The Canadian Avalanche Association's New Guidelines for Managing Snow Avalanche Risk

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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.

RÉSUMÉ

Reconnaissant la nécessité de normaliser les nouvelles pratiques innovantes canadiennes de gestion de risque d'avalanche et de répondre à la demande croissante des organismes avec une fonction régulatrice, la Canadian Avalanche Association a récemment lancé un projet de deux ans pour réviser et mettre à jour ses lignes directrices sur les pratiques exemplaires pour la gestion des risques d'avalanche. Ce document présente les points saillants et des exemples pratiques de la première de deux nouvelles publications qui couvre les aspects techniques de la gestion des risques d'avalanche . La pièce maîtresse de cette publication sont des lignes directrices pour la planification et la gestion du risque opérationnel pour les activités terrain d'utilisation des terres avalanche commune au Canada.

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 intended to inform practice from frontline work to advanced avalanche program design. The content follows a framework for both planning and operations based on, the ISO 31000 process (CSA, 2010). It is a 125 page, comprehensive avalanche risk management resource that 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

The avalanche risk management process (Figure 1) has a sequence of steps for planning (with a typical time extent of weeks or longer) and a similar sequence for operations (with a typical time extent of hours to days). Each stage consists of establishing the context, risk assessment then risk treatment (mitigation). For operational risk management (but not planning), the final step of risk assessment is avalanche forecasting. On the sides of the flowchart in the middle of Figure 1 are boxes for Monitoring and Review as well as for Communication and Consultation, which apply to all stages of the risk management process.

The process applies to hazard management as well as risk management. Avalanche hazard is defined in terms of the likelihood of avalanche release and avalanche magnitude (CAA, 2016). Avalanche risk includes the components of avalanche hazard as well as the exposure in space and time of elements at risk and their vulnerability.

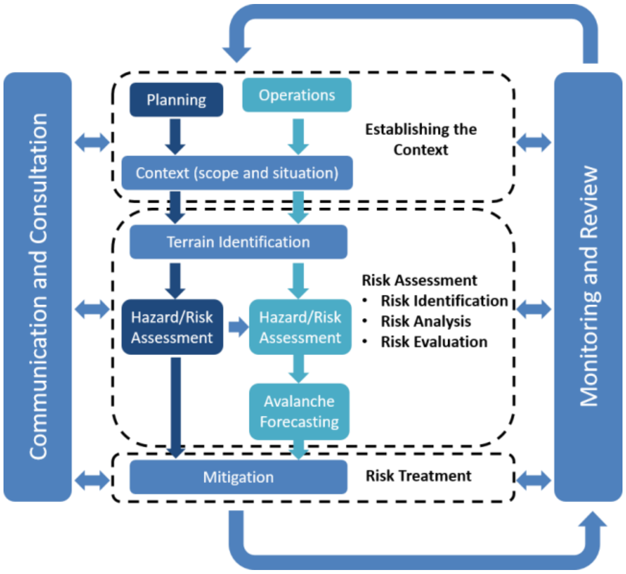

Figure 1. The avalanche risk management process. The center of the diagram illustrates the parallel paths that focus on either planning or operational activities and identifies how this structure aligns under the ISO 31000 umbrella (CSA, 2010).

2.1 Planning

Avalanche planning involves the study of avalanche hazard, risk, and/or mitigation for specific objectives. This is separate from avalanche operations in that the focus of the specific objectives is long term (possibly permanent), and result in maps, plans and reports. Some planning projects include engineering such as the design of static defences.

2.2 Operations

Avalanche operations refers to activities that include avalanche forecasting tasks and the direction and implementation of short-term mitigation measures in order to achieve specific organizational objectives. After establishing the context, the key stages in the risk assessment are identifying terrain, assessing the current hazard or risk, forecasting the hazard or risk for future hours or days, and mitigating the hazard or risk if required. Because of time constraints, operational assessments are usually qualitative, often relying on judgement (Vick, 2002). This process is applied in diverse types of operations such as preparing avalanche regional scale warnings for backcountry recreationists, ski guiding, avalanche programs for lift-based and backcountry ski programs, roads, work sites, etc. The risk treatments are different for different types of programs and include closures, stabilizing snow slopes with explosives, and selecting low risk routes.

