-1}$

PLK

μ	0.25
Log (M/D)	2.70
R	0.30

LEM

Starting Segment	10
V_i	45 $m \cdot s^{-1}$
μ	0.5

DAN-W

Slab thickness	2.5 m		
Material Properties			
	Start Zone	**Track**	**Runout**
ρ	300 $kg \cdot m^3$	300 $kg \cdot m^3$	300 $kg \cdot m^3$
μ	0.155	0.155	0.2
ξ	1360 $m \cdot s^{-2}$	1360 $m \cdot s^{-2}$	1360 $m \cdot s^{-2}$
Erosion Depth	0.15 m	0.30 m	0.30 m
Internal Friction Angle	35°	35°	35°

AVAL-1D

d_o	2.5 m
ρ	300 $kg \cdot m^3$
ξ	2500 $m \cdot s^{-2}$
μ	0.16

Powder Flow

PCM

	Start Zone	Track	Runout
μ	0.155	0.155	0.100
M/D	700 $m \cdot s^{-1}$	700 $m \cdot s^{-1}$	700 $m \cdot s^{-1}$

PLK

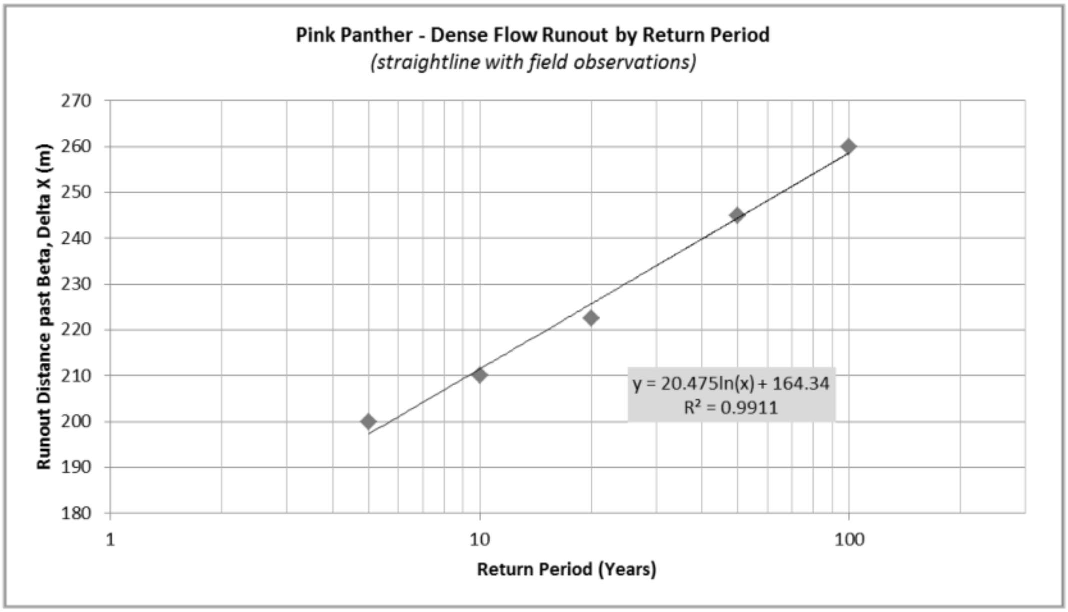
μ	0.20
Log (M/D)	2.90
R	0.40

AVAL-1D

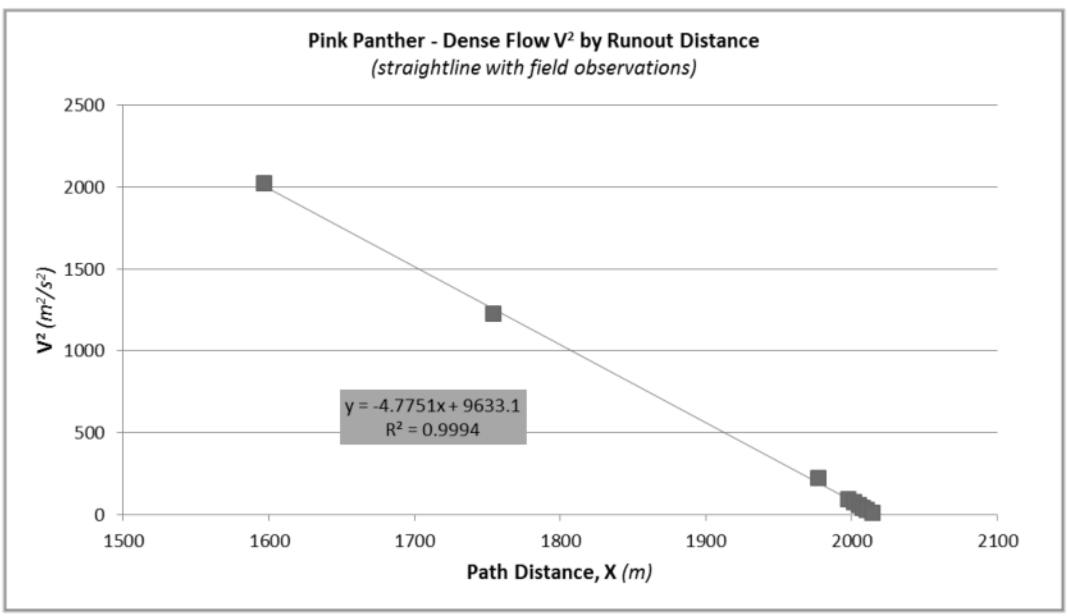
Erodible Snow Layer	
e	0.47-0.60
h	0.00-0.30
ρ	150
Release Zone	
do	1.5
ρ	250
s	0.1
Return Period	30 years
Region	Sudalpen

