

ESTIMATING EXTREME AVALANCHE RUNOUT FOR THE LIZARD RANGE, FERNIE, BRITISH COLUMBIA, CANADA

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ABSTRACT: Identifying the extreme avalanche runout is an important part of public safety for development in mountainous areas. Extreme avalanche runout is typically estimated using a combination of historical and vegetation records as well as statistical and dynamic models. The two main types of statistical models ($\alpha - \beta$ and Runout Ratio) are based on predicting runout past the β -point, which is generally defined as the point where the slope angle first decreases to 10° while descending the slope. Statistical models are commonly used for avalanche hazard mapping in Canada; however, the existing models cover broad geographical areas and may not accurately predict runout in some development areas. Located in southeastern British Columbia, the Lizard Range is a sub-range of the Canadian Rocky Mountains. Numerous recreational and residential developments are located in this area including the City of Fernie. Likely because of the heavy snowfall in this area, residential development in mountainous terrain in this area is intense. Possibly due to the heavy snowfall in this area, the existing statistical models for the Canadian Rocky Mountains tend to underestimate extreme avalanche runout for this area when compared to field evidence of extreme runout. Using a data set of 28 avalanche paths with vertical drops greater than 350 m, we use the existing Canadian statistical models to show how these models underestimate extreme avalanche runout for the Lizard Range.

1. INTRODUCTION

In Canada, avalanche hazard to structures and utilities is commonly mitigated by identifying and avoiding areas threatened by avalanches. Hazard mapping professionals commonly use a combination of field studies, terrain analysis, and research of historical records along with statistical and dynamic models to define extreme avalanche runout. When available, the extreme runout point predicted by statistical and dynamic

models is compared to field observations (vegetative damage) for accuracy.

There are two classes of statistical models which are commonly used in Canada: the alpha-beta (Lied and Bakkehoi, 1980) and runout ratio models (McClung et al., 1989). Both models are based on predicting avalanche runout past the beta point, which is generally defined as the point where the slope angle first decreases to 10° while descending the slope (Figure 1).

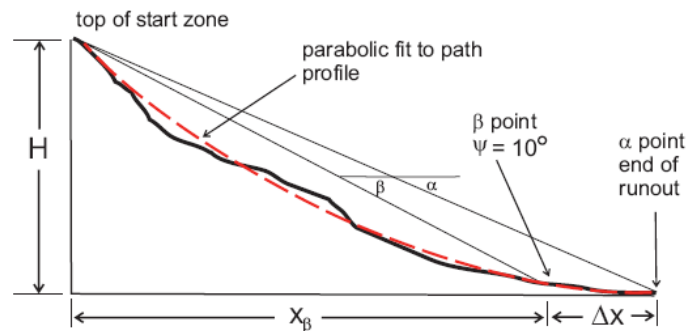


Figure 1: Geometry and parameters used to derive the alpha-beta and runout ratio models (after CAA, 2002).

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The alpha beta model was first developed by Lied and Bakkehoi (1980), using data from 192 Norwegian avalanche paths with well defined extreme runout positions. They found that beta was the only significant predictor and since then, alpha-beta models have been developed by others for other mountain ranges in Europe and North America.

The runout ratio model was first developed by McClung et al. (1989) by applying extreme value statistics to avalanche runout data. McClung et al. (1989) found that the runout ratio for extreme events ($\Delta x/X_\beta$) obeyed a Gumbel (extreme value) distribution, and that the Gumbel parameters u and b could be used to predict extreme runout for specific non-exceedence probabilities in a given path. The non-exceedence probability, P , is defined as the fraction of avalanche paths in a particular mountain range that do not exceed a specific runout ratio.

In Canada, the parameters for these models have been defined based on large geographical areas: the Coast Mountains (Nixon and McClung, 1993) and the combined Rocky/Purcell Mountains (McClung et al., 1989). A Columbia Mountains model has also been developed by Delparte et al. (2008); however, the runouts predicted in this model are based on a 40 year observation period and may not represent extreme runout. In addition, a Canada-wide short slope model (Jones and Jamieson, 2004) has been developed for slopes with less than 350 m vertical drop, with the beta point defined as where the slope first reaches 24° rather than 10° .

The Lizard Range is a sub-range of the Canadian Rocky Mountains and is located in the southeastern corner of British Columbia near Fernie, BC (Figure 2).

