Case study of a large snow avalanche in the Selkirk Mountains and reflections on the Canadian size classification

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ABSTRACT

We review a large avalanche in the Columbia Mountains that prompted discussion about the 5-level size classification that has been used since 1981. The results of a practitioner survey and a large dataset of avalanches near BC highways are used to reflect on the 1981 size classification. The emphasis on destructive potential in the 1981 classification has important advantages but the typical values of deposit mass or volume of Size 4 and 5 avalanches are lower than for other classifications and lower than the data from BC highways. The survey showed good consistency between respondents when using the full sizes (5 levels) or half-sizes (9-10 levels).

RESUME

Nous passons en revue d'un grand avalanche dans la chaine Columbia qui a ouvert une discussion au sujet de la classification de taille de 5 niveaux qui a été utilisée depuis 1981. Les résultats d'une enquête sur les professionnels et d'un traitement de données d'avalanches près des autoroutes en Colombie-Britannique sont utilisés pour réviser le classement 1981 de taille. L'accent sur les capacités de destruction du classement 1981 présente des avantages importants, mais les valeurs typiques d'accumulation de masse ou de volume de taille 4 et 5 avalanches sont plus faibles que celles des autres classifications et inférieurs aux données des autoroutes Colombie-Britannique. L'enquête a montré une cohérence entre les tailles complètes (5 niveaux) ou demi-tailles (9-10 niveaux).

1 INTRODUCTION

On the morning of 15 February 2011, a large dry slab avalanche ran down the south face of Mt. Tumbledown into Carnes Creek northeast of Revelstoke, BC. Observations of the forest damage, runout length and dimensions of the deposit indicated it was a Size 5 according to the “Canadian” size classification scale (McClung and Schaerer 1981, denoted MS 1981). In spite of the documented forest damage and deposit dimensions, practitioners debated whether it was a Size 5. Some argued that in Canada Size 5 avalanches only occur in the Himalayas or Bear Pass in northwestern BC. We review this well documented avalanche in Section 2.

This paper focusses on the classification of avalanche size based on destructive potential, which has its origins in a 3-level scale in USDA (1961, p. 25) and perhaps earlier documents. This evolved into a 5-level scale of destructive potential (e.g. Perla, 1980). MS 1981 used data from 744 avalanches at Rogers Pass over two winters to calibrate their 5-level scale. For reviews of other classification scales including the R-scale in which avalanches are rated relative to the path, see McClung and Schaerer (1981, 2006, p. 322).

The MS 1981 scale has had remarkable success over the last 33 years. It has been adopted in Canada, New Zealand and Iceland as well as United States where it is an optional supplement to the R-scale. Recently, Moner et al. (2013) have recommended its adoption in Europe. The 5-level classification is based on the destructive potential. For damage to objects such as cars, trees or people, observers should imagine the object in the track (middle portion of the path) where velocity and impact pressure (components of destructive potential) reach a maximum (Table 1). This position of the imaginary object has also been interpreted to be the start of the runout zone. Although the levels of destructive potential for the five classes are quite different —some factors increase tenfold — the classification into one of five levels requires experience. However, many avalanche practitioners have limited experience with the Size 4 and 5 avalanches, and others, such as some foresters and engineers, may find the subjective estimation of destructive potential to imaginary objects be challenging. Some have questioned why deposit volume or mass, which can be quantitatively estimated or measured, is not used to define avalanche size. Others have questioned whether the typical deposit mass associated with (but not defining) the larger sizes of avalanches is sufficiently high. To address these questions, we present the results of a survey of practitioners in Section 3 and a comparison of deposit volumes from different sources in Section 4.

The objectives for this study are:

1. To present a case study of a large avalanche illustrating the estimation of destructive potential, deposit volume and mass as well as application of MS 1981 size classification.
2. To present the variability/consistency of size ratings from a survey of avalanche practitioners. This survey includes the use of half-sizes, which

McClung and Schaerer (1981, 2006) proposed is impractical due to uncertainty in the classification of destructive potential.