Appendix C: Summary of Runout-Return Period and Velocity Fitting

Dense Flow

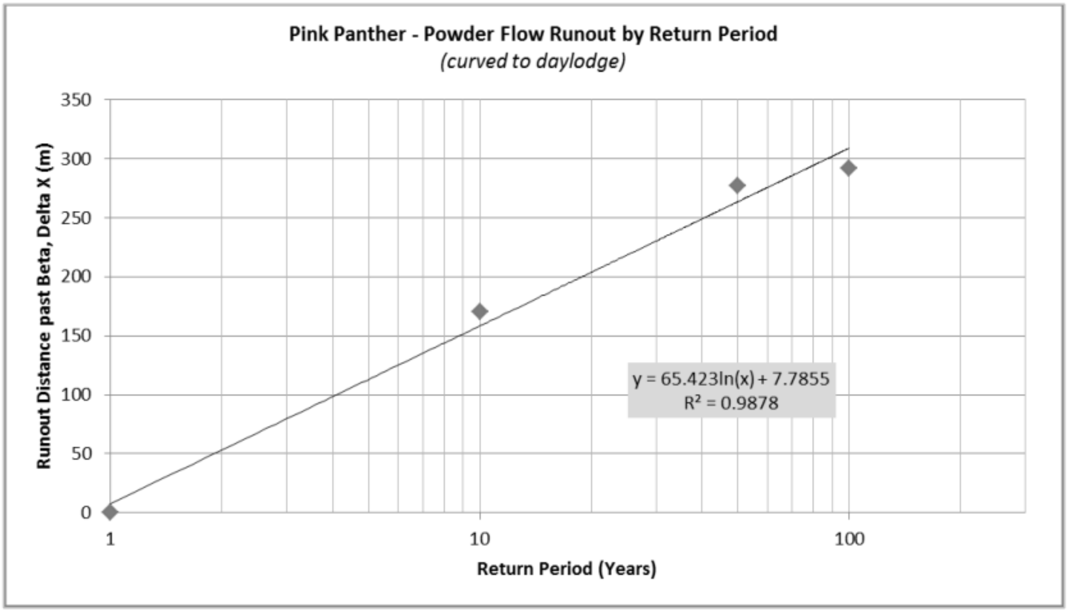


Runout ΔX *(m)*	Return Period *(years)*
0	1
200	5
210	10
223	20
245	50
260	100

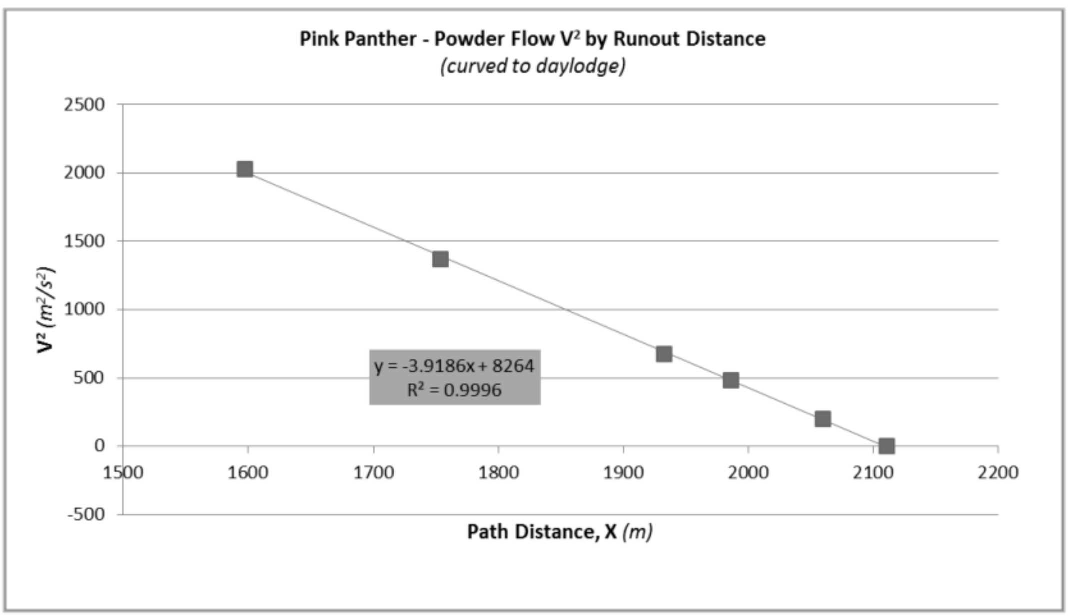


Runout ΔX *(m)*	Velocity *($m \cdot s^{-1}$)*
-157	45
0	35
223	15
244	9.5
248	8.5
251	7.5
254	6.5
256	5.5
260	3.5

