Effect of reporting rate on vulnerability with an example for snow avalanche risk to backcountry recreationists in Canada

Bruce Jamieson[1,2,a] and Alan S.T. Jones[3]

[1] *Snowline Associates Ltd., Calgary, Canada*
[2] *Dept. of Civil Engineering, University of Calgary, Canada*
[3] *Dynamic Avalanche Consulting Ltd., Revelstoke, BC, Canada*

Abstract. The vulnerability component in risk assessments or risk-based design may be based on damage models, expert judgement or records of damage. When based on records of damage, we show the calculated vulnerability is sensitive to the reporting rate for events that did not cause the specified level of damage, and derive an adjustment to the vulnerability. Using recreationists caught in snow avalanches in Canada – for which non-fatal involvements are poorly reported – we apply the adjustment and discuss the resulting vulnerability.

1 Introduction

In assessments for snow and other hazards, risk includes three components: probability of the event (typically for each scenario of specified magnitude), exposure of elements of value, and vulnerability. This third component, vulnerability V, is the expected fraction of loss, $0 \leq V \leq 1$, given that the elements of value are impacted. Vulnerability can be based on damage models, records of damage, or expert judgement. When vulnerability V is based on records, the reporting rate for events that caused a specified level of damage, N_D, and events that did not, N_N, should be similar, otherwise the vulnerability will be biased towards the better recorded event.

2 Adjusting vulnerability for the reporting rate

When based on records of damage, vulnerability V can be expressed

$$V = \frac{N_D}{N_{Impacted}} = \frac{N_D}{N_D + N_N} \qquad (1)$$

While events that cause damage tend to be well recorded, in some situations events that do not cause damage are not as well recorded. If the reporting rate for events that do not cause the specified level of damage is R < 1, then the corrected vulnerability V_R is

$$V_R = \frac{N_D}{N_D + N_N/R} \qquad (2)$$

which assumes that all events that cause the specified level of damage, N_D, are recorded.

From Eq. 1,

$$N_N = N_D(1/V - 1) \qquad (3)$$

Substituting Eq. 3 in Eq. 2 yields

$$V_R = \frac{V}{V + (1-V)/R} \qquad (4)$$

Figure 1 shows the adjusted vulnerability V_R for R = 0.1, 0.4 and 0.9. For most risk assessment applications, R ≥ 0.9 likely yields sufficient accuracy; however, lower values of the reporting rate could compromise the accuracy of vulnerability and hence risk calculations.

[a] Corresponding author: bruce.jamieson@snowline.ca

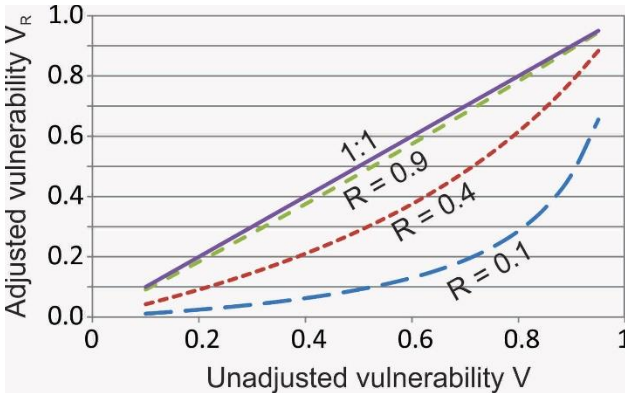

Figure 1. Sensitivity graph for the effect of the reporting rate R on vulnerability.

Equation 3 is not specific to risk due to snow hazards. It can be applied to any hazard for which vulnerability is based on records of damage. It may be relevant to risk to structures such as masts, snowpack support structures and buildings due to snow creep, snow glide or snow avalanches. However, we recognize that vulnerability may — alternatively — be based on damage models [1] or expert judgement. Also, many structures threatened by natural hazards are designed based on safety factors applied to expected loads [2] rather than on risk.

3 Example for the vulnerability of recreationists caught in potentially fatal snow avalanches

Most studies of vulnerability for people caught in snow avalanches assume that all non-fatal involvements are reported. However, in a recent Canadian study Jamieson and Jones [3] used the results of a survey to argue that only about 10 % of persons caught in, but not killed by, an avalanche during recreation in Canada are reported.

In Canada, avalanche size is reported based on a five level scale for destructive potential from 1 (relatively harmless) to 5 (largest known) [4] (Table 1). Half-sizes are often used. The size classes are sometimes prefixed by a D to distinguish the classes from other international classifications.

Table 1. Classes of avalanche size by destructive potential [4]

Size[a]	Destructive potential	Typical mass (t)	Typical path length (m)
D1	Relatively harmless to people.	<10	10
D2	Could bury, injure or kill a person.	10^2	100
D3	Could bury a car, destroy a small building, or break a few trees.	10^3	1000
D4	Could destroy a railway car, large truck, several buildings, or a forest with an area up to 4 ha.	10^4	2000
D5	Largest snow avalanches known; could destroy a village or a forest of 40 ha.	10^5	3000

[a] the D prefixing the number is a recent addition to distinguish the classes from another numerical avalanche size classification also used in North America.

Based on Canadian data for recreationists caught in potentially fatal avalanches (Size D2 and larger), the unadjusted vulnerability V is 0.19 [5]. The vulnerability adjusted for R = 0.10 is V_R = 0.03 (Eq. 4) as shown in Table 2.

Jamieson and Jones [3] identified three factors that contribute to this surprisingly low vulnerability:

- The recreationists are typically caught when on skis or a snowmobile high in an avalanche path (Figure 2).
- They have some skill to escape a moving avalanche.
- They wear avalanche transceivers, and are accompanied by other recreationists capable of companion rescue with transceivers, shovels and probes.