3. For each of the avalanche sizes, to compare the associated deposit volume from different sources, including a large dataset of avalanches near BC highways.
4. To discuss the merits of a classification defined by destructive potential vs one defined by deposit mass or volume.

Table 1. Classes of avalanche size by destructive potential[1]

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

[1] McClung and Schaerer 1981, 2006, p. 322

Figure 1. Annotated photo of the 15 February 2011 avalanche showing the boundary of the dense flow (solid black line), damage from the suspension layer (orange dashed line) and evidence of an air blast or suspension layer (dotted pink line). The top and bottom elevations of the avalanche were 2660 and 1310 m.

2 CASE STUDY: TUMBLEDOWN MOUNTAIN, 15 FEBRUARY 2011

On the morning of 15 Feb 2011, a large dry slab avalanche released spontaneously on the south face of Mt. Tumbledown in the Selkirk Mountains north of Revelstoke, BC. The maximum width of the slab was about 600 m (Figure 1). The crown height averaged about 4 m and reached a maximum of about 8 m. It ran from elevation 2660 m to 1310 m over a distance of 3 km, roughly 1 km farther than the longest known runout in this path. It destroyed about 3 hectares of forest on the south face of Tumbledown then flowed to the southwest along Carnes Creek where it destroyed another 17 hectares of forest

(Figures 1 and 2). Many of the destroyed trees along Carnes Creek were over 200 years old.

The deposit was about 650 m long in the gully on Tumbledown south and extended 1150 m along Carnes Creek (Figure 2). The deposit was up to 260 m wide and up to 32 m deep. It was not fully melted until the summer of 2012. (The deposit depths are based on a difference of readings from a GPS with an aneroid altimeter using a reference point near the bottom of the deposit. Estimated accuracy of depths is ± 2 m.)