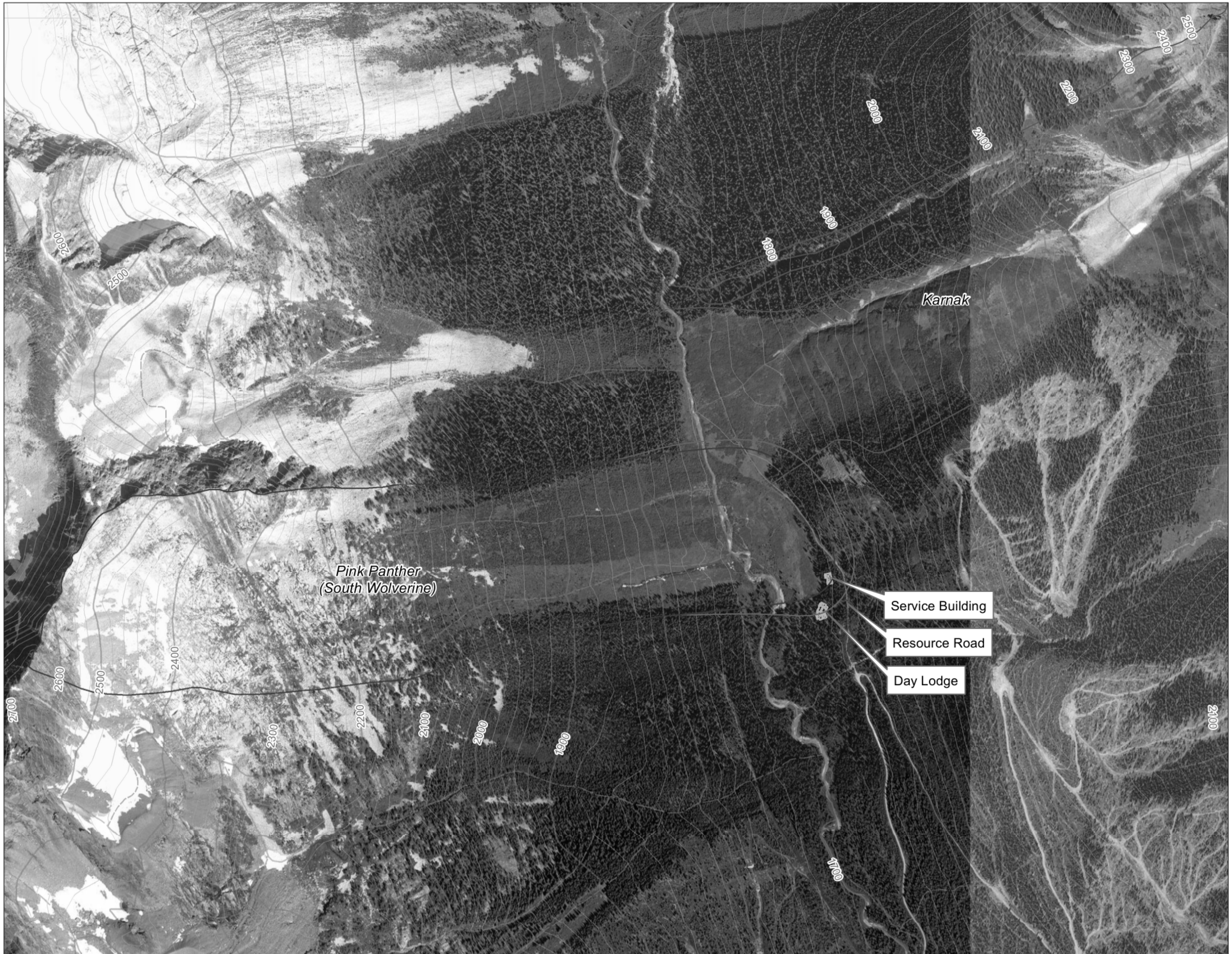
Powder Flow



Runout ΔX *(m)*	Return Period *(years)*
0	1
170	10
277	50
292	100



Runout ΔX *(m)*	Velocity *(m·s⁻¹)*
-157	45
0	37
179	26
232	22
306	14.1
357	0



Jumbo Glacier Resort

Day Lodge and Service Building Overview Map

Legend

Estimated Historical (~100-year) Avalanche Path Extent

Avalanche Risk Zoning

White Zone (Low Risk)

Blue Zone (Moderate Risk)

Red Zone (High Risk)

River

Building

Contour Line - 20 m

Index Contour

Intermediate Contour

Index Contour - Glacier

Intermediate Contour - Glacier

NOTES:

1. Map scale is intended for 11" x 17" (ANSI B) paper size. Actual scale may vary depending on printed paper size and printer settings.
2. Pink Panther White, Blue and Red avalanche risk zones determined according to CAA (2002) Guidelines for Snow Avalanche Risk Determination and Mapping in Canada.
3. Karnak avalanche path boundary represents the estimated limit of historical (100-year) avalanche effects.

Data Sources:

1. Daylodge and service building location provided by Pheidias Project Management Corp., received 12 December, 2014.
2. This map is to be read with the accompanying report "Snow Avalanche Risk Zoning: Jumbo Glacier Resort".
3. Base imagery from Bing Maps (imagery date 2005).
4. Contours from BC TRIM.

