# Modern Snow Avalanche Terrain Mapping for Industrial Projects

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ABSTRACT
Snow avalanche hazard mapping is a normal part of the avalanche risk assessment and mitigation process for industrial projects. In Canada, guidelines for avalanche hazard mapping were formally established just over a decade ago (CAA, 2002); primary mapping types include locator, atlas, and risk mapping. Although considered useful in the context of fixed elements at risk (e.g. access roads, camps, worksites, and infrastructure), there are drawbacks to incorporating these types of mapping for the exploratory phase of large projects (e.g. pipelines, mining) that typically involve roving fieldwork over vast expanses of uncharted terrain. In the past few years, a new type of mapping - Avalanche Terrain Exposure Scale (ATES) zone mapping (Campbell and Gould, 2012 & 2013) - has emerged as a useful tool to classify and categorize large geographic areas for roving in avalanche terrain. ATES zone mapping provides valuable input into daily fieldwork planning and can also be used as a rough navigation tool by work crews while in field. This paper explores the approach and utility of both established avalanche mapping types, as well as ATES zone mapping in industrial workplace settings with large geographic scope.

RÉSUMÉ
La cartographie des dangers d'avalanche est une norme dans l'évaluation des risques d'avalanche et du processus d'atténuation pour les projets industriels. Au Canada, les lignes directrices pour la cartographie des dangers d'avalanche existent depuis une décennie (CAA, 2002) ; les types de cartographie primaires comprennent localisateur, atlas, et la cartographie des risques. Bien que considéré comme utile dans le contexte d'éléments fixes à risque (par exemple, les routes d'accès, les camps, les chantiers et les infrastructures), il y a des inconvénients à l'intégration de ces types de cartographie pour la phase exploratoire de grands projets (par exemple, les pipe-lines, les mines) qui impliquent les itinérants sur le terrain sur de vastes étendues de terrain inconnu. Au cours des dernières années, un nouveau type de cartographie -la cartographie de la zone Avalanche Terrain Exposure Scale (ATES) (Campbell et Gould, 2012 & 2013) - a émergé comme un outil indispensable pour classifier et catégoriser les immenses zones géographiques pour itinérants en terrain avalancheux. La cartographie des zones ATES contribue énormément à la planification quotidienne de travail sur le terrain et peut également être utilisé comme un outil de navigation rugueux par les équipes de travail dans les territoires avalancheux. Ce document examine l'approche et l'utilité de ces deux types de cartographie d'avalanche, ainsi que la cartographie ATES des zones industrielles dans les milieux de travail avec une grande portée géographique.

## 1 BACKGROUND

Snow avalanches occur in large numbers every winter in many provinces and territories in Canada. Although considered a mountain slope hazard, dangerous avalanches are not restricted to the mountains; they can occur anywhere where there is a combination of deep snow and steep terrain, regardless of the proximity to the mountains or remoteness of the site (Figure 1). As a result, avalanche risks must be considered for any industrial project that involves locating workers or infrastructure where the combination of deep snow and steep terrain exists. And as with any slope hazard, mapping is one of the primary tools used to assess and mitigate avalanche risk.

Figure 1. An avalanche fracture line from a recent avalanche on a slope adjacent to the airport runway in Whitehorse, YT. This slope is also just above the Whitehorse downtown core (photo: M. Ledwidge).

Avalanche mapping can be traced as far back as the late 19th century in the European Alps (Frutiger, 1980), although more modern hazard maps really began to emerge during the post WW II era. Historical mapping techniques mainly involved reviewing and analyzing the extent of historical events that affected areas in and around villages located in mountain valleys. An understanding of where avalanches have flowed previously provides a strong basis for determining where avalanches may flow in the future. In Canada, modern avalanche mapping uses information from historical avalanche occurrences when possible. However, the vast majority of industrial projects do not occur where previous knowledge of avalanche occurrences exists. As a result, mapping in Canada must involve analysis of imagery, topography, dendrochronology, and potentially numerical and digital terrain modelling guided by experience and professional judgment. Mapping resolution and detail may vary considerably, and must take into account the intended purpose. Since elements at risk for industrial projects may include everything from buildings and infrastructure to roads to workers roving in remote locations, often more than one type of mapping is desirable.

This paper describes types of mapping currently used extensively for avalanche risk planning and mitigation for industrial projects in Canada. Although conventional mapping types are described in detail in CAA (2002), and CAA (2011), a new type of mapping (ATES zoning) has emerged as a useful type for limited exposure (of short duration) to expansive areas associated with some industrial projects.