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 - not reduced – in assessments. 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 or refining the models used to combine the relevant factors. 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,
3. include natural variability and residual epistemic uncertainty in assessments, and
4. communicating 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, Figure 2 shows the uncertainty in avalanche likelihood and magnitude (size) for two scenarios: a wind slab avalanche and a deep slab avalanche.

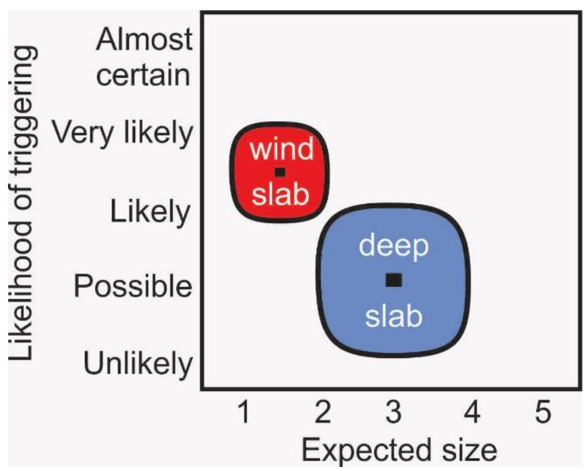

Figure 2. For a given forecast area, day, and character of avalanche, this avalanche hazard chart displays the qualitative uncertainly and variability in expected avalanche size (1 to 2 for wind slabs and 2 to 4 for deep slabs) and in the likelihood of triggering (likely to very likely for wind slabs and unlikely to likely for deep slabs) (CAA, 2016) (after Statham et al., in prep.).

In planning, uncertainty is sometimes quantified and sometimes not. Confidence intervals as shown in Figure 3 are one way of quantifying uncertainty.

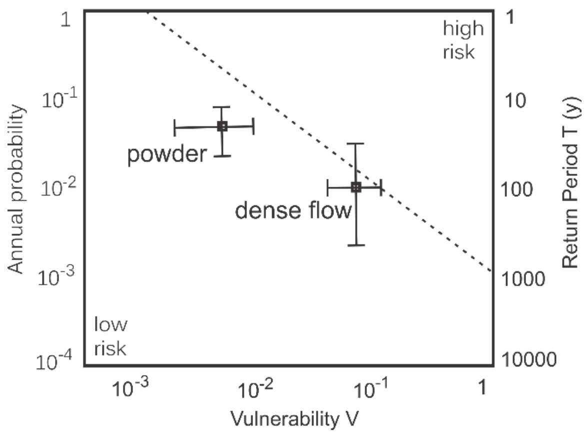

Figure 3. This example risk graph shows the quantitative uncertainty in annual probability and vulnerability as whiskers (confidence intervals) for two hypothetical scenarios: a dense flow avalanche and a powder avalanche that threaten a ski lift tower. The dense flow scenario has lower probability of impact and greater vulnerability, whereas the powder avalanche scenario has higher probability and lower vulnerability. Since diagonal lines such as the dashed line represent a constant level of risk (product of probability of impact and vulnerability), the dense flow scenario - especially considering its uncertainty - constitutes higher risk to the tower (CAA, 2016).

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 in regards to risk mitigation. These aids can be used to encapsulate advanced avalanche knowledge or operational risk management expertise and make it broadly accessible.

There are many types of assessment and decision aids described in Chapter 7 of CAA (2016), including risk matrices, assessment tables, checklist sums, snowpack evolution models, and decision trees. Conlan and Jamieson's (2015) checklist sum for forecasting deep slab avalanches is an example. As inputs, it includes four questions about the snowpack, six about the weather and one about previous avalanches in the area. Depending on the weighted sum of yes answers, the tool indicates deep slab avalanches are unlikely, possible or likely in the forecast area.

These decision aids can help reduce uncertainty. If the decision aid and expert decision give results, e.g. risk, both of which are in the acceptable range, uncertainty is reduced. If one gives a result in the acceptable range and the other gives a result in the unacceptable range, then the decision-maker can mitigate according to the result in the unacceptable range, or gather additional targeted information and re-assess, which usually reduces uncertainty.