NORTH

Meters

0 125 250 375 500

Scale: 1:10,000

Contour Interval 20 m

Coordinate System: NAD 1983 UTM Zone 11N

Unit: Meter

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

Drawing Number:	14-0056-OBO-001
Date:	19/03/2015
Designed by:	Alan Jones, P. Eng
Reviewed by:	Greg Johnson, P. Eng
Drawn by:	Chris Argue, Dipl. T

Jumbo Glacier Resort
Day Lodge and Service Building Snow Avalanche Risk Zoning Map

Legend

Estimated Historical (~100-year) Avalanche Path Extent

Avalanche Risk Zoning

White Zone (Low Risk)

Blue Zone (Moderate Risk)

Red Zone (High Risk)

River

Building

Contour Line - 20 m

Index Contour

Intermediate Contour

Index Contour - Glacier

Intermediate Contour - Glacier

NOTES:
1. Map scale is intended for 11" x 17" (ANSI B) paper size. Actual scale may vary depending on printed paper size and printer settings.
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3. Base imagery from Bing Maps (imagery date 2005).
4. Contours from BC TRIM.

NORTH

Meters

0 30 60 90 120

Scale: 1:2,500
Contour Interval 20 m
Coordinate System: NAD 1983 UTM Zone 11N
Unit: Meter

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

Drawing Number:	14-0056-OBO-002
Date:	19/03/2015
Designed by:	Alan Jones, P. Eng
Reviewed by:	Greg Johnson, P. Eng
Drawn by:	Chris Argue, Dipl. T