IN THE PURSUIT OF STANDARDS – THE NEXT STEP IN CANADA'S AVALANCHE RISK MANAGEMENT GUIDELINES

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ABSTRACT: Recognizing the need to standardize new and innovative Canadian avalanche risk management practices and respond to increasing demand from regulatory bodies, the Canadian Avalanche Association recently embarked on a two-year project to revise and update its best practice guidelines for avalanche risk management. This paper provides highlights and practical examples from the first of two new publications, which covers the technical aspects of avalanche risk management. The centerpiece of this publication are guidelines for planning and operational risk management for common avalanche terrain land-use activities in Canada.

KEYWORDS: Avalanche, Risk, Management, Guidelines, Planning, Operations

1. INTRODUCTION

The *Guidelines for Snow Avalanche Risk Determination and Mapping* and *Land Manager's Guide to Snow and Avalanche Hazards*, both published by the Canadian Avalanche Association (CAA) in 2002 (CAA, 2002a, 2002b), provided an important reference for technical and engineering practices related to the assessment and mitigation of avalanche risk. However, the period between 2002 and 2016 has seen remarkable change and growth in Canadian planning and operational avalanche risk management practices. With support from the National Search Rescue Secretariat's New Initiatives Fund and our sponsor organization, Parks Canada, the CAA was able to fund a two-year project involving leading industry experts to update and revise our guideline documents to reflect current practice.

The recently published *Technical Aspects of Snow Avalanche Risk Management* (CAA, 2016) is the first of two documents and the focus of this paper. It presents technical guidelines for avalanche risk assessment and mitigation that is intended to inform practice, from the planning of avalanche risk management to day-to-day operational work. This 125 page, comprehensive avalanche risk management resource includes new and innovative content in areas such as:

- A risk assessment process that applies to both planning and operational activities.
- Uncertainty in avalanche risk management.
- Guidelines for avalanche terrain identification, classification and mapping.
- An overview of avalanche risk assessment and decision aids.
- Modern avalanche risk mitigation techniques.
- Up-to-date guidelines for avalanche terrain land-use in Canada.

2. THE AVALANCHE RISK MANAGEMENT PROCESS

As shown in Fig. 1, the avalanche risk management process aligns with the ISO 31000 risk management process (CSA, 2010), and has a parallel sequence of steps for the planning (Section 2.1) and operational (Section 2.2) stages. Each stage consists of establishing the context, risk assessment then risk treatment. The steps followed in each stage are not fundamentally different; however, in operations the distinct step of avalanche forecasting may comprise the endpoint of an operational objective or may lead to mitigation activities. Fig. 1 also shows that Monitoring and Review as well as Communication and Consultation apply to all stages of the risk management process.

This process applies to avalanche hazard management as well as risk management.

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Avalanche hazard is defined in terms of the likelihood of avalanche release and avalanche magnitude. Avalanche risk includes the components of avalanche hazard as well as the exposure in space and time of elements at risk and their vulnerability.

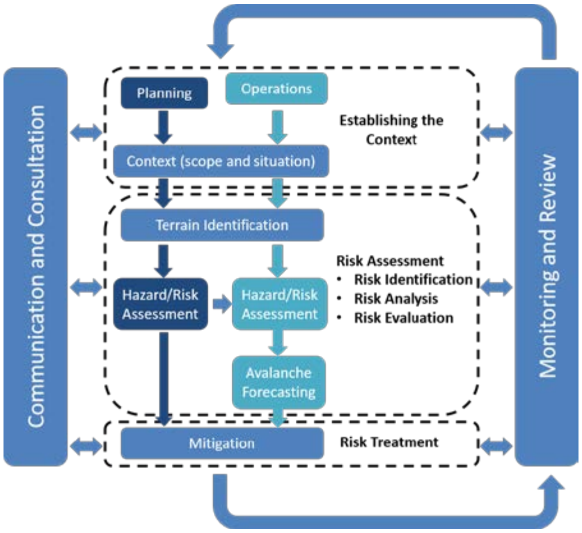

Fig. 1: The avalanche risk management process. The center of the diagram illustrates the parallel paths that focus on either planning or operational activities and identifies how this structure aligns under the ISO 31000 umbrella (CSA, 2010).