3 TERRAIN IDENTIFICATION

Understanding and communicating the subject of avalanche terrain are important components in both the planning and operational stages of avalanche risk management. Avalanche terrain identification involves the analysis of topography, vegetation and surficial materials, 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.

The method(s) used and level of effort put into avalanche terrain identification depend upon the context (i.e. stage, scope and situation) and the resulting level of detail required. 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.

Ground-based survey of avalanche terrain for planning purposes is often completed when the ground is snow-free in the summer or fall, which allows for detailed investigation of vegetation and surficial materials in the runout zone (required for estimating return periods to various locations), and eliminates the concern for avalanche risk that may be present during winter or spring field study. But ground surveys can also occur during winter operations on days when avalanche risk is low. Slope angle and shape, ground cover, clues from dendrochronology, and measured dimensions of the avalanche terrain are typical recorded parameters. Although summer and fall field visits are preferred, observations of paths on snow-covered ground aids in understanding the snowpack distribution across the terrain in study. In addition, late winter or spring observations, after large avalanches have occurred, help to visualize patterns of avalanche flow.

Aerial views allow expert observers to quickly interpret terrain from several angles. Often patterns and clues emerge from aerial reconnaissance that otherwise would not be evident from a ground-based survey. Helicopters are often the preferred aircraft for aerial reconnaissance, due to their ability to fly slow and hover; airplanes may also be used as a lower-cost alternative. Although not considered a replacement for aerial reconnaissance from aircraft, drones are increasingly being used to supplement ground observations, especially during the planning stage. Aircraft are sometimes used to provide point clouds for LiDAR and photogrammetric models.

3.1 Level of Effort

The level of effort put into an avalanche hazard/risk assessment, and the corresponding extent of investigation required, depends on the objectives and 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 (Table 1) (after BCMoFLNRO, 1999). The four-level TSLE scale represents the extent of field surveying from A (most field surveys) to D (least field surveys) recommended for adequate avalanche terrain identification at the preferred map scale.

Table 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	Typical assessment scale	% of avalanche terrain field-surveyed	Method of surveying	Rate of field progress per day (ha)
A	1:1,000 to 1:10,000	Terrain feature- to slope-scale	50 – 100	Ground surveys by foot traverses.	20 – 100
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
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.	1,500 – 5,000
D	1:20,000 to 1:50,000	Path- to mountain-scale	0	No field surveys. Desktop investigations only.	n/a

4 TERRAIN CLASSIFICATION

Terrain classification systems are intended to categorize avalanche terrain into areas with common attributes. These attributes 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) (Table 2) or they can include some elements of avalanche hazard (e.g. frequency-magnitude relationships) (Figure 4). The two main types of classification systems used in Canada include impact-based classification and terrain exposure classification.

4.1 Impact Based Classification and Mapping

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 Figure 4. 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 (Figure 5) with associated zoning recommendations for development of occupied structures (Section 6.1).

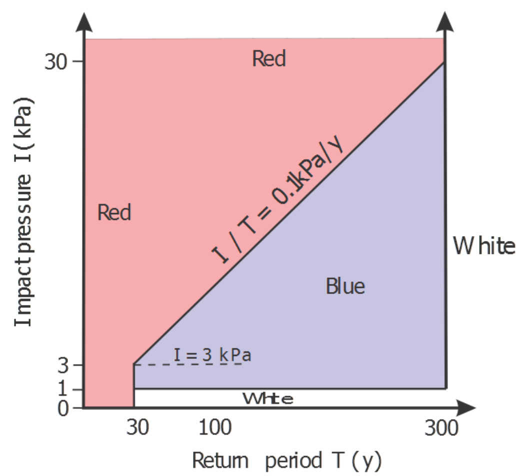

Figure 4. Hazard zones for occupied structures in Canada (CAA, 2016).