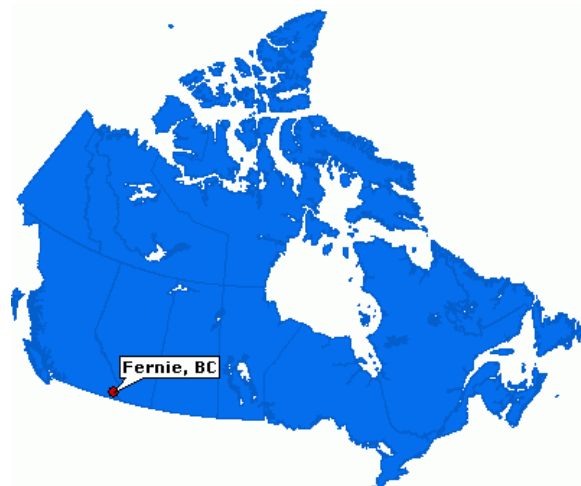


Figure 2: Map of Canada with the location of Fernie, British Columbia.

There are numerous residential, recreational and industrial developments in mountainous terrain in this area. Unlike the central and northern Rocky Mountains which are characterized by a continental snow climate (cold, thin snowpack), the Lizard Range is known for having more of a transitional snow climate with milder temperatures, and a deeper snowpack (McClung and Schaerer 2006). Claus et al. (1984) refer to this climate as “Rocky Mountain Wet”. Haegeli and McClung (2007) suggest that there may be a north-south division in snowpack characteristics within the Rocky Mountains.

Avalanche hazard mapping professionals conducting work in this region have anecdotally indicated that the existing Rocky/Purcell Mountain statistical models tend to underestimate extreme avalanche runout when compared to field observations.

The overall intent of this study is to derive alpha-beta and runout ratio parameters for the Lizard Range based on a statistical analysis of avalanche paths in the area. These models can be used by hazard mapping professionals in the future to estimate extreme avalanche runout for projects in the Fernie region.

2. METHODS AND ANALYSIS

2.1 *Study Area and Site Selection*

Local knowledge suggests that the heavy snowfall area around Fernie may not be limited to the Lizard Range; however, for this study, we have only used avalanche path data from the Lizard Range. Future analysis may include avalanche path data from outside the Lizard

Range, but within the South Rocky Mountain heavy snowfall area.

The avalanche path profiles used for this study included paths with little to no uphill runout and paths that are not confined or channelized in the track and runout zone. The paths selected for field surveying were also chosen based on ease of access (road or trail access) and having a mature vegetation record in the runout zone (minimal logging or fire in the runout zone). Since the overall intent of this study is to develop statistical models for tall paths in the South Rockies, the field surveys were limited to paths with a vertical fall height larger than 350 m.

2.2 *Field Methods*

Based on the avalanche path characteristics described above, avalanche paths were identified using digital imagery from Google Earth (Version 5.1, 2010). Topographic maps (1:20,000) with 20 m contour intervals were obtained and used to estimate the initial boundaries of the avalanche paths and to calculate slope angles and slope segment lengths from the top of the starting zone to past the extreme runout position. Prior to the field survey, the beta point location was initially estimated from the topographic maps.

The field survey was conducted in June 2010, and involved measuring slope angles and slope

segment lengths from above the beta point to a point beyond the extreme runout position (alpha point). A clinometer was used to measure the slope segment angles and a laser rangefinder or hip chain to measure the slope distances. GPS waypoints and altimeter readings were also collected at the ends of each slope segment. Laser rangefinder and hip chain data were used as the primary measurement of slope segment length, and GPS waypoints were substituted when these were not available. The alpha point was identified in the field by observing vegetative growth and damage in the runout zone. The beta and alpha angles were measured in the field where possible, and calculated from the topographic slope profile where vegetation and/or weather prevented taking a field measurement.

The intent of the runout survey was to identify the runout location of the 100 year event; however, the true runout event identified is likely on the order of 30 – 300 years (McClung et al., 1991), introducing random error into the analysis.

2.3 *Analysis*

Specific parameters for the existing alpha-beta and runout ratio models in Canada along with the number of paths used to develop the models are summarized in Table 1.

Table 1: Comparison of statistical model parameters for Canadian mountain ranges.

Area	Alpha Beta				Runout Ratio					Reference
	a	R ²	Se	n	u	b	R ²	Se	n	
Coast Mountains	0.90	0.74	1.70	31	0.096	0.092	0.96	0.021	20	Nixon and McClung, 1993
Rocky and Purcell Mountains	0.93	0.75	1.75	53	0.092	0.065	0.97	0.012	53	McClung et al., 1989
Columbia Mountains	0.9	0.89	1.1	35	-	-	-	-	-	Delparte et al., 2008
Canadian Short Slopes ($H < 350$ m)	-	-	-	-	0.494	0.441	0.98	0.080	46	Jones and Jamieson, 2004

For this preliminary analysis, we have used the existing statistical models to illustrate the limitations in predicting extreme runout for the Lizard Range. Extreme avalanche runout was calculated for the Fernie data set using the alpha

beta and runout ratio models for the Canadian Rocky/ Purcell mountains and for the Canadian Coast mountains. For comparison, we calculated extreme runout for both the 50% non-

exceedence probability, P(0.5), and the 85% non-exceedence probability, P(0.85).