In the absence of these factors, vulnerability would be higher [3].

We recognize that the definition of "potentially fatal" based on the Canadian size classification [4] may contribute to the low vulnerability. This adjusted vulnerability does not apply to non-recreationists (Figure 3) and will not apply to countries with a different definition of a potentially fatal avalanche.

The vulnerability adjusted for non-reporting is difficult to validate. In a study of the efficacy of balloon packs, Haegeli et al. [6] reasonably assumed that most non-fatal involvements would be reported in fatal avalanches. However, the selection criteria included deployed balloon packs, excluding many of the smaller potentially fatal avalanches in which recreationists are often caught. Further, Haegeli et al. did not partition their results by avalanche size [4], which is required for comparison with the adjusted vulnerability in Table 2. We sought individual well documented avalanches with numerous people caught and at least one fatality, and found one such avalanche. The Size D3 avalanche on 2013-03-13 about 18 km west of Revelstoke, BC caught 50 to 100 people in the runout zone, injured 32 and killed 2 [7], making it suitable for comparison with the adjusted vulnerability V_R. In this single avalanche with many involvements, 0.02 to 0.04 of those caught were killed. While vulnerability from a single avalanche cannot be used to validate the vulnerability, the fatality rate is not inconsistent with vulnerability V_R = 0.07 for a Size 3 avalanches based on R = 0.10 (Table 2).

Table 2. Avalanche vulnerability for recreationists in Canada by avalanche size, 1984-2011 [5]

Avalanche size [4]	Relative frequency of recreationists caught (n = 1343)	Probability of death if caught, V_R	
		R = 1	R = 0.10
D2	0.55	0.07	0.007
D2.5	0.22	0.20	0.02
D3	0.17	0.43	0.07
D3.5	0.06	0.63	0.15
Frequency-weighted vulnerability		0.19	0.03

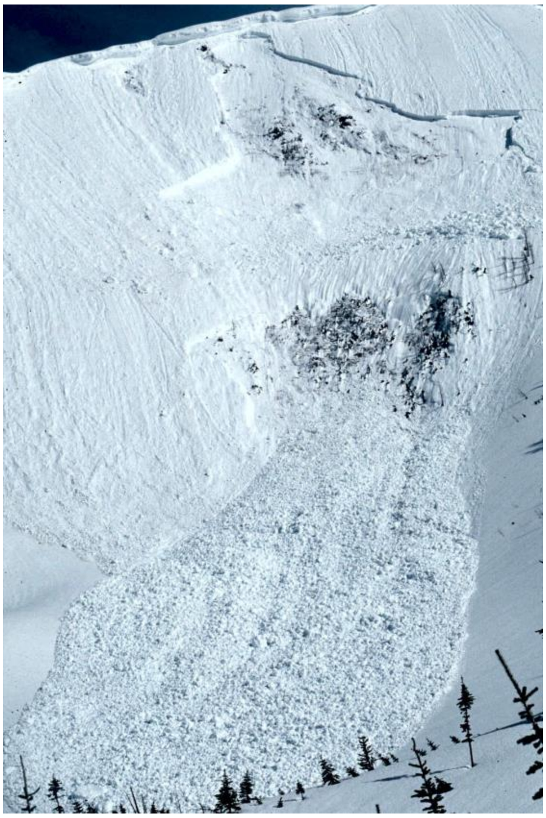

Figure 2. When caught, recreationists are typically caught near the top of an avalanche such as this whereas non-recreations are typically caught in the runout of the avalanche. B. Jamieson photo.

Figure 3. This person standing at the toe of a stopped avalanche illustrates two common characteristics of a non-recreationist caught in an avalanche, e.g. caught low in path, and not on skis or snowmobile. B. Jamieson photo.

In a 2012 study [8], Jamieson et al. assumed a reporting rate for non-fatal involvements of R = 0.05 to 0.10 and used the adjusted vulnerability to calculate the risk to backcountry skiers for various levels of avalanche danger. While this required simplifying assumptions for exposure and terrain, it illustrates an application of adjusting vulnerability for reporting rate in risk calculations.

4 Summary

For risk-based design or risk assessments, vulnerability can be based on records of damage, expert judgement, or damage models. When based on records of damage, incomplete recording of events that did not cause specified levels of damage can lead to overestimation of vulnerability. We are unsure how many vulnerability calculations, including those relevant to snow hazards, are based on records of damage. This paper derives an equation to adjust vulnerability for incomplete recording of specified levels of damage.

We demonstrate the vulnerability adjustment using recreationists caught in snow avalanches, for which underreporting of non-fatal involvements is common in Canada. The adjusted vulnerability is lower than most previously published values. This is attributed to underreporting of non-fatal involvements as well as factors relating to recreational exposure to avalanches, the skill of victims to sometimes escape a moving avalanche, and rescue capability by suitably equipped companions. The definition of “potentially fatal” varies between countries and may also affect the adjusted vulnerability. The vulnerability to snow avalanches of people outside buildings or on roads will be higher.

For avalanche vulnerability calculations, we propose that recreational activity be analyzed separately from non-recreational activity. Avalanche involvements during recreation or avalanche mitigation work are characterized by

1. the victim or another person in the group of recreationists triggers the avalanche
2. the victim is usually caught high in the path (Figure 2)
3. the victim is usually on skis, snowboard or snowmobile
4. the victim has some training and skill to escape the moving avalanche
5. the victim is usually wearing an avalanche transceiver and surviving members of the group have transceivers, avalanche probes, shovels and skill in companion rescue.

None of these five characteristics are common for non-recreational exposure to avalanches (Figure 3). While the contribution of the individual factors to vulnerability has received little attention, this would be worthwhile research.

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