## 2 LOCATOR MAPPING

Locator mapping is typically used early in the planning phase for industrial projects to identify potential hazard locations along access routes. This type of mapping is also useful for identifying avalanche paths affecting project right-of-ways or fixed facility locations in order to prioritize for further study. Avalanche paths on locator maps are identified by an arrow indicating location and flow direction with approximate downslope extent (Figure 2). Typically locator maps are presented at a scale of 1:20,000 to 1:50,000. Using freely available imagery and digital elevation information, locator mapping of all paths with potential to produce avalanches larger than Size 2 (McClung and Schaerer, 2006), which is sufficiently large to bury, injure or kill a person, is often completed as a desktop exercise with field checking normally only required in locations detailed imagery is not available.

Although useful for providing baseline information as to where avalanche hazards exist, locator mapping does not provide aerial extent (width and length) of the hazard, nor sufficient detail for locating facilities in and around the path. In addition, since locator mapping generally excludes small avalanche paths (≤ Size 2 potential) and short avalanche slopes involving terrain traps (i.e. terrain features that increase the consequences of being caught in an avalanche, such as cliffs and ravines), it does not provide sufficient information for roving field for which these more subtle terrain features can pose a risk.

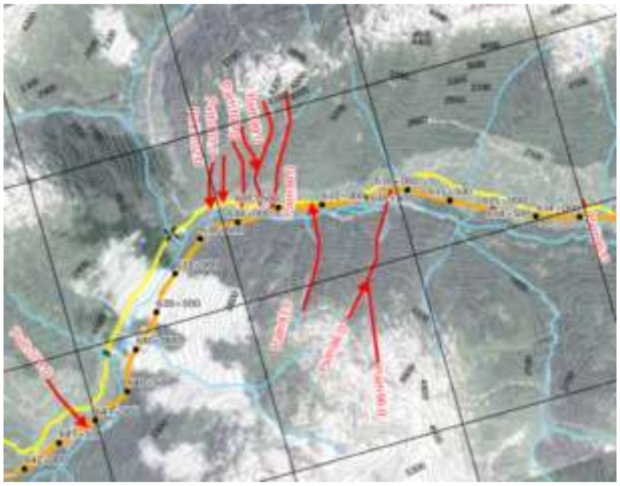

Figure 2. Example of locator mapping for combined energy corridor and access roads

## 3 ATLAS MAPPING

Also commonly referred to as 'avalanche path mapping', avalanche atlas mapping is polygon based mapping of avalanche paths that illustrates the approximate aerial extent of all avalanche paths affecting a study area. Paths may be illustrated along a linear corridor, but they may also be illustrated in and around a project site where fixed facilities such as construction camps or project infrastructure is planned (Figure 3). If used in the context of a complete avalanche atlas (e.g. for an access road avalanche control program), oblique photographs, and a data sheet with path attribute information may accompany the mapping, and include further details on terrain, magnitude-frequency relationships, and exposure.

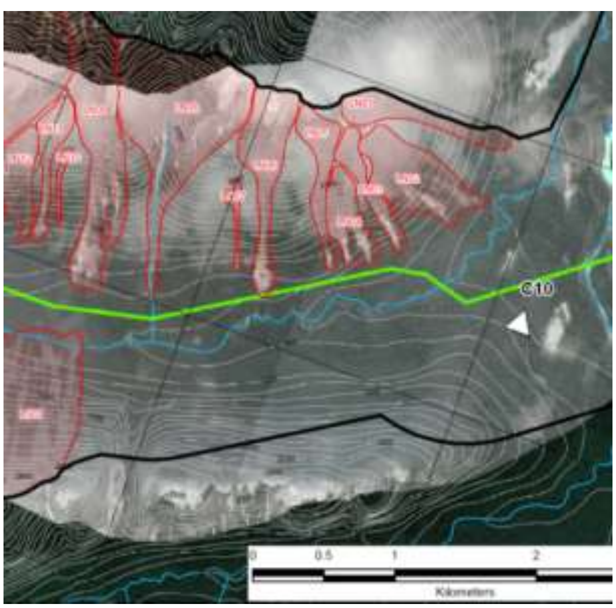


Figure 3. Example of avalanche atlas mapping for an energy corridor.