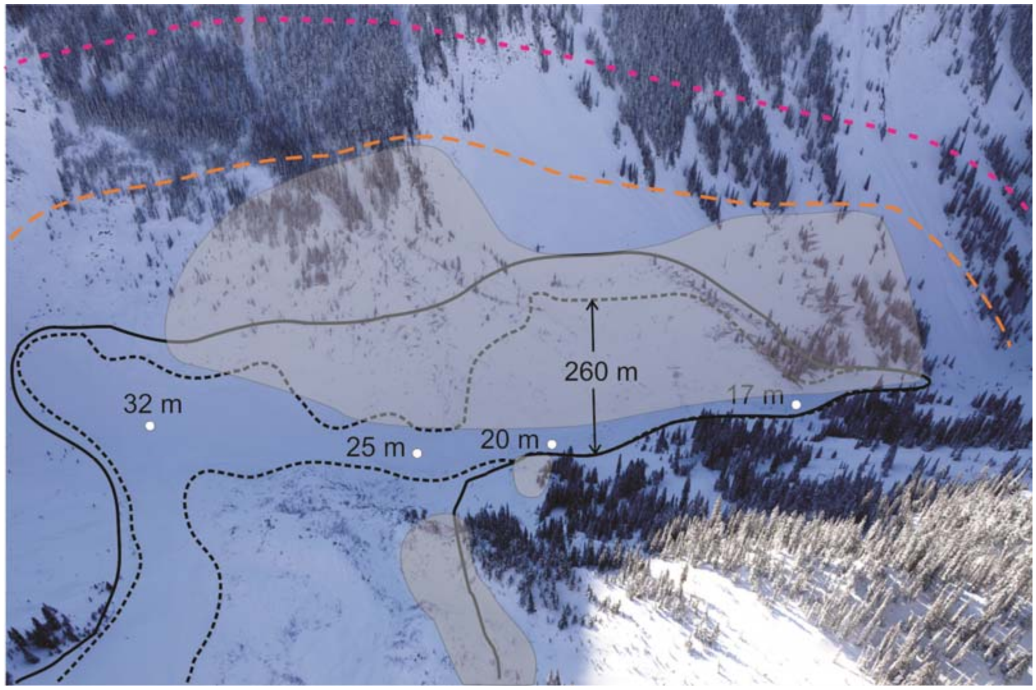

Figure 2. Annotated photo of the lower part of the avalanche on 15 February 2011 showing the boundary of the dense flow (solid black line), damage from the suspension layer (orange dashed line), evidence of an air blast or suspension layer (dotted pink line), perimeter of deposit (dotted black line), depth measurements (white dots). Twenty hectares of forest were destroyed within the shaded areas.

This avalanche prompted discussion among avalanche practitioners about whether the avalanche was a Size 5. Measurements showed that 20 hectares of forest – including many trees over 200 years old along Carnes Creek – were destroyed. The path boundaries show the avalanche had the destructive potential to destroy a similar area of forest where more frequent avalanches inhibited regrowth. The avalanche ran 3 km. The area of the deposit was approximately 20 hectares (~1000 m x ~150 m + ~650 m x ~70 m). Point measurements of depth (based on difference of altimeter readings) shown in Figure 2 suggest an average of about 20 m. Even if there had been 3 m of snow on the ground prior to the avalanche, this suggests a deposit volume of 3,300,000 m^3. Using the deposit density in the range of 400 to 600 kg/m^3 in Table 2, this yields mass estimates of 1.3 to 2 x 10^6 t). Even if the deposit depth had averaged 10 m, this yields mass estimates of 8 to 12 x 10^5 t. Looking at Table 1, we see that the avalanche satisfies the text description of destructive potential for a Size 5 avalanche. It also satisfies the typical length and exceeds the typical mass. Dynamics modeling indicates the avalanche reached a speed of about 60 m/s and an impact pressure of about 900 kPa at about 2100 m. Although impact pressure is rarely considered in estimating avalanche size, this avalanche approximates the typical impact pressure for Size 5 avalanches from Table 1. The avalanche far exceeds the values for a Size 4 avalanche in Columns 2 to 5 of Table 1. In the Discussion, we return to why practitioners may have been hesitant to classify this and other avalanches of similar magnitude as Size 5s.

Table 2. Estimated density and volume ranges for the typical deposit masses from MS 1981.

Size	Typical mass (t)	Est. density[1] (kg/m^3)	Est. typical[1] volume (m^3)
1	10	100-250	40-100
2	100	150-300	300-700
3	1000	200-400	2,500-5,000
4	10000	300-500	20,000-35,000
5	100000	400-600	150,000-250,000

[1] the higher values of density and lower values of volume are for wet deposits.

3 THE PRACTITIONER SURVEY

Moner et al. (2013) conducted a survey in which European and North American practitioners rated the size of 18 avalanches using the classification with which they were most familiar. At the time of the 2013 publication, there were only nine respondents using the 1981 scale. That number has now grown to 22, each of whom classified the size of the 18 avalanches in the survey. All these respondents were experienced avalanche practitioners familiar with the MS 1981 size classification.

3.1. Integer size scale (5+ levels)

In the first part of the survey, the respondents used the integer scale from 1 to 5. Two respondents classified the smallest avalanche (#17) as a Size 0 and one respondent did not classify #17.

We were interested in the consistency between respondents. Figure 3 shows the quartiles for each avalanche in the survey. For each avalanche, the median equalled the mode. The percentage of respondents who agreed on the size (selected the mode) varied from 59% for avalanche #6 to 91% (#18) and averaged 79%. All of the respondents rated the size within 1 level of the mode for all 18 avalanches. Since the scale is ordinal, the spread could be different for different ordinal values; however, this is not apparent in the limited dataset shown in Figure 3.

