Current and future snow avalanche threats and mitigation measures in Canada

Cam Campbell

Laura Bakermans

Bruce Jamieson
The University of Calgary

CURRENT AND FUTURE SNOW AVALANCHE THREATS AND MITIGATION MEASURES IN CANADA

Prepared for:
Public Safety Canada

Prepared by:
Cam Campbell, M.Sc.[1]
Laura Bakermans, M.Sc., P.Eng.[2]
Bruce Jamieson, Ph.D., P.Eng.[3]
Chris Stethem[4]

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[1] Canadian Avalanche Centre, Box 2759, Revelstoke, B.C., Canada, V0E 2S0. Phone: (250) 837-2748. Fax: (250) 837-4624. E-mail: ccampbell@avalanche.ca
[2] Department of Civil Engineering, University of Calgary, 2500 University Drive NW. Calgary, AB, Canada, T2N 1N4, Canada. E-mail: lbakermans@yahoo.ca
[3] Department of Civil Engineering, University of Calgary, 2500 University Drive NW. Calgary, AB, Canada, T2N 1N4, Canada. Phone: (403) 220-7479. Fax: (403) 282-7026. E-mail: bruce.jamieson@ucalgary.ca
[4] Chris Stethem and Associates Ltd., 120 McNeill, Canmore, AB, Canada, T1W 2R8. Phone: (403) 678-2477. Fax: (403) 678-346. E-mail: cstethem@snowsafety.ca

EXECUTIVE SUMMARY

This report presents the results of the Public Safety Canada funded project to inventory current and predict future trends in avalanche threats and mitigation programs in Canada. The project also updated the Natural Resources Canada website and map of fatal avalanche incidents.

Avalanches have been responsible for at least 702 fatalities in Canada since the earliest recorded incident in 1782. Sixty-one percent of these fatalities occurred in British Columbia, with 13% in Alberta, 11% in Quebec and 10% in Newfoundland and Labrador. The remainder occurred in Ontario, Nova Scotia and the Yukon, Northwest and Nunavut Territories. Fifty-three percent of the fatalities were people engaged in recreational activities, while 18% were people in or near buildings, 16% were travelling or working on transportation corridors and 8% were working in resource industries. The remainder are either unknown or engaged in other activities such as hunting or avalanche control work.

Currently 1370 avalanche paths threaten the British Columbia highway network. Highways in Alberta, Quebec, Newfoundland and the Yukon Territory, as well as railways and ports in British Columbia, are also threatened. Some of these transportation corridors do not have avalanche hazard mitigation programs.

There are over 187 chairlift ski areas in Canada. Approximately 34 are located in British Columbia, 17 in Alberta, 46 in Ontario and 69 in Quebec with the remainder in Manitoba, Saskatchewan, New Brunswick, Newfoundland, Nova Scotia and the Yukon Territory. Thirteen ski areas in British Columbia, and six in Alberta, have avalanche hazard mitigation programs, while the remaining 168 across the country either rely solely on skier compaction of the snowpack to reduce the likelihood of avalanches or do not have sufficient snowfall or terrain to produce avalanches.

Self-directed winter backcountry recreation is prevalent in the mountainous regions of British Columbia, Alberta, Quebec, Newfoundland and the Yukon Territory. Backcountry avalanche danger bulletins are freely available to the public for most popular recreation areas in British Columbia, Alberta and Quebec. Backcountry avalanche safety courses are provided in British Columbia, Alberta, Quebec, Newfoundland and the Yukon Territory. National parks in British Columbia and Alberta employ wardens who are trained in avalanche search and rescue. In addition, Parks Canada has restrictions in place pertaining to custodial groups accessing avalanche terrain within parks during the winter.

Commercial mechanized backcountry recreation operations, such as helicopter and snowcat skiing, are mostly located in British Columbia, where it is a major component of the winter tourism industry. Avalanche hazard mitigation for these operations includes the use of guides who are responsible for avalanche forecasting, mitigation and rescue.

Avalanches also threaten natural resource extraction operations in the mining, forestry and oil and gas sectors, primarily in western Canada. Many of these are intermittent operations with varying degrees of avalanche hazard mitigation. Some hydroelectric dams and powerlines in British Columbia also use avalanche hazard mitigation measures.

Current and future trends in threatened activity include an increase in recreational activities, throughout Canada in the past decade and these activities are expected to continue growing in the next twenty years. This includes ski areas, commercial and self-directed backcountry recreation throughout Canada.

Natural resource industry activity throughout Canada has recently and will probably continue to fluctuate with commodity prices. However, these activities are currently and expected to continue to move into areas that are more hazardous. This is due to depletion of resources in the easily accessible, and generally safer, areas and glacial retreat making alpine areas more economically viable.

The number of transportation corridors threatened by avalanches has also, and is expected to continue to, increase due to access roads being built for new mining, forestry and hydroelectric power generation operations.

Avalanche hazard assessments have been recently completed for many residential and public land use areas in Canada and, consequently, there is a decrease in threatened residential and public land use areas. However, this threat is not expected to be eliminated, or even reduced to a level equivalent with other natural hazards, until legislation and standards are in place.

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1. INTRODUCTION

The purpose of this report is to present the final results of the Public Safety Canada funded project aiming to inventory avalanche threats and mitigation programs in Canada and to project future trends. This report also provides suggestions for updating the Natural Resources Canada website and map of fatal avalanche incidents. This report is intended for the Honourable Stockwell Day, Public Safety Minister, and his staff. This report is also intended for Clair Isrealson, Executive Director, and John Kelly, Operations Manager, of the Canadian Avalanche Centre, and their staff.

This report first introduces some important concepts in avalanche formation and motion and definitions of avalanche hazard, in Chapter 2. Next, Chapter 3 provides a summary of avalanche fatalities in Canada and identifies some important trends.

Chapter 4 then addresses the first goal of the project with an inventory of activity threatened by avalanches and mitigation measures currently in place. Information for this chapter was obtained from various sources, including informal interviews and internet searches, and is consequently presented at varying levels of detail and accuracy. Furthermore, due to the intermittent nature of some activities and widespread distribution of others, it would be a challenging task to inventory all activity that is currently threatened by avalanches in Canada. Chapter 4, therefore, is not a comprehensive list but an overview of the most important threatened activities and mitigation programs in Canada.

Chapter 5 addresses the second goal of the project with an analysis of current and prediction of future trends in threatened activity. One limitation of this chapter is that some assertions regarding trends in threatened activity may not be supported by data. The report then finishes with suggestions for further research and conclusions and recommendations.

The appendices address the third goal of the project: to suggest updates for the Natural Resources Canada website and map of fatal avalanche incidents. Appendix A contains maps, which due to financial restrictions, were created with Google Earth rather than a full-featured Geographical Information System. This significantly limited the spatial analysis that could be performed on the incident and activity data. Furthermore, the maps use avalanche activity zones that were derived at the national scale and assumed accurate at the provincial scale, but are not suited to smaller scale reproduction or visualization. Appendices B, C and D contain suggested updates to the Natural Resources Canada website.

2. AVALANCHES

The following section was reprinted from Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D. and Walker, S. (2003). Snow Avalanche Hazard in Canada - a Review. *Natural Hazards*, Vol. 28, Section 2.1, p. 488 – 491, with kind permission from Springer Science and Business Media.

2.1 Formation and motion of avalanches

"A snow avalanche ensues when a pent up snow mass loses its hold and is discharged from the mountainside" (Seligman, 1936, p. 292). Underlying this simple description is a complex process combining steep slopes, gravity, accumulation and deformation of snow cover and short-term fluctuation in weather phenomena.

The two general types of snow avalanches are called *loose snow avalanches* and *slab avalanches* (McClung and Schaerer, 1993). These may occur in both dry and wet snow.

Loose snow avalanches start at a point, usually at or near the surface of the snow cover, within a cohesionless layer. As the snow moves down slope, a build up of snow is entrained in a spreading triangular pattern. If the snow is wet and the underlying snow cover is weak, loose snow avalanches can remove the snow cover to ground and entrain small amounts of surface material.

Slab avalanches are usually the larger and more dangerous type of snow avalanche. A cohesive slab of snow fails on an underlying weak layer or weak interface, where the shear stress exceeds the shear strength between snow grains. A slab may consist of a surface layer of new snow, or it may contain several layers of new and old snow. Propagating fractures below and surrounding the slab allow the failure to spread over large areas (Figure 1). The width of these slabs is highly dependant on terrain (McClung and Schaerer, 1993). Snow slab widths in excess of one kilometre are observed during large avalanche cycles, where the terrain in the starting zone is suited to wide propagation (Figure 2).

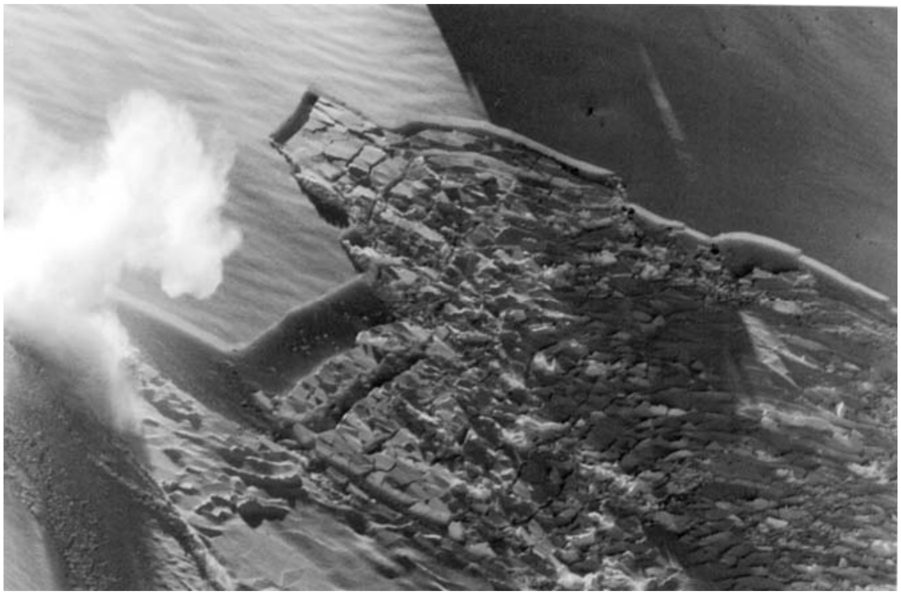


Figure 1. A slab avalanche breaking away from the slope. Photographer: C. Stethem.

A triggering mechanism is required to upset the balance of strength and stress in the snow cover. These may be natural factors such as precipitation (snow or rainfall), wind deposition of snow, rapid temperature change including solar radiation, cornice fall, icefall or earthquake (Canadian Avalanche Association, 2000). The trigger may also be an artificial (human induced) effect such as skiers or snowboarders, snowmobiles, hikers, vibrations from machinery and traffic, and explosives.

The terrain of a snow avalanche path is divided into three areas: the start zone where the snow breaks away; the runout zone where the moving snow and entrained debris stop; and the track, which connects the start and runout zones (Martinelli, 1974).

Figure 2. A large start zone above three avalanche paths where a wide-fracture propagation could occur. Photographer: C. Stethem.

The primary variable in avalanche terrain is a slope incline that allows avalanches to start and accelerate (McClung and Schaerer, 1993). Dry snow avalanches initiate at an area where the slope is greater than 25°. Large slab avalanches are most commonly observed to start where the slope incline is in the 30° to 45° range (Perla and Martinelli, 1976). Wet snow avalanches can release on terrain of lower incline, with the slush flow avalanches in Arctic regions being the most extreme examples. One such event occurred in June 1970 in Ungava Bay, Quebec. An avalanche that started on terrain with an incline of 16° resulted in the destruction of an oil tank farm (Stethem and Schaerer, 1979).

Secondary terrain factors in the start zone of avalanches include orientation to wind and sun, forest cover, ground surface roughness, slope dimension and configuration, and elevation (McClung and Schaerer, 1993). These influence the depth of accumulated snow, snow cover characteristics, anchorage of the snowpack, threshold depth for avalanches, potential mass of avalanches and flow characteristics.

Incline also remains the critical factor for the continued motion of avalanches down the track. A typical track angle is in the 15° to 30° range (McClung and Schaerer, 1993). Within the track, avalanche speed may remain steady, increase or decrease (Schaerer, 1981). This change in speed results from changes in the mechanical properties of the snow and the friction with the underlying surface (McClung and Schaerer, 1993) over varying terrain features and inclines. Velocity of snow avalanches ranges up to 250 kmh^{-1} in dry snow and 125 kmh^{-1} in wet snow (Mears, 1992).

A runout zone is the area where an avalanche decelerates and stops. Typical inclines for the runout zone are 15° or less (McClung and Schaerer, 1993). Statistical models used to determine the potential runout distance of maximum avalanches commonly use the 10° point to define the beginning of the runout zone (Lied and Bakkehoi, 1980; McClung *et al*., 1989). Runout distances of 1000 metres or more can be observed where large avalanches run on slopes with an incline of 5° to 10° (Mears, 1992).

2.2 Avalanche hazard

Hazard refers to a source of potential harm, or a situation with the potential for causing harm, in terms of death or losses, including damage to health, property, the environment, or other things of value. In the context of snow avalanches, it is a measure of the likelihood of avalanches and their destructive potential, independent of exposure. Several methods for rating avalanche hazard exist and different operations tailor their hazard ratings to their operational needs.

In Canada, destructive potential is expressed with the Canadian snow avalanche size classification system (Table 1). The probability of avalanches is often expressed in terms of expected return period. This is a function of both magnitude and frequency and represents the expected average length of time between avalanches reaching or exceeding a given location.

Table 2 lists some typical threshold return periods and critical avalanche sizes for threatened activities.

Table 1. Canadian snow avalanche size classification system and typical factors (McClung and Schaerer, 1981).

Size	Description	Typical mass (tonnes)	Typical path length (m)	Typical impact pressures (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 avalanche known; could destroy a village or a forest of 40ha	10^5	3000	1000

Table 2. Typical threshold return periods and critical avalanche sizes for threatened activities (CAA, 2002a).

Land use		Typical threshold return period (years)	Critical avalanche size
Transportation corridors	Highway and railway[1]	30	>2
		10 (Active program)	>2
	Industrial road	30	>2
		1 – 10 (Active program depending on traffic volume)	>2
Ski areas	Ski lift bases	100	>2

Land use		Typical threshold return period (years)	Critical avalanche size
	Ski lift towers	30	>2
	Ski area terrain	10	>1
Backcountry recreation	Commercial backcountry operations	10	≥2
Energy and transmission[2]	Transmission line	100	>2
	Surface pipeline	100	>2
	Telephone line	10	>2

[1]*Avalanche deposits contaminated by rocks, woody debris and soil are critical on railways where derailment is a key risk consideration.*

[2]*Avalanches that may contain rocks or woody debris are critical for considering potential damage to utility structures.*

2.2.1 Transportation corridors

Avalanches causing traffic hazards and economic loss due to delays can affect highways, resource roads and railways. This includes hazard to traveling public and workers on major transportation routes (e.g. car traveling on highway, railway workers).

2.2.2 Ski areas

Ski runs, ski lifts, base facilities and access roads are subject to avalanche hazard. This includes people and facilities.

2.2.3 Backcountry recreation

Backcountry recreationists including people engaged in self-directed and commercial recreation activities (e.g. backcountry skiing, mechanized (helicopter and snowcat) skiing, snowmobiling, ice climbing, out-of-bounds skiing, snowshoeing, hiking) are subject to avalanche hazard.

2.2.4 Resource industries

Logging access roads, harvesting operations, standing timber resources and reforestation are subject to avalanche hazard (Jamieson *et al*., 1996). Mining access roads and operations are subject to avalanche hazard. These include people and facilities.

2.2.5 Energy and transmission

In areas where remote generation facilities are linked by cross-mountain transmission lines to urban centers and industrial plants, high voltage transmission lines are subject to avalanche hazard (Stethem et al., 2003).

2.2.6 Residential and public land use

Residences and public facilities are subject to avalanche hazard. This includes people who are inside and near buildings.

2.3 Avalanche hazard mitigation

Active avalanche mitigation refers to measures that are applied to instigate avalanche occurrence or to stabilize slopes in order to reduce the risk of avalanches and to assess the accuracy of avalanche forecasts. Active mitigation measures include explosive control measures such as:

- Helicopter bombing: dropping small or large explosive charges from helicopters.
- Hand charging: placing small explosives.
- Case charging: large amounts of pre-placed explosives.
- GazEx: remote controlled propane exploders (Figure 3).
- Avalanche Guard: remote controlled explosive deployment devices (Figure 4).
- Avalaunchers: pressurized gas propelled explosive projectiles.
- Artilliary: military specified explosive projectiles.

Active mitigation measures also include:

- Ski cutting: triggering avalanches by skiing across the top of a start zone.
- Boot or ski packing: manual compaction of the snowpack, usually early in the winter, to inhibit the formation of basal weak layers.
- Skier compaction: manual compaction of the snowpack throughout the winter.

Figure 3. A GazEx exploder near Kootenay Pass, British Columbia. Photographer: British Columbia Ministry of Transportation Snow Avalanche Program.

Figure 4. An Avalanche Guard protecting the Trans-Canada Highway near Revelstoke, British Columbia. Photographer: British Columbia Ministry of Transportation Snow Avalanche Program.

Passive avalanche mitigation, also known as structural protection, refers to measures that are permanently installed to reduce or eliminate avalanche hazard. Passive control measures include defense structures within the track or runout zone, such as:

- Snowsheds: reinforced concrete sheds designed to protect roads and railways (Figure 5).
- Retarding mounds: earthen or masonry mounds arranged in such a manner to break up the flowing snow into crosscurrents which internally dissipate its kinetic energy.
- Reinforced concrete walls: designed to arrest or deflect avalanches (Figure 6).
- Diversion dikes or berms: reinforced concrete or earthen structures designed to divert avalanches.
- Catchment basins: basin or depression in the ground designed to arrest avalanches.
- Splitting wedges: reinforced concrete, wood or earthen wedges designed to divert avalanches around either side of a structure (e.g. transmission line tower).

Passive control measures that inhibit avalanche initiation within start zones include:

- Fences: supporting structures arranged to retain snow and prevent avalanches.
- Reforestation: planting trees to retain snow and prevent avalanches.
- Wind baffles: walls or panels arranged to induce irregular wind drifting patterns that break the continuity of slabs.

Figure 5. A snow shed protecting the Trans-Canada Highway at Rogers Pass, British Columbia. Photographer: C. Stethem.

Figure 6. A reinforced concrete wall protecting Highway 5 near Coquihalla Pass in British Columbia. Photographer: British Columbia Ministry of Transportation Snow Avalanche Program.

2.3.1 Transportation corridors

Local and regional snowpack, weather and avalanche information is usually obtained through field observations, automated weather stations and through participation in the Canadian Avalanche Association (CAA) daily industry information exchange (InfoEx).

Generally, transportation corridors are closed temporarily when snowpack and weather conditions indicate that avalanches could affect them; closures are maintained until conditions change, either naturally or through active avalanche control measures. Signs are used extensively to alert highway travellers and identify 'no-stopping' zones in areas exposed to avalanche paths. Passive avalanche control structures include snowsheds, retarding mounds, walls, diversion dikes and catchment basins.

While helicopter bombing is the most common means of active avalanche control, methods include artillery such as 105 mm Howitzers, GazEx and Avalanche Guard. These alternative active control measures reduce closure times, as they can be deployed under any weather conditions.

2.3.2 Ski areas

Avalanche mitigation measures for chairlift ski areas vary in complexity from reducing the likelihood of avalanches solely through skier compaction to avalanche control programs. Avalanche control programs for large ski areas such as Whistler Blackcomb and Lake Louise have a team of forecasters who collect manual snowpack, weather and avalanche observations from sites within the ski area. Ski area forecasters also obtain weather information from a network of automated weather stations within the ski area, and weather, snowpack and avalanche information through participation in the InfoEx.

Passive control measures used by ski areas include avalanche hazard assessment and ski area design to reduce risk. Passive control measures also include either permanent or temporary closures, depending on the extent and timing of the avalanche hazard, of runs and zones within the ski area. Early winter boot packing is another mitigation measure used by ski areas primarily in continental climates where low-density basal snow can create avalanches later in the winter. Active control measures include: helicopter bombing, bomb trams, case charging, hand charging, avalaunchers and ski cutting.

2.3.3 Backcountry recreation

The Canadian Avalanche Centre (CAC) developed a three-tiered approach to structure the suite of public avalanche information products used by most public backcountry avalanche centres in Canada. These tiers reflect the avalanche training and experience of the intended user. The first tier involves basic avalanche conditions reported daily to the general public through various media outlets and the CAC website. This avalanche conditions report, dubbed the Backcountry Avalanche Advisory, uses icons to represent the four classes of avalanche conditions: good, serious, poor and variable. It also provides travel advice and guidance to amateur recreationists (Table 3). The first tier also has an educational component in the form of an online glossary and an online avalanche first responders course.

Table 3. The Canadian Avalanche Centre's Backcountry Avalanche Advisory.

Avalanche conditions	**Travel advice**	**Guidance for amateur recreation**
 **Good**	Normal caution	Avalanches are infrequent but possible. Appropriate conditions for informed backcountry travel.
 **Serious**	Extra caution	Avalanches will occur with human and other triggers. Avalanche training and experience are essential for safe backcountry travel.
 **Poor**	Not recommended	Avalanches are occurring frequently. Inappropriate conditions for backcountry travel without extensive avalanche training and experience.
 **Variable**	Extra caution	Conditions change from good with frozen snow to poor with melted snow. Avalanche training and experience are essential to monitor conditions for safe travel.

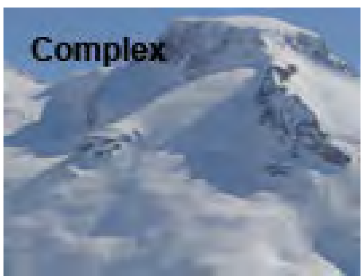
The second tier of products is directed at backcountry recreationists with at least basic avalanche training and experience. These products include the avalanche danger scale, the avalanche terrain exposure scale (ATES) and the Avaluator decision support tool, which are also used by Parks Canada in British Columbia (BC) and Alberta (see below). The avalanche danger scale (Table 4) uses five classes of avalanche danger that are recognized internationally: low, moderate, considerable, high and extreme. In addition, the scale provides a qualitative estimation of avalanche probably and likely triggering magnitude as well as recommendations for backcountry travel. This scale is under revision at the time of this report and the most current version can be found at www.avalanche.ca.

Table 4. The Canadian avalanche danger scale.

Danger level	Avalanche probability and avalanche trigger	Recommended action in the backcountry
LOW	Natural slab avalanches highly unlikely. Human- triggered avalanches unlikely.	Travel is generally safe. Normal caution advised.
MODERATE	Natural slab avalanches unlikely. Human- triggered avalanches possible.	Use caution in steeper terrain on certain aspects.
CONSIDERABLE	Natural avalanches possible. Human- triggered avalanches probable.	Be increasingly cautious in steeper terrain.
HIGH	Natural and human- triggered avalanches likely.	Travel in avalanche terrain is not recommended.
EXTREME	Widespread natural or human- triggered avalanches certain.	Travel in avalanche terrain should be avoided and travel confined to low angle terrain well away from avalanche path runouts.

The avalanche terrain exposure scale (ATES) describes the overall seriousness of a backcountry trip with respect to exposure to avalanche hazard (Table 5). The CAC and Parks Canada have classified many of the most popular backcountry trips in BC and Alberta according to the ATES.

Table 5. The avalanche terrain exposure scale (ATES).

Description	Class	Terrain Criteria
	1	Exposure to low angle or primarily forested terrain. Some forest openings may involve the runout zones of infrequent avalanches. Many options to reduce or eliminate exposure. No glacier travel. (Photo: Grant Statham)
	2	Exposure to well defined avalanche paths, starting zones or terrain traps; options exist to reduce or eliminate exposure with careful routefinding. Glacier travel is straightforward but crevasse hazard may exist. (Photo: Grant Statham)
	3	Exposure to multiple overlapping avalanche paths or large expanses of steep, open terrain; multiple avalanche starting zones or terrain traps below; minimal options to reduce exposure. Complicated glacier travel with extensive crevasse bands or icefalls. (Photo: Bill Mark)

The Avaluator (Haegeli and McCammon, 2006) is a new rule-based decision support tool for amateur self-directed recreationists. A key part of the Avaluator is a pocket card (Figure 7) that assists with planning backcountry trips and facilitates field decisions. This card uses the ATES rating for a particular trip and the avalanche danger for the day and region of the trip, to inform users to use normal or extra caution or if the trip is not recommended for that day. The card also prompts users to make weather, snowpack and avalanche observations during their trip, and informs them to use normal or extra caution or if the trip is not recommended based on the observed number of contributory factors from past incidents.

The focus of the Avaluator is the decision making process when planning for or traveling in the backcountry. The primary target groups are self-directed recreationists with limited experience in avalanche terrain. Simple decision tools, like the Avaluator, aim at starting users towards the development of comprehensive avalanche risk management expertise. The Avaluator is an awareness tool and does not have any predictive capabilities. In other words, it cannot be used to predict the likelihood of an avalanche incident happening. Instead, it provides the user with a measure of how often the current conditions were observed in past incidents.