2.1 Planning

Avalanche planning involves the analysis of avalanche hazard and risk, and proposed mitigation for specific objectives. The focus of the specific objectives is long-term (possibly permanent), and typically results in maps, plans and reports. Avalanche hazard and/or risk assessments for planning may lead to the design of long-term engineered mitigation measures, or the description of operational measures to mitigate risk, or a combination of these two approaches.

2.2 Operations

Operational avalanche risk management includes avalanche forecasting tasks and the implementation of short-term mitigation measures in order to achieve specific organizational objectives. It is often a real-time activity often in the immediate proximity of the avalanche hazard, though selected steps may be undertaken at a time before assessment and mitigation activities are conducted.

Operational avalanche hazard and/or risk assessments occur in a number of different contexts, from office-based forecasters relying on incoming data from numerous sources, to individual or teams of professional guides and forecasters working in the field. It usually follows a structured workflow that assesses both hazard and risk, usually done as a sequential, two-step process. The conceptual model of avalanche hazard (Statham et al., in prep.) is regularly used as a component of the hazard assessment sub-step. It can also be a less structured process, when considered in the context of real-time slope-scale risk management in the field (e.g. guiding a heliski group through complex terrain by managing exposure and vulnerability).

2.2.1 Avalanche Forecasting

Avalanche forecasting is the prediction, over a specified scale of terrain, of current and/or future (e.g. with the range of a weather forecast) avalanche hazard and/or risk based on the expected likelihood of triggering, avalanche size and runout. In keeping with the definition of risk, operational avalanche forecasting typically involves assessment of avalanche hazard and risk separately and in sequence. Forecasters normally assess avalanche hazard first, followed by a risk assessment focusing on the effects of the avalanche hazard on the element-at-risk.

2.3 Uncertainty in planning and operations

Consistent with engineering definitions, uncertainty is partitioned into aleatoric uncertainty and epistemic (knowledge source) uncertainty. Aleatoric uncertainty pertains to natural variability over time and space, and should be considered in assessments because it cannot be reduced. Examples of aleatoric uncertainty include variations in snowpack height over terrain or the variable number of vehicles on a road crossing an avalanche path. Epistemic (knowledge source) uncertainty arises from limited knowledge or understanding and can potentially be reduced by gathering more information. The most common way of reducing epistemic uncertainty is to identify knowledge gaps and seek targeted information to reduce the uncertainty.

The following steps are used to deal with uncertainty in planning and operations:

1. Acknowledge the existence of uncertainty.
2. Reduce epistemic uncertainty when practical.

3. Include natural variability and residual epistemic uncertainty in assessments.
4. Communicate the unreduced uncertainty to those responsible for the risk.

In avalanche operations, uncertainty is rarely quantified and qualitative safety margins such as "stay well away from slopes over 40°" are common in the mitigation of avalanche risk. As an example of qualitative uncertainty being included and communicated in an avalanche hazard assessment, Fig. 2 shows the uncertainty in avalanche likelihood and magnitude (size) for two scenarios: a wind slab avalanche and a deep slab avalanche.