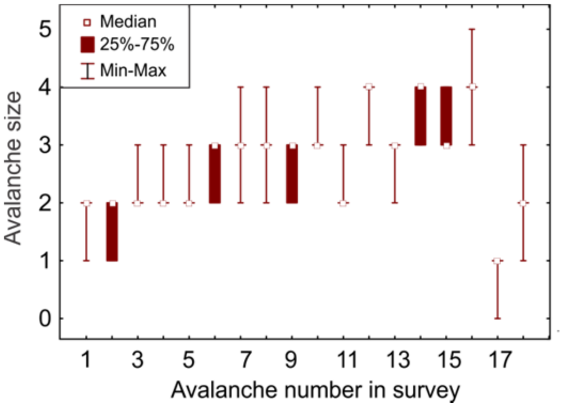

Figure 3. Box plots of the size ratings (integer scale) for the 18 avalanches in the survey.

3.2. Half-size scale (9+ levels)

In the second part of the survey, the 22 respondents classified the same 18 avalanches using the half-size scale. Although MS 1981 asserted that uncertainty in classifying avalanche size would limit the classification to the five integer levels, practitioners often use the intermediate levels 0.5, 1.5, 2.5, 3.5 and 4.5. Half sizes from 1.5 to 4.5 are recognized in CAA (2007) but 0.5 is not. The use of half-sizes in the survey was popular with practitioners; the percentage of half-size ratings per respondent ranged from 17% to 61% and averaged 44%.

Again, we focused on consistency of the ratings. Figure 4 shows the quartiles for each avalanche in the survey. Except for avalanche #6, the mode and median were equal. The percentage of respondents who agreed on the size (selected the mode) varied from 41% for avalanche #15 to 77% (#1, #8, #12, #13) and averaged 62%. All of the respondents rated the size within 1 level of the mode. For the 18 avalanches, 95 to 100% (average 97%) of ratings were within a half-size of the mode.

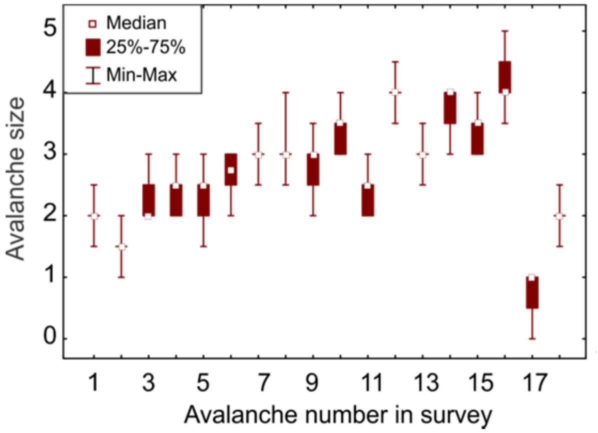

Figure 4. Box plots of the size ratings (half-size scale) for the 18 avalanches in the survey.

4 DEPOSIT VOLUME BY SIZE

MS 1981 give the typical deposit mass for each size. Other classifications of destructive potential (e.g. Perla 1980; European scale in Moner et al. 2013) state the deposit volume for each size. To compare the deposit quantity, we estimate the range of deposit volume from the typical masses in MS 1981 using the range of densities for each size in Table 2.

Figure 5 includes deposit volumes by size for a large dataset from MoTI. The volumes are based on the product of estimated width, length and depth of the deposit. Average values should be recorded, although some observers may have recorded maximum values for width and length. Some of these estimates may be from a distance or made during poor visibility. Table 3 compares estimated and measured deposit volumes for five avalanches between Size 4 and 5. For four of the avalanches, the estimated average depth was used for the measured volume so only the deposit area was determined accurately. The estimations exceed the measured deposit volumes by 2 to 178% and average 86%. We expect many of the estimated deposit volumes in Figure 5 may be twice the actual values. This will have a small effect on the size classification in which deposit mass or volume increases by approximately a factor of 10.