3. DATA

In total 28 paths were analyzed, including 12 path surveys from the Cedar Creek Valley, 6

path surveys from the Lizard Creek Valley, 5 path surveys conducted for various land development projects in the area and 5 path surveys from Mt. Fernie. Descriptive statistics for the path surveys are provided in Table 2.

Table 2: Descriptive statistics for the Lizard Range avalanche paths.

	Mean	Standard Deviation	Range of Values	
			Minimum	Maximum
α	23.2	2.1	19.8	27.8
β	26.1	2.8	20.5	33.7
δ	9.1	3.0	2.4	16.1
y'' (m^{-1})	1.6×10^{-4}	7×10^{-5}	7.40×10^{-5}	4.10×10^{-4}
H (m)	793	122	400	1000
Δx (m)	326	183	10	880

For comparison, the mean alpha angles for the Canadian Rockies and British Columbia Coast Mountains are summarized in Table 3.

Table 3: Mean alpha angles and number of paths for three Canadian mountain ranges.

Range	Mean α ($^\circ$)	n
Rocky and Purcell Mountains	27.8	125
Coast Mountains	26.8	31
South Rocky Mountains	23.2	28

Lower alpha angles imply longer runout distances compared to vertical drop and the mean alpha angle of 23.2 $^\circ$ for the Lizard Range data indicates longer running avalanches in the Lizard Range when compared to the Rocky and Purcell and Coast Mountain data.

4. RESULTS

A summary of mean Δx , or distance between the calculated extreme runout position and the beta point using the alpha-beta and runout ratio models for the Canadian Rocky/Purcell Mountains and Coast Mountains is provided in Table 4.

Table 4: Summary of mean runout distances from Coast Mountains and Rocky/ Purcell Mountain models.

	Alpha Beta		Runout Ratio		Field Observed Mean
	P(0.5)	P(0.85)	P(0.5)	P(0.85)	
	m	m	m	m	
Rocky/ Purcell Mountain Model	208	522	158	312	326
Coast Mountain Model	314	764	197	399	

Using the Rocky Mountain alpha-beta model, these data show that extreme runout in the Fernie area is generally underestimated for 50% non-exceedence probability and overestimated for the 85% non-exceedence probability. Using

the Coast Mountain alpha-beta model, extreme runout is slightly underestimated for the 50% non-exceedence probability and overestimated by a factor of 2 for the 85% non-exceedence probability.

Extreme avalanche runout predictions using the runout ratio model show that extreme avalanche runout is underestimated using the Rocky/Purcell Mountain runout ratio model for both the 50% and 85% non-exceedence probabilities. Using the Coast Mountain runout ratio model, extreme runout is underestimated for the 50% non-exceedence probability and overestimated for the 85% non-exceedence probability.

5. DISCUSSION AND CONCLUSIONS

This paper presents the preliminary analysis and results and illustrates how the existing runout models underestimate extreme runout for the Lizard Range.

This paper presents an initial analysis of 28 avalanche paths in the Fernie area of British Columbia. Predictive runout modelling using the Rocky/Purcell Mountain and Coast Mountain statistical models shows that these models may not be suited for predicting extreme avalanche runout in the Lizard Range. Both of these models appear to underestimate extreme runout in this region.

A possible explanation for the longer running avalanches in the Fernie area is that the region has higher snowfall than other parts of the Rocky and Purcell Mountain ranges. Local knowledge suggests that the area immediately around Fernie receives anomalously high snowfall when compared to other areas in the Rockies. For example, Environment Canada climate normals for the area show that the average annual snowfall in the Fernie area is 357 cm, while just 30 km to the north in Sparwood the average annual snowfall is 248 cm.

Another possible explanation for this discrepancy is that existing Canadian statistical models are for mountain ranges which cover very broad geographical areas. Both the Coast and Rocky/ Purcell mountain ranges extend for hundreds of kilometres in an east west direction and over 1000 km north/south. Data collected for this project are limited to an area within 12 km of Fernie.

More avalanche paths need to be surveyed to derive alpha-beta and runout ratio parameters unique to the Lizard Range. In addition, the relationship between snowfall and runout in the Rocky Mountains using snowfall and runout data from Fernie and Sparwood needs to be investigated to provide a useful tool for hazard

mapping professionals to predict extreme runout in the Fernie area.

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