The second tier of public avalanche information products also includes the classroom and field based Avalanche Skills Training Level I course. These courses are available in BC, Alberta, Quebec, Newfoundland and the Yukon Territory.

The third tier of public avalanche information products includes educational components such as the classroom and field based Avalanche Skills Training Level II course, which is available in BC, Alberta, Quebec, Newfoundland and the Yukon Territory. The CAC also hosts an annual backcountry avalanche workshop in BC and Alberta. This tier also includes advanced weather and snowpack information products available on the CAC website.

Figure 7. The Avaluator decision support pocket card. On one side, the trip planner uses the ATES rating and the avalanche danger to inform users of travel recommendations. On the other side a checklist of obvious clues prompts the user to look for danger signs and aids in slope evaluation by making travel recommendations.

Commercial backcountry operations employ guides to perform active monitoring of snowpack conditions, avalanche forecasting, peer information exchange through InfoEx and avoidance of avalanches by terrain selection. Guides also conduct avalanche control with explosives and by other means. A third area of responsibility for guides within commercial operations is performing avalanche search and rescue and delivery of avalanche safety training to guests. Industry associations such as HeliCat Canada and the Backcountry Lodges of British Columbia Association have established guidelines for guide training and certification.

2.3.4 Resource industries

Avalanche hazard mitigation programs for resource industries is typically implemented by avalanche consulting companies. Mitigation measures include terrain and snowpack risk assessments of worksites and access roads, avalanche search and rescue training and equipment for workers and active and passive control measures.

Active avalanche control programs, which operate only when work is ongoing, typically rely upon on-site evaluation of conditions by a trained client representative. Active control measures such as case charging, hand charging and helicopter bombing by a consultant is initiated when on-site conditions reach pre-determined threshold levels.

2.3.5 Energy and transmission

Avoidance by transmission tower location is the most common method of reducing the hazard. Where towers are located within avalanche paths, additional defensive methods such as splitting wedges, diversion berms, strengthened tower designs and modified conductor designs are employed.

2.3.6 Residential and public land use

Residential and public land use areas generally rely on avoidance to reduce avalanche hazard. Avalanche hazard assessments are performed to identify potentially hazardous areas and zoning is applied accordingly. In areas for which avoidance is not possible, such as areas developed before hazard assessments were performed or areas threatened by new avalanche hazards created by deforestation, passive control measures are often applied.

3. FATAL AVALANCHE INCIDENTS IN CANADA

Information extracted from the CAC Avalanche Incident Database indicates that, up to and including the winter of 2006-07, there have been 349 fatal avalanche incidents in Canada, corresponding to 702 fatalities. While efforts have been made to ensure that the database is as extensive and accurate as possible, these figures are likely low estimates due to incomplete reports and limited historical records. The earliest fatal avalanche incident included in the database occurred in 1782.

Table 6 summarizes the fatal avalanche incidents, organized by province and by activity. The following categories have been used to describe the activity in which each group/person was engaged in when affected by the avalanche:

- Recreation: Self-directed and commercial recreation activities (e.g. backcountry skiing, mechanized skiing, snowmobiling, ice climbing, out-of-bounds skiing, snowshoeing and hiking).
- Transportation: Travel or work on major transportation routes (e.g. car traveling on highway and railway workers).
- Resource industry: Industry related work (e.g. outdoor mine site and logging)
- Building: People who are inside or near a building.
- Other: Other activity (e.g. hunting and avalanche control work)
- Unknown: Unknown activity at the time of the avalanche.

Using the same group activity categories, Google Earth based maps of the fatal avalanche incidents have also been prepared. Maps of regional snow avalanche activity and known fatal avalanche incidents, Canada-wide and on a provincial scale, are included in Appendix A. A ranked list of significant avalanche incidents can be found in Appendix B, and details of selected incidents can be found in Appendix C.

Avalanches have been responsible for at least 702 fatalities in Canada since the earliest recorded incident in 1782 (Table 6). Fifty-three percent of the fatalities were people engaged in recreational activities, while 18% were people in or near buildings, 16% were travelling or working on transportation corridors and 8% were working in resource industries. The remainder are either unknown or engaged in other activities such as hunting or avalanche control work. Sixty-one percent of these fatalities occurred in BC, with 13% in Alberta, 11% in Quebec and

10% in Newfoundland and Labrador. The remainder occurred in Ontario, Nova Scotia and the Yukon, Northwest and Nunavut Territories.

Table 6. Fatal avalanche incidents in Canada, displayed by province and by activity. The number of fatalities is shown. Avalanche incident data were obtained from the Canadian Avalanche Centre Avalanche Incident Database.

	Recr-eation	Transp-ortation	Resource industry	Building	Other	Unknown	Total
British Columbia	246	106	52	18	6	3	**431**
Alberta	92	0	0	0	1	0	**93**
Saskatchewan	0	0	0	0	0	0	**0**
Manitoba	0	0	0	0	0	0	**0**
Ontario	3	0	0	0	0	0	**3**
Quebec	12	1	1	51	0	14	**79**
Newfoundland & Labrador	5	1	5	51	6	2	**70**
New Brunswick	0	0	0	0	0	0	**0**
Nova Scotia	0	0	0	5	0	0	**5**
PEI	0	0	0	0	0	0	**0**
Yukon	15	0	0	0	0	0	**15**
Northwest Territories	1	0	0	0	1	0	**2**
Nunavut	0	0	0	0	2	0	**2**
Unknown	1	1	0	0	0	0	**2**
Total	**375**	**109**	**58**	**125**	**16**	**19**	**702**

For most provinces, the majority of the fatalities were people involved in recreational activities, however in Quebec and Newfoundland and Labrador the majority of the fatalities were people inside or near buildings. Furthermore, 82% of the fatalities involving people in or near buildings were in these two provinces. Newfoundland and Labrador is the region with the highest percentage (73%) of fatalities involving people in or near buildings. Furthermore, many incidents in Newfoundland and Labrador affected people in their homes (Liverman, 2007).

There have been 329 avalanche fatalities in Canada in the last 30 avalanche years, from 1978 to 2007 (Figure 8). Each avalanche year includes the months of October, November and December from the previous year. Three hundred and two (92%) of these fatalities were people involved in recreation, which is much greater than the historical proportion of recreational fatalities (53%) shown in Table 6. This can be attributed to both the increase in popularity of winter backcountry recreation and the decrease in fatalities of people in or near buildings (18% to 4%), travelling or working on transportation corridors (16% to 0%) or working in resource industries (8% to 1%).

This decrease in fatalities of people involved in activities other than recreation is due to improved mitigation measures. For instance, after the implementation of the British Columbia Ministry of Transportation (BC MoT) Snow Avalanche Program in 1976, there have been no fatalities of people travelling or working on roadways in BC. Furthermore, a corresponding increase in the number of fatalities is expected with the increasing number of people are venturing into the mountains for recreation. However, while the annual fatality rate for recreationists has increased in recent years, the number of fatalities on a per capita basis is actually decreasing. Presumably, this lower proportion can be attributed to better avalanche information and public awareness (Jamieson and Geldsetzer, 1996).

Over the past 30 avalanche years, 25% of the 302 recreational fatalities were self-directed backcountry skiers and snowboarders, 22% were commercial snowcat or helicopter skiers and snowboarders, 21% were snowmobilers, 13% were mountaineers and the remaining 19% were other self-directed recreationists such as ice climbers, snowshoers, hikers and out-of-bounds skiers and snowboarders. Over the past 10 avalanche years, 38% of the 123 recreational fatalities were self-directed backcountry skiers and snowboarders, 28% were snowmobilers, 10% were commercial snowcat or helicopter skiers and snowboarders, 8% were out-of-bounds skiers and snowboarders and 3% were mountaineers. This trend reflects the increase in popularity of self-directed backcountry and out-of-bounds skiing and snowboarding as well as snowmobiling. It also reflects the improved mitigation measures used by commercial snowcat and helicopter skiing and snowboarding operations.

The average number of fatalities for the past ten avalanche years (14 fatalities per avalanche year) is greater than the average number of fatalities for the past 30 avalanche years (11 fatalities per avalanche year). This suggests that that avalanche fatality rate is increasing. However, over the last four winters (2004 to 2007), the avalanche fatality rate has been on a decreasing trend, as shown in Figure 8, with an average of nine fatalities per winter since 2004. Due to incomplete records, historical fatality rates cannot be accurately determined. The 30-year proportion of fatalities for each province is not significantly different from the historical proportion.

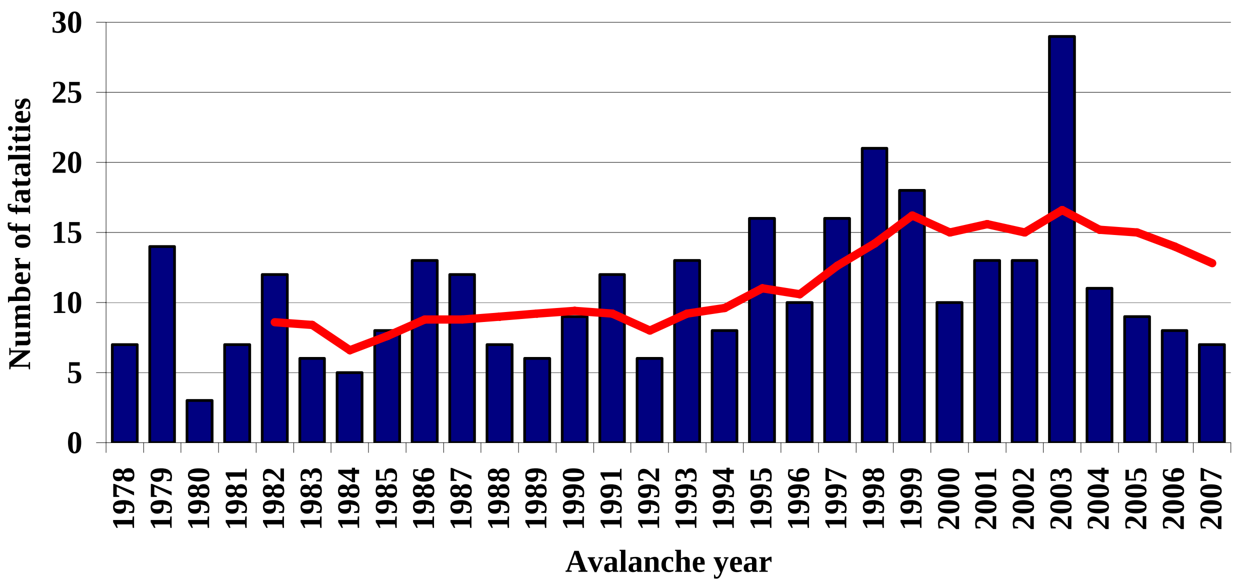


Figure 8. Number of avalanche fatalities per avalanche year for the 30-year period from 1978 to 2007. Each avalanche year includes the months of October, November and December from the previous year. The five-year running average (red line) is also shown. Avalanche incident data were obtained from the Canadian Avalanche Centre Avalanche Incident Database. N = 329.

4. INVENTORY OF ACTIVITY AND MITIGATION

4.1 Transportation corridors

4.1.1 Roadways

Yukon - Highway 2

An avalanche technician has been on contract to the territorial government since the highway opened in 1986. Mitigation activities protect the highway, the traveling public and commercial transportation. Site-specific weather information is obtained from one remote weather station, 2 road level weather stations and local observations. The road is closed, typically 1 week per winter, as a passive control measure. Active helicopter bombing is undertaken, on average, twice per winter.

British Columbia - Provincial highway network

One thousand three hundred and seventy avalanche paths threaten the BC highway network in 60 avalanche prone locations throughout the province (Map 11). Sixty kilometres of the South Klondike Highway (Highway 2) are affected by avalanches. Avalanche paths threaten approximately 16 km of the Trans-Canada Highway (Highway 1) through the Kicking Horse Canyon, directly east of Golden. Construction equipment, work areas, haul roads and site offices are exposed to avalanche terrain. Approximately 40 km of the Trans-Canada Highway (Highway 1) traverses Glacier National Park, where it is exposed to more than 130 different avalanche paths. Many of the avalanche paths have overlapping runout zones and can be triggered from multiple locations.

The mandate of the BC MoT Avalanche and Weather Program is to ensure safe travel on provincial highways and to minimize disruptions to traffic. Thirty-six people are employed with the program, including 22 field technicians based out of offices located in Hope, Pemberton, Revelstoke, Nelson, Penticton, Terrace and Stewart.

Weather data are collected through a network of more than 100 automated Roadside Weather Stations and Remote Avalanche Weather Stations. Measurements made at each station include temperature, relative humidity, hourly precipitation, wind direction, wind speed and height of snow. The BC MoT crews and other stakeholders, including the CAC, can access weather information from the entire network. All weather and avalanche information is stored in a custom-built computer software program, Snow Avalanche and Weather System, allowing it to be used in support of decisions and to improve understanding of avalanche and weather features for various areas of the province. In addition to the electronic weather data, avalanche technicians incorporate reports of regional avalanche conditions, avalanche occurrence observations and field observations of snowpack conditions in their avalanche hazard assessments.

While helicopter bombing is the most common means of active avalanche control, methods include a 105 mm Howitzer (Bear Pass), 23 GazEx exploders (Kootenay Pass and Duffy Lake) and 6 Avalanche Guard devices (Revelstoke area). Passive control structures include snowsheds (Coquihalla Pass and Revelstoke area), retarding mounds (various), deflecting berms (various) and reinforced concrete walls (Coquihalla Pass).

British Columbia - Highway 1: Kicking Horse Canyon

This is the only location in BC where a private company provides avalanche forecasting and control services for a provincial highway. In addition to protection of the travelling public and highways maintenance personnel, the safety of construction crews currently working on a major highway upgrading project in the Kicking Horse Canyon is a concern. Construction equipment, work areas, haul roads and site offices are exposed to avalanche terrain.

Throughout the winter season, one to two staff are available daily to address avalanche forecasting and control needs. From an office in Golden, staff issue daily avalanche hazard bulletins and typically complete twice-daily road patrols. Site-specific weather information is obtained from three BC MoT automated weather stations that provide information such as hourly precipitation, wind speed, temperature, relative humidity and height of snow. On an approximately weekly basis, staff complete snowpack profiles and tests. Snowpack, weather and avalanche information is also obtained through participation in the InfoEx. The frequency of bulletins, road patrols and snowpack observations increases as necessary with changing conditions.

The existing highway alignment includes protective walls and catchment ditches to minimize avalanche deposits on the highway. Additional passive defence structures will be constructed as part of the upgrading project, with the intention that an active control program will not be required upon completion. Currently, active avalanche control via helicopter bombing is undertaken as needed, typically several times per season. Highway closures and restrictions on construction activities and are imposed when increased hazard warrants. Construction personnel are required to wear avalanche beacons and to complete avalanche safety training twice annually.

In addition to the considerations regarding the safety of the public, maintenance personnel and construction crews, there is pressure to keep the highway open and to coordinate closures with neighbouring avalanche control programs.

British Columbia - Highway 1: Glacier National Park

The Avalanche Control Section of Parks Canada is responsible for avalanche mitigation activities for the highway within Glacier National Park, avalanche mitigation activities for the Canadian Pacific Railway (CPR) line through Glacier National Park in cooperation with a private company hired by CPR (Section 4.1.2) as well as preparation of the daily public backcountry avalanche bulletin (Section 4.3.1).

Nine automated weather stations provide information such as air temperature, precipitation, wind direction, wind speed and relative humidity at different locations within the park. Frequent road patrols and daily field visits by Avalanche Control Section staff supply information about avalanche activity and snowpack structure. In addition to roving observations, weather and snowpack conditions are monitored regularly at study plots located at the Rogers Pass summit (1315 m) and the Mt. Fidelity Observatory (1905 m). Snowpack, weather and avalanche information is also obtained through participation in the InfoEx.

Within Glacier National Park, approximately 1.5 km of Highway 1 is protected by five snowsheds. Additional passive control measures in Glacier National Park include retarding mounds and an assortment of dams, benches, basins and fences that divert and retain avalanche debris. Signs alert highway travellers when they are in avalanche exposed areas, designated as 'no stopping' zones. Work by highway personnel in avalanche areas is restricted under conditions of increased avalanche hazard.

Mobile avalanche control is undertaken with road closures and artillery fire. Royal Canadian Horse Artillery personnel, posted at the Rogers Pass summit from December to April, operate two 105 mm Howitzers under the direction of the Avalanche Control Section forecasters. Nineteen fixed gun positions provide capacity for active control of more that 250 start zone targets. When avalanche activity is expected to affect the highway or nearby railway line, or when the snowpack structure provides opportunity to remove build-up from the many start zones, the forecaster initiates closures at appropriate locations. Artillery control, using indirect sighting systems that can be applied at night and under adverse weather conditions, is then undertaken to reduce the avalanche hazard. Closures are coordinated with neighbouring control programs (i.e. BC MoT and CPR) to minimize traffic delays. In a typical winter season, approximately 55 individual road closures will occur, lasting from one hour to multiple days; longer closures are usually tied to other problems such as road conditions, slide clearing or avalanche hazard outside the control area. The majority of closures are two to four hours in duration (Schleiss, 1989).

British Columbia - Highway 1: Mount Revelstoke National Park

The Avalanche Control Section of Parks Canada in Glacier National Park also monitors eight avalanche paths in Mount Revelstoke National Park. These paths are all south or southeast facing paths off of an unnamed peak south of Mt. Klotz. Most of these have mid elevation start zones prone to producing effective avalanches in wet avalanche cycles or extreme weather events with a warming trend. Only two have alpine start zones. Return intervals for effective avalanches range between five and twenty years. These avalanche paths are located over approximately seven kilometres of the Trans-Canada Highway; the CPR mainline is not affected by avalanches within Mount Revelstoke National Park as it is located safely on the opposite side of the Illecillewaet River.

Because of the proximity, the Avalanche Control Section can use the same sources of snowpack, weather and avalanche information as for Highway 1 through Glacier National Park. Passive measures such as signing and warning are usually sufficient protection for these paths. In extreme conditions active control is conducted using helicopters.

British Columbia/Alberta – Various: Banff, Yoho and Kootenay National Parks

In addition to preparation of the daily public avalanche bulletin (Section 4.3.1), Parks Canada is responsible for closure and control decisions for the following roadways within Banff, Yoho and Kootenay National Parks:

- Highway 1 (Trans-Canada Highway; approx. 120 km - west of Banff to east of Golden)

- Highway 93 North (Icefields Parkway; approx. 75 km - Saskatchewan Crossing to Lake Louise)
- Highway 93 South (approx. 100 km - west of Banff to Radium Hot springs)
- Sunshine Village Ski & Snowboard Resort access road (Sunshine Road)
- Field back road

Site-specific weather information is obtained from remote telemetry weather stations. Parks Canada field teams collect snowpack and avalanche observations, typically daily. Snowpack, weather and avalanche information is also obtained through participation in the InfoEx.

Passive control measures within the parks consist of a diversion dike on the Trans-Canada Highway (Mount Stephen) and retarding mounds in the runout of several paths on the Sunshine Road and several paths on Highway 93 South (Vermilion). Signs alert highway travellers and identify 'no-stopping' zones in areas exposed areas. Active avalanche control via helicopter bombing is undertaken for all of the transportation corridors on an as needed basis, typically during 6-10 cycles per year. Several GazEx exploders are in place for explosive control on the Sunshine Village access road.

Alberta - Highway 93 North: Jasper National Park

Parks Canada is responsible for control and closure decisions for Highway 93 North (Icefields Parkway) from Jasper to Saskatchewan Crossing (approximately 155 km), as well as for public safety in the park (Section 4.3.1).

Area-specific weather information is obtained from two Parks Canada weather stations (Parker Ridge and Mount Colemon) and the Marmot Basin ski resort weather station. Parks Canada field teams collect snowpack and avalanche observations. Snowpack, weather and avalanche information is also obtained through participation in the InfoEx.

Signs alert highway travellers and identify 'no-stopping' zones in areas exposed areas. Active control measures include helicopter bombing, hand charging, avalauncher explosive projectiles and ski cutting. When snowpack and weather conditions indicate that avalanches could affect the highway, it is closed until avalanche control measures can be applied or conditions improve. In the past two winter seasons, seven (2006-07) and five (2005-06) control missions have been completed.

Alberta - Smith-Dorrien/Spray Lakes Road

Avalanche mitigation activities are undertaken as part of the Kananaskis Country program (Section 4.3.1). The primary roadway concern is the portion of the Smith-Dorrien/Spray Lakes Road below the east end of Mount Rundle. Winter recreationists, including a commercial sled dog operation, mainly use this road.

Site-specific weather information is collected daily at the Chester weather and snow study plot. A remote weather site on the east end of Mount Rundle provides real-time data for that area. Staff obtain additional relevant weather information by compiling satellite imagery, Environment Canada text forecasts, aviation weather products and local television weather forecasts. The scheduled public safety team member gathers snowpack information daily with assistance from Conservation Officers and/or volunteers. Snow study helicopter flights are done once a month around Kananaskis Country, in partnership with the Alberta Environment Water Surveys Department.

The road is closed when avalanche activity is expected to affect the road. Pressure is applied by the sled dog operation if avalanche control cannot be undertaken in a timely fashion and the road is closed. Active avalanche control for this section of road, via helicopter bombing, is undertaken when necessary; none has been required in the past 3 years.

Alberta - Cameron Lake Road : Waterton Lakes National Park

Infrastructure at potential risk from avalanches in Waterton Lakes National Park includes the Cameron Lake Road and ski trail, the Parks Canada Works Compound and the southwestern portion of the Waterton townsite, which encompasses sixteen private leaseholder cabins and a number of Parks Canada facilities and roads.

Site-specific weather and snowpack information is collected manually at one station. Additional weather information is obtained from remote weather stations maintained by Parks Canada, Environment Canada and the Alberta government. Snowpack, weather and avalanche information is also obtained through participation in the InfoEx.

Avalanche mitigation activities are primarily passive, focussing on awareness and the provision of information through the regular avalanche bulletins (Section 4.3.1) and management plans. The park Avalanche Safety Plan allows for closure of the Cameron Lake Road, the Parks

Canada Works Compound and the southwest portion of the community if the threat of a large avalanche is present. A short section of the Cameron Lake Road is designated as a 'no-stopping' zone in the winter months due to avalanche concerns.

Quebec - Highways 132 and 198: Gaspésie

Staff from the Haute-Gaspesie Avalanche Centre (HGAC) are involved with the Quebec Ministry of Transportation on an avalanche safety program for Highways 132 and 198 in Haute-Gaspésie, where a total of 62 avalanche paths affect the road over a distance of 60 km. The avalanche mitigation program includes passive control measures such as land use planning, warning signs, staff training and monitoring. To date, there are no active control measures. Approximately ten Ministry of Transportation staff members manually collect data from two weather stations to help forecast high risk periods. Roads are closed during and after storms, as required due to elevated avalanche hazard.

Quebec - Highways 138 and 299

There have been avalanche incidents on Highway 138 in Basse-Côte-Nord and Highway 299 across the Gaspe Peninsula where there are currently no mitigation programs in place.

Newfoundland – Highway 1: Humber Gorge

The Trans-Canada Highway through Humber Gorge in Newfoundland is subject to avalanche hazard, however there are currently no mitigation measures in place.

4.1.2 Railways

Alberta/British Columbia - Canadian Pacific Railway (CPR)

A private company undertakes avalanche forecasting and control for railway lines through the Mountain Subdivision (Lake Louise to Sicamous) and the Kootenay Subdivision (from Elkford to Nelson). Travelling freight trains, CPR employees and maintenance crews are exposed to avalanche hazard in these areas. Parks Canada is responsible for avalanche control within Glacier and Yoho National Parks. Up to four staff members, based in forecast offices in Golden, Revelstoke and Fernie, are employed in CPR related avalanche mitigation measures daily throughout the winter. The CPR line is a major freight corridor and there is considerable financial pressure to keep it open.

Avalanche hazard bulletins are issued to CPR personnel daily; updates are provided during the day if appropriate due to changing weather conditions. Access to Ministry of Transportation and Parks Canada weather stations provides some site-specific weather information. Relevant snowpack observations are obtained from Parks Canada, and from snowpack profile and test information collected on an approximately weekly basis. Section 4.1.1 outlines other sources of weather, snowpack and avalanche information used by the private company's forecasters.

Passive control measures along the CPR line through this area include snowsheds and tunnels, retaining walls and containment berms (e.g. Mount Stephen). Appropriate railway maintenance activities are determined based on the daily hazard and previously completed location-specific terrain assessments. Rail closures and avalanche control via helicopter bombing, are undertaken as needed, the latter typically several times per season. CPR employees are required to complete avalanche safety training on an annual basis.