The wide range of deposit volume for specific sizes in Figure 5 suggests some dimensions may have been recorded inaccurately. Consequently, we focused on the interquartile range and median values for each size.

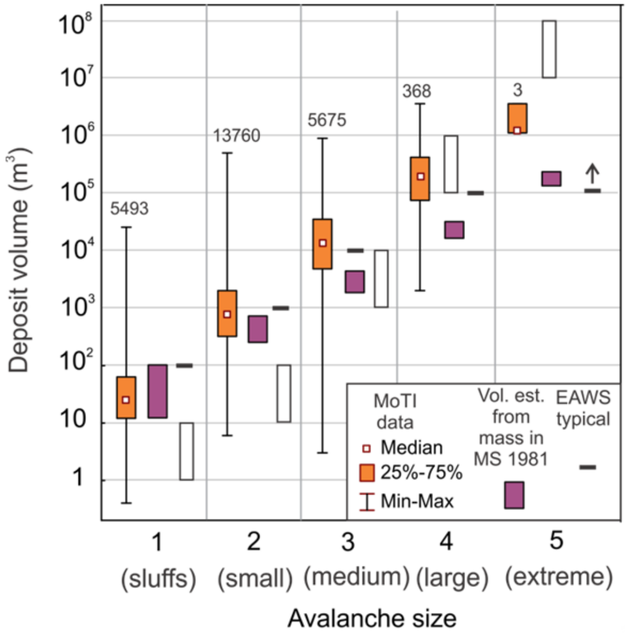

Figure 5. Avalanche volume by size. Orange boxes with whiskers are from BC MoTI data. Half-size avalanches not shown. Numbers above the whiskers indicate the number of avalanches. Purple boxes are the volume ranges estimated from typical mass (MS 1981) and the ranges of typical deposit density in Table 2. Black bars are typical volume from European Avalanche Warning Services (Moner et al. 2013). White boxes are ranges from Perla (1980); labels in parentheses below numerical sizes are from Perla (1980).

Figure 5 shows a strong correlation between deposit volumes and avalanche size, indicating the importance of the deposit mass or volume in the size classification.

Keeping in mind that the mid-range deposit volumes – at least for Size 4 and 5 avalanches - in the MoTI dataset (Figure 5) may be twice the actual values, we compared the mid-range values for these large avalanches with measured volumes from other sources. Naaim et al. (2010) provide deposit volumes (± 20-30%) for 49 avalanches in the unusually large Taconnaz path near Chamonix, France. Since 1900, there have been 29 avalanches with a deposit volume > 10^5 m^3 including five with a deposit volume > 10^6 m^3. (Each of these 29 avalanches ran at least 5 km.) Hence in 110 years, this single large path has produced five deposits consistent with mid-range deposits of the MoTI Size 5 avalanches and five to ten times greater than the typical value for Size 5 avalanches. Further, the 2011 Size 5 from Mt Tumbledown (Section 2) had a deposit volume of ~ 10^6 m^3. For Size 4 avalanches, Alan Jones of Dynamic Avalanche Consulting provided measurements of four such avalanches in the Montrose path in the South Coast Range of BC with deposit volumes between 1.9 x 10^5 and 2.5 x 10^5 m^3 (average 2.2 x 10^5 m^3). Hence, while the low and high values in the MoTI dataset may involve errors, the mid-range deposit volumes for Size 4 and 5 avalanches are consistent with some measured deposits from other sources.

We also compared the deposit volumes from the MoTI dataset with three classifications of destructive potential in Figure 5: Perla (1980), MS 1981 and EAWS (Moner 2013). These show the best agreement for deposit volumes for Size 3 avalanches. For Sizes 1 and 2, Perla's (1980) volume ranges are lower than from the other sources. For Size 4 avalanches, deposit volume estimates from the typical masses in MS 1981 are roughly an order or magnitude lower than MoTI data, and Perla's (1980) typical volume, and substantially lower than the EAWS typical volume. For Size 5 avalanches, deposit volumes from MS 1981 are an order of magnitude lower than the MoTI data and two orders of magnitude lower than the range from Perla (1980). With regard to the MoTI data, underestimation of the destructive potential could have increased the mid-range estimates of deposit for Size 4 and Size 5 avalanches. We return to this matter in the Discussion.