For areas where detailed imagery exists, atlas mapping can often be completed with sufficient resolution for preliminary site planning with 1:20,000 to 1:50,000 scale mapping. Field checking is normally completed before mapping is finalized. As with locator mapping, small avalanche paths (≤ Size 2 potential) are not always indicated due to the scale of the mapping. Furthermore, small slopes that normally would only have the potential to produce relatively harmless avalanches, but involve terrain traps, are not always mapped at this scale.

If greater accuracy is desired, detailed field surveys including vegetation analysis and slope profiling are often used in conjunction with numerical avalanche modelling. With this added analysis, mapped avalanche paths may incorporate risk zones (Figure 4) in order to locate building and structures according to zoning recommendations described in CAA (2002). Typically risk zone maps, and atlas maps for other applications requiring greater accuracy, will be displayed at 1:5000 or 1:10,000 scale.

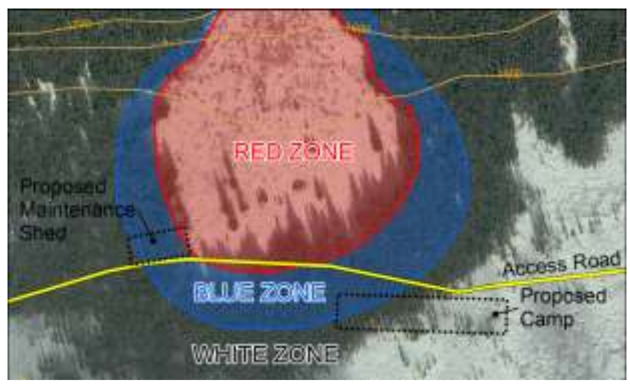


Figure 4. Example of more detailed risk zone map for a construction camp.

## 4 AVALANCHE TERRAIN EXPOSURE SCALE (ATES) ZONE MAPPING

Although locator and atlas mapping is often adequate for preliminary planning of project sites and access roads, unless detailed field checking is completed (at potentially significant time and effort) their application for providing terrain and hazard guidance for roving backcountry field work is limited. These limitations have recently been overcome with the development of ATES zone mapping (Campbell and Gould, 2013). This new type of mapping is useful for indicating the seriousness of avalanche terrain for roving field workers who are generally not limited to a fixed location or particular access route for their work.

Terrain within a predetermined study area is zoned according to a four-class scale. A general description of the four classes and typical colour scheme is provided in Table 1. The model for delineating ATES zones is outlined in Table 2. The parameters in Table 2 are listed generally in order of importance, with the intent of placing more emphasis on the top two or three parameters. The parameter thresholds are intended to be used as general guidelines to inform expert judgement in zoning avalanche exposure to people. There may be exceptions where zones don't explicitly meet all parameter thresholds for the class at which they're zoned.

Table 1. *ATES zone class general description (based on Statham et al. (2006) and Campbell & Gould (2013)).*

| Class | Terrain and Exposure Criteria |
|---|---|
| 0 | Non-avalanche terrain (optional) |
| 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 |

Zoning with this model usually begins with GIS analysis followed by detailed field surveys. However, terrain can often be reliably zoned using a combination of these and other resources, such as topographic maps, air photos, and intimate knowledge of the terrain. Zones should be delineated in such a way that uses the lowest class possible (except Class 0, which is optional) at a scale of 100 – 1000 m. Detailed methods for preliminary zoning and field surveys are described in Campbell et al. (2012). An example map is provided in Figure 5.

Since ATES zone mapping uses an exposure scale developed for travelling in avalanche terrain, it is not intended to provide an accurate extent of avalanche hazard. There are areas (islands of safety) in all four classes that are not exposed to avalanches, and are 100% safe. However, these 'islands of safety' in Class 3 terrain would be much smaller and exposure much less frequent than those in Class 1 terrain. Class 0 is considered to be essentially 100% free of avalanche exposure.

Figure 5. Example of ATES zone mapping for an energy corridor. ATES classes are indicated by colour as green (1), blue (2), red (3), and none (0).

The primary advantage to ATES zone mapping is that it provides a simple and easily understood terrain scale that can be incorporated in a rule-based operational safety system. Figure 6 illustrates an example fieldtrip planning matrix that can provide daily risk guidance to field workers. The table takes into account the ATES class, the daily danger level (Statham et al., 2010) and whether crews have avalanche safety training.

| Regional Hazard/Danger Rating | | ACTION | | |
|---|