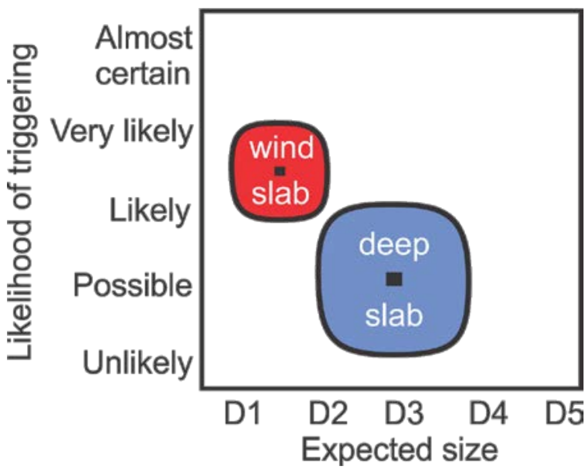

Fig. 2: For a given forecast area, day, and character of avalanche, this avalanche hazard chart displays the qualitative uncertainly and variability in expected avalanche size (D1 to D2 for wind slabs and D2 to D4 for deep slabs) and in the likelihood of triggering (likely to very likely for wind slabs and unlikely to likely for deep slabs) (CAA, 2016) (after Statham et al., in prep.).

2.4 Assessment and Decision Aids

Assessment/decision aids are support tools that explicitly help decision makers combine multiple observations or factors to produce an assessment and/or decision regarding risk mitigation. These aids can capture advanced avalanche knowledge or operational risk management expertise and make it broadly accessible. Chapter 7 of CAA (2016) describes numerous types of assessment and decision aids including risk matrices, assessment tables, checklist sums, snowpack evolution models, and decision trees. While most of the currently available assessment and decision aid are unable to replace the judgement of an experience forecasters, they can be used as 'second opinions' to help reduce uncertainty. If the decision aid and expert decision give similar results (e.g. both put risk in the acceptable range) uncertainty is reduced. If assessments diverge, the decision-maker can either choose mitigate according to the more conservative assessment or gather additional targeted information to reduce uncertainty.

3. TERRAIN IDENTIFICATION

Avalanche terrain identification involves the analysis of topography, and vegetation, observations and records of avalanche activity, snow supply and climate characteristics, and/or numerical runout modeling (e.g. Jamieson and Sinickas, 2015) to identify the location and extent of avalanche terrain. In general, avalanche terrain identification methods can be categorized as those that take place either in an office (i.e. a desktop study) or in the field.

Desktop investigations during both the planning and operational stages often begin with analysis of terrain photographs and imagery, topographic maps, oral and written avalanche activity records, and/or snow supply and climate data. Google Earth™ or other GIS-based digital terrain models are helpful tools to gain a general impression of terrain during the initial stages, or for advanced analysis when required. In most cases, a preliminary desktop investigation is conducted in preparation for field investigations.

Avalanche terrain identification often requires verification and supplementary observations from the field since not all avalanche paths, particularly those in forests or in steep northerly quadrants, can be accurately identified on photographs or maps. Furthermore, field observations often provide information helpful for assessing the frequency of previous avalanches. Aerial views allow expert observers to quickly interpret terrain from several angles. Often patterns and clues emerge from aircraft that otherwise would not be evident from a ground-based survey. Ground-based survey includes investigation of vegetation, including clues from dendrochronology, as well as measurement of topographical parameters, including slope angle and shape, surface roughness and dimensions of the avalanche terrain.

Tbl. 1: Terrain Survey Levels of Effort (TSLE) recommend the extent to which terrain identification and mapping should be checked from the field (after BCMoFLNRO, 1999).

TSLE	*Preferred map scale*	*Typically assessment scale*	*% of aval. terrain field surveyed*	*Method of surveying*	*Field progress per day*
A	1:1,000 to 1:10,000	Terrain feature- to slope-scale	50-100	Ground surveys by foot traverses.	20-100 ha
B	1:20,000 to 1:50,000	Slope- to path-scale	20-50	Ground surveys by foot traverses, supported by vehicle and/or flying.	500-1,200 ha
C	1:20,000 to 1:50,000	Path- to mountain-scale	1-20	Vehicle and flying with selected ground observations, supported by desktop investigations.	1,200-5,000 ha
D	1:20,000 to 1:50,000	Path- to mountain-scale	0	No field surveys. Desktop investigations only.	n/a

3.1 Level of Effort

The level of effort put into an avalanche terrain identification depends on the amount of detail required to meet the objectives, which is influenced by the stage of assessment (i.e. planning or operational), along with size of the study area or assessment scale, complexity of the terrain, and element(s) at risk, including exposure-time characteristics. The level of effort can be determined by the preferred map scale using Terrain Survey Level of Effort (TSLE) scale (Tbl. 1) (after BCMoFLNRO, 1999). The four-level TSLE scale represents the extent of field surveying from A to D (most to least effort) recommended for adequate avalanche terrain identification at the preferred map scale.