Alberta/British Columbia - Canadian Pacific Railway (CPR): Banff, Yoho and Kootenay National Parks

A private company hired by CPR as well as Parks Canada are responsible for avalanche forecasting and control decisions, respectively, for the CPR line within Banff, Yoho and Kootenay National Parks (approximately 120 km). Section 4.1.1 outlines sources of weather, snowpack and avalanche information used by the private company's forecasters. Mitigation activities are undertaken in conjunction with those for the nearby Highway 1 (Section 4.1.1). Active avalanche control via helicopter bombing is undertaken for all of the transportation corridors within the parks on an as needed basis, typically during six to ten cycles per year.

British Columbia - Canadian Pacific Railway (CPR): Glacier National Park

A private company hired by CPR as well as Parks Canada Avalanche Control Section are responsible for avalanche forecasting and control decisions, respectively, for the CPR line within Glacier National Park (approximately 40 km). Section 4.1.1 outlines sources of weather, snowpack and avalanche information used by the private company's forecasters. The Connaught and Mount MacDonald tunnels (8.0 and 14.7 km long, respectively) shelter train traffic from exposure to avalanche paths through the Rogers Pass summit area. Additional passive control measures in Glacier National Park include snow sheds, retarding mounds and an assortment of dams, benches, basins and fences that divert and/or retain avalanche debris. Work by railway personnel in avalanche areas is restricted under conditions of increased avalanche hazard. Active control measures, as described in Section 4.1.1, are undertaken in conjunction with mitigation activities for the Trans-Canada Highway.

British Columbia - Canadian National Railway (CN)

The BC North avalanche safety program in place for Canadian National Railway (CN) includes the Bulkley subdivision (east of Terrace; CN mile 119.0 to 120.5) and the Skeena subdivision (west of Terrace; CN mile 27.0 to 53.0). Within the two subdivision, which include a total track length of 16 miles, there are five avalanche zones. The area can be one of the most active avalanche areas in the province. The program is in place to protect employees and the public, to protect trains from derailments caused by avalanches, and to minimize delays to time-critical train movements.

Infrastructure protected includes the railway main line to and from Prince Rupert. No structures other than the rails and ties are located in any avalanche paths, although the rail right-of-way is used by both CN employees and public passenger trains. The mitigation program is run cooperatively with the BC MoT mitigation program for Highway 16, which is located adjacent to the CN right-of-way.

Avalanche mitigation activities are based out of an office in Terrace and a workshop trailer at Salvus maintenance camp, 60 km west of Terrace. One contractor is employed full time with avalanche-related activities, with assistance from one CN employee. This program is operated in conjunction with the BC MoT Terrace-Tyee program; two BC MoT avalanche technicians and three to five BC MoT maintenance contractor employees assist with avalanche mitigation activities as required.

Site-specific weather information is obtained from the BC MoT Road Weather Information System and from a weather station located at the Shames Mountain ski area. Shames Mountain ski patrol make weather observations using instruments provided by CN. Information about the snowpack structure is obtained from various test profile sites, which are accessed by helicopter and occasionally through the Shames Mountain ski area. Snowpack, weather and avalanche information is also obtained through participation in the InfoEx.

Passive control measures include restriction of maintenance work and train movement during periods of elevated hazard. There are electronic slide detector fences and earth deflector berms in some runout zones. Active control measures include large amounts of strategically placed explosives, known as case charging, helicopter bombing and artillery fire (105 mm recoilless rifles from six fixed gun towers). Typically five to ten active mitigation activities are undertaken per winter.

British Columbia - Canadian National Railway (CN): Mount Robson

The CN line through Mount Robson Provincial Park is exposed to avalanche paths on Klapperhorn Mountain and Overlander Mountain. Avalanche monitoring and control for this area employs one person, for approximately two days each winter month.

Hourly weather information is obtained from a CN remote weather station located at an elevation of approximately 2135 m on Overlander Mountain. Manual snow profiles are completed at the same location, typically twice per month. Weather, snowpack and avalanche information is also obtained through participation in the InfoEx. Passive control measures include a snow shed and electronic slide detector fences along the rail line. Active avalanche control via helicopter bombing is undertaken as required, typically once per winter season.

British Columbia - Canadian National Railway (CN): Tumbler Ridge

The CN (formerly British Columbia Railway) branch line to Tumbler Ridge is exposed to avalanche hazard near the head of the Table River (approximately 50 km southwest of Tumbler Ridge). Two long tunnels constructed in this area to facilitate the mountain crossing provide protection from some avalanche paths. Operation of this branch line is tied to mining activity in the Tumbler Ridge area; after closures in recent years, it is currently operating. Active avalanche control, via helicopter bombing, is undertaken several times each winter when the rail line is in operation.

British Columbia - Canadian National Railway (CN): Pine Pass

The CN (formerly British Columbia Railway) line between Prince George and Chetwynd is exposed to avalanche hazard in the Pine Pass area (approximately 75 km west of Chetwynd). Deflection berms have been constructed as passive avalanche mitigation measures. Active avalanche control via helicopter bombing is undertaken as required, typically a few times each winter.

4.1.3 Ports

British Columbia - Port of Stewart

Shipping in the Port of Stewart is exposed to avalanche risk from avalanche paths along the side of the Portland Canal. Potential effects include wave generation and damage to dock facilities. The BC MoT, which is responsible for a road threatened by avalanche paths in the same area (Mount Rainey), undertakes forecasting and control (Section 4.1.1). Active control work has been done infrequently via helicopter bombing over the years.

4.2 Ski areas

In addition to the provinces highlighted in the following sections, there are also chairlift ski areas in Manitoba, Saskatchewan, New Brunswick, Newfoundland, Nova Scotia and the Yukon (Map 12).

4.2.1 British Columbia

There are approximately 34 chairlift ski areas in BC. All have expert level ski runs, which suggests open slopes steep enough to produce avalanches. The majority are within the high avalanche activity zone, as shown in Map 13, which suggests the potential for a snowpack that is prone to producing avalanches most winters. All chairlift ski areas in BC have an open-boundary policy that allows self-directed backcountry skiers to use the chairlifts and runs to access the uncontrolled backcountry, at their own risk. However, not all chairlift ski areas have popular backcountry ski destinations that are accessible from their chairlifts and runs.

Information provided by the Canada West Ski Areas Association indicates that, as of May 2007, 13 ski areas in BC have avalanche control programs. Respondents to an Avalanche Control Blasting Program survey completed by the CAA in the winter of 2006-07 included Kicking Horse Mountain Resort (Golden), Panorama Mountain Village (Invermere), Fernie

Alpine Resort (Fernie), Big White Ski Resort (Kelowna), Apex Mountain Resort (Penticton), Whitewater Winter Resort (Nelson), Red Mountain Resort (Rossland), Mount Washington Ski Resort (Comox), Whistler Blackcomb (Whistler) and Grouse Mountain Resort (North Vancouver).

4.2.2 Alberta

There are approximately 17 chairlift ski areas in Alberta. All have expert level ski runs, which suggests open slopes steep enough to produce avalanches. The majority are within the high avalanche activity zone, as shown in Map 13, which suggests the potential for a snowpack that is prone to producing avalanches most winters. Most chairlift ski areas in Alberta have an open-boundary policy that allows self-directed backcountry skiers to use the chairlifts and runs to access the uncontrolled backcountry, at their own risk. However, not all chairlift ski areas have popular backcountry ski destinations that are accessible from their chairlifts and runs.

Information provided by the Canada West Ski Areas Association indicates that, as of May 2007, 6 ski resorts in Alberta have avalanche control programs. Respondents to an Avalanche Control Blasting Program survey completed by the CAA in the winter of 2006-07 included Sunshine Village Ski Resort (Banff), Lake Louise Mountain Resort (Lake Louise), Castle Mountain Resort (Pincher Creek) and Ski Norquay (Banff).

4.2.3 Ontario

There are approximately 46 chairlift ski areas in Ontario. All have expert level ski runs, which suggests open slopes steep enough to produce avalanches. However, the majority are within the very low avalanche activity zone, as shown in Map 14, which suggests there are very isolated avalanche slopes and avalanches rare.

4.2.4 Quebec

There are approximately 69 chairlift ski areas in Quebec. All have expert level ski runs, which suggests open slopes steep enough to produce avalanches. The majority are within the low avalanche activity zone, as shown in Map 14, which suggests there are isolated avalanche slopes with infrequent avalanches that occur mostly in extreme winters. Some Quebec ski areas are within the moderate avalanche activity zone, which suggests some avalanche paths could produce avalanches most winters. Recently a class 2 avalanche that involved artificial snow occurred at Owl's Head ski area (Wendy Herron, personal communication). However, skier compaction of the snowpack within avalanche start zones greatly reduces the potential for avalanches.

4.3 Backcountry recreation

4.3.1 Self-directed backcountry

There are currently 616 self-directed backcountry trips listed on the CAC trip planning website, and the list is being populated on an ongoing basis. This total includes 485 ski, 97 snowmobile and 34 out-of-bounds trips, although a small proportion (< 5%) of the trips are listed in more than one category of recreation. The approximate locations of these trips and other popular self-directed backcountry recreation areas are shown on Map 15. The majority of self-directed backcountry activity takes place in BC (Map 16) with Alberta, Yukon, Quebec and Newfoundland also having popular areas.

British Columbia/Alberta - Canadian Avalanche Centre (CAC)

Based in Revelstoke, BC, the CAC provides public avalanche bulletins and reports for popular winter backcountry recreation areas in BC and Alberta. Six avalanche forecasters are employed by the CAC during the winter months. Public avalanche bulletins are issued by the CAC at least three times per week for each of the public avalanche bulletin regions described below (Map 17). However, smaller bulletin regions would result in more accurate danger forecasts (Jamieson et al., 2007). These bulletins are issued more frequently during times of rapidly changing conditions or times of high use (e.g. Christmas holidays). However, more frequent bulletins would result in more accurate danger forecasts (Jamieson et al., 2007). Additional Special Public Avalanche Warnings are issued by the CAC with the support of the BC Provincial Emergency Program at times when the avalanche risk to backcountry recreationists is elevated.

- Northwest: This region includes the Coast Mountains east of Prince Rupert, north of Kitimat and east of Stewart, the Skeena Mountains from Ningunsaw Pass in the north to New Hazelton in the south, and the Hazelton Mountains between Terrace and Smithers.

- North Columbia: This region includes areas north and east of Kamloops, east of the Fraser Plateau north to Prince George, the Cariboos and Selkirks west of the Rocky Mountain trench between McBride and Golden and areas north of Highway 1 between Kamloops and Golden (excluding Glacier National Park).
- South Columbia: This region includes the eastern side of the Okanagan Valley from Osoyoos to Enderby, areas south of Highway 1 from Sicamous to Golden (excluding Glacier National Park), areas west of the Columbia River between Golden and Kimberley, and areas north of Kaslo and northwest of Castlegar.
- South Coast: This region includes mountain areas in the Squamish to Pemberton corridor, the eastern Coast range from Lilloet through the Fraser Canyon to Hope, the Coquihalla and Manning Park areas and mountain areas adjacent to the Fraser Valley. This region does not include the Vancouver North Shore Mountains or Vancouver Island.
- Kootenay Boundary: This region includes mountain areas east of Greenwood, southeast of Castlegar, the Selkirk Mountains near Nelson, Kootenay Pass, and the southern Purcell range west of Kimberley and Cranbrook to the United States border
- South Rockies: This region includes mountain areas in the Elk Valley between Fernie and Elkford, areas east of the Rocky Mountain trench between Canal Flats and Cranbrook, and areas within the BC side of the Crowsnest Pass. This region does not include Kananaskis Country or areas in Kootenay or Waterton Lakes National Parks.

A public report is issued weekly by the CAC for the North Rockies region, which includes the Rocky Mountain ranges south of the Peace Reach of Williston Lake and north of the Fraser River. The west boundary lies on the Parsnip Reach of Williston Lake, the Crooked River, Bear and Summit Lakes. The east boundary runs from Hudson's Hope, west of Chewynd and Tumbler Ridge, then east of Kakwa Recreation Area, south along the Alberta/BC border, and west of Mt. Robson Park.

Two partner organizations prepare avalanche bulletins which are also available from the CAC website. Whistler Blackcomb issues a daily bulletin for the backcountry area around Whistler, BC. The North Shore Avalanche Advisory Group issues an avalanche report, covering backcountry areas in the north shore mountains near Vancouver, BC, approximately 3 times per week.

British Columbia - Chilkoot Trail National Historic Site of Canada

An information-based avalanche prevention program is currently being developed by Parks Canada for the Chilkoot Trail National Historic Site of Canada. Information available to the public via signs, brochures and the internet will include area-specific terrain information and recommendations for travel.

British Columbia - Glacier National Park

The Avalanche Control Section of Parks Canada in Glacier National Park consists of two forecasters and six avalanche technicians. Every day throughout the winter, at least one forecaster and three technicians are working to evaluate snowpack and weather conditions within the park. Avalanche forecasting and control operations are based at the Rogers Pass summit.

The Avalanche Control Section prepares a daily public avalanche bulletin for the areas adjacent to, and directly accessed from, the Highway 1 corridor in Glacier National Park. Responsibilities also include avalanche forecasting and control for Highway 1 (Section 4.1.1) and the CPR line in cooperation with a private company hired by CPR (Section 4.1.2). Road access in Glacier National Park makes it a very popular destination for backcountry recreationists (Map 16). Section 4.1.1 outlines sources of weather, snowpack and avalanche information used by the Avalanche Control Section.

All avalanche paths facing the transportation corridors passing through Glacier National Park are closed for the winter season under Parks Canada Agency authority. Entry into some of these closed areas may be permitted periodically when avalanche control activities are certain not to take place. Some areas of the park are permanently closed for avalanche research and monitoring.

Two to three Parks Canada public safety wardens, trained in avalanche search and rescue, are also stationed at the Rogers Pass summit on a daily basis throughout the winter. The public avalanche bulletin (Map 17), winter travel information and route descriptions are available to the public at the Rogers Pass Centre. In addition, Parks Canada produces free avalanche terrain maps and photos (Figure 9) for select trips in Glacier National Park that are available on their website and posted on large signs at trailheads. All popular backcountry trips within Glacier National Park are rated with ATES and the ratings are made available to the public through their website, on brochures available at the visitor centre and posted on signs at trailheads. Furthermore, Parks

Canada requires that a certified guide accompany all custodial groups accessing challenging avalanche terrain and no custodial groups are permitted in complex avalanche terrain within a national park during the winter.

Figure 9. An example of an avalanche terrain map and photo that is available on the Parks Canada website and posted at trailheads for selected trips in Glacier, Banff, Jasper, Yoho and Waterton Lakes National Parks.

British Columbia - Mount Robson Provincial Park

The Berg/Kinney Lake trail in Mount Robson Provincial Park is exposed to an avalanche path approximately 1 km from the trailhead. Winter backcountry recreationists use this trail; however, the heaviest use is by hikers during the normal park operating period from early May to late September. No winter conditions information or backcountry avalanche bulletin is provided for Mount Robson Provincial Park. Information on trailhead signs, on the BC Parks website and in brochures identifies the potential for avalanches and recommends proper equipment for parties pursuing mountaineering objectives or winter backcountry recreation within the park. No active avalanche control is undertaken during the winter months. Active control of the avalanche path threatening the Berg/Kinney Lake trail is undertaken via helicopter bombing during the seasonal start-up in early May, if necessary.

British Columbia/Alberta - Banff, Yoho and Kootenay National Parks

Six Parks Canada employees are involved in day to day avalanche mitigation activities for Banff, Yoho and Kootenay National Parks in the winter. Additional staff are present during training or as required for search and rescue. Parks Canada is responsible for public safety in the parks, as well as control and closure decisions for several transportation corridors within the parks (Section 4.1.1 and Section 4.1.2).

A combined public avalanche bulletin (i.e. encompassing all three parks) is issued daily for use by backcountry recreationists. The forecast area covers the east and west sides of the Continental Divide, from the Wapta Icefields area in the north to the Sunshine Village area in the south (Map 17). It also includes the Main Range area from Lake Louise to Bow Summit. Section 4.1.1 outlines the sources of snowpack, weather and weather information used by Banff, Yoho and Kootenay National Parks employees.

In addition, Parks Canada produces free avalanche terrain maps and photos (Figure 9) for select trips in Banff and Yoho National Parks that are available on their website and posted on large signs at trailheads. All popular backcountry trips within Banff, Yoho and Kootenay National Parks are rated with ATES and the ratings are made available to the public through their website, on brochures available at the visitor centre and posted on signs at trailheads. Furthermore, Parks Canada requires that a certified guide accompany all custodial groups accessing challenging avalanche terrain and no custodial groups are permitted in complex avalanche terrain within a national park during the winter.

Alberta - Jasper National Park

Parks Canada staff involved with the Jasper National Park avalanche control program include 7 full-time employees and 7 part-time employees. Parks Canada is responsible for public safety in the park, and for control and closure decisions for Higway 93 North (Section 4.1.1). A public avalanche bulletin is issued daily for Jasper National Park. The forecast area covers the Continental Divide, eastwards to the Maligne Lake drainage, and from Saskatchewan River Crossing in the south to Hwy 16 in the north. Section 4.1.1 outlines the sources of snowpack, weather and weather information used by Jasper National Park employees.

In addition, Parks Canada produces free avalanche terrain maps and photos (Figure 9) for select trips in Jasper National Park that are available on their website and posted on large signs at trailheads. All popular backcountry trips within Jasper National Park are rated with ATES and the ratings are made available to the public through their website, on brochures available at the visitor centre and posted on signs at trailheads. Furthermore, Parks Canada requires that a certified guide accompany all custodial groups accessing challenging avalanche terrain and no custodial groups are permitted in complex avalanche terrain within a national park during the winter.

Alberta - Kananaskis Country

An avalanche mitigation program is in place in Kananaskis Country, extending from Canmore to Plateau Mountain (N-S) and from the BC/Alberta border to Bragg Creek/Turner Valley (W-E). A public safety team of three is employed full time in avalanche mitigation and rescue activities. Conservation Officers and qualified volunteers assist with snow study and weather data collection, typically twice per week. A daily public avalanche bulletin is produced throughout the winter season. In addition, staff undertake a daily review of the Smith-Dorrien/Spray Lakes Road (Section 4.1.1). Active avalanche control is also undertaken, via hand charging, for cross-country ski trails in Peter Lougheed Provincial Park when necessary; none has been required in the past 5 years. Section 4.1.1 outlines the sources of snowpack, weather and weather information used by the forecasters.

No passive control structures are in place. Where possible, roads and ski trails in the area were designed to avoid avalanche paths. Winter recreational use is limited in some areas by a seasonal road closure over Highwood Pass, in place to eliminate human disturbance to calving elk.

Alberta - Bighorn Country

Three Alberta government employees are involved in avalanche mitigation activities elsewhere in Alberta. These occur in the Hinton area, Nordegg area and the Crowsnest Pass area. The Crowsnest area, particularly, is a popular destination for recreational snowmobiliers. The government employees work in collaboration with a CAC contracted forecaster.

Mitigation activities consist of a weekly public avalanche report prepared by the forecaster in consultation with a CAC forecast team. This report region includes the Rocky Mountains between the Alberta/BC border and the Forestry Trunk Road, north of the Red Deer

River. The northern boundary goes east on the Cline River, north on the height of land between Coral and McDonald Creeks, east through Coral Lake to the confluence of the Bighorn River and Sunkay Creek, then parallel to highway 11 through Shunda Creek, and then encircles Nordegg.

Snowpack information is gathered from weekly snow profiles, accessed via snowmobile north or south of Highway 3 along the Alberta side of the divide. The forecaster also does monthly helicopter snow study flights with the southern Alberta Environment Water Survey Crews.

Alberta - Waterton Lakes National Park

Three Parks Canada employees are involved with the preparation of twice-weekly avalanche bulletins in Waterton Lakes National Park. The forecast covers the upper Cameron Valley and continental divide areas. Additional staff assist with collection of daily weather and snowpack data and avalanche observations. Section 4.1.1 outlines the sources of snowpack, weather and weather information used by Waterton Lakes National Park employees.

In addition, Parks Canada produces free avalanche terrain maps and photos (Figure 9) for select trips in Waterton Lakes National Park that are available on their website and posted on large signs at trailheads. All popular backcountry trips within Waterton Lakes National Park are rated with ATES and the ratings are made available to the public through their website, on brochures available at the visitor centre and posted on signs at trailheads. Furthermore, Parks Canada requires that a certified guide accompany all custodial groups accessing challenging avalanche terrain and no custodial groups are permitted in complex avalanche terrain within a national park during the winter.

Avalanche mitigation activities are primarily passive, focussing on awareness and the provision of information through the regular avalanche bulletins and management plans. The park Avalanche Safety Plan allows for closure of the Cameron Lake Road, the Parks Canada Works Compound and the southwest portion of the community if the threat of a large avalanche is present. A short section of the Cameron Lake Road is designated as a 'no-stopping' zone in the winter months due to avalanche concerns.

Yukon - Kluane National Park

At this time, there is no avalanche mitigation program in Kluane National Park. Maintained trails within the park are not exposed to significant avalanche slopes. A weekly 'Ski Trail Condition' report is prepared by park staff in the winter and early spring; this report, which includes some general observations of snowpack stability and signs of recent avalanche activity, is not a bulletin or forecast.

A Parks Canada public safety program is in place, informing park users about the likelihood of avalanches within the areas they travel and recommending appropriate equipment for self rescue. Public safety wardens in the park are trained in avalanche search and rescue. Furthermore, Parks Canada requires that a certified guide accompany all custodial groups accessing challenging avalanche terrain and no custodial groups are permitted in complex avalanche terrain within a national park during the winter.

Quebec - Haute-Gaspesie Avalanche Centre

The HGAC provides avalanche forecasting in the Chic-Chocs, Gaspésie area. Four full time staff are involved with the HGAC program through the winter, collecting field weather, snow and avalanche data and writing a public avalanche bulletin twice a week. Weather data are obtained from two automated remote weather stations and two manual weather stations. The forecast area, which is less than 1000 km^2, includes many popular winter backcountry destinations. No active control measures are in place. Warning signs are posted, and bulletin information made available on-line and by telephone.

HGAC staff are also involved with public education, professional training, various public avalanche awareness programs across the province, and avalanche research with the University of Rimouski.

4.3.2 Commercial backcountry

British Columbia

There are 29 members of the Backcountry Lodges of British Columbia Association. These lodges offer a mixture of guided and self-guided commercial backcountry trips. The majority of the lodges are located in the south-eastern portion of the province, while some member lodges are also located in the Whistler area, near Prince George and near Smithers.

HeliCat Canada members include 18 helicopter skiing and 12 snowcat skiing operations in BC. In addition, there are 14 probationary members that are typically newer operations getting started in the mechanized ski industry. The majority of the snowcat skiing operations and many helicopter skiing operations are located in the south-eastern portion of BC. There are also helicopter skiing operations located in the Whistler area, near Bella Coola and near the northern communities of Atlin, Stewart, Terrace and Hudson's Hope.

Information provided by the British Columbia Commercial Snowmobile Operators Association (BCCSOA) indicates that there are currently about seventeen commercial snowmobile operations that operate in Challenging or Complex avalanche terrain, as defined by the ATES. These include operations located near Mackenzie, Valemount, Clearwater, Revelstoke, Golden, Invermere, Fernie and Whistler. Avalanche mitigation programs undertaken by commercial snowmobile operations vary in complexity. However, the BCCSOA is presently developing best management practices for commercial snowmobile operations, to be implemented by member operations within the next few years. Recommendations for guide training and participation in the InfoEx, accepted guide-to-client ratios and minimum standards for record keeping and safety equipment are examples of items that will be addressed.

British Columbia/Alberta/Yukon

Independent mountain and ski guides operate during the winter in the mountainous regions of BC, Alberta and the Yukon Territory. Furthermore, Parks Canada requires that a certified guide accompany all custodial groups accessing challenging avalanche terrain within a national park during the winter. Mitigation utilized by guides involves a high degree of training in avalanche forecasting, mitigation and search and rescue. Avalanche hazard is generally mitigated through avoidance by terrain selection and ski cutting.

Newfoundland

One snowcat skiing operation operates out of Benoits Cove, Newfoundland and there are snowmobile tour companies on the northern peninsula.

Quebec

One commercial snowcat skiing operation operates on Mount Logan in the Chic Chocs of Quebec and another is under development.

4.4 Resource industries

Many intermittent industrial operations are exposed to avalanche hazard during the winter months (Map 18). One consulting company provided a list of forestry, mining and hydroelectric related avalanche mitigation projects undertaken since 1980. Located throughout the southeastern portion of BC (Map 19), these projects included preparation of 77 assessment reports and responsibility for 50 active road control programs (both assessment and control were undertaken on about 35 of these projects).

4.4.1 Mining

Many small mines in the Yukon, Northwest Territories and northern BC (Map 19) require avalanche mitigation programs while in operation. The number of mine sites currently operating changes often as mineral prices and investments fluctuate.

Substantial property damage has occurred at small mine sites as a result of avalanches. Avalanche mitigation measures include avalanche hazard assessment, avoidance by design of infrastructure location and active forecasting and control programs. Typical methods of active avalanche control for small mining operations include avalaunchers, artillery and helicopter bombing.