Table 3. Comparison of measured and estimated deposit volumes for five large avalanches at Bear Pass

Path	Date	Size	Average deposit depth (m)	Deposit volume		
				Measured (m^3)	Estimated (m^3)	Overestimation (%)
Strohn 35.1	11 May 1992	4	3 est.	477,000	675,000	42
E. Strohn 35.5	10 Apr 2001	4.5	8 meas.	1,335,700	2,444,000	83
Entrance 37.7	6 Jan 2003	4.5	5 est.	495,000	1,375,000	178
Gunner 40.4	21 Nov 2011	5	3 est.	1,179,000	1,200,600	2
E. Strohn 35.5	23 Jan 2011	4	3 est.	282,000	630,000	123

5 DISCUSSION

5.1 Potential classification biases

When an avalanche is initially observed and its size classified from a distance, e.g. from a helicopter or across the valley, and then subsequently classified on site, the initial classification is often low. This is our experience and has been reported by many experienced observers. (Similarly, we have often underestimated the height of crown fractures from a distance and suspect this occurs for other experienced observers.)

When estimating size, focusing on the runout zone is appropriate for the deposit mass or volume, or the size of an object that could have been buried. However, for estimating the destructive effect on an object, observers should imagine the object in the track or start of the runout zone. Also, when estimating the area of potential forest damage for Size 4 or 5 avalanches, the track and runout zone should be considered. Hence, assigning a size based only on runout zone observations and interpretations could lead to underestimation of size.

Avalanches that measurements proved to be Size 5 were often initially classified as Size 4 or 4.5, even by observers who walked on the deposit when visibility was good. This reluctance to classify avalanches as Size 5 may be due to the phrase “Largest snow avalanches known” (Table 1), which creates the impression that such avalanches only occur rarely in mountains such as the Himalayas. However, Perla’s (1980) size classification as well as measured deposit volumes from the Taconnaz path in the French Alps suggest that deposits from extreme avalanches may be an order of magnitude larger.

Deposit volume or mass is often an important factor in classifying avalanche size according to MS 1981. As noted in Section 4, when deposit volume is based on the product of deposit width, length and depth, the volume tends to be overestimated. Limited data in Table 3 suggests it may average almost twice the actual value. Calculating the deposit area as an ellipse will tend to reduce this overestimation, but only by about 20%.

5.2 Use of mass or volume instead of the more subjective component of destructive potential

MS 1981 proposed a scale for avalanche size based on “all observables” that would help estimation of the destructive potential. For estimating the damage to people, cars or trees, the observer should imagine the object in the track or beginning of the runout zone. They noted that “mass is not the only important variable.” Over the decades since 1981, some have argued that a wider variety of observers could better estimate mass or volume of the deposit than the destructive potential, which requires experience with avalanches of various sizes. For example, Weir (2002, p. 18) provides an example that interprets the classification in terms of avalanche mass only. However, over the last two decades, risk concepts and analysis have been increasingly applied to avalanche work. The destructive potential scale in MS 1981 has proven to be a valuable index of vulnerability (e.g. Weir 2002; Canadian Avalanche Association 2002; Jamieson and Jones 2012).

Also, avalanche practitioners, many of whom have considerable experience with Size 1, 2 and 3 avalanches may be less accurate when estimating the size of large avalanches for which they have limited observations. We agree, but note that an order of magnitude will suffice for most variables and that the multi-variable approach will tend to reduce classification uncertainty.

Given the value of the size classification based on destructive potential for the many risk-based applications and the sufficiency of order-of-magnitude estimates, we support the “all observables” approach to destructive potential the 1981 scale. Only when an observer’s uncertainty regarding the potential damage to objects is large should the observer focus on deposit mass or volume.