4. TERRAIN CLASSIFICATION

Terrain classification systems are intended to categorize avalanche terrain into areas with common characteristics. These characteristics may be topographical (e.g. slope angle and/or forest density), related to avalanche exposure (e.g. degree of interaction of the element at risk with starting zones) (Tbl. 2) or they can include some elements of avalanche hazard (e.g. frequency-magnitude relationships) (Fig. 3). The two main types of classification systems used in Canada include impact-based classification and terrain exposure classification.

4.1 Impact Based Classification

Impact-based classification results from a detailed assessment of hazard or risk that considers avalanche magnitude in terms of impact. This type of terrain classification is most common for fixed (unmoving) facilities during the planning stage of risk assessment.

A hazard zone model for occupied structures is shown in Fig. 3. Red, blue and white hazard zone classes are defined by the expected impact pressure and return period of an avalanche within an avalanche path. This is an impact-based classification system that often leads to maps (Fig. 4) with associated zoning recommendations for development of occupied structures (Section 7.1).

4.2 Terrain Exposure Classification

Terrain exposure classification categorizes avalanche terrain according to severity with respect to the exposure of an element at risk. This type of terrain classification is most common for backcountry travel activities (e.g. roving workers, recreationists) where the element at risk is mobile. Terrain exposure classifications are generally applied as a single overall rating for a defined area or route (e.g. Statham et al., 2006), or as multiple classified zones within a defined area or along a particular route (e.g. Campbell and Gould, 2014) (Fig. 5).

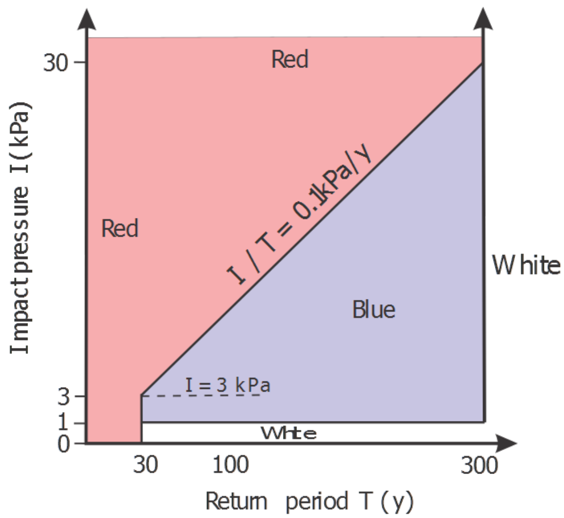

Fig. 3: Hazard zones for occupied structures in Canada (CAA, 2016).

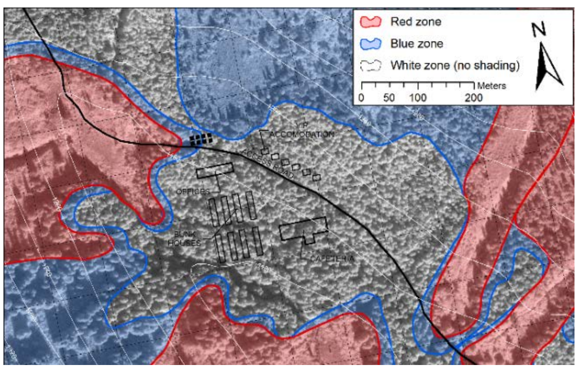

Fig. 4: Example hazard map for occupied structures. This map shows colour-coded zones classified according to an impact-based classification system such as the system for occupied structures (Fig. 3) (CAA, 2016).