Stewart, BC is one example of an area currently showing an increase in the level of exploration activity. There are several gold properties in the area subject to intermittent exploration or operations (e.g. Cheni Gold and Premier Gold). Intermittent aggregate mining is also taking place in the Bear River, an area subject to avalanche hazard. The following sections provide an overview of the scope and extent of Canadian mining operations for which avalanche mitigation measures have been undertaken.

Yukon - Macmillan Pass

The Macmillan Pass mineral area is located near the border with the Northwest Territories, approximately 220 km northeast of Ross River. This is a past exploration area, subject to intermittent operations. Avalanche hazard mapping and helicopter control have been used as mitigation measures in the past. Production mines have never been built due to the remote location.

Yukon - Ketza River Mine

Operations at the Ketza River Mine have been intermittent since the 1980's. YGC Resources Ltd. is currently promoting a project to reopen the mine, located approximately 70 km south of Ross River. A hazard assessment has been completed and a site safety plan has been implemented for active avalanche control. An avalauncher has also been tested as an alternative control method.

Northwest Territories - Cantung Tungsten Mine

There is an avalanche mitigation program in place for the Cantung mine, located near the Yukon Border. Helicopter bombing is applied occasionally for active avalanche control. Road access to the mine is east from Watson Lake, off the Campbell Highway. The mine has closed and reopened several times since the mid 1980s.

British Columbia - Tulsequah Chief Mine

This is an old mine site and current exploration area with approvals for new mining. It is located near Atlin. Risk analysis, atlas mapping for roads and zoning for mine facilities have been completed.

British Columbia - Trident Copper Project

The Trident Copper Project, which has operated intermittently, is located near Toad River. Avalanches affect the drill sites and access routes. Avalanche hazard mapping and forecasting have been applied.

British Columbia - Golden Bear Mine

A deflection berm was constructed above the mill at the Golden Bear Mine, located approximately 145 km west of Dease Lake. Helicopter bombing and an avalauncher have been used in the past for active avalanche control.

British Columbia - Galore Creek Mine

Construction of facilities for the Galore Creek mine (copper and precious metals), located approximately 150 km northeast of Stewart, is currently underway. At this time there is no road access to the site. The access road is to be constructed from Highway 37 north of Ningunsaw Pass, near Bob Quinn. The mine site and access road will require avalanche mitigation measures. Active avalanche control via helicopter bombing is currently undertaken. One GazEx installation is planned for summer 2007.

British Columbia - Eskay Creek Mine

The Eskay Creek mine (gold and silver) is located approximately 80 km northwest of Stewart. There is avalanche terrain in the area and some active avalanche control is undertaken. Road access is from Highway 37, north of Ningunsaw Pass and Bob Quinn.

British Columbia - Kemess Mine

The Kemess mine (gold and copper) is located approximately 430 km northwest of Prince George. Helicopter bombing and hand charging are used for active avalanche mitigation.

British Columbia - Cirque Property

This exploration area, located near Fort St. John, is not in production. The hazard to the access road and potential hazard to mine facilities have been assessed and some site mapping has been completed.

British Columbia - Blue Pearl Mine

The access road to the Blue Pearl mine (molybdenum), located on Hudson Bay Mountain in Smithers, is threatened in three locations by one avalanche path. A private company consisting of one staff member, with an assistant available on an on-call basis, oversees mitigation activities. Snowpack information is collected during weekly site visits; these visits increase in frequency if changing weather conditions suggest increased potential for avalanche activity. No site-specific weather information is available for forecasting purposes. No active control measures are utilized. The road is closed when avalanche activity is expected to affect the road.

British Columbia - Huckleberry Mine

The Huckleberry mine (copper and molybdenum) is located approximately 90 km southwest of Houston. There is currently no avalanche program, although there is some avalanche terrain in the area. Road access to the mine is approximately 125 km from Houston via a logging road to Tahtsa Lake.

British Columbia - Elk Valley Coal

A small avalanche program, consisting of an observer and occasional active avalanche control measures, is in place at the Elk Valley Coal mine near Elkford. There is some avalanche terrain in the area, but the primary concern is steep pit slopes. Access to the mine site is by road from Elkford.

Quebec - Raglan Mine

The Raglan Mine is a remote site located near Salluit in northern Quebec. In addition to its primary metals, nickel and copper, the mine produces palladium, platinum and cobalt. A tank farm and the road from the mine to the port at Deception Bay are exposed to slush flow hazard. The tank farm was partially destroyed in 1970. Site planning has been done, berms and ditches have been built around the tank farm and a hazard monitoring program put in place for the slush flow hazard to the road.

4.4.2 Forestry

Numerous intermittent forestry operations operate throughout the winter in BC, Alberta and Quebec. Map 18 shows a select few. Winter logging can be less damaging to the environment and is therefore preferred, but given the nature of the terrain currently being logged this increases the potential for avalanche hazard.

British Columbia

In BC, avalanche forecasting and control programs to reduce the risk to forestry workers are common. Furthermore, there are safety regulations in place that require safe work procedures for employees in operations that are at risk from snow avalanches (Redfern, 1998; WCB of BC, 1998). Avalanche risk assessments are made for some proposed clearcut sites and harvest is avoided where there is risk of secondary impact to downstream facilities such as highways (Jamieson *et al*., 1996). However, a consistent policy of risk management for timber harvest areas is presently lacking in that the Forest Practices Code of BC does not currently include any reference to snow avalanches. The BC Ministry of Forests has a handbook for management of avalanche prone forest terrain (Weir, 2002), however the choice of where and when to make risk assessments will remain the responsibility of local foresters.

Alberta

In Alberta, logging is restricted to slopes with an incline of less than 45% (Jamieson *et al*., 1996).

Quebec

Logging in steep terrain is also occurring in the Gaspé region of Quebec.

4.4.3 Oil and gas

Several oil and gas access routes and a few well sites are subject to avalanche risk in the Rocky Mountains of Alberta and BC. These locations are scattered from the Oldman and Flathead River drainages in the south to the Liard River basin in the north. Avalanche risk to the access routes is a factor in well site maintenance. When and where required, avalanche forecasting and active avalanche control by helicopter bombing are employed to reduce the risk.

Oil and gas pipelines are usually buried below the ground surface at a depth where avalanche hazard is no longer a concern. Pipelines may be exposed above ground where aerial river crossings are built. Where emergency pipeline maintenance is required during winter, avalanche forecasting and active avalanche control by helicopter bombing are employed. Examples of pipeline routes, which cross avalanche terrain, are the Pacific Northern Gas and Westcoast Gas pipeline routes.

4.5 Energy and transmission

Several electricity transmission lines in Western Canada cross avalanche terrain (Map 20). Examples of power lines with multiple defensive measures include the Kemano-Kitimat Powerline, the Meziadin-Stewart powerline and the Terrace- Prince Rupert powerline.

4.5.1 British Columbia – Revelstoke Dam

Prior to construction of the Revelstoke Dam by BC Hydro and Power Authority in the early 1980's, avalanche hazard assessment reports were completed for the dam and associated infrastructure. Avalanche mitigation was implemented primarily by identification and avoidance of hazard areas. Where required, additional structural reinforcements were incorporated into the design of infrastructure. There is no active avalanche control program.

4.5.2 British Columbia - Alcan Kemano-Kitimat powerline

An avalanche mitigation program is in place to protect the powerline that provides electricity from the Kemano hydroelectric generation station to Alcan's aluminium smelter facility (approximately 80 km). Excess power from Kemano is sold to BC Hydro and Power Authority for distribution over the provincial power grid. The smelter is a major economic driver of northwest BC and power sales provide significant revenue to Alcan.

Passive control measures include earth deflector berms and splitters to protect powerline towers in runout zones. Tower bases are also reinforced for avalanche impact forces. A catenary system was constructed to lift the powerlines above valley bottom, eliminating approximately ten towers exposed to avalanche hazard.

One contractor is involved with avalanche mitigation activities. Active control and forecasting is not done on a regular basis; these measures are implemented only to protect temporary worksites during repair of damaged towers. In these instances, site-specific weather information is obtained via manual observations at the Kemano townsite. Information about the snowpack structure is collected at various test profile sites accessed by helicopter. Active avalanche control measures for protection of worksites at damaged tower locations consist of helicopter bombing.

4.6 Residential and public land use

The following sections provide an overview of the scope and extent of residential areas in Canada for which avalanche hazard assessments have been completed. This is not a comprehensive list. The locations of these areas are shown on Map 21.

Northwest Territories

- Tungsten

British Columbia

- Telegraph Creek
- Stewart
- Horatzky Creek (Kemano)
- Gates Lake (Birken)
- Kicking Horse Mountain Resort (Golden)
- Panorama
- several areas near Fernie
- several areas near Sparwood
- Cayoosh Creek
- Hemlock Valley
- Argenta
- Hope

In BC, subdivision development is excluded from runout zones where impact pressures of 30 kPa or greater are expected with an approximate return period of 300 years (BC MOTH, 1996). Furthermore, a professional engineer must certify that the land is safe for development under the Land Title Act of British Columbia.

Quebec

Following the avalanche incidents in Blanc-Sablon and Kangiqsualujjuaq, an avalanche zoning study, which included recommendations for mitigation, was completed for isolated communities in Quebec. The Norwegian Geotechnical Institute (Lied and Domass, 2001) undertook this work. Communities evaluated in the study include the following:

- Kangiqsualujjuaq (identified risk to buildings and occupants)
- Kangirusk (identified risk near school)
- Quaqtaq (identified risk to buildings)
- Kangiqsujuaq (identified risk to oil tanks and future housing)

- Salluit (identified risk to oil tanks)
- Ivujivik (buildings outside hazard zone)
- Inukjuak (short banks, identified risk to persons on foot)
- Blanc-Sablon (identified risk to buildings)
- Rivière Saint Paul (identified risk to buildings)
- Vieux – Fort (identified risk to buildings)
- Baie du Milieu (no risk to town found)
- Saint – Augustin (identified risk to buildings)
- Pakuashipi (no risk to town found)
- La Tabatière (identified risk to buildings)

Following completion of the study, houses and buildings (schools in particular) were relocated in several villages in Ungava. Walls, snow fences and earth mounds were also constructed in some areas, but were not found to be very effective as a whole.

Newfoundland and Labrador - Outer Battery

In the summer of 1998, fences were constructed at the Outer Battery, St. John's. The primary purpose of these structures was to prevent rockfall, with a secondary purpose to mitigate avalanche hazard to buildings below.

5. CURRENT AND FUTURE TRENDS IN ACTIVITY AND MITIGATION

5.1 Transportation corridors

The number of transportation corridors threatened by avalanches is increasing due, in large, to access roads being built for new natural resource extraction and hydroelectric power operations. Widespread exploration is underway in remote areas not currently served by roads. The access roads to these deposits in mountainous regions will likely be subject to avalanche hazard, due to the geomorphology of alpine terrain. Highway closures have increasing costs due to increasing volume, especially commercial vehicles, and to an increased cost of delays associated with just-in-time delivery. These costs are growing faster than mitigation programs.

5.2 Ski areas

Like all winter recreation activities, chairlift ski area activity is currently and expected to continue to grow in the next twenty years. This includes expansion of current and development of new chairlift ski areas. Furthermore, the trend in skiing and snowboarding is towards steeper runs and new developments in equipment are making this more accessible. Furthermore, chairlift ski areas are expanding into and advertising steeper runs and consequently, the amount of hazardous terrain for a given ski area is increasing.

5.3 Backcountry recreation

Hägeli (2005) estimates self-directed backcountry activity for most areas in BC and Alberta has been increasing over the past ten years. The increase in these activities appears to be steady or slightly less dramatic in the last ten years than in the previous two decades. The disciplines with the highest growth rate are snowmobiling and out-of-bounds skiing and snowboarding (Hägeli, 2005). This creates a need for public avalanche safety programs to target diverse user groups, such as snowmobilers and young out-of-bounds skiers and snowboarders, which starts with an understanding of risk perception and risk propensity. Current and recent research projects, led by Dr. Pascal Haegeli and Dr. Ian McCammon, focus on these needs and understandings. Furthermore, the CAC is currently improving their public safety products in response to this growth in activity. Improvements include higher frequency and spatial resolution for bulletins, snowmobile and youth outreach programs and new and improved educational programs such as online training.

Recreational activity is also increasing in eastern Canada. This includes self-directed backcountry skiing and snowboarding in the Haute-Gaspesie region of Quebec and snowmobiling on the northern peninsula of Newfoundland. Although efforts are being made by the HGAC to improve their public safety products, consistent funding remains a limiting factor. Furthermore, there is currently no public avalanche safety program in Newfoundland and Labrador.

In the 1970s, there were six active members of HeliCat Canada, formerly BC Helicopter and Snowcat Skiing Operators Association. Throughout the 1980s membership grew to seven active and one probationary member. A much larger increase occurred in the 1990s when HeliCat Canada membership grew to 16 active and 11 probationary members. Then in the current decade, membership has already grown to 29 active and 14 probationary members (HeliCat Canada, 2007). This illustrates an increasing trend in mechanized commercial backcountry activity in BC.

The Backcountry Lodges of BC Association feels that the backcountry market, at least in the Kootenays, Sea to Sky, Okanagan and Cariboo-Chilcotin areas of BC, is fairly saturated and cannot sustain much more development.

5.4 Resource industries

Extraction of natural resources is a cyclical activity that depends strongly on the business cycle. Predicting future activity is difficult owing to wildly fluctuating markets. However, one factor that cannot be ignored is that as resources are depleted in easily accessed locations there is more pressure to explore remote areas for new resources. Avalanches will threaten many of these remote areas as the very nature of mountain terrain favorable for avalanche formation means that these areas are among the least accessible and therefore least explored areas in the country. Therefore, regardless of economic activity it can be expected that activities in avalanche terrain related to natural resource extraction will increase by 2026. With this increase in activity comes a need for decision support for resource industries that includes local and perhaps even site-specific avalanche hazard bulletins or advisories.

Snow avalanches are an increasing concern in the forestry sector. Logging operations are moving onto steeper mountainous terrain in BC (Redfern, 1998) as the accessible resource on lower elevations and gentler slopes is being depleted. At present, the forestry industry in BC is focusing on beetle kill wood; however, in 2026 the focus will be shifted back to the alpine valleys.

Climate change is resulting in glacial retreat, which is making some high mountain sites economically viable for mineral extraction (such as Galore Creek in northern BC), but given the geomorphology of glaciated alpine terrain these areas are exposed to the snow avalanche hazard. In Newfoundland and Labrador new developments in the resource industries are vulnerable to avalanches, but with better planning, environmental impact studies and increased awareness the risk is low.

The resource economy in Canada is relatively ‘safe’ as compared to many parts of the world; therefore, even if costs such as labor are higher, the long-term outlook for the returns is more secure.

5.5 Energy and transmission

In the case of hydro power the current environmental mood favors smaller projects in alpine valleys as compared to the large reservoir construction of the 1950-1980 period. The northern Rockies are the current ground for natural gas exploration, these areas tend to have a higher avalanche hazard when compared to the traditional foothill and plains regions.

5.6 Residential and public land use

Avalanche hazard assessments have been recently completed for many residential and public land use areas in Canada, some in response to major avalanche incidents. This and recently published technical guidebooks for avalanche hazard mapping (CAA, 2002a) and managing avalanche hazards (CAA, 2002b), have helped to reduce the threatened residential and public land use areas in Canada. However, the risk will not be reduced to levels comparable with other natural hazards until standards and legislation are in place. Rural community and resort growth over the next twenty years will place increasing importance on land use zoning for the avalanche hazard.

In Newfoundland and Labrador there is an overall decline in risk for residential areas. Population as a whole is decreasing and it is becoming increasingly urbanized. As well, there is an increased awareness of geological hazards in municipal planning. As such, risk in rural communities is decreasing. There are still communities, however, such as Corner Brook and St. Anthony, with a history of avalanches but with no plans to install mitigation measures.

6. SUGGESTIONS FOR FURTHER RESEARCH

Future projects would benefit from spatial analysis of activities taking place in avalanche activity zones and fatalities. This would require that the avalanche activity zones be resolved at smaller scales using modern techniques. Furthermore, our zoning methods, which are not standards, need to change to use Geographical Information Systems.

This report also recommends that there is a review of the Public Safety Canada mandate and business plans to understand their current focus and initiatives. Then, based on those priorities, propose additional projects that would build capacity for Public Safety Canada and provincial Emergency Measures Organizations to develop more detailed risk assessments and contingency plans, etc., for exceptional avalanche winters.

The Canadian avalanche industry would benefit from the development of guidelines that outline the best practices for avalanche protection in Canada. This would establish a minimum standard for avalanche safety and help operations grade their mitigation programs These guidelines could be developed through polling of industry stakeholders.

Further research could also include a study of the impact of increasing costs of delays on transportation corridors with respect to avalanche mitigation measures as major impacts are likely. This could also include a comparison of active control costs versus passive control costs. It would also be useful to look at the effect of beetle killed forest and forest fires on avalanche formation, runout and zoning as a change in the forest cover in or near a start zone would result in a change in avalanche hazard. Furthermore, a study of the effect of climate change on avalanche formation, runout and zoning would be beneficial.

More precise predictions of threatened future residential and public land use as well as recreational activities could be made by intersecting forecasts on population growth and recreation growth with avalanche terrain. This would involve analysis with Geographical Information Systems, aerial photographs and site visits.

7. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this report, it can be concluded that avalanches are responsible for substantial loss of life and property damage in Canada. Even though avalanche hazard tends to be greater in the mountainous regions of Canada, avalanches are a nationwide natural hazard affecting all regions to some extent. Furthermore, avalanches affect both voluntary and involuntary activities in Canada.

Avalanche hazards will continue to exist and in most cases increase in the foreseeable future. Avalanche hazard mitigation measures are effective at reducing risk and with increasing activities there will be an increasing demand for these measures. Although there is growing activity in Eastern Canada there are no additional mitigation efforts to date.

With respect to public safety, this report recommends that a program be established for Newfoundland and Labrador and funding is secured to ensure the longevity of the Quebec program. Western Canada would benefit from public avalanche bulletins with higher spatial and temporal resolution. This would require additional funding to establish ridgetop automated weather stations, increased data sharing capacities and numerical avalanche prediction models. The CAC Avalanche Incident Database is the only comprehensive avalanche database in existence for Canada. This report recommends that Public Safety Canada help pay for the costs (approximately $10,000 annually) associated with keeping the CAC Avalanche Incident Database current.

With respect to residential and public land use, this report recommends that the CAA Guidelines for Snow Avalanche Risk Determination and Mapping in Canada (CAA, 2002a) be adopted by the appropriate jurisdictions. In addition, land-use planners, geographers and engineers should be familiar with at least the basics of identifying avalanche hazards and recognize when avalanche expertise is needed. This would be achieved by adopting the CAA Land Managers Guide to Snow Avalanche Hazards in Canada (CAA, 2002b) into the curricula of their training and certification programs.

Further research should focus on continued spatial analysis of incident and activity data and further development of the avalanche activity zones and hazard zoning methods with Geographical Information Systems. Detailed risk assessments and contingency plans for exceptional avalanche winters should be developed. Guidelines for industry best practices with regard to avalanche mitigation measures should be developed and standards should be established. A cost-benefit analysis of increasing activities versus mitigation measures should be performed. The effect of climate change, beetle-killed forest and forest fires on avalanche hazard should be assessed. Finally, further research should also focus on increasing the precision of predictions on future threatened activity.

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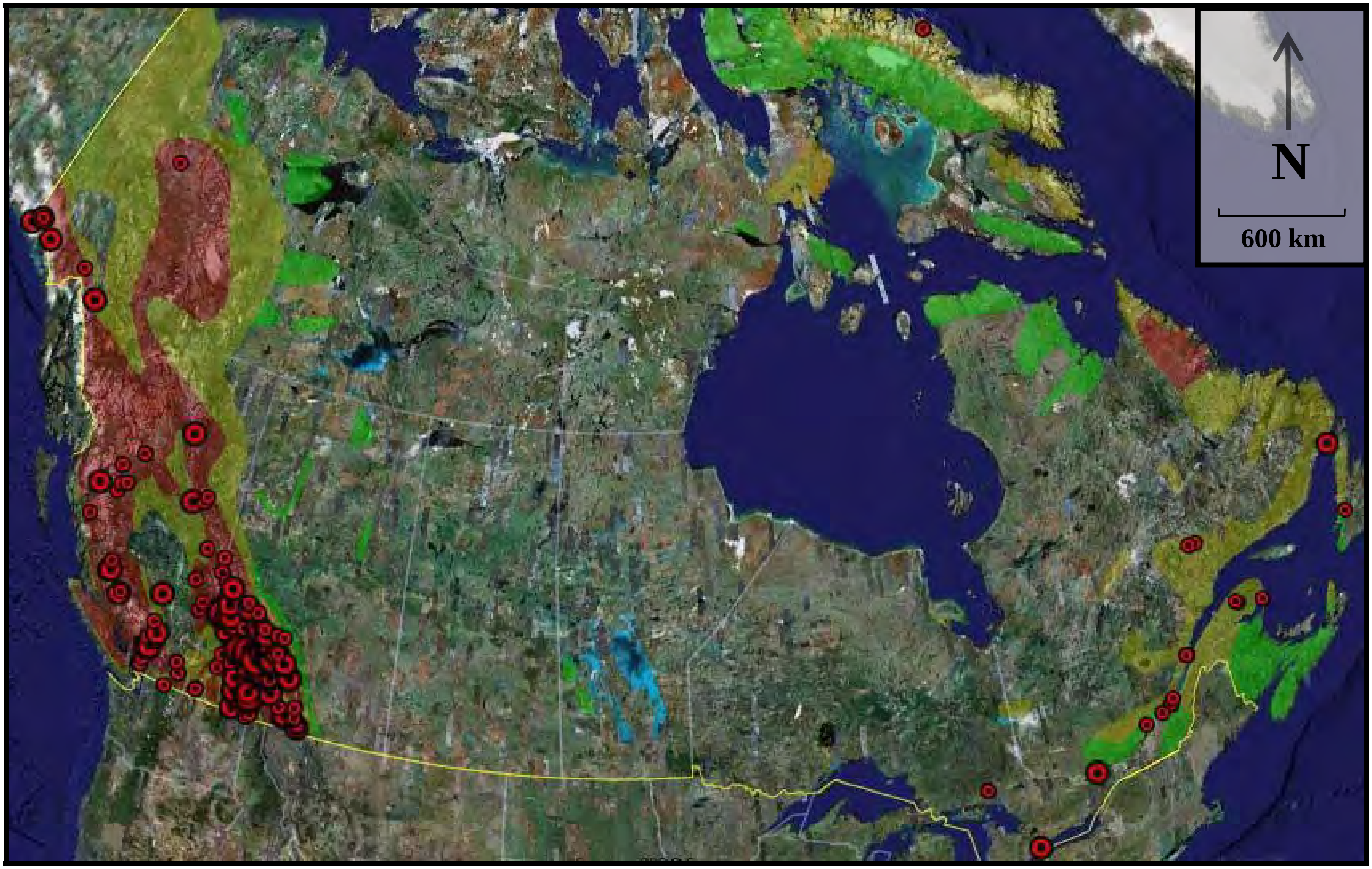
APPENDIX A: MAPS

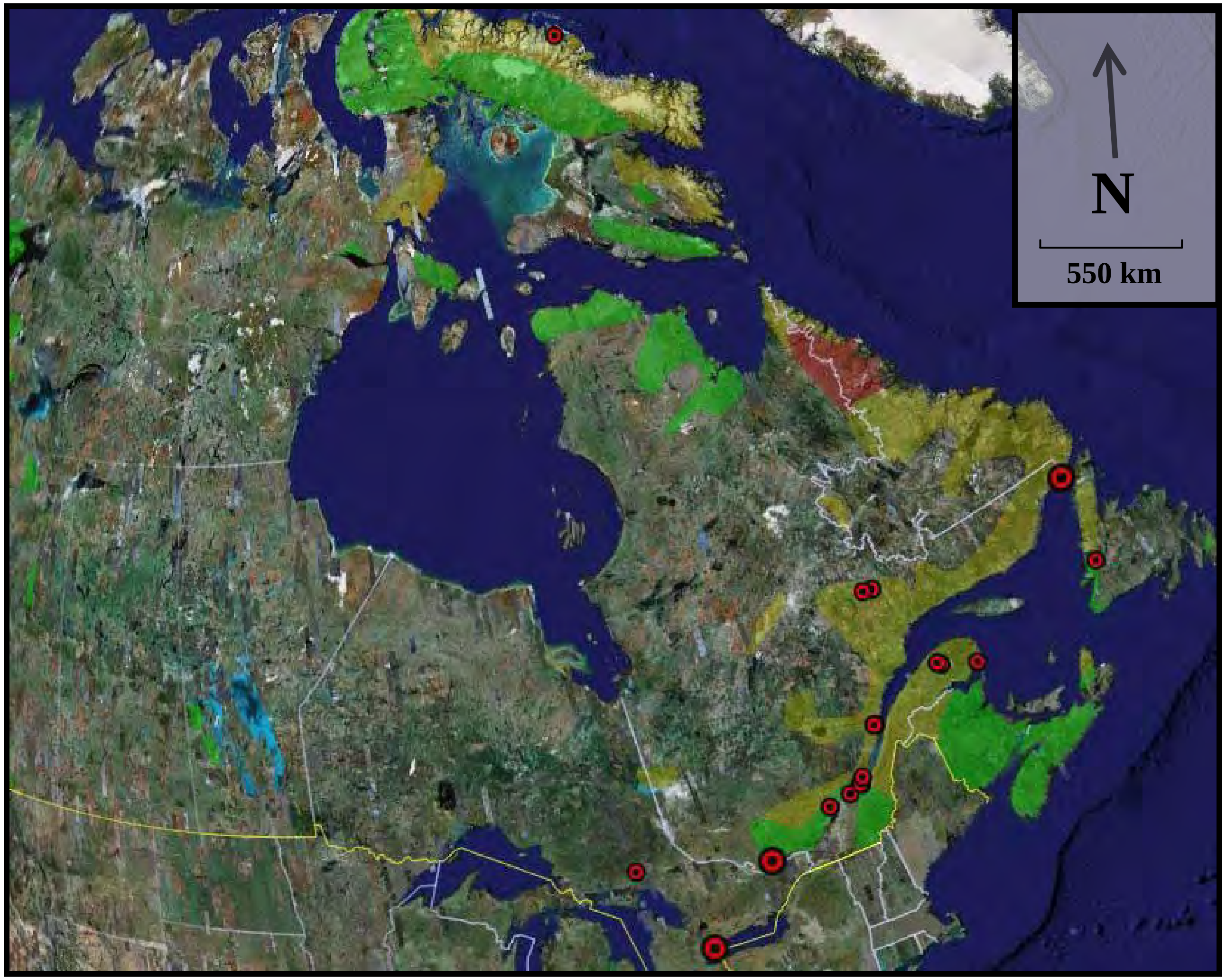
The locations and zones used for the following maps were visualized using Google Earth. In order to identify areas in which avalanches can occur, shape files delineating avalanche terrain into zones of high, moderate or low avalanche activity (Table A.1) are overlaid onto the following maps. These avalanche activity zones are based on average maximum snow depth values and terrain steepness (Jamieson and Brooks, 1998). Because of the map scale and the qualitative method used to delineate the avalanche activity zones, they are approximate and not suitable for site-specific assessments of snow avalanche activity or hazardor small-scale visualization.