5.3 Use of deposit volume instead of mass

MS 1981 chose deposit mass instead of deposit volume since mass is a component of force in Newton’s Second Law and hence it should be more indicative of destructive potential than deposit volume (D. McClung, pers. comm., 2014). However, deposit mass cannot be measured; it is always calculated from volume and density measurements or, more often, density estimates. Sufficient density measurements over the area and depth of a deposit are rarely done. Almost always density is estimated or taken from tables such as Table 2. The size classification should not be highly sensitive to the density ranges for each size since these vary by a factor or two or less and the typical mass for different sizes differ by an order of magnitude. The advantages of using mass (over volume) in the scale include: mass is more closely related to destructive potential; and the acceptance of the 1981 scale by several countries. Notably, the other scales in Figure 5 use volume to quantify the deposit.

5.4 Changes to the typical mass in the 1981 scale

For Sizes 1 and 2, Figure 5 shows reasonable agreement between the volume estimates derived from MS 1981, the European Avalanche Warning Service (EAWS), and the mid-range data from BC MoTI. For Size 3, the typical range of deposit volume estimates derived from MS 1981 is below the mid-range estimates from MoTI data and EAWS. However, for the Size 4 and 5 avalanches, the typical range from MS 1981 is substantially below the MoTI data and the typical values from Perla (1980). For Size 5, EAWS only provides a minimum value. However, for Size 4 the EAWS value is also above the typical range from MS 1981.

For Size 4 and 5 avalanches, MoTI data could be above the MS 1981 range because the observers have systematically overestimated deposit dimensions or underestimated destructive potential, or because the typical values for the larger sizes from MS 1981 are low.

Arguments supporting larger typical values of deposit volume or mass for Size 4 and 5 avalanches:

- The mid-range deposit volumes from MoTI are consistent with a small number of measured values from other sources. This is true even if the mid-range deposit volumes are reduced by a factor of two to account for overestimation of the deposit area.

- While it is possible that MoTI observers have systematically underestimated the destructive potential to objects, the MoTI size ratings were determined by more than 75 experienced observers over three decades so their ratings could be considered representative of avalanche practitioners. Further, there are major differences in destructive potential to objects for the different sizes of avalanches which will tend to reduce classification uncertainty.
- MS 1981 noted that to calibrate their scale, they used data from the highway corridor in Glacier National Park where explosive control reduces the deposit mass and increases the frequency of avalanches.
- Perla's (1980) typical volumes are substantially larger for Size 4 and 5 avalanches, and EAWS's typical value is larger for Size 4 avalanches (and says little about the typical volume of Size 5 avalanches).
- While the typical deposit area is not part of the definitions in MS 1981, it is likely correlated with the area of potentially damaged forest for large avalanches. Assuming typical area of damaged forest for large avalanches is roughly comparable to the deposit area (as in the case study in Section 2), then the deposit depth for a Size 4 would be 0.5 to 1 m over 4 hectares, and 0.4 to 0.6 m over 40 hectares for a Size 5 avalanche (Table 1). Even if the deposit areas were half that of the potential forest damage, the corresponding deposit depths (0.8 to 2 m) would be well below what is typical of a Size 4 or 5 avalanche deposit.

5.5 Use of half-sizes

When the 22 practitioners rated the 18 avalanches in the survey, they agreed on the size for 79% of the ratings using full sizes and for 62% of the ratings using half sizes. Their ratings were within 1 size for all the ratings using the full-size scale and within a half-size for 97% of the ratings using the half-size scale. While this consistency of ratings appears to support the use of the half-sizes, we note that only 22 practitioners participated in the survey and that the participants were experienced avalanche practitioners. Further, there were more Size 2 and 3 avalanches than larger avalanches for which practitioners have less experience. Also, variability would likely be larger for observers less familiar with avalanches in motion, and the ratings by such observers are important. A larger survey involving more respondents including non-avalanche practitioners and more large avalanches would be helpful.