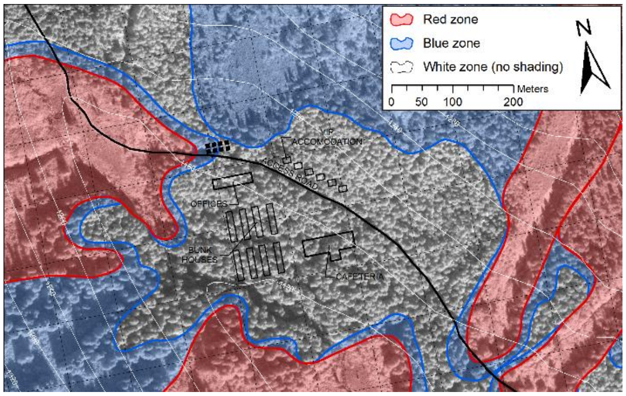

Figure 5: Example hazard map for occupied structures. This map shows colour-coded zones classified according to an impact-based classification system such as the system for occupied structures (Figure 4) (CAA, 2016).

4.2 Terrain Exposure Classification and Mapping

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 or recreationists) where the element at risk (e.g. a person) 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) (Figure 6).

The Avalanche Terrain Exposure Scale (ATES) (Statham et al., 2006) is one example that includes three models: technical, communication (Table 2) and zoning. Independent analysis of specified terrain parameters leads to terrain classification through default or weighted thresholds, which can be subjective (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 6.2).

Table 2. Communication Model for the Avalanche Terrain Exposure Scale (ATES) (Statham et al., 2006).

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.

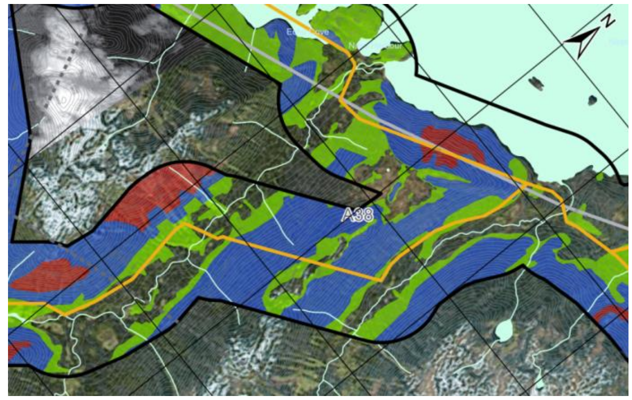

Figure 6. Example of ATES zone mapping (Campbell and Gould, 2014) for an energy corridor (orange line). ATES classes are indicated by colour as green (Class 1), blue (Class 2), red (Class 3), and no shading within the study area (Class 0) (Campbell and Gould, 2014).

5 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) (after Wilhelm et al., 2000; and Schweizer, 2004). *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 the period 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). Table 3 list example mitigation measures by strategy (direct vs. indirect) and duration (short term vs. long term).

Table 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 (e.g. warning signs).	• Location planning. • Zoning (e.g. Section 6.1). • Reinforcement and design of structures.
Direct	• Artificial triggering (e.g. Figure 7). • Snowpack compaction (e.g. from skiers).	• Snowpack support structures (e.g. Figure 8). • Protection forest. • Tunnels. • Snow sheds (Figure 9). • Retarding mounds (Figure 10), breakers or arresters. • Reinforced concrete walls. • Diversion dikes or berms. • Catchment basins and benches. • Splitting wedges (Figure 11). • Catching nets.

Figure 7. Example of helicopter explosive control. M. Boissonneault photo.

Figure 8. Example of supporting structures in the starting zones of avalanche paths in the European Alps. B. Gould photo.

Figure 9. Example of a snow shed located along the Coquihalla Highway (Hwy 5) east of Hope, BC. BC MoTI photo.

Figure 10. Example of retarding mounds in the runout zones of avalanche paths in the Rohr Ridge area, located on the Duffey Lake Road (Hwy 99) east of Pemberton, BC. B. Gould photo.

Figure 11. Example of a splitting wedge protecting two lattice transmission line structures in runout zones of avalanche paths. BC MoTI photo.

6 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.

6.1 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. This means that 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 (Table 1), and include numerical runout modelling and frequency-magnitude analysis. Impact-based classification (Figure 5) should be displayed on a hazard zone map (Figure 6) 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 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.

6.2 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. Figure 12 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		

Figure 12. 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.

7 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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