Table A.1. Avalanche activity zones based on terrain characteristics and average maximum snow depth (AMSD). Avalanche terrain and activity is also given for each zone.

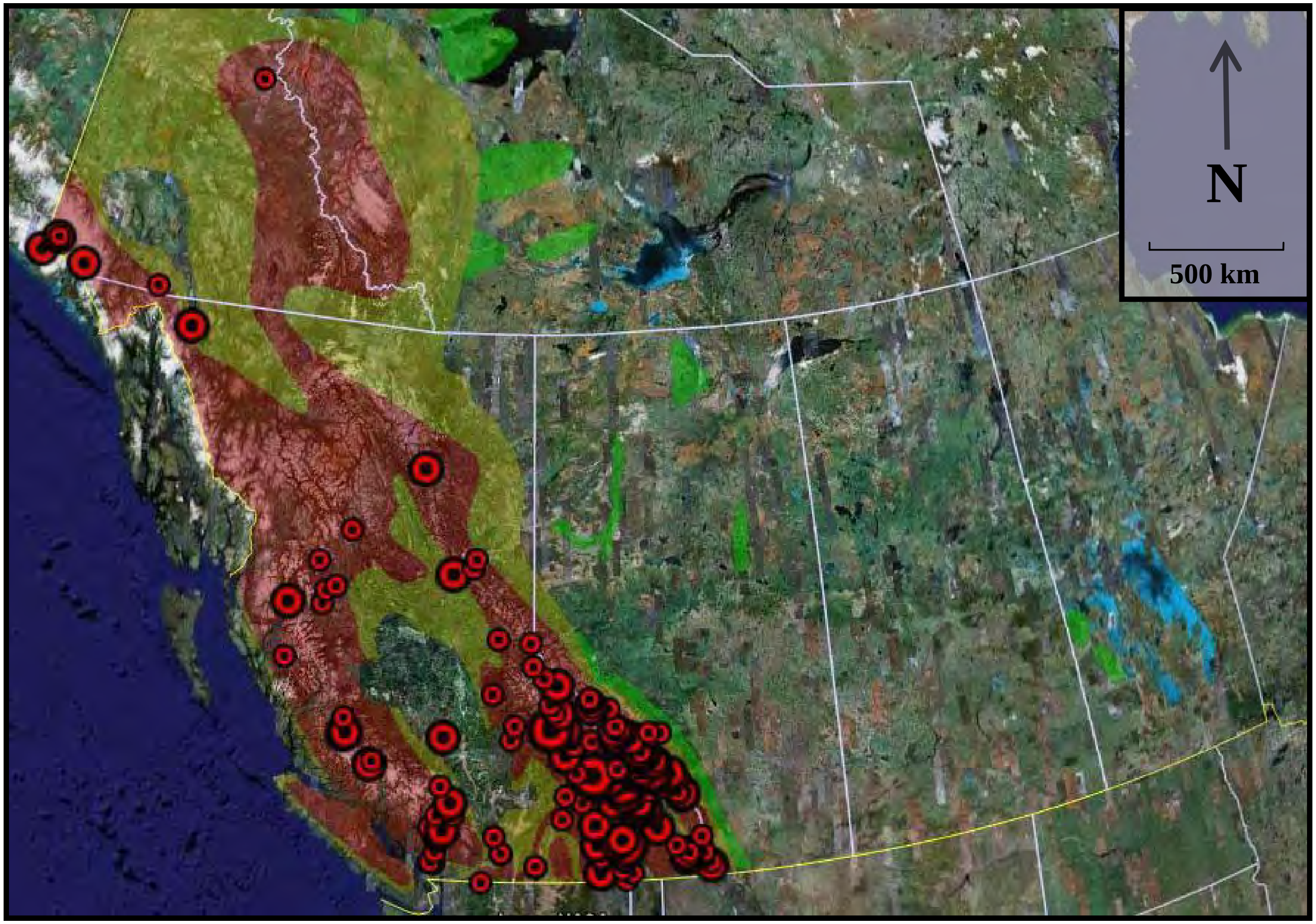
Avalanche activity zone	**Terrain characteristics and average maximum snow depth**	**Avalanche terrain and activity**
High	Mountainous and AMSD > 100 cm	Numerous avalanche paths, many with avalanches most winters
Moderate	Mountainous and AMSD ranging between 50 to 100 cm, or many steep hills and AMSD >100 cm	Reduced density of avalanche paths, some with avalanches most winters
Low	Many steep hills and AMSD ranging between 50 and 100 cm	Isolated avalanche slopes. Infrequent avalanches, mostly in extreme winters.
Very low (no overlay)	Mainly gentle terrain or AMSD < 50 cm	Very isolated avalanche slopes. Avalanches rare.



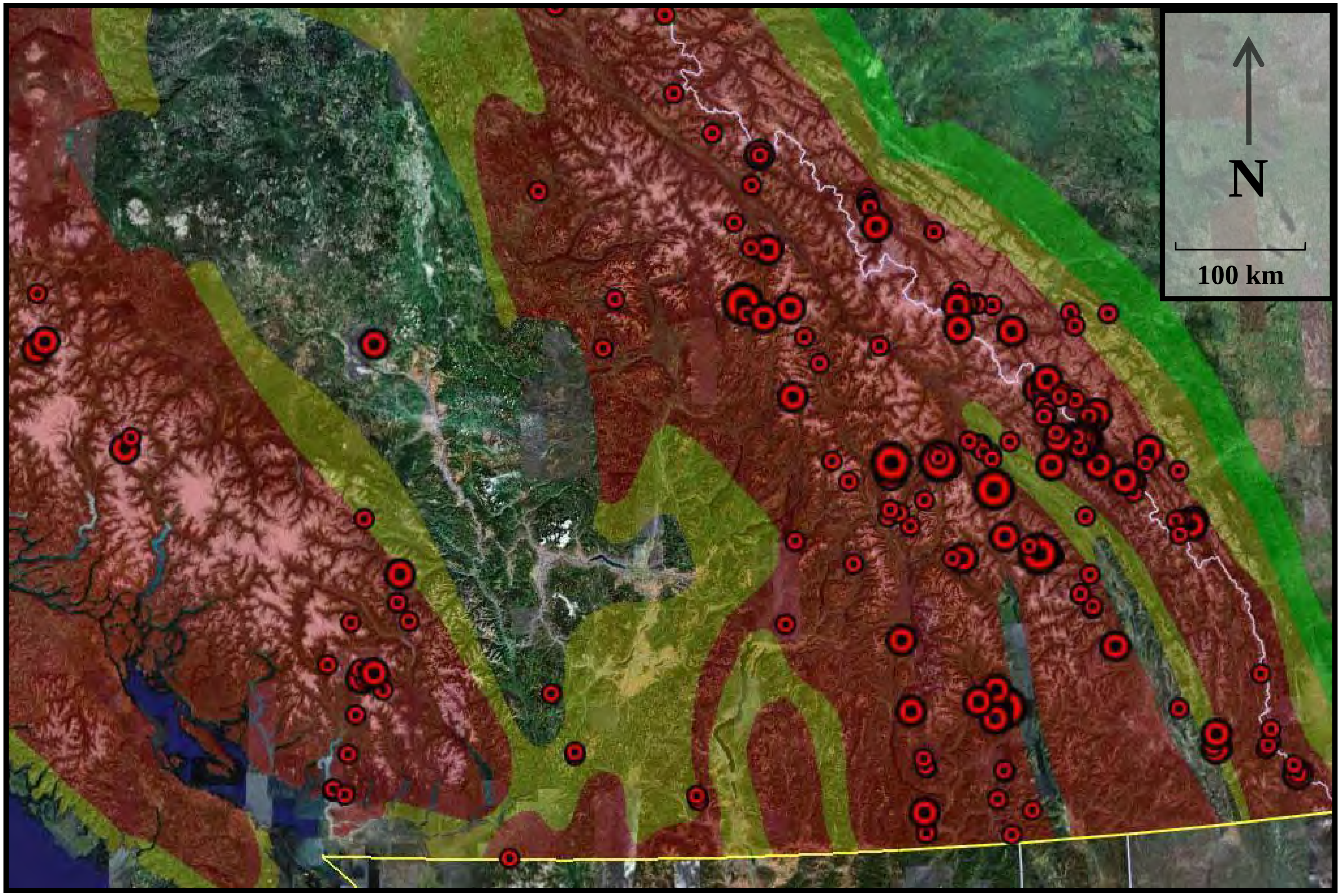
Map 1. Fatal avalanches for recreational activities and avalanche activity zones in Canada. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



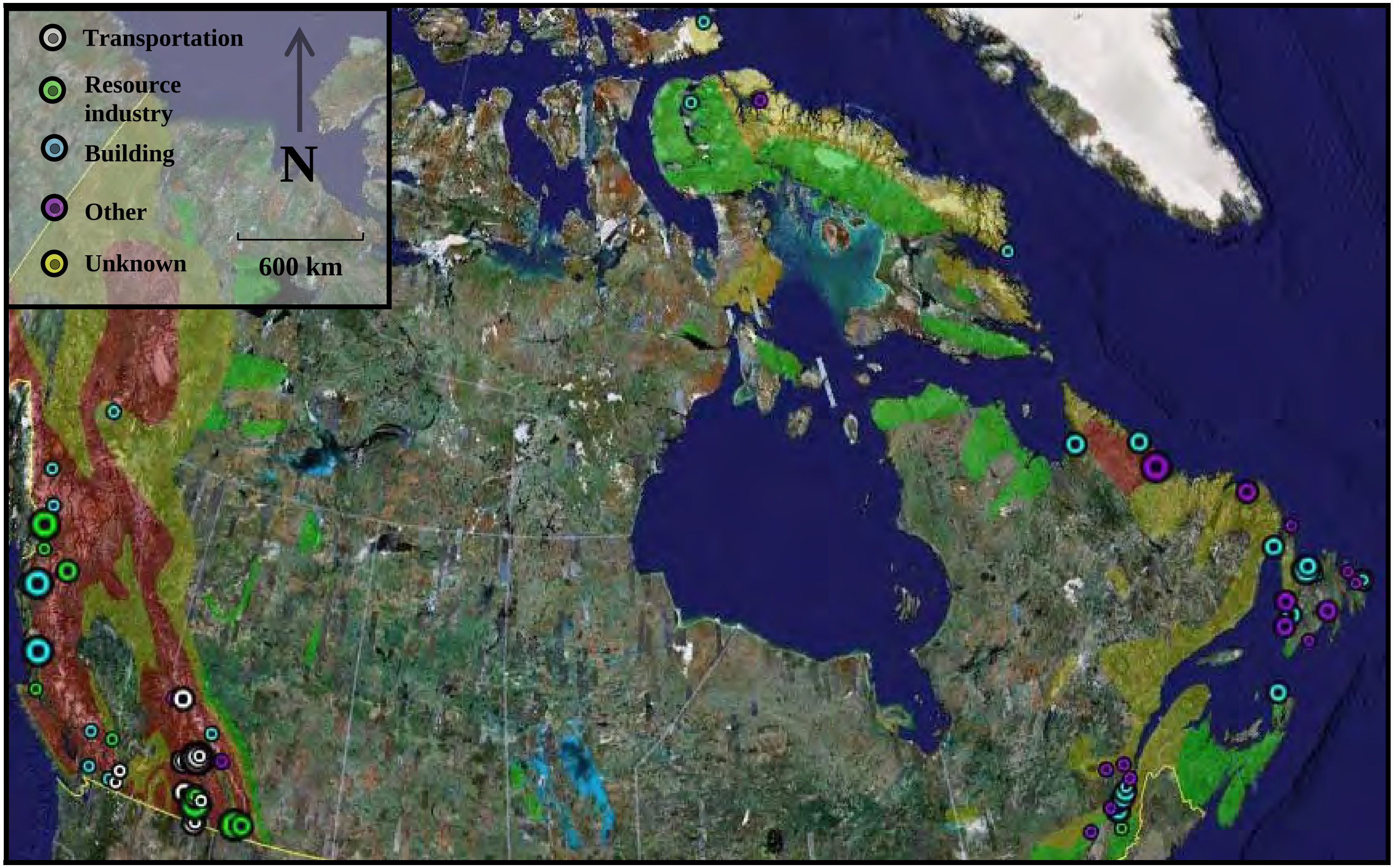
Map 2. Fatal avalanches for recreational activities and avalanche activity zones in eastern Canada. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



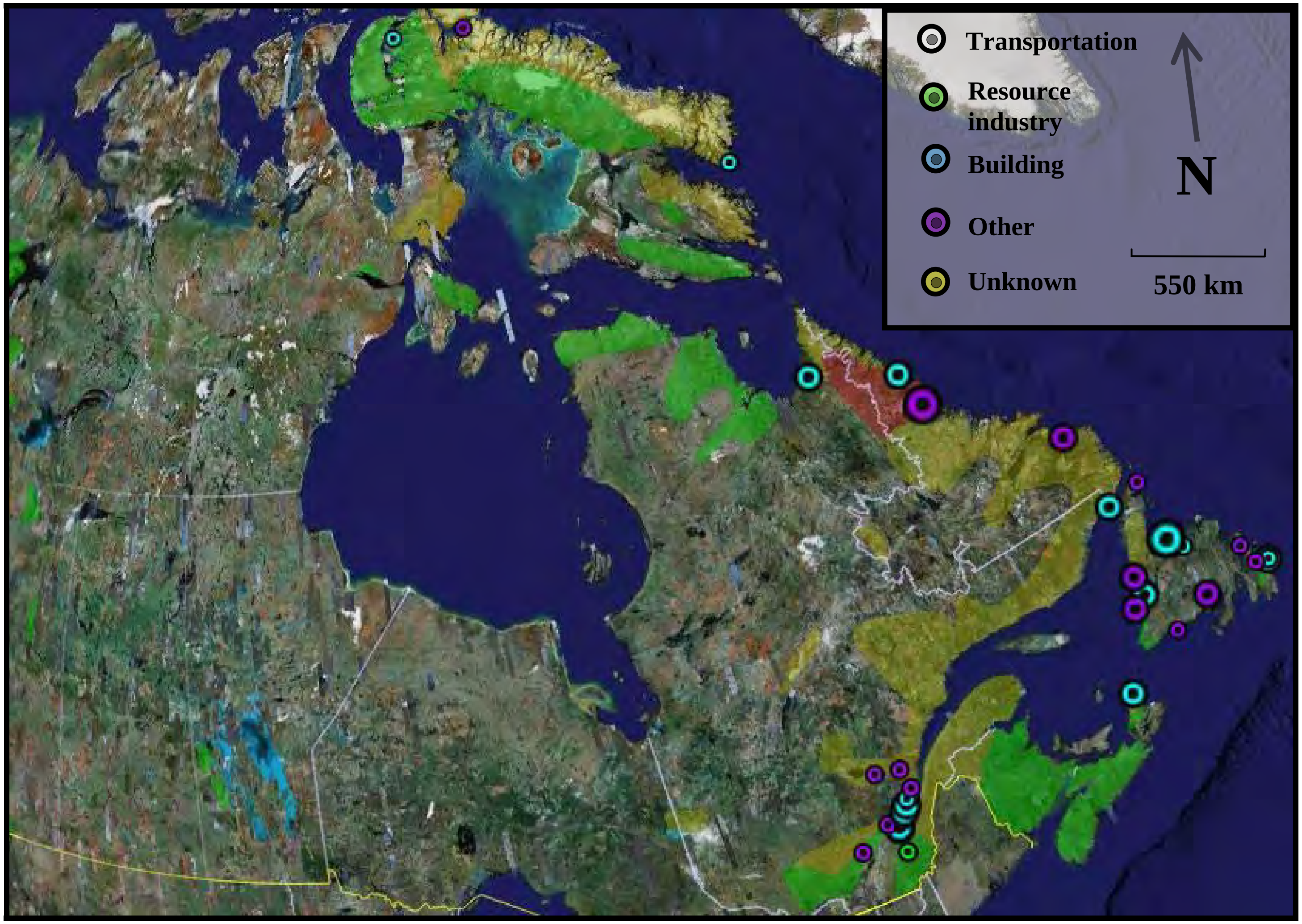
Map 3. Fatal avalanches for recreational activities and avalanche activity zones in western Canada. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



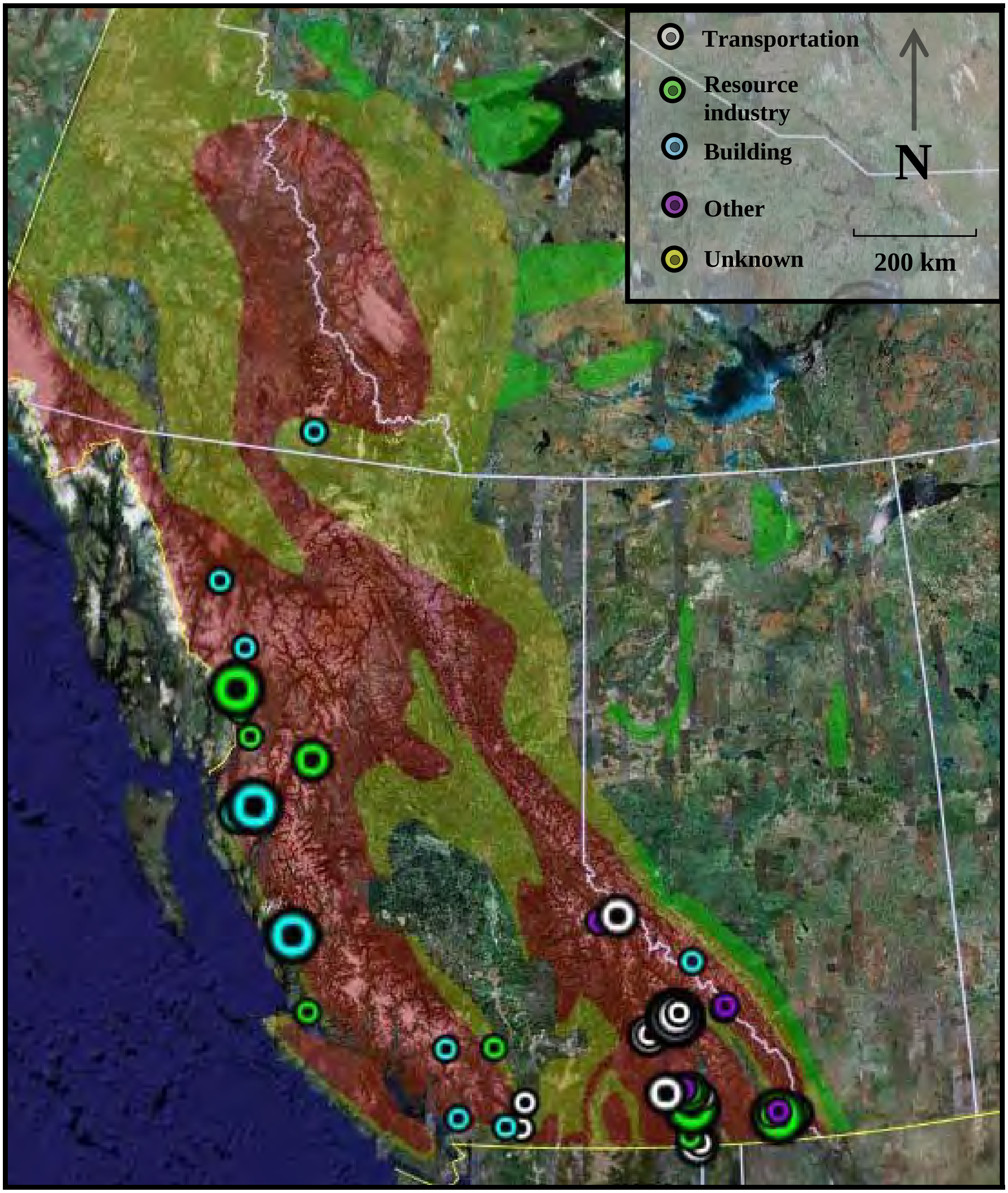
Map 4. Fatal avalanches for recreational activities and avalanche activity zones in southern British Columbia. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



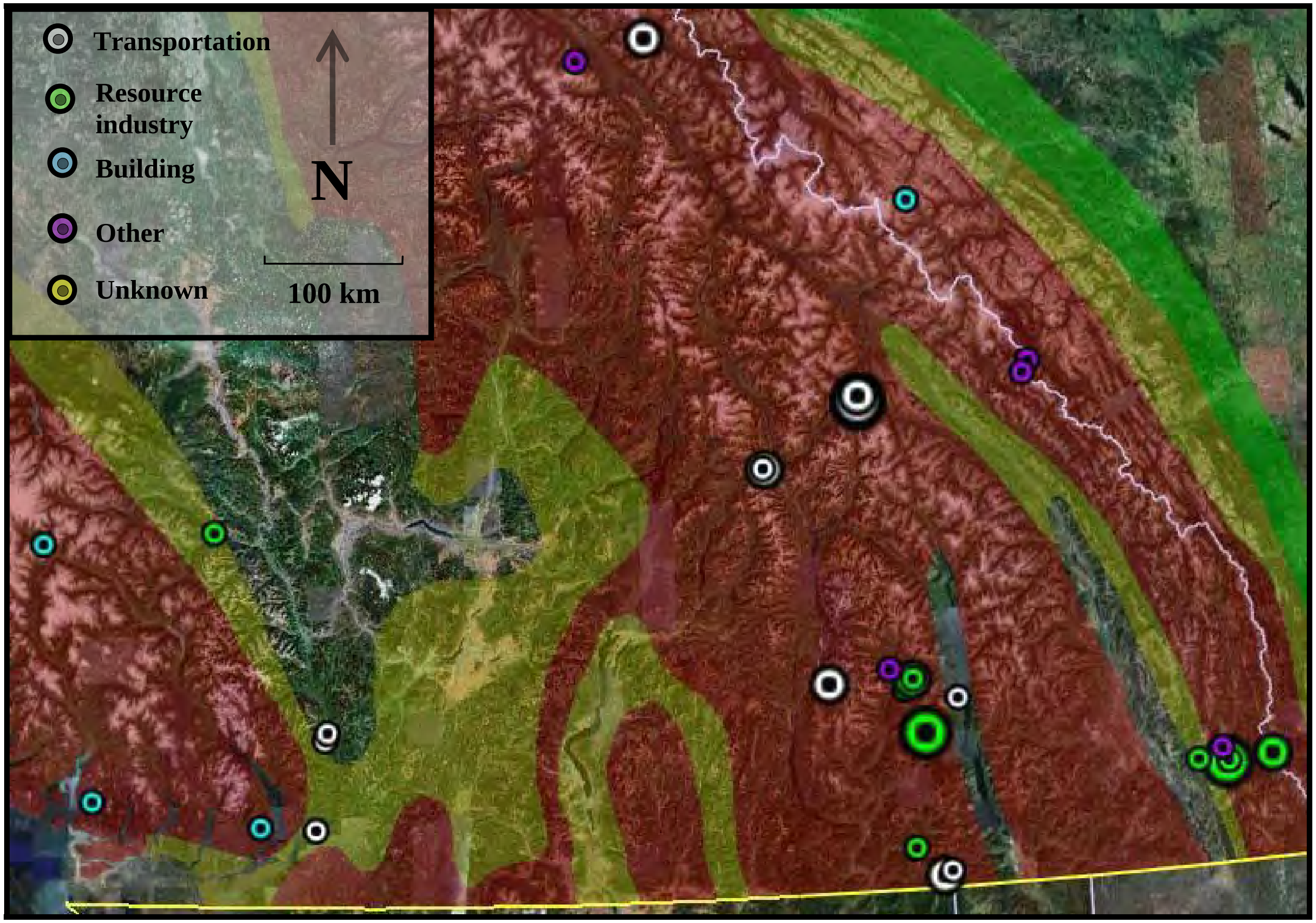
Map 5. Fatal avalanches and avalanche activity zones in Canada. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