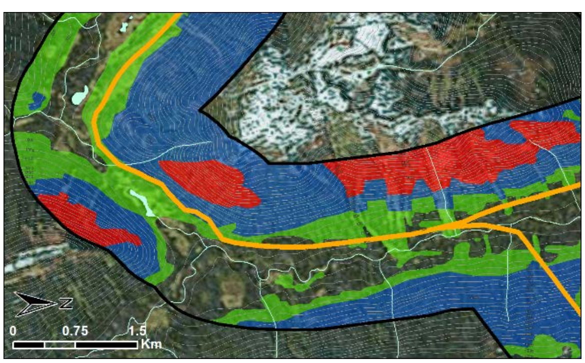

Fig. 5: Example of ATES zone mapping (Tbl. 2) for an energy corridor (orange line). ATES classes are indicated by colour as green (Class 1), blue (Class 2), red (Class 3), and no shading within the study area (Class 0) (Campbell and Gould, 2014).

The Avalanche Terrain Exposure Scale (ATES) (Statham et al., 2006) is one example that includes three models: technical, communication (Tbl. 2) and zoning. Independent analysis of specified terrain parameters leads to terrain classification through default or weighted thresholds, which can involve expert judgement (Campbell and Gould, 2014). This is a terrain exposure classification system that is often used as an input to a risk matrix for procedure and policy based risk controls (Section 7.2).

Tbl. 2: Communication model for the Avalanche Terrain Exposure Scale (ATES) (after Statham et al., 2006; and Campbell and Gould, 2014).

Class	*Description*
0	Non-avalanche terrain.
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.
2	Exposure to well defined avalanche paths, starting zones or terrain traps; options exist to reduce or eliminate exposure with careful route finding.
3	Exposure to multiple overlapping avalanche paths or large expanses of steep, open terrain; multiple avalanche starting zones and terrain traps below; minimal options to reduce exposure.

5. HAZARD, RISK AND TERRAIN CLASS MAPS

Hazard, risk and terrain class maps are a detailed representation of avalanche hazard, risk or terrain class often used for risk control based on procedure and policy, planning transportation corridors and pedestrian areas, as well as hazard zoning for occupied structures. Figs. 4 and 5 show example maps for impact and terrain exposure based classification respectively.

Maps typically display hazard, risk or terrain class in one of two formats:

- Linear (e.g. for a transportation corridor, transmission line or ski run).
- Polygonal (e.g. for occupied structures or a backcountry recreation area).

6. MITIGATION MEASURES

Avalanche risk mitigation, also referred to as "avalanche protection" or "risk control", may involve single or multiple layers of systems or techniques to reduce or eliminate avalanche risk. Often an integrated approach to mitigation is used and is incorporated at various stages and scales. For example, the avalanche risk to roads is reduced by:

1. Location planning (e.g. reducing the length of a road exposed to avalanches during the design phase).
2. Static defenses (e.g. snow sheds, diversion dikes and retarding mounds).
3. Warning signs to reduce the number of vehicles stopping in avalanche paths.
4. Short-term measures (e.g. forecasting, road closures and artificial triggering) to reduce the likelihood of avalanches reaching open roads.

As another example, avalanche risk to a ski lift could be reduced by:

1. Locating the towers and terminal stations where avalanche frequency and/or impact pressures are low.
2. Reinforcing the lift towers to withstand expected impact pressures.
3. Compaction of the snowpack and artificial triggering of avalanches on the slopes above the exposed towers.

CAA (2016) categorizes measures according to the strategy for intervening with the avalanche process (direct versus indirect) and the duration in which the intervention occurs (short term versus long term). *Direct* intervention strategies act on the avalanche hazard, whereas *indirect* intervention strategies adjust the exposure and vulnerability of the element at risk. *Long term* is considered effective over periods of several years, while *short term* is effective for hours to a winter season, depending on the context. Long-term measures are specified during the planning stage, while short-term measures are applied during the operational stage (and typically outlined during the planning stage). Tbl. 3 lists example mitigation measures by strategy (direct vs. indirect) and duration (short vs. long term).

