SNOW AVALANCHE RISK MANAGEMENT IN CANADA

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Abstract

The snow avalanche hazard affects western, northern and eastern Canada with an average of 12.5 fatalities per year during the period 1990-1999 through 2002-2003. During heavy snow winters large avalanches block the valley bottoms, disrupting economic activity and causing human loss. During light snow winters deep weak layers are often observed to form in the snowpack and human triggering of avalanche by recreationists can lead to significant loss of life. During the 2002-2003 winter, which was below average in snowfall, 28 recreationists died. Established methods of risk reduction in transportation and ski areas have reduced the risk to well within accepted standards of risk. National guidelines for land use planning in avalanche terrain have been developed to assist planners and land managers by applying accepted standards of risk management. The main challenge today is to reduce the risk in recreation, where the majority of fatal accidents are now observed. Improved public avalanche bulletins and related decision making tools, combined with improved risk perception can result in effective recreational risk reduction.

1. INTRODUCTION

Over the past century, snow avalanche risk management in Canada has evolved largely in response to accidents, which had a particular impact on one region or industry sector. In the early 1900s, most avalanche victims in Canada were transportation and mine workers exposed to involuntary risk. More recently, the majority of avalanche victims are recreational backcountry users engaged in voluntary risk activities (Jamieson and Stethem, 2002).

The Canadian Avalanche Association (2002 a, b) has developed guidelines for assessment of avalanche risk and mapping practice in Canada. These are readily applied in industrial, transportation and municipal settings, where the numbers of accidents are now relatively few.

The current challenge is to reduce the risk to backcountry recreationists engaged in voluntary risk activities. By early April the 2002-2003 winter had claimed 28 avalanche victims, all in recreational backcountry settings (Canadian Avalanche Association unpublished data). This is the largest number since the winter of 1964-1965, when 34 fatalities were recorded (Stethem & Schaerer, 1979, 1980). In that earlier winter only one of the victims was a recreationist and 33 died in mining and town site accidents.

The objective of this paper is to explore the current state of avalanche risk management in Canada and outline future challenges and potential solutions.

2. IMPACT OF THE AVALANCHE HAZARD IN CANADA

Fatalities and property damage from avalanches have been recorded in British Columbia, Alberta, Yukon, the Northwest Territories, Quebec, Newfoundland, Ontario and Nunavut (Stethem et. al., 2003). There have been more than 600 recorded fatalities caused by snow avalanches in Canada since the mid-1800s (Jamieson and Stethem, 2002). In the ten years from 1990-1991 to 1999-2000 a total of 125 people were killed, an average of 12.5 per year. Of these 109 were involved in recreational activities (Jamieson and Stethem, 2002).

Worst-case snow avalanche scenarios for Canada can be described for either involuntary or voluntary activities and these may differ markedly. The differences lie in natural versus artificial triggers and heavy versus light snow winters.

For involuntary activity the scenario of a 100-year avalanche winter is envisioned (Stethem et al, 2003). In this case, early winter formation of a weak layer in the snowpack is followed by a heavy snowfall winter. Heavy snowfall means an abundance of new snow loading over the weak layer and natural triggering of slab avalanches. This results in major avalanche cycles, which produce numerous avalanches to the valley elevation, blocking transportation routes and isolating communities and resort areas throughout the Western Cordillera. The net impact is felt in both economic and human terms.

The winter of 1971-72 was a heavy snowfall winter (Figure 1), which was regarded by avalanche specialists as a 100-year winter. Eighteen fatalities were observed, well above the average of 7 per year at that time.

In the case of voluntary activity the worst-case scenario is similar in that a persistent weak layer is observed to form in the snowpack, typically during early winter, however the snowfall amounts are often below average. The winters of 1976-1977, 1978-1979, 1997-1998 and 2002-2003 (Schaerer, 1987; Canadian Avalanche Association, unpublished data) all stand out as above average in numbers of fatalities (approximately twice the average), and all but 2 of these fatalities are recreationists. In the case of 1977, 1979 and 2003 the snowpacks are below average in depth during early winter (Figure 1) and persistent weak layers form in the snowpack during this time period. In the case of the 1997-98 winter, the snowpack starts off as average but then falls below average in mid-winter when persistent weak layers are once again observed to form.