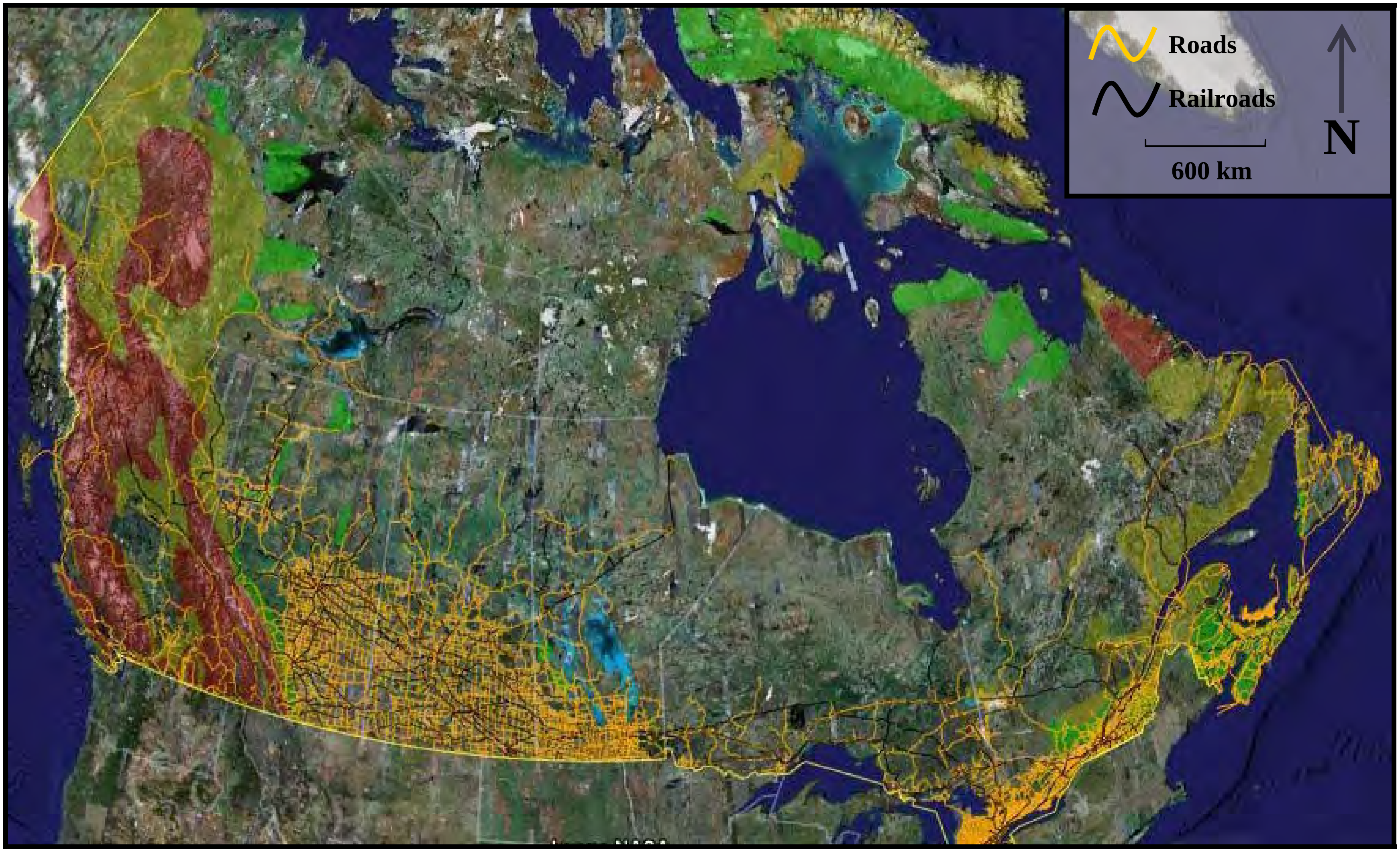
Map 6. Fatal avalanches and avalanche activity zones in eastern Canada. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



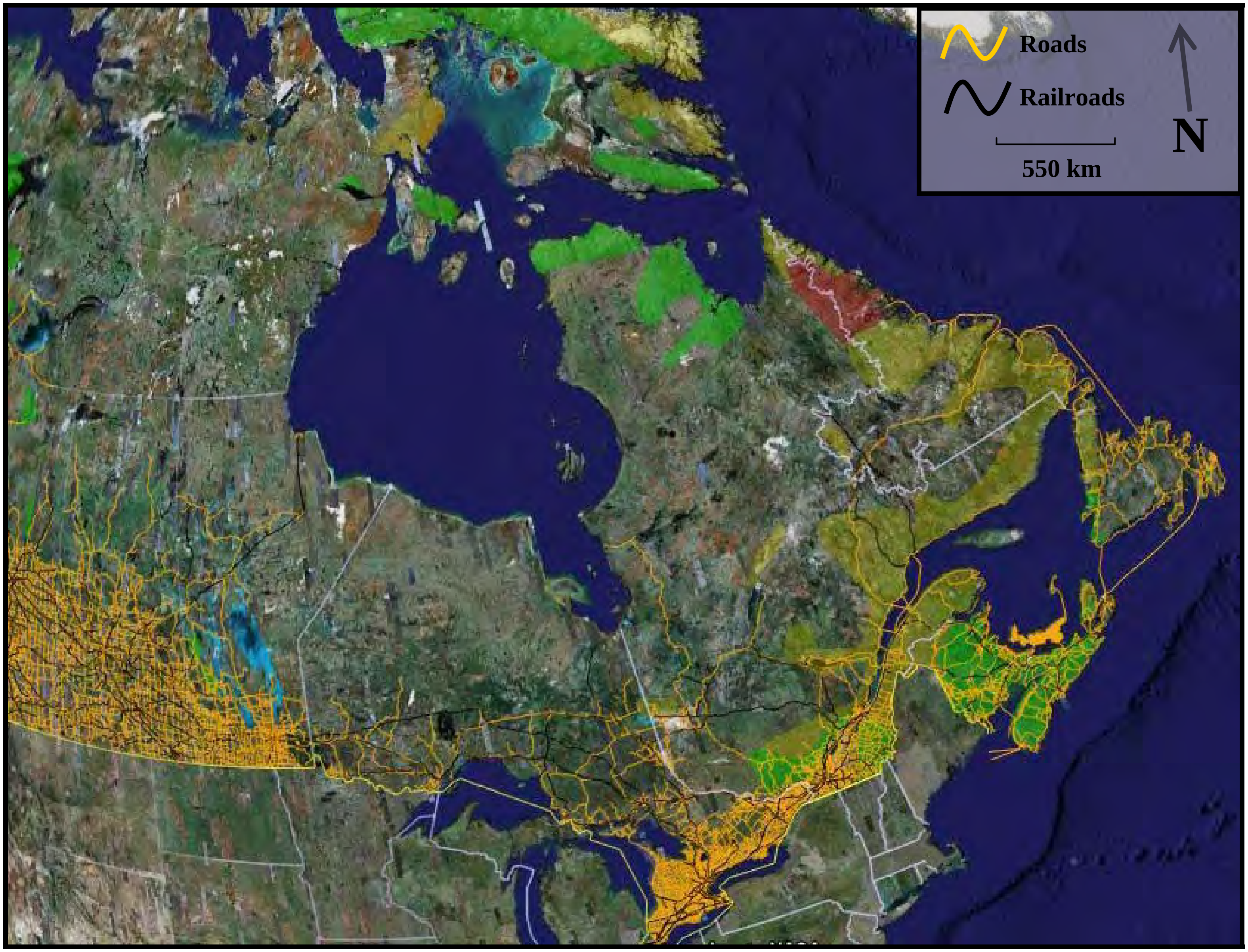
Map 7. Fatal avalanches and avalanche activity zones in western Canada. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



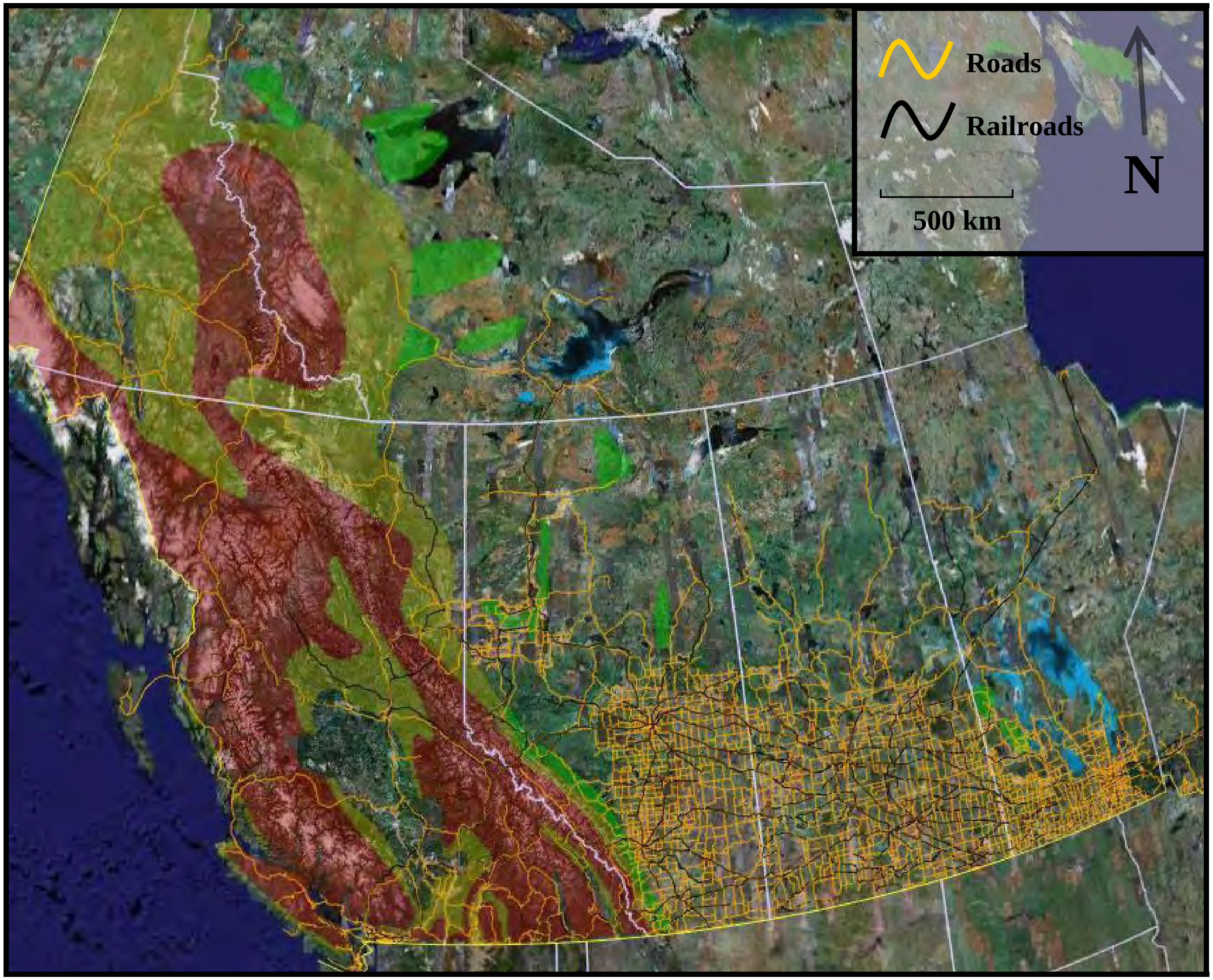
Map 8. Fatal avalanches and avalanche activity zones in southern British Columbia. The size of the symbol represents the number of fatalities for each incident, with small symbols corresponding to one fatality, medium sized symbols corresponding to two to five fatalities and large symbols corresponding to more than five fatalities. Avalanche incident information obtained from Canadian Avalanche Centre Avalanche Incident Database.



Map 9. Transportation corridors and avalanche activity zones in Canada. This is not a comprehensive list.

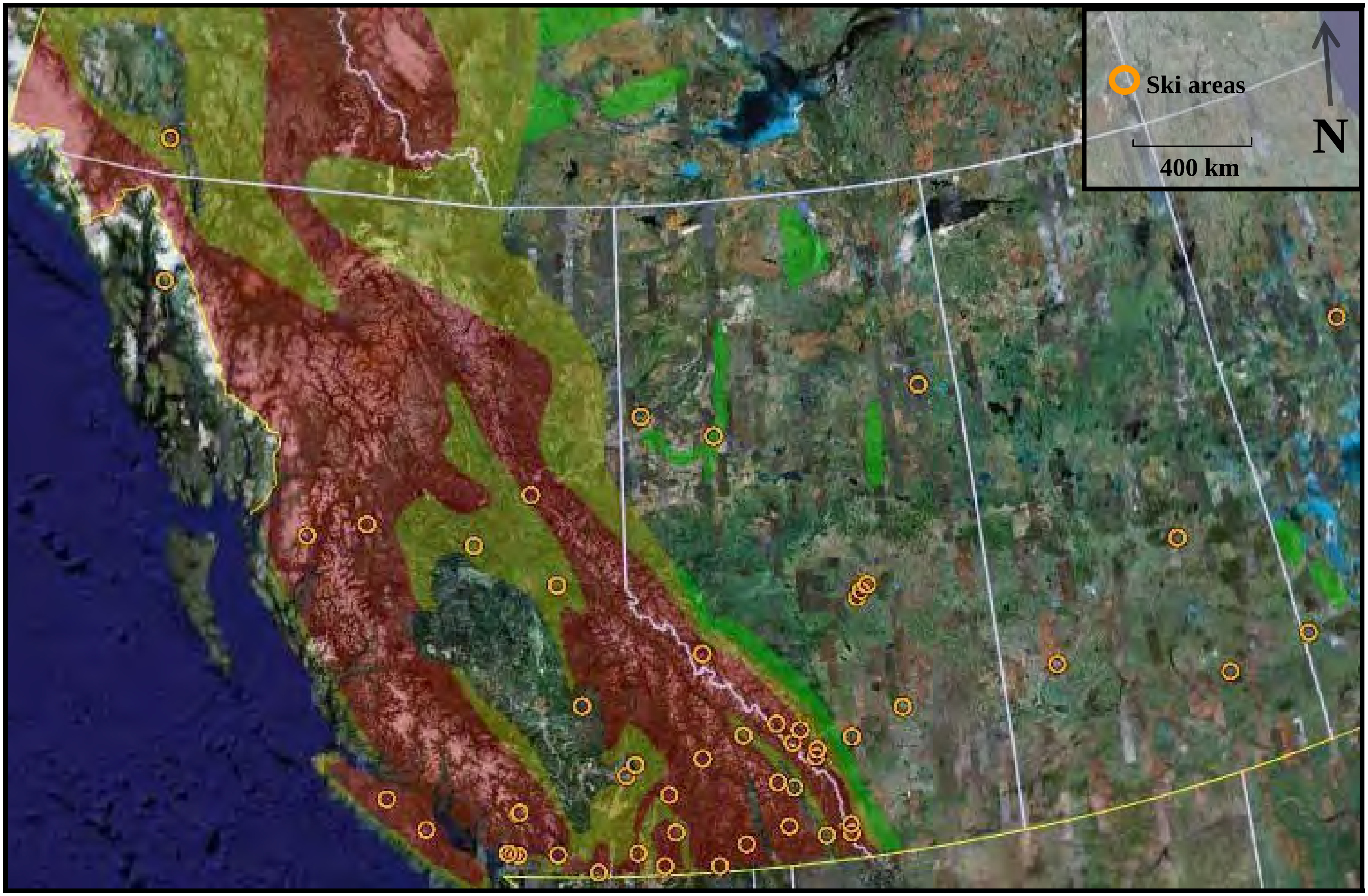


Map 10. Transportation corridors and avalanche activity zones in eastern Canada. This is not a comprehensive list.

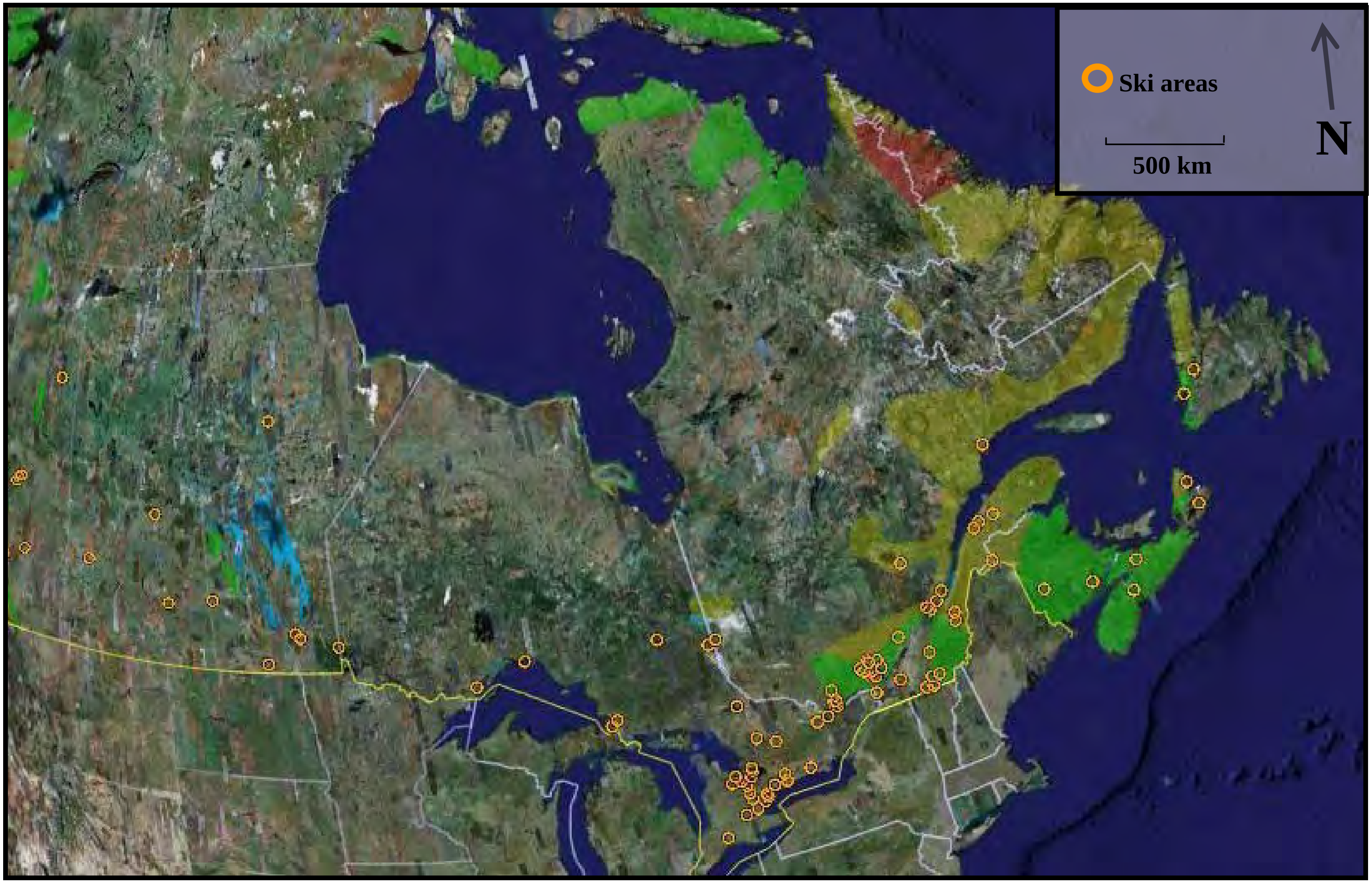


Map 11. Transportation corridors and avalanche activity zones in western Canada. This is not a comprehensive list.

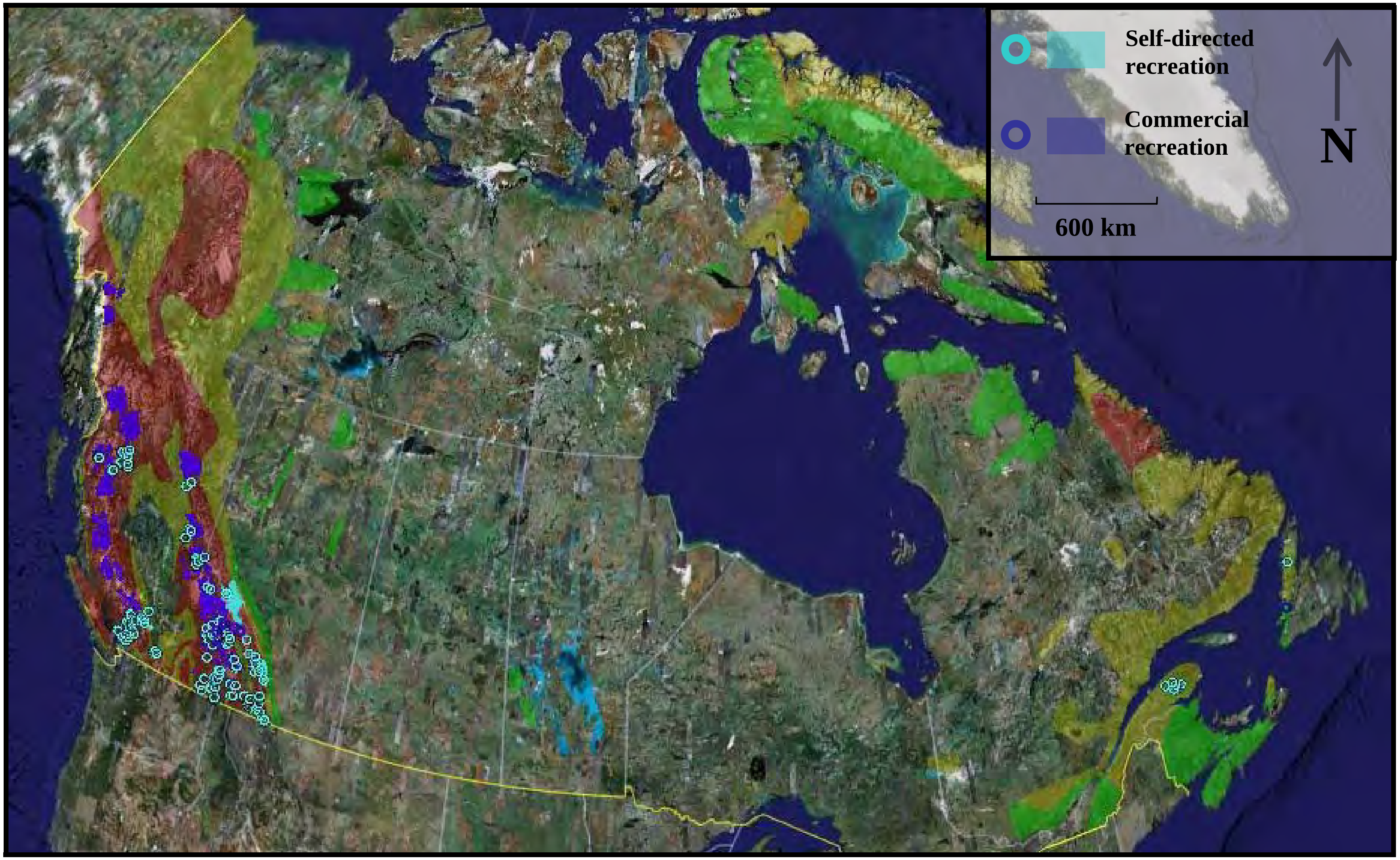
Map 12. Ski areas and avalanche activity zones in Canada. This is not a comprehensive list.