Tbl. 3: Avalanche mitigation measures categorized by the strategy for intervening with the avalanche process (direct vs. indirect) and duration in which the intervention occurs (long term vs. short term). Many short term mitigation measures require avalanche forecasting to be effective.

	Short term	*Long term*
Indirect	• Precautionary evacuation. • Restricted access. • Backcountry trip planning. • Backcountry route finding. • Backcountry group management. • Avalanche safety equipment. • Risk communication.	• Location planning. • Zoning (e.g. Section 7.1). • Reinforcement and design of structures.
Direct	• Artificial triggering. • Snowpack compaction.	• Snowpack support structures. • Protection forest. • Tunnels. • Snow sheds. • Retarding mounds, breakers or arresters. • Reinforced concrete walls. • Diversion dikes or berms. • Catchment basins and benches. • Splitting wedges. • Catching nets.

6.1 Example: Terrain Coding

A common strategy for operational risk evaluation and mitigation relies on detailed terrain identification (Section 3), classification (Section 4) and mapping maintained as an inventory of ski runs and/or operational zones. This list is used as a reference point to systematically evaluate risk on a run-by-run (or zone-by-zone) basis, and then track and communicate the status of each run for purposes of trip planning and access restriction. Typically accomplished by a team of avalanche forecasters or guides before going into the field, terrain coding follows a specific analysis of avalanche risk considering forecasted avalanche hazard and exposure points in the terrain.

Each run or zone is subsequently coded as either open (green) if the risk is acceptable, or closed (red) if it isn't (Fig. 6). If there are identified knowledge gaps, some operations will conditionally open a run or zone pending a set of prescribed conditions, typically illustrated with yellow coding. For example, a run can be conditionally open if the large cornice above the landing in absent. If the cornice is in fact determined to be absent after field investigations then the run can be opened after discussions with the avalanche forecaster, but if the cornice continues to threaten the landing zone then the run must remain closed.

Run list: Friday 2015/03/13

Crystalline Drainage

Crystalline Glacier (green)	Sun Light (green)
Crystalline High Right (green)	Sundance (green)
Crystalline Low Right (green)	Thierry's (green)
Crystalline Boulder (green)	Vertigo[3] (yellow)
Crystalline High Left[1] (yellow)	White Out (green)
Tequila Sunrise[2] (yellow)	Billy Goat (red)
Crystalline Low Left (green)	Kid Goat (red)
Crystalline Moraine (green)	Noble Chute (green)
Tetragon (green)	Blue Rudi (green)
Tetragon Low (green)	Rudi's Revenge[4] (yellow)
Twilight (green)	Hoya Hoya (green)
Twilight Shoulder (green)	Up Yours (green)

(green)	**Green run** – open for guiding by consensus decision
(yellow)	**Yellow run** – potentially open for guiding using a set of conditions that must be recorded in footnote and then met with consensus in the field
(red)	**Red run** – closed for guiding, consensus not required.

Fig. 6: An example of a run list for a helicopter skiing operation (courtesy of Canadian Mountain Holidays).

7. AVALANCHE TERRAIN LAND-USE GUIDELINES

CAA (2016) provides thresholds for avalanche size and/or impact pressure and return periods to initiate avalanche planning for most activities and corresponding elements at risk in avalanche terrain. It also provides guidance for typical hazard/risk assessments for new developments or activities, and for mitigation strategies during both the planning and operational stages of avalanche risk management.

7.1 Example: Occupied Structures

Typical thresholds specified for occupied structures in municipal, residential, commercial and industrial areas include impact pressures of ≥ 1 kPa with a return period of ≤ 300 years. If an initial hazard assessment determines that avalanches with impact pressures ≥ 1 kPa have the potential to affect the area proposed for development once every 300 years or more frequently, then a risk assessment must be undertaken and mitigation considered.