6 CONCLUSIONS

The avalanche size classification of MS 1981 has been adopted in Canada and in at least three other countries. The emphasis on destructive potential has made the classification useful as a vulnerability index for avalanche risk assessments. Although some users have argued that destructive potential is partly subjective and proposed that deposit mass or volume be the defining variable, we support the "all observables" approach to destructive potential in MS 1981. While recognizing the subjectivity in destructive potential to an imaginary object in the track or start of the runout zone, there are substantial differences in the other variables between the five levels – mass increases by an order of magnitude – which facilitates classification into one of five levels.

The large dataset from observations of avalanches near BC highways shows a strong correlation between avalanche size and deposit volume, indicating the importance of deposit volume in classifying avalanche size.

Since mass must be calculated from estimated density or very sparse density measurements, the column in the classification for typical deposit mass could be supplemented with a column for typical deposit volume.

Arguments in Section 5.4 suggest that the typical values of deposit mass in MS 1981 for Size 4 and 5 avalanches could be increased.

The phrase "largest snow avalanches known" may be deterring some observers from classifying extreme avalanches as Size 5.

Practitioners often use half sizes. The limited data in the practitioner survey suggest that experienced practitioners can classify about 97% of avalanches within a half size with an agreement rate of about 62%. We recommend an expanded survey involving more respondents and more large avalanches, followed by discussion of the value of half sizes.

Some of the questions about the avalanche size classification that motivated this paper suggest the need for better training. The case study in Section 2 is an example of classifying the size of an avalanche based on MS 1981. Other examples, including those from Moner et al.'s (2013) survey, could be developed and placed online to refocus on the definitions in MS 1981 and improve training for avalanche practitioners and others.

Discussion by avalanche practitioners and technical review should precede any changes to the current classification. We hope this paper prompts useful discussion.

REFERENCES

Canadian Avalanche Association (CAA). 2002. *Guidelines for Snow Avalanche Risk Determination and Mapping in Canada.* McClung, D., Stethem, C., Schaerer, P., Jamieson, B., eds., Canadian Avalanche Association, Revelstoke, BC, Canada.

Canadian Avalanche Association (CAA). 2007. *Observation Guidelines and Recording Standards for Weather, Snowpack an Avalanches*. Revelstoke, British Columbia, Canada.

Jamieson, B. and Jones, A.S.T. 2012. Vulnerability: Caught in an avalanche – then what are the odds*? International Snow Science Workshop*, Anchorage, Alaska, 1: 1-8.

McClung, D.M. and Schaerer. P.A. 1981. Snow avalanche size classification. Canadian Avalanche Committee. *Avalanche Workshop*, 3-5 Nov. 1980. Associate Committee on Geotechnical Research. Technical

Memorandum 133, National Research Council of Canada, 12-27.

McClung, D.M. and Schaerer, P.A. 2006. The Avalanche Handbook. The Mountaineers, Seattle, USA.

Moner, I., Orgué, S., Gavaldà, J. and Bacardit, M. 2013. How big is big: results of the avalanche size classification survey. *International Snow Science Workshop*, Grenoble, France.

Naaim, M., Faug, T., Naaim, F.and Eckert, N. 2010. Return period calculation and passive structure design at the Taconnaz avalanche path, France. Ann. Glaciol. 51(54), 89–97.

Perla, R.I. 1980. Avalanche release, motion, and impact. In Colbeck, S.C., ed. *Dynamics of Snow and Ice Masses*. Academic Press, New York, 397-462.

US Department of Agriculture. 1961. *Snow Avalanches: A Handbook of Forecasting and Control Measures*. Agriculture Handbook No. 194. USDA Forest Service.

Weir, P. 2002. *Snow Avalanche Management in Forested Terrain*. BC Ministry of Forests, Victoria, BC.

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