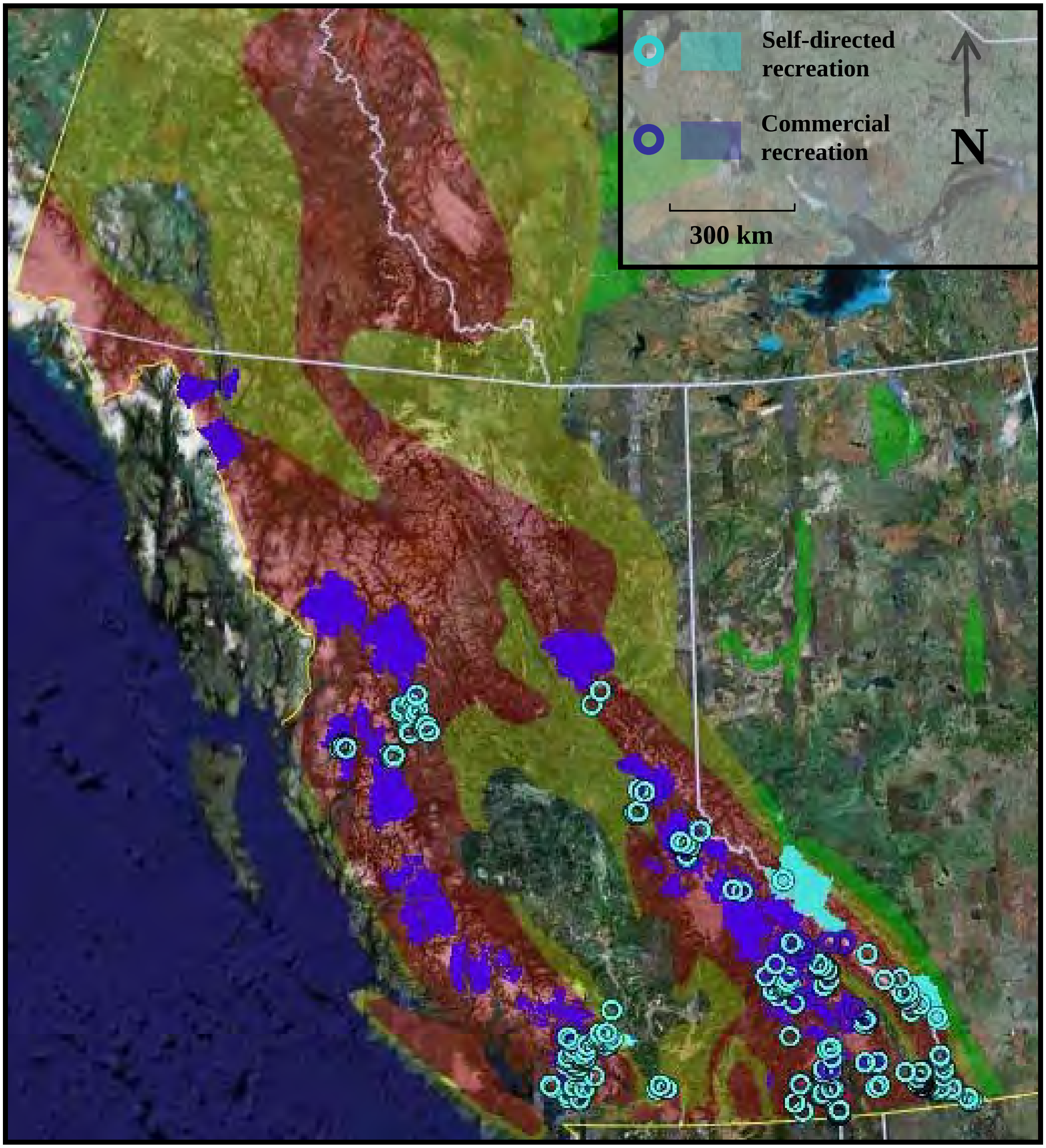
Map 13. Ski areas and avalanche activity zones in western Canada. This is not a comprehensive list.



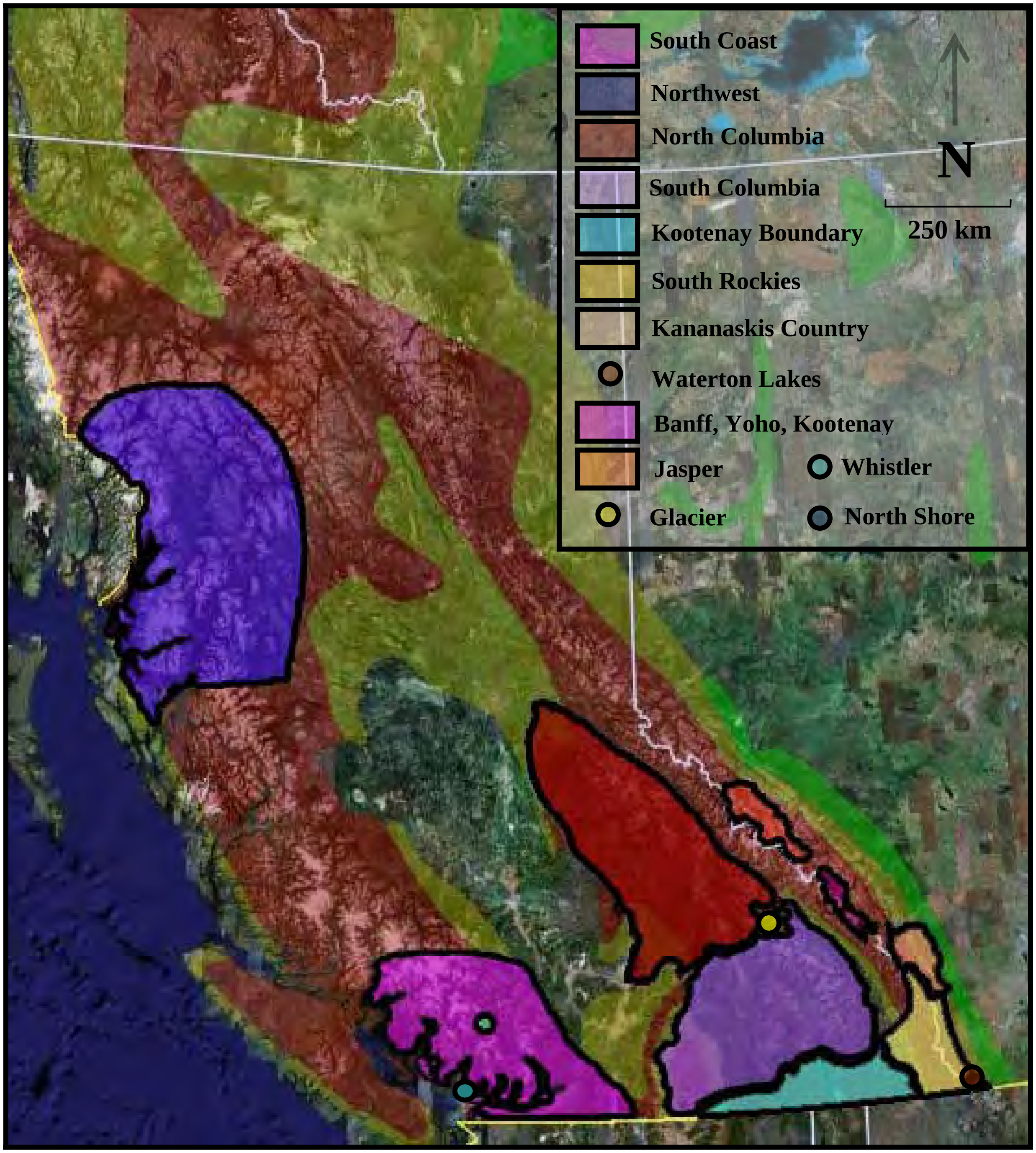
Map 14. Ski areas and avalanche activity zones in eastern Canada. This is not a comprehensive list.



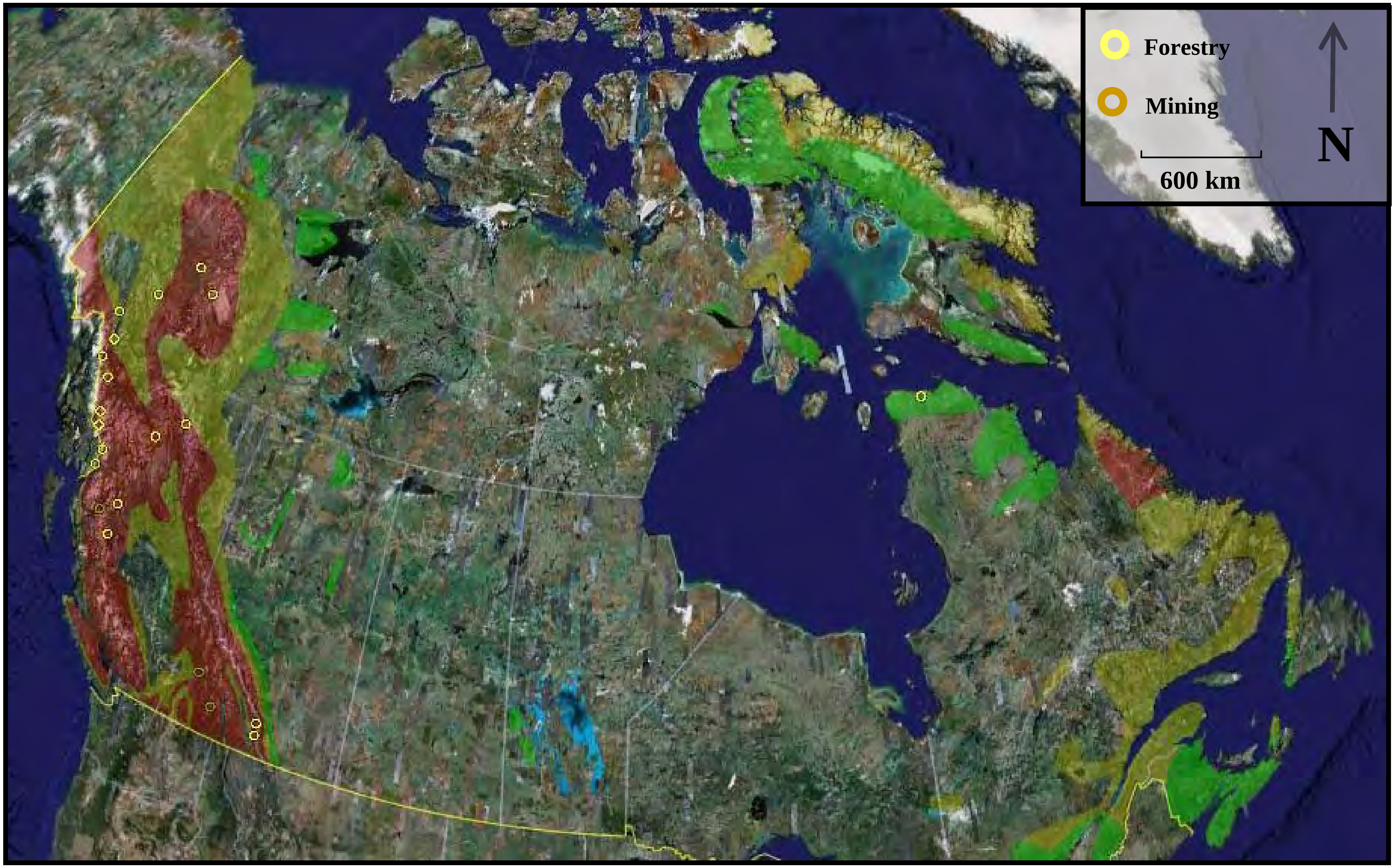
Map 15. Backcountry recreation and avalanche activity zones in Canada. This is not a comprehensive list.



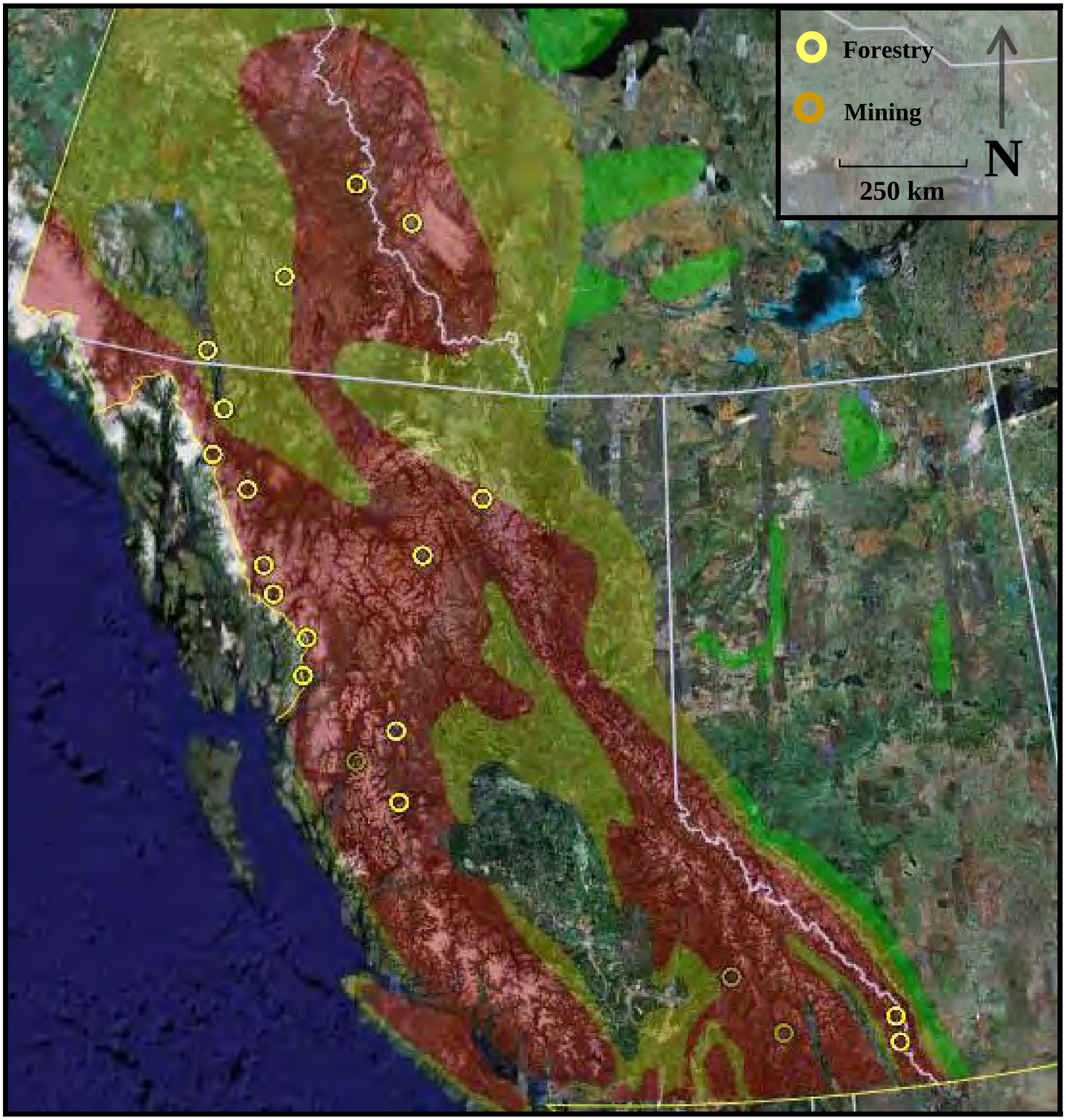
Map 16. Backcountry recreation and avalanche activity zones in western Canada. This is not a comprehensive list.



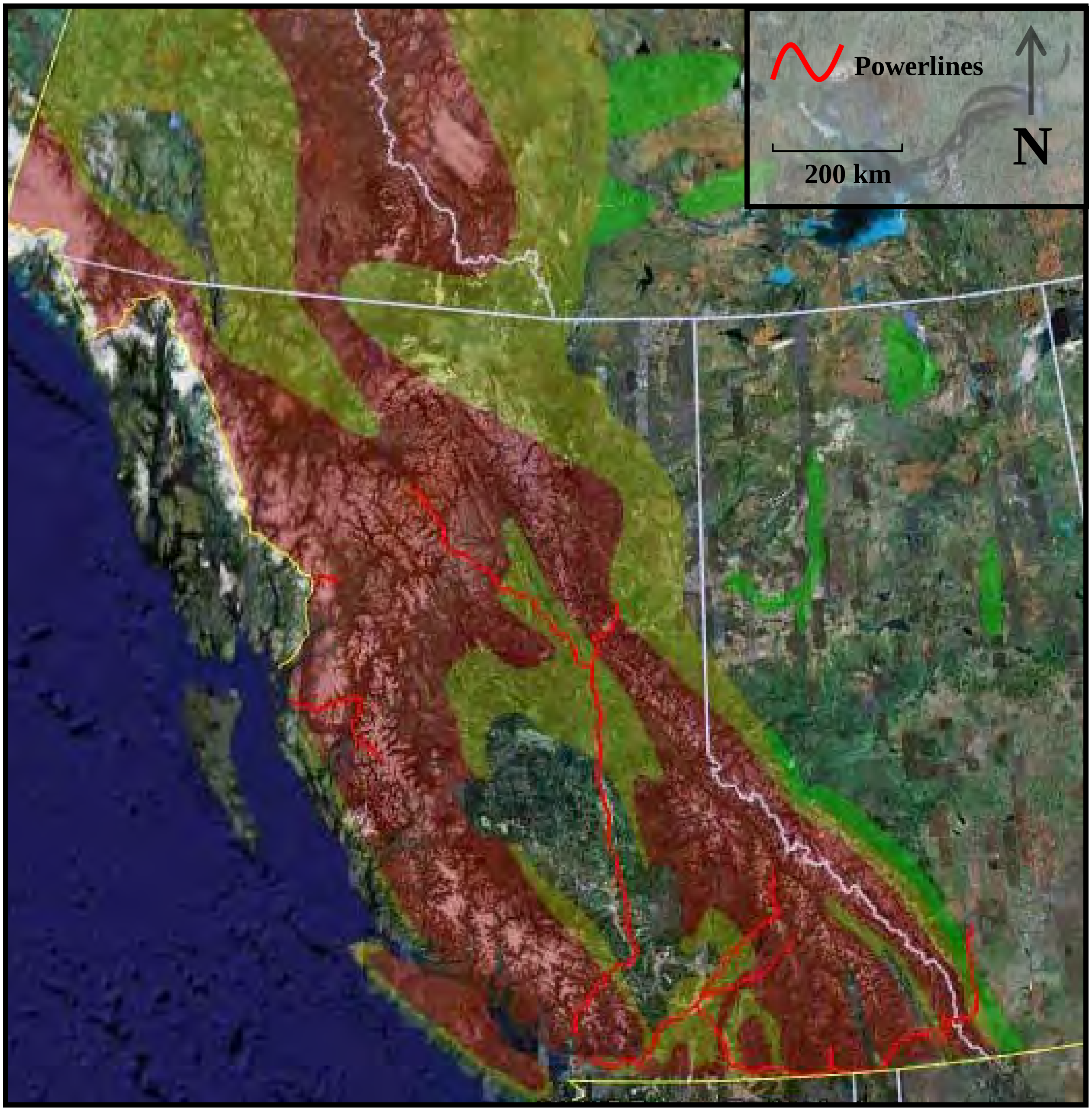
Map.17. Canadian Avalanche Centre and Parks Canada public avalanche bulletin regions in western Canada. The North Shore, Whistler, Glacier National Park and Waterton Lakes National Park bulletin regions are difficult to see at this scale, therefore placemarks were used to show approximate location and do not represent the size or shape of the regions.



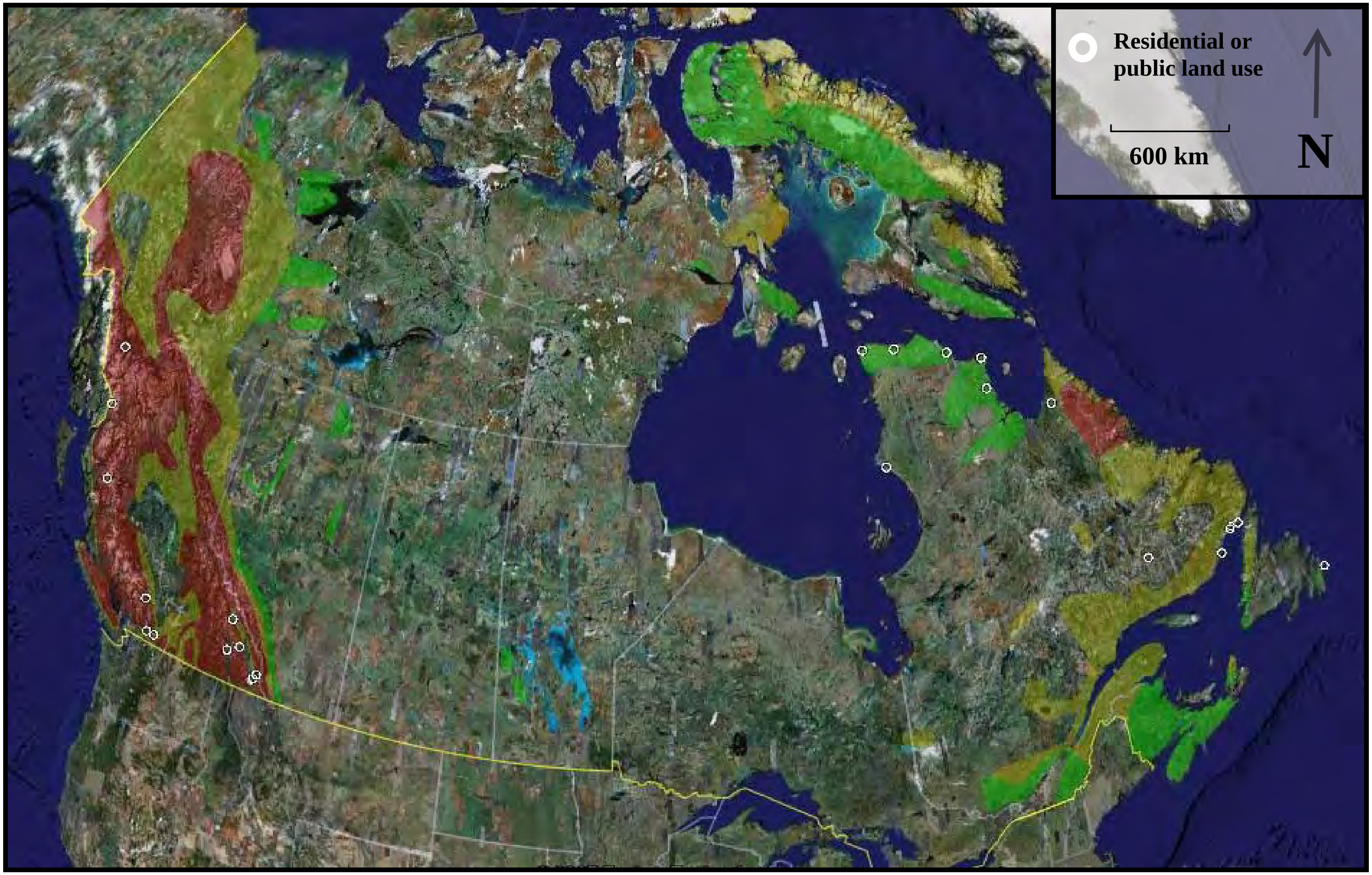
Map 18. Resource industries and avalanche activity zones in Canada. This is not a comprehensive list.



Map 19. Resource industries and avalanche activity zones in western Canada. This is not a comprehensive list.



Map 20. Powerlines and avalanche activity zones in western Canada. This is not a comprehensive list.



Map 21. Residential and public land use areas and avalanche activity zones in Canada. This is not a comprehensive list.

APPENDIX B: RANKED LIST OF CANADIAN AVALANCHE INCIDENTS

Public Safety Canada (2005) notes the following criteria for inclusion of an event in the Canadian Disaster Database:

- 10 or more people killed
- 100 or more people affected/injured/evacuated or homeless
- an appeal for national/international assistance
- historical significance
- significant damage/interruption of normal processes such that the community affected cannot recover on its own

Many of the avalanche events currently included in the Canadian Disaster Database do not meet these criteria.

The following list of fatal avalanche incidents in Canada has been compiled from the Canadian Avalanche Centre Avalanche Incident Database. Any avalanche incident which resulted in three or more fatalities was considered a disastrous event and is included on the list. This is consistent with the definition of a disastrous landslide event in Canada (Evans, 2003).

Events are ranked first by the number of fatalities, followed by the number of people injured. Where the number of fatalities and injured are the same, more recent events have been given a higher ranking.