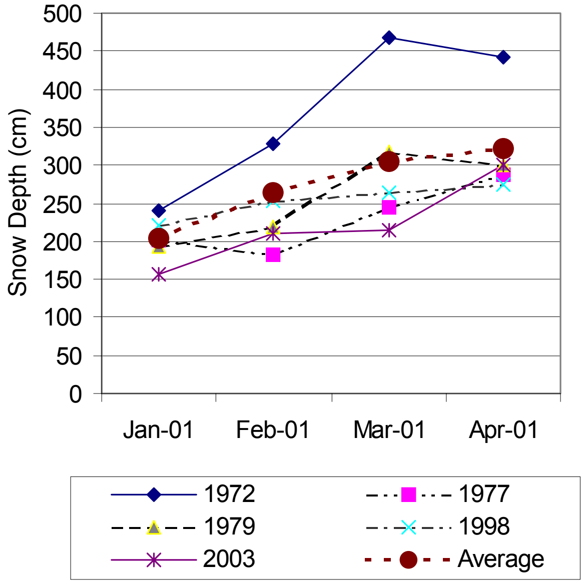

Figure 1. Mount Fidelity snow depth

Snow machines, climbers or skiers (and snowboarders) provide a potential avalanche trigger by introducing shear stresses, which decrease over depth within the snowpack (Föhn, 1987). Thin snowpacks mean that when persistent weak layers are present, they will remain near the snow surface, resulting in an increased potential for human triggering of slab avalanches (Figure 2). Hence the worst-case scenario in recreation is often a below average snow winter where persistent weak layers linger near the snow surface.

Figure 2: A deep slab avalanche on a persistent weak layer, triggered by explosives during the winter of 1978-79, a below average snow winter. C. Stethem photo.

3. RISK REDUCTION IN TRANSPORTATION

Significant advances have been made in risk management for involuntary risk activities in transportation over the past century in Canada. The challenges faced by rail and highway operations are similar.

One of Canada's greatest avalanche disasters occurred on the Canadian Pacific Railway at Rogers Pass in 1910. Sixty-two 62 workmen were killed when an avalanche overran a worksite where a previous avalanche was being cleared (Schaerer, 1987). Following that event, the section of rail involved was placed in a tunnel to avoid the avalanche terrain and grades at the summit of Rogers Pass.

Structural or passive measures that are now used on Canada's railways and highways include numerous tunnels and snowsheds (Figure 3), grade relocations and earthworks. Active measures include avalanche hazard forecasting, explosive avalanche control (Figure 4), traffic warning and traffic control. These are applied in combination with structural measures to manage the snow avalanche hazard on transportation networks.

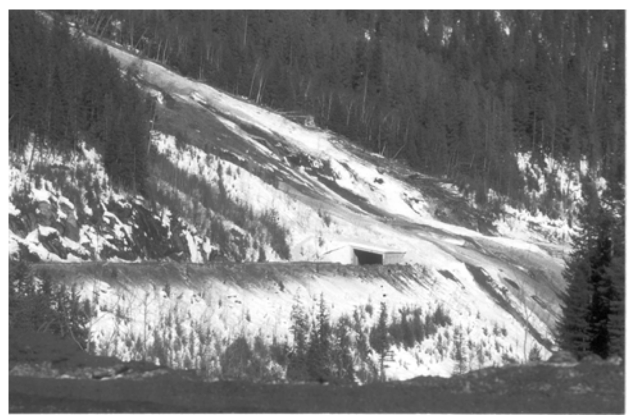

Figure 3: Avalanche over a snowshed on the Trans-Canada Highway near Rogers Pass, BC. C. Stethem photo

Advances in remote sensing in recent years have made a significant impact in avalanche prediction and risk reduction. These tools allow avalanche forecasters to monitor weather, snowpack and avalanche occurrences in alpine terrain under all weather conditions (Figure 5). The potential now exists to combine real time remote sensing with modeling of snow cover development (Giraud et al, 2002). In combination with selected field observations between storms, this will allow avalanche forecasters to assess avalanche potential over wide geographic areas.