During the planning stage, a risk assessment should be carried out at the avalanche path-scale for an exposure time scale of decades. The level of effort for avalanche terrain identification should be TSLE: A (Tbl. 1), and include numerical runout modelling and frequency-magnitude analysis. Impact-based classification (Fig. 3) should be displayed on a hazard zone map (Fig. 4) and used for zoning according to the following recommendations:

- White zone (low hazard) – Construction of occupied structures is normally permitted.
- Red zone (high hazard) – Construction of occupied structures should not be permitted.
- Blue zone (moderate hazard) – Construction of occupied structures may be permitted with specified conditions.

Considerations for development of occupied structures in a blue zone include:

- Number of occupants.
- Timing of occupancy.
- Whether the structure is a place of refuge during a storm.
- Whether the occupants are aware of, and accept the risk associated with avalanches.
- Whether the structure is critical infrastructure for essential and/or emergency services.
- Whether access can be effectively restricted to allow for occupancy only during periods deemed to be safe as determined by a qualified person.
- Whether an effective precautionary evacuation plan can be implemented that can quickly evacuate the entire structure during high hazard periods.

Conditions that may be specified for the development of occupied structures in a blue zone include: structures reinforced to withstand avalanche impact; structures protected by long-term runout zone mitigation measures (e.g. diversion dikes or catchment basins); restricted access and evacuation plans; or a combination of these.

Sufficient mitigation for occupied structures in municipal, residential, commercial and industrial areas is typically achieved at the planning stage. Otherwise, operational risk management with short-term mitigation measures (e.g. avalanche forecasting; precautionary evacuation; temporary curfew and restricted access) are used to reduce the residual risk to an acceptable level.

7.2 *Example: Backcountry Travel for Non-avalanche Workers*

Typical thresholds specified for non-avalanche related roving backcountry work (e.g. exploration and survey crews) include avalanches large enough to harm a person with an expected return period of 30 years or less. If there is any concern for worker avalanche safety, then a planning risk assessment should be conducted. "If [the] avalanche risk assessment indicates that a person working at the workplace will be exposed to a risk associated with an avalanche, a written avalanche safety plan is developed and implemented" (WSBC, 2014).

Avalanche safety plans for backcountry travel will typically include operational risk management techniques such as policy for avalanche safety equipment and training and procedure for safe travel, including pre-trip planning. Fig. 7 is an example backcountry fieldtrip planning matrix that outlines daily requirements to field workers. The matrix combines the operational avalanche hazard rating with the terrain exposure class (Section 4.2) of the intended field site, and work requirements for field crews.

Hazard Rating	Backcountry Travel Work Requirements		
5	Work plan approval	On-site guidance	On-site guidance
4	Work plan approval	On-site guidance	On-site guidance
3	Safety equipment Rescue training	Work plan approval	On-site guidance
2	Safety equipment Rescue training	Work plan approval	On-site guidance
1	Safety equipment Rescue training	Safety equipment Rescue training	Work plan approval
	Class 1	Class 2	Class 3
	Terrain Exposure Class		

Fig. 7: Example of backcountry field trip planning matrix for non-avalanche workers. Operational avalanche hazard ratings, approval, guidance and training must come from a qualified person.

8. LAND MANAGERS GUIDE

Management of avalanche risk also depends on human competency, the regulatory environment and societal tolerance of risks. A forthcoming companion document: *A Land Managers Guide to Law, Ethics and Human Resources for Addressing Snow Avalanche Risk in Canada* (CAA, in prep), will assist land managers and risk owners working with avalanche professionals. It is intended to help decision makers, including those who are legally accountable for avalanche-associated risks, understand their responsibilities and how to carry them out. In particular:

- Social context and the non-regulatory environment, including societal risk tolerances, corporate responsibility, communications and ethics and accountability.
- Avalanche-specific regulations, as well as general application regulations and non-regulatory policy that apply to avalanche risk management.
- Professional regulation and best practice in human resources, including competency profiles, scope of practice and training programs.

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