Rank	Snow Avalanche Event	Date	Dead	Injured	Regions Affected	Event Description	Activity	
1	Rogers Pass, Glacier National Park, BC	March 4, 1910	58	1	BC	Railway workers killed by an avalanche.	Non-recreational	Transportation
2	Granduc Mine, 30 km NW of Stewart, BC	February 18, 1965	26	20	BC	After several days of heavy snowfall, an avalanche destroyed the southern portion of the Granduc Mine camp. 68 of the 154 people in the camp were caught in the avalanche.	Non-recreational	Resource industry
3	near Nain, NL	1782	22		NL	An avalanche struck an Esquimaux winter house with 31 people inside.	Non-recreational	Building
4	Kangiqsualujjuaq, QC	January 1, 1999	9	25	QC	An avalanche struck the school gymnasium while a New Year's Eve party, attended by more than 100 community members, was taking place.	Non-recreational	Building
5	Bugaboo Mountains, BC	March 12, 1991	9		BC	A group of 13 heli-skiers triggered a large avalanche while skiing down. 10 members were caught; 6 completely buried and 3 partially buried.	Recreational	Commercial
6	Molly Gibson Mine, near Slocan, BC	December 25, 1902	9		BC	Miners killed by an avalanche.	Non-recreational	Resource industry
7	promontoir de Québec, QC		8		QC	Houses hit and destroyed by an avalanche.	Non-recreational	Building
8	Glacier CPR Station, Glacier National Park, BC		8		BC	Railway workers killed by an avalanche.	Non-recreational	Transportation
9	Ocean Falls, BC	January 13, 1965	7	5	BC	An avalanche occurred in a period of very wet weather, carrying trees, mud and boulders down two watercourses on the alluvial fan. Several buildings and a wooden roadbed were destroyed.	Non-recreational	Building
10	Mount Temple, Banff National Park, AB	July 11, 1955	7	2	AB	A group of 11 teenage youths, roped together, were caught in an avalanche while crossing a snow slope.	Recreational	Self-directed
11	Mount Cheops, Glacier National Park, BC	February 1, 2003	7		BC	A 17-member school group skiing up Connaught Creek was hit by a large natural avalanche.	Recreational	Commercial
12	Durrand Glacier, near Revelstoke, BC	January 20, 2003	7		BC	21 backcountry skiers were ascending in two groups when an avalanche occurred. 2 subsequent avalanches were triggered sympathetically, the second of which overtook the lower group.	Recreational	Commercial

Rank	Snow Avalanche Event	Date	Dead	Injured	Regions Affected	Event Description	Activity	
13	Thunder River Drainage, near Blue River, BC	March 23, 1987	7		BC	A guided group of 9 heli-skiers was caught by an avalanche.	Recreational	Commercial
14	Spillimacheen Range, near Golden, BC	February 14, 1979	7		BC	A guided group of 10 heli-skiers was caught by an avalanche.	Recreational	Commercial
15	North Route Café, 45 km W of Terrace, BC	January 22, 1974	7		BC	8 people were waiting out a storm in a small café (North Route Café) when an avalanche struck the building.	Non-recreational	Building
16	promontoir de Québec, QC		7		QC		Non-recreational	Building
17	Kokanee Glacier Park, BC	January 2, 1998	6		BC	A group of 6 backcountry skiers was caught by an avalanche.	Recreational	Self-directed
18	Coal Creek, near Fernie, BC	December 30, 1912	6		BC	Miners killed by an avalanche.	Non-recreational	Resource industry
19	Bett's Cove, NL		6		NL	An avalanche struck a building with 6 occupants.	Non-recreational	Building
20	Rogers Pass, Glacier National Park, BC		6		BC	Railway workers killed by an avalanche.	Non-recreational	Transportation
21	The Battery, St John's, NL	February 16, 1959	5		NL	Residents killed when an avalanche struck a building.	Non-recreational	Building
22	Petite-Rivière-Saint-François, QC	March 12, 1936	5		QC	A building was struck by an avalanche or slushflow.	Non-recreational	Building
23	Tilt Cove, Baie Verte, NL	March 11, 1912	5		NL	Residents killed when an avalanche struck a building.	Non-recreational	Building
24	Big Pond, Cape Breton, NS		5		NS	A house with 9 occupants was struck by an avalanche.	Non-recreational	Building
25	Saint-Joseph de Lévis, QC		5		QC	A building was struck by an avalanche.	Non-recreational	Building
26	Lévis, QC		4	7	QC	2 houses were struck by an avalanche.	Non-recreational	Building
27	Fortress Mountain, Kananaskis Country, AB	November 29, 1997	4		AB	A groupof 4 snowboarding/skiing out of bounds, prior to season opening, were caught by an avalanche.	Recreational	Self-directed

Rank	Snow Avalanche Event	Date	Dead	Injured	Regions Affected	Event Description	Activity	
28	Healy Creek, Banff National Park, AB	February 11, 1990	4		AB	A group of 5 backcountry skiers was eating lunch in a forested area adjacent to a slide path when a large slide occurred; 4 were buried .	Recreational	Self-directed
29	Clemina Creek, south of Valemount, BC	March 29, 1986	4		BC	A group of 11 snowmobilers was struck by an avalanche.	Recreational	Self-directed
30	Burntstew Basin, Whistler, BC	April 8, 1972	4		BC	A group of 4 skiers was caught by an avalanche.	Recreational	Self-directed
31	Mount Saint Elias, YT	August 11, 1971	4		YK	A party of 5 mountaineers was swept away by an avalanche from above. 1 remained on the surface when the avalanche stopped.	Recreational	Self-directed
32	Mount Waddington, BC	July 30, 1960	4		BC	Climbers struck by an avalanche.	Recreational	Self-directed
33	Saint-Tite-des-Caps, QC	March 12, 1936	4		QC	4 people were unhurt after an avalanche struck a building.	Non-recreational	Building
34	McLean Point, 50 km ESE of Prince Rupert, BC	February 11, 1943	3	11	BC	Three avalanches swept down on a road workers' camp, destroying buildings and burying the victims	Non-recreational	Building
35	Phalanx Glacier, near Whistler, BC	December 16, 1996	3	1	BC	A guided group of 11 helicopter skiers triggered an avalanche which caught 2 party members. Additional party members were caught by a subsequent avalanche that sympathetically released.	Recreational	Commercial
36	Mount Edith Cavel, Jasper National Park, AB	February 19, 1972	3	1	AB	While digging a snow cave in preparation for an overnight bivouac, 4 climbers were caught by an avalanche	Recreational	Self-directed
37	Mount Wilson, Banff National Park, AB	February 13, 2004	3		AB	A party of 3 ice climbers was swept off their route by an avalanche.	Recreational	Self-directed
38	Fairy Creek, near Fernie, BC	March 26, 2003	3		BC	A group of 5 snow machines parked on a knoll at the base of a highmarking slope. The slope was triggered by a highmarker and the subsequent avalanche overtook the riders on the knoll below.	Recreational	Self-directed
39	Misty Mountain, 16 km W of Kaslo, BC	January 28, 2002	3		BC	A group of 5 unguided backcountry skiers was caught by an avalanche.	Recreational	Self-directed

Rank	Snow Avalanche Event	Date	Dead	Injured	Regions Affected	Event Description	Activity	
40	Mount Cerebrus, Monarch Icefield, BC	May 17, 1996	3		BC	3 mountaineers were ascending the west slopes of Mount Cerebrus when they triggered a small slough which swept them over rock and ice cliffs. The slough triggered a larger avalanche that then buried them. The event was observed by 2 remaining party memb	Recreational	Self-directed
41	Snowdome, Jasper National Park, AB	March 20, 1993	3		AB	A party of 3 ice climbers was swept off their route by an avalanche.	Recreational	Self-directed
42	Mount Bryce, Banff National Park, AB	June 14, 1987	3		BC	4 British Armed Forces members were caught by a cornice-triggered avalanche.	Recreational	Self-directed
43	Mount Logan, Kluane National Park, YT	June 11, 1982	3		YK	7 climbers were caught by an avalanche which struck their tents.	Recreational	Self-directed
44	Conrad Icefield, near Golden, BC	February 23, 1981	3		BC	A group of helicopter skiers was caught by an avalanche.	Recreational	Commercial
45	Bugaboo Mountains, BC	March 17, 1977	3		BC	A guided group of 12 helicopter skiers triggered an avalanche which caught 3 party members.	Recreational	Commercial
46	Chancellor Peak, Yoho National Park, BC	December 12, 1976	3		BC	A party of 3 climbers was carried over steep rocky terrain and buried by an avalanche.	Recreational	Self-directed
47	Kootenay Pass, BC	January 16, 1976	3		BC	An avalanche struck a convertible travelling on the highway. All 5 passengers were thrown from the vehicle as it was swept from the road and carried down a long, steep embankment.	Non-recreational	Transportation
48	Giant Mascot Mine, near Hope, BC	March 5, 1972	3		BC	A truck carrying 3 mine workers was buried by an avalanche. Nearby, a bulldozer was clearing avalanche debris from previous slides.	Non-recreational	Resource industry
49	30 km east of Fernie, BC	December 23, 1971	3		BC	3 men travelling along a forestry road in a pickup truck and small tractor encountered avalanche deposits on the road. While investigating the deposit, they were struck by a second avalanche.	Non-recreational	Resource industry
50	Corner Brook, NL	March 4, 1935	3		NL	Residents killed when an avalanche struck a building.	Non-recreational	Building
51	Noble No.5 Mine, Sandon, BC	January 6, 1913	3		BC	Miners killed by an avalanche.	Non-recreational	Resource industry

Rank	Snow Avalanche Event	Date	Dead	Injured	Regions Affected	Event Description	Activity	
52	Rogers Pass, Glacier National Park, BC		3		BC	Railway workers killed by an avalanche.	Non-recreational	Transportation

APPENDIX C: SUGGESTED REVISIONS TO AVALANCHE INFORMATION ON PUBLIC SAFETY CANADA WEBSITE

Canadian Disaster Database: http://www.publicsafety.gc.ca/res/em/cdd/search-en.asp

Search Criteria: Snow Avalanche, All Locations, All Time Periods

<table>
<tr><td colspan="2">1. Snow Avalanche: Glacier National Park BC, 1999

Statistics
Dead: 1 Injured: 4 Evacuated: 0
Regions Affected: BC

Event Description
Disaster
Snow Avalanche: Glacier National Park, BC, Dec 7, 1999. One skier was killed and four others injured after being swept up in a wall of snow that rumbled down a mountain in BC's Glacier National Park. The 400-metre-wide slide occurred on the west shoulder of Mt. MacDonald in a popular back-country skiing area.

References
Disaster
Emergency Preparedness Canada/Protection civile Canada
Estimated Cost</td></tr>
<tr><td>Suggested revisions</td><td>none</td></tr>
<tr><td>References</td><td>Canadian Avalanche Centre Avalanche Incident Database

Alpine Club of Canada. 2006. Alpine Accidents in Canada. Retrieved February 2007, from Alpine Club of Canada, Edmonton Section web site: http://alpineclub-edm.org/accidents/index.asp</td></tr>
</table>

2. Snow Avalanche: Kangiqsualujjuaq QC, 1999 Statistics Dead: 9 Injured: 25 Evacuated: Unknown Regions Affected: QC Event Description Disaster Snow Avalanche: Kangiqsualujjuaq QC, Jan 1 1999. The Inuit community of Kangiqsualujjuaq, grieved after 9 died in Quebec's worst avalanche. Four adults and five children died in the tragedy after tonnes of snow came cascading down the sheer face of a 365-metre-high cliff at 1:30 am on Jan 1, knocking out a wall and swamping those inside the gymnasium where the New Year's Eve party was being held. Some of the 25 injured were in critical condition and 10 other buildings were evacuated. Estimated Cost: $2,900,000 References Disaster Emergency Preparedness Canada/Protection civile Canada Estimated Cost Emergency Preparedness Canada; Press; Canadian Red Cross Annual Report	
Suggested revisions	'... snow came cascading down a <u>*steep 110*</u>-metre-high <u>*slope*</u> at 1:<u>*45*</u> am on...' '... swamping the gymnasium where the New Year's Eve party was being held. <u>*People were inside and standing just outside the gymnasium when the avalanche struck*</u>. Some of the ...'
References	Canadian Avalanche Centre Avalanche Incident Database Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D. and Walker, S. 2003. Snow Avalanche Hazard in Canada - a Review. *Natural Hazards*, 28, 487-515.

3. Snow Avalanche: Blanc Sablon QC, 1995

Statistics
Dead: 2 Injured: 0 Evacuated: 69
Regions Affected: QC

Event Description
Disaster
Snow Avalanche: Blanc Sablon (lower north coast) QC, Mar 10 1995. An large snow storm provoked an avalanche (2000 m³ of snow). Two people were killed, a house destroyed, 24 residences were evacuated. The avalanche affected 69 people in total.

Estimated Cost: $368,000

References
Disaster
Gouvernement du Québec, Ministère de la Sécurité publique, Direction générale de la sécurité et de la prévention.
Estimated Cost
Gouvernement du Québec, Ministère de la Sécurité publique, Direction générale de la sécurité et de la prévention

Suggested revisions	'Blanc-Sablon' '*A* large snow storm...' The CAC Avalanche Incident Database indicates that 13 houses were evacuated.
References	Canadian Avalanche Centre Avalanche Incident Database Jamieson, B., and Geltsetzer, T. 1996. *Avalanche Accidents in Canada, Vol. 4, 1984-1996*, Canadian Avalanche Association, Revelstoke, BC.

4. Snow Avalanche: Bugaboo Glacier Provincial Park BC, 1991 Statistics Dead: 9 Injured: 0 Evacuated: 0 Regions Affected: BC Event Description Disaster Snow Avalanche: Bugaboo, Purcell Mountains BC, Mar 12 1991. Nine heli-skiers were killed in a massive avalanche in Bugaboo Glacier Provincial Park. References Disaster Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux. Estimated Cost	
Suggested revisions	none
References	Canadian Avalanche Centre Avalanche Incident Database

5. Snow Avalanche: Banff AB, 1990 Statistics Dead: 4 Injured: 0 Evacuated: 0 Regions Affected: AB Event Description Disaster Snow Avalanche: Banff AB, Feb 11 1990. Four people from Calgary were killed by an avalanche while cross-country skiing in Banff National Park. References Disaster Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux. Estimated Cost	
Suggested revisions	'...while *backcountry skiing* in Banff...'
References	Canadian Avalanche Centre Avalanche Incident Database Jamieson, B., and Geltsetzer, T. 1996. *Avalanche Accidents in Canada, Vol. 4, 1984-1996*, Canadian Avalanche Association, Revelstoke, BC.

6. Snow Avalanche: Blue River BC, 1987 Statistics Dead: 7 Injured: 0 Evacuated: 0 Regions Affected: BC Event Description Disaster Snow Avalanche: Blue River BC, Mar 23 1987. An avalanche took the lives of 6 American heli-skiers and their Canadian guide. References Disaster Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux. Estimated Cost	
Suggested revisions	none
References	Canadian Avalanche Centre Avalanche Incident Database Jamieson, B., and Geltsetzer, T. 1996. *Avalanche Accidents in Canada, Vol. 4, 1984-1996*, Canadian Avalanche Association, Revelstoke, BC.

7. Snow Avalanche: Golden BC, 1981 Statistics Dead: 3 Injured: 0 Evacuated: 0 Regions Affected: BC Event Description Disaster Snow Avalanche: Golden BC, Feb 23 1981. An avalanche killed 3 heli-skiers near Conrad Icefield, west of Golden, BC References Disaster Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux. Estimated Cost	
Suggested revisions	'...Conrad Icefield, ***south*** of Golden...'
References	Jamieson, B. 2001. Snow avalanches**.** In: *A Synthesis of Geological Hazards in Canada*. Bulletin 548, G.R. Brooks (ed.). Geological Survey of Canada, 81-100.

8. Snow Avalanche: Golden BC, 1979 Statistics Dead: 7 Injured: 0 Evacuated: 0 Regions Affected: BC Event Description Disaster Snow Avalanche: Golden BC, Feb 14 1979. An avalanche took the lives of seven heli-skiers in the Purcell Range southwest of Golden, BC. References Disaster Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux. Estimated Cost	
Suggested revisions	'...in the *Spillimacheen* Range...'
References	Canadian Avalanche Centre Avalanche Incident Database Schaerer, P.A. 1987. *Avalanche Accidents in Canada III, A Selection of Case Histories, 1978-1984*, Institute for Research in Construction, Publication 27950, 138 p. Jamieson, B. 2001. Snow avalanches**.** In: *A Synthesis of Geological Hazards in Canada*. Bulletin 548, G.R. Brooks (ed.). Geological Survey of Canada, 81-100. Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D. and Walker, S. 2003. Snow Avalanche Hazard in Canada - a Review. *Natural Hazards*, 28, 487-515.

9. Snow Avalanche: Terrace BC, 1974

Statistics
Dead: 7 Injured: 0 Evacuated: 1
Regions Affected: BC

Event Description
Disaster
Snow Avalanche: Terrace BC, 1974. 7 dead, one survivor; eight people were waiting out a storm in a small café when an avalanche struck the building.

References
Disaster
Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux.
Estimated Cost

Suggested revisions	'Snow Avalanche: Terrace BC, *1974*' 'Snow Avalanche: *45 km west of* Terrace BC, *Jan 22 1974*. 7 dead, one survivor; eight people were waiting out a storm in a small café *(North Route Café)* when an avalanche struck the building.'
References	Canadian Avalanche Centre Avalanche Incident Database 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, Publication 17292, 114 p. Jamieson, B. 2001. Snow avalanches**.** In: *A Synthesis of Geological Hazards in Canada*. Bulletin 548, G.R. Brooks (ed.). Geological Survey of Canada, 81-100.

10. Snow Avalanche: Granduc Mine BC, 1965 Statistics Dead: 26 Injured: 22 Evacuated: 0 Regions Affected: BC Event Description Disaster Snow Avalanche: Granduc Mine BC, Feb 18 1965. An avalanche destroyed a miner's camp; 26 dead, 22 injured. References Disaster Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux. Estimated Cost	
Suggested revisions	'Injured: *20*' '...26 dead, *20* injured.'
References	Canadian Avalanche Centre Avalanche Incident Database 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, Publication 17292, 114 p. Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D. and Walker, S. 2003. Snow Avalanche Hazard in Canada - a Review. *Natural Hazards*, 28, 487-515.

11. Avalanche: The Battery, St. John's Harbour NF, 1959 Statistics Dead: 5 Injured: 9 Evacuated: 0 Regions Affected: NF Event Description Disaster Avalanche: The Battery, St. John's Harbour NF, Feb 16 1959. A severe storm hit St. John's with winds of up to 220 km/h and left 55 cm of snow on the ground. An avalanche struck two houses and swept them down the slope, hitting two other houses. Over 50 rescue workers and residents worked for 12 hours, digging through the snow and the debris to free trapped residents. In the Outer Battery, another avalanche (caused by the same storm) buried a house that withheld the weight of the snow. The strong structure protected the residents; however, they were trapped until dug out by rescue workers. This was the second avalanche to affect The Battery in 40 years. Inspection of the slopes has shown that a rockfall risk exists, and that The Battery is frequently affected by rockfalls. The City of St. John's has recently constructed safety fences to protect against rockfalls and avalanches in the Outer Battery area. References Disaster Geological Survey of Newfoundland and Labrador; Memorial University of Newfoundland/Commission géologique de Terre-Neuve et du Labrador Estimated Cost	
Suggested revisions	none
References	Canadian Avalanche Centre Avalanche Incident Database Batterson, M., Liverman, D.G.E., Ryan, J., and Taylor, D. 1999. The Assessment of Geological Hazards and Disasters in Newfoundland: An Update. *Current Research,* Newfoundland Department of Mines and Energy, Geological Survey, Report 99-1, 95-123. Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D. and Walker, S. 2003. Snow Avalanche Hazard in Canada - a Review. *Natural Hazards*, 28, 487-515.

12. Snow Avalanche: Lake Louise AB, 1955 Statistics Dead: 7 Injured: 0 Evacuated: 0 Regions Affected: AB Event Description Disaster Snow Avalanche: Mount Temple, Lake Louise AB, Jul 11 1955. 7 skiers killed; inexperienced climbers were swept away by an avalanche. References Disaster Emergency Preparedness Canada and National Atlas of Canada. Natural Hazards Poster-Map, 1996; Geomatics Canada. Estimated Cost	
Suggested revisions	'Injured: *2*' '... Jul 11 1955. *7 killed when a group of 11 inexperienced climbers were swept away by an avalanche*.'
References	Canadian Avalanche Centre Avalanche Incident Database 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, Publication 17292, 114 p. Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D. and Walker, S. 2003. Snow Avalanche Hazard in Canada - a Review. *Natural Hazards*, 28, 487-515.

13. Snow Avalanche: Rogers Pass BC, 1910 Statistics Dead: 62 Injured: 0 Evacuated: 0 Regions Affected: BC Event Description Disaster Snow Avalanche: Rogers Pass BC, Mar 5 1910. 62 dead (Canadian Pacific Railway workers), one survivor; an avalanche struck workers as they cleared the tracks of snow dumped by a previous slide. References Disaster Emergency Preparedness Canada. Significant Disasters in Canada, September, 1995; A list of disaster information gathered from the press./Protection civile Canada. Les catastrophes importantes au Canada, septembre 1995. Liste de renseignements sur les catastrophes tirés des journaux. Estimated Cost	
Suggested revisions	'Rogers Pass BC, Mar *4* 1910.' 'Dead: *58*' 'Injured: *1*' 'Snow Avalanche: Rogers Pass BC, Mar *4* 1910. *58* dead (Canadian Pacific Railway workers), *two* survivors; an avalanche...'
References	Canadian Avalanche Centre Avalanche Incident Database C. English (Revelstoke Museum and Archives), personal communication, May 30, 2007 Nicholson, P. and Rota, K. 1998. *Research report regarding the snowslide at Rogers Pass, March 4th, 1910*. Revelstoke Museum and Archives, 2 p.

APPENDIX D: SIGNIFICANT LANDSLIDES AND AVALANCHES OF THE 19TH AND 20TH CENTURIES

http://www.publicsafety.gc.ca/res/em/nh/lsa/lsa-sig-en.asp

Twenty-five events are listed. Eighteen refer to debris flow, mudslide or rockslide; these events, which are shaded in the following list, have not been reviewed. Of the seven avalanche events, one (1965 slush avalanche, Ocean Falls, BC, 7 fatalities) did not come up in the PSC Canadian Disaster Database search for snow avalanche events.

Suggested revisions for each avalanche event, if any, are italicized and underlined.

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1 **1999 Fatalities: 9**; injured: 25

Kangiqsualujjuaq, QC / January / Tonnes of snow cascaded down a *steep slope* and knocked out a school gymnasium wall. Victims inside *and just outside the gymnasium were* participating in a New Year's Eve party. Ten other buildings were evacuated.

2 **1991 Fatalities: 9**

Purcell Mountains, BC / March / Snow avalanche struck helicopter skiing party.

3 **1990 Fatalities: 7**

Joe Rich and Southern BC / June / Debris avalanche and mudslides caused by heavy rains closed 3 highways and reduced TransCanada highway traffic; eight homes destroyed in four communities by mudslides.

4 **1981 Fatalities: 9**

M-Creek Bridge, Highway 99, BC / October / Cars plunged into creek after debris flow had destroyed bridge during heavy rains.

5 ***1974*** **Fatalities: 7**

North Route Cafe, BC / *January* / Snow avalanche destroyed roadside café.

6 **1971 Fatalities: 31**

St-Jean-Vianney, QC / May / Rapid retrogressive flowslide in Leda Clay swept away 40 homes.

7 **1965 Fatalities: 7**

Ocean Falls, BC / January / Slush avalanche/debris flow caused by melting snow struck community.

8 **1965 Fatalities: 26**; *injured: 20*

Granduc Mine, BC / February / Snow avalanche struck sleeping quarters of mining camp.

9 **1964 Fatalities: 5**

Newfoundland / January / Ramsay Arm, BC / September / Debris flow caused by heavy rains struck logging camp.

10 **1962 Fatalities: 9**

Rivière Toulnustouc, QC / December / Workers killed by landslide in marine clay caused by blasting.

11 **1957 Fatalities: 7**

Prince Rupert, BC / November / Debris avalanche triggered by heavy rains buried 3 houses.

12 **1955 Fatalities: 7***; injured: 2*

Mount Temple, Lake Louise, AB / July / Inexperienced climbers swept away by snow avalanche.

13 **1921 Fatalities: 37**

Britannia Beach, BC / October / Outburst flood caused by breach of landslide dam swept away more than 50 houses.

14 **1915 Fatalities: 56**; injurred: 22

Jane Camp, BC / March / Rock avalanche from above portal of mine swept into mining camp.

15 **1910 Fatalities: *58***

Rogers Pass, BC / March / Workers clearing snow from previous avalanche on CP tracks buried by second avalanche.

16 **1909 Fatalities: 22**; injurred: 15

New Westminster, BC / November / Slump of railway embankment; train derailed.

17 **1908 Fatalities: 33**

Notre-Dame-de-la-Salette, QC / April / Landslide in Leda Clay into Lièvre River caused a wave containing blocks of ice which destroyed homes.

18 **1905 Fatalities: 15**

Spences Bridge, BC / August / Landslide into Thompson River caused wave which swept victims away.

19 **1903 Fatalities: 70**; injurred: 23

Frank, AB / April / Rock avalanche buried the coal mining town of Frank.

20 **1897 Fatalities: 7**

Red Mountain, BC / Debris flow struck railway camp.

21 **1895 Fatalities: 5**

Saint-Luc-de-Vincennes, QC / Landslide in Leda Clay.

22 **1891 Fatalities: 35**

North Pacific Cannery, BC / Debris flow or flood caused by breach of landslide dam after heavy rains.

23 **1889 Fatalities: 45**

Québec, QC / Rockslide onto houses on Champlain Street.

24 **1877 Fatalities: 5**

Sainte-Geneviève-de-Batiscan, QC / Landslide in Leda Clay.

25 **1841 Fatalities: 32**

Québec, QC / Rockslide onto houses on Champlain Street.