Figure 4: A 105 mm howitzer used to apply explosives for avalanche control at Rogers Pass, BC. C. Stethem photo.

Figure 5: Remote precipitation gauge and ultrasonic snow depth sensor used to monitor snow accumulation during storms. B. Jamieson photo.

The success of risk reduction in transportation is clear from recent history. The last avalanche fatalities involving members of the public on an open road occurred in 1976 (Stethem & Schaerer, 1979). The annual probability of death due to avalanche on an open road is approximately 3×10^{-6} (Jamieson and Stethem, 2002), which is well within the commonly accepted range of involuntary risk due to a specific cause of 10^{-5} to 10^{-6} (Fell, 1994).

Since 1980 at total of four transportation workers have been killed in avalanches. Three of these were not on the route but rather travelling on skis in avalanche terrain while assessing the avalanche hazard to the route.

4. RISK REDUCTION IN LAND USE PLANNING

Two accidents in the winter of 1964-65 resulted in thirty-four fatalities in British Columbia. On January 13, 1965 seven resident of Ocean Falls, BC were killed by naturally triggered wet snow avalanches (Stethem & Schaerer, 1980). A total of 1.4 m of new snow fell on the town over 8 days in early January, followed by 133 mm of rain on January 13th, which triggered the avalanches. Later that winter, on February 18th twenty-six workmen were killed at Granduc Mines, BC. Heavy snowfall triggered a huge slab avalanche that removed the full depth of the snow cover above the Leduc Camp (Stethem & Schaerer, 1979). Cold temperatures and thin snowpacks during early winter had resulted in an unstable base to the snowpack, which was then covered by over 4m of new snow during February.

On February 16, 1959, five residents were killed in their homes by avalanches at the village of Outer Battery near St. John's, Newfoundland (Schaerer, 1987; Liverman et al., 2001). This occurred following a storm that deposited over 0.5 m of new snow accompanied by winds of over 200 km/h. On January 1, 1999, an avalanche struck Satuumavik School at Kangiqsualujjuaq, Quebec, killing nine people and injuring 25 others (Quebec, 1999). Blizzard conditions and deep snow accumulation on the slope behind the school preceded the avalanche.

These accidents are cases where land use planning is the means by which risk reduction can be achieved. Avalanche mapping and zoning in land use planning in Canada has evolved largely in response to such accidents. The regional nature of these concerns and solutions resulted in adoption of a variety of statutes and policies on avalanche risk. The need for national guidelines for land use planning was recognized by the National Search and Rescue Secretariat, which recently sponsored a project through Parks Canada and the Canadian Avalanche Association to develop guidelines for avalanche risk determination and mapping.

The objectives of the Canadian Avalanche Association's (CAA) Avalanche Hazard Mapping (AHM) Project (Stethem et al, 2002) were:

- To establish uniform Canadian guidelines for avalanche risk evaluation and mapping for facilities affected by snow avalanches.
- To inform land managers about avalanche hazards and their mitigation.
- To design a training curriculum to provide uniform delivery of such guidelines and methods to planners, engineers, geoscientists and avalanche professionals.

Two new publications resulted from the AHM project:

- *Guidelines for Snow Avalanche Risk Determination and Mapping in Canada* (Canadian Avalanche Association, 2002a). These are technical guidelines, which are directed at consultants and planners working with snow avalanches.
- *Land Managers Guide to Snow Avalanche Hazards in Canada* (Canadian Avalanche Association, 2002b). This guidebook provides a general description of the snow avalanche hazard, how it is assessed and mapped by planning professionals, and how to find avalanche-planning expertise.

In a general sense, risk is the chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment or other things of value (Canadian Standards Association, 1997). Risk determination under the Canadian Guidelines includes avalanche return period, the probable consequences of an avalanche and probable exposure to the avalanche. Consequences are defined by predicted avalanche impact pressure or destructive potential, based on the five part Canadian system for classifying avalanche size (McClung and Schaerer, 1981).

The Canadian guidelines include the following applications:

- Work sites
- Transportation routes (rail and road)
- Energy and communication structures (transmission lines, surface pipelines and telephone lines)
- Recreation operations (ski areas, commercial backcountry operations)
- Forest harvest areas
- Occupied structures

Thresholds to initiate action are defined by avalanche return periods and critical avalanche sizes for work sites, transportation routes, energy structures and recreation operations. The typical action or planning and map types are described for each application. Locator maps, which identify potential avalanche terrain, are typically used in planning for these applications. When the project moves into construction and operation, avalanche atlases are often prepared to clearly illustrate the potential avalanche terrain for a series of locations.

For example, in a highways application the thresholds are: a return period of 30 years and a Size >2 for planning and passive control measures; or 10 years and Size >2 for an active avalanche control programme. An avalanche atlas is typically used for an operating highway.

Forestry is a major industry in Canada. Forest harvest practices can lead to creation of new avalanche paths in cutblocks (Type I problem) or the expansion of existing avalanche paths running into cutblocks (Type II problem). Either type can result in a potential for damage to the standing forest or to pre-existing down slope facilities and other resources, such as transportation routes.

The Guidelines recommend an initial assessment by the forestry proponent to identify if there is a concern for snow avalanches. This is based on slope incline (critical threshold 30º) and snow supply sufficient for destructive avalanches. If a potential for snow avalanches is identified, then a detailed avalanche risk analysis is completed.

The potential avalanche risk resulting from forest harvest is assessed using risk matrices, which combine avalanche frequency (or return period) and destructive potential based on avalanche size to determine a qualitative risk rating (i.e. high, moderate or low). Moderate risk will normally require modification of the harvest design.

Figure 6: A Type II wet snow avalanche running from above into a cutblock in British Columbia. Bruce Jamieson photo.

Two application matrices are given, one for risk to the forest and one for risk to forest and down-slope facilities or essential resources. For example, where a highway lies below a potential forest harvest area, the moderate risk threshold is a Size 3 avalanche with an average frequency of 1:30 years, or a Size 2 avalanche with an average frequency of 1:3 years. In the case of exposure of the forest resource only, a greater risk is accepted. In this case the moderate risk threshold is a Size 3 avalanche with an average frequency of 1:10 years, or a Size 2 avalanche with an average frequency of 1:1 year. Forest harvest practices that are likely to result in Size 4 (or larger) avalanches are unacceptable regardless of frequency. These matrices are based on research by the Avalanche Research Group at the University of British Columbia.

The risk for occupied structures is defined in terms of predicted avalanche impact pressure and return period (Figure 7). The zone definitions are:

- White zone - An area with an estimated avalanche return period of >300 years, or impact pressures <1 kPa and a return period >30 years.
- Red zone - An area where the return period is ≤30 years and/or impact pressures are ≥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.
- Blue zone - 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 and the impact pressure is greater than or equal to 1 kPa.

The critical values of 30 years, 300 years and 30 kPa, and the zoning colour scheme are similar to those developed in Switzerland (Switzerland, 1984).

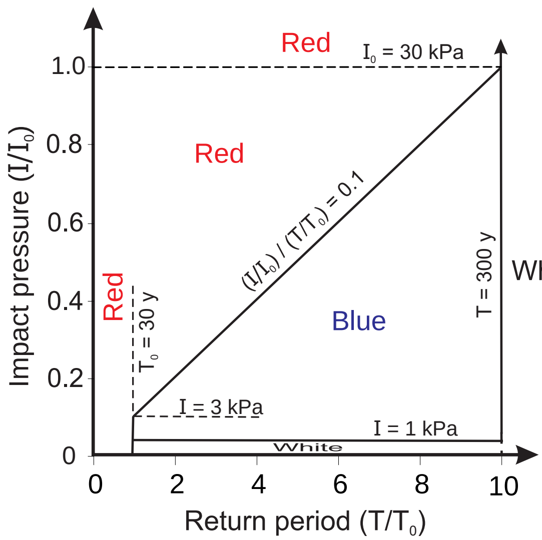

Figure 7: Definition of Red, Blue and White zones for land use planning.

New construction of permanently occupied structures, such as residential subdivisions, are only recommended in the white zone, whereas some temporarily occupied structures, such as industrial plants, may possibly be permitted in the blue zone with specified conditions for avalanche protection.

In the alpine countries of Europe, where land is at a premium, structural avalanche defences are often used to increase the area of developable land (Figure 8). In Canada we have an advantage in that in most cases of new development land use planning can be used to avoid the avalanche hazard.

Figure 8: A diversion berm in Switzerland used to reduce the risk of destructive avalanches spreading into the developed area beyond. C. Stethem photo.

Avalanche accidents in residential areas in recent years in Canada have been in locations where relatively short slopes produced the avalanches. These include one fatality at Telegraph Creek, BC in 1989 (Jamieson and Geldsetzer, 1996), two in Blanc Sablon Quebec in 1995 (Jamieson and Geldsetzer, 1996) and nine in Kanggiqsualujjuaq Quebec in 1999 (Government of Quebec, 1999).

In response to these accidents and the recognition by researchers of the need for development of methods for analysis and mapping of short avalanche paths (McClung and Lied, 1987; Schaerer, 1991), recent research at the University of Calgary has focused on the development of such methods. Jones (2002) has developed a statistical method that can be applied to such cases.

5. RISK REDUCTION IN RECREATION

There is no doubt that in terms of human loss the challenge in avalanche protection in Canada is to reduce the risk in recreational use of steep snow covered terrain (Figure 9). The number of recreational backcountry users has exploded in recent years, particularly with the growth of interest in ski and snowboard touring, mechanized skiing and snowmobiling. Snow avalanches are the primary natural hazard to which these groups are exposed.

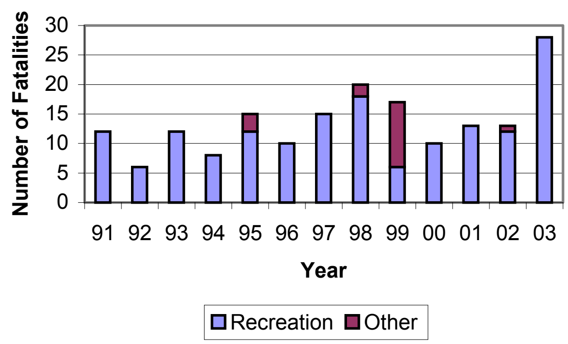

Figure 9. Avalanche fatalities in Canada 1991 to 2003.

During the period 1990-1991 to 2002-2003, one hundred and seventy nine people have been killed in snow avalanches in Canada, including 28 in 2002-2003 (to April 7^{th}) (Canadian Avalanche Association, unpublished data). Of these fatalities, one hundred and sixty two, or 90%, were recreationists. Within the recreational grouping, 16% were in commercially guided backcountry operations and 84% in unguided backcountry recreation.

The tools applied for risk reduction in recreation vary widely. Forecasting, temporary closure, slope compaction and explosive avalanche control are the key tools used in avalanche protection for ski runs within lift serviced ski area boundaries (Perla and Martinelli, 1976). Of the roughly 20,000 explosive charges used in Canada in each year, approximately 75% are used in lift serviced ski areas (M. Bossineault, pers comm. 2001). Hazard mapping and location planning are used in combination with strengthened design and diversion structures to protect ski lift installations. The risk of death to the public within open in bounds ski runs is approximately 1.3×10^{-7}. This risk is substantially higher for out of bounds skiers who venture beyond the controlled area, often without adequate skills and equipment for backcountry skiing.

The risk reduction methods employed in mechanized backcountry skiing (helicopter and snowcat) include avalanche forecasting, route selection by professional guides, limited compaction and limited explosive avalanche control. The limited nature of explosive use is due to the vast areas of terrain, which are used by these operations relative to lift serviced ski areas. Similarly, with respect to compaction these operation have a very low skier density as compared to a ski area and therefore only a few runs receive repeated skier compaction. Explosives and compaction can only be applied effectively over a select portion of the terrain, which is often the most heavily used and closest to the base. Commercial hut based ski touring operations employ avalanche forecasting and route selection by professional guides.

The winter of 2002-2003 underlines the challenge of risk reduction for backcountry recreation (Figure 10). Backcountry skiers (or snowboarders) and snowmobilers make up the majority of victims. Skiers have long been recognized as risk takers in the backcountry. The first snowmobile avalanche fatality in Canada was in 1973. In some recent winters snowmobilers make up the majority of avalanche victims (Canadian Avalanche Association files).

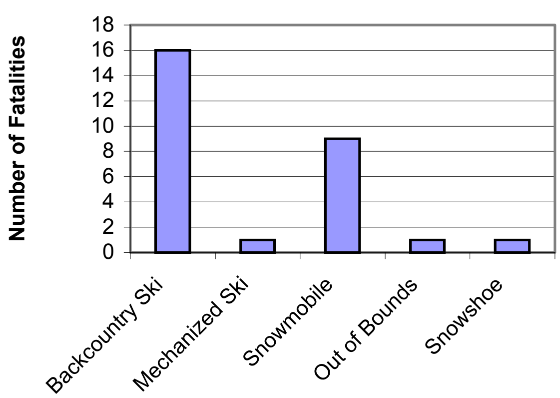

Figure 10. Avalanche fatalities 2002 to 2003

Clearly, improved tools are needed to reduce the risk for these groups. A strong effort is also required to shape the risk perception (Wilde, 1994) of these groups. Many backcountry travelers' decisions combine some sense of invulnerability with a powerful desire to ski in powder or to hill climb on a snowmobile. The challenge is captured by McClung in the Introduction to the Avalanche Handbook (McClung and Schaerer, 1993): 'Safe backcountry skiing requires a logically sequenced risk reduction strategy'.

Recent backcountry accidents have resulted in calls for a variety of measures including improved public avalanche bulletins, improved tools for decision making in the terrain, explosive use in the backcountry, restrictions on backcountry use under elevated levels of avalanche risk and even closures of portions of the backcountry.

Explosive use in the backcountry is an impractical concept. Explosive use is limited by area of terrain. The backcountry in Canada is simply too vast to consider any effective application of explosive control. Liability is also a limiting factor. Once you begin, where do you draw the line and what happens when an accident occurs in an area where you have not undertaken explosive control?

Liability also handicaps the restriction of backcountry use based on avalanche danger level. What happens where an accident occurs without the specified elevated danger level? The question of responsible use of the backcountry also counters the idea of restriction. Why should the so-called 'responsible user' be precluded from travel in the backcountry when there are routes and methods of travel, which effectively reduce the risk?

The answer to risk reduction may lie in a three pronged approach: 1) an improved avalanche bulletin; 2) improved tools for decision-making and 3) education and awareness campaigns to improve risk perception. The present day avalanche bulletin is provided on a three day a week basis for some areas of terrain in southern Alberta and British Columbia. The ideal would be a bulletin that provided information on a seven day a week basis over a wide variety of geoclimatic zones in the mountainous regions of Canada. The recreationist could then take the bulletin information, supplement it with reliable local observations and apply simple decision making tools to assess the avalanche terrain and risk on the route.

6. CONCLUSIONS

Heavy snow winters are traditionally associated with large avalanches to the valley bottom, disruption of economic activity and significant loss of life in mountain regions. Experience has shown that light snow winters are more often associated with human triggering of slab avalanche and above average numbers of avalanche fatalities in recreation. Risk reduction in transportation and ski areas have reduced the risk to well within accepted standards of risk. The Canadian Avalanche Association 's Guidelines for Avalanche Risk Determination and Mapping (Canadian Avalanche Association, 2002 a) provide consultants and land managers with national planning standards. The main challenge today is to reduce the risk in recreation, where the majority of fatal accidents are now observed. Improved public avalanche bulletins and related decision making tools, combined with improved risk perception can result in effective recreational risk reduction.

Liverman D.G.E., Batterson M.J., Taylor D., and Ryan J. 2001. Geological hazards and disasters in Newfoundland. Canadian Geotechnical Journal, 38, 936-956.

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8. REFERENCES

Canadian Avalanche Association, 2002a. Guidelines for Snow Avalanche Risk Determination and Mapping in Canada. McClung, D.M., C.J. Stethem, P.A. Schaerer and J.B. Jamieson (eds.). Canadian Avalanche Association, Revelstoke, BC. Canada 23 pp.

Canadian Avalanche Association, 2002b. Land Managers Guide to Snow Avalanche Hazards in Canada. Jamieson, J.B., C.J. Stethem, P.A. Schaerer and D.M. McClung (eds.). Canadian Avalanche Association, Revelstoke, BC, Canada, 25 pp.

Canadian Standards Association. 1997. Risk Management: Guideline for Decision Makers. Canadian Standards Association CAN/CSA-Q850-97.
46 pp.

Chief Coroner of Quebec: 1999, Report of a public inquiry, Office of the Chief Coroner, Kangiqsualujjuaq, Noveau-Quebec.

Fell, R. 1994. Landslide risk assessment and acceptable risk. *Canadian Geotechnical Journal* **31**, 261-272.

Föhn, P. 1987. The stability index and various triggering mechanisms. In Salm, B. and H. Gubler (eds), *Avalanche Formation, Movement and Effects,* International Association of Hydrological Sciences, Publication 162, pp 223-228.

Giraud, G., E. Martin, E. Brun and J.P. Navarre. 2002. CrocusMepraPC Software: A tool for local simulations of snow cover stratigraphy and avalanche risks. *Proc. of the International Snow Science Workshop 2002*, Penticton, BC. ISSW Canada Inc., 123-129.

Jamieson, B. and Geldsetzer, T.: 1996, *Avalanche Accidents in Canada, Vol. 4, 1984-1996*, Canadian Avalanche Association, Revelstoke, B.C., 193 pp.

Jamieson, B. and C. Stethem. 2002. Snow avalanche hazards and management in Canada: Challenges and Progress. *Natural Hazards* **26**, 35-53.

Jones, A.S.T. 2002. Avalanche Runout Prediction for Short Slopes. MSc thesis, Department of Civil Engineering, University of Calgary, Calgary, Canada. 126 pp.

McClung, D.M. and P.A. Schaerer. 1981. Snow Avalanche Size Classification. Proc. Avalanche Workshop, Nov. 3-5, 1980, Vancouver, BC Assoc. Committee on Geotechnical Research Tech. Memo. 133, National Research Council, Ottawa, 12-27.

McClung, D.M. and K. Lied. 1987. Statistical and geometrical definition of snow avalanche runout. *Cold Regions Science and Technology,* **13**(2), 107-119.

McClung, D.M and Schaerer, P.A.: 1993, *The Avalanche Handbook*, The Mountaineers, Seattle, 9.,

Perla, R. and Martinelli, M.: 1976, The avalanche handbook, US Department of Agriculture, Forest Service, Agriculture Handbook 489.

Schaerer, P.A.: 1987: Avalanche accidents in Canada III: a selection of case histories of accidents, 1978 to 1984, National Research Council of Canada IRC Paper No. 1468, 138 pp.

Schaerer, P.A. 1991. Suggestions for snow research. In: CSSA 1991 Symposium, Centre for Snow Science at Alta. April 20, 1991.

Stethem, C.J. and Schaerer, P.A.: 1979, Avalanche accidents in Canada I: a selection of case histories of accidents, 1955 to 1976, National Research Council of Canada, DBR Paper No. 834, 114 pp.

Stethem, C.J. and Schaerer, P.A.: 1980, Avalanche accidents in Canada II: a selection of case histories of accidents, 1943 to 1978, National Research Council of Canada, DBR Paper No. 926, 75 pp.

Stethem, C., McClung, D., Jamieson, B. and Schaerer, P. 2002. Canadian avalanche hazard mapping project. *Proc. of the International Snow Science Workshop 2002*, Penticton, BC. ISSW Canada Inc., 555-560.

Stethem, C., B. Jamieson, P. Schaerer, D. Liverman, D. Germain and S. Walker. 2003. Snow avalanche hazard in Canada – a review. *Natural Hazards* **28,** 487-515**.**

Switzerland. 1984. Richtlinien zur Berücksichtigung der Lawinengefahr bei raumwirksamen Tätigkeiten. Bundesamt für Forstwesen, EISLF, EDMZ, Bern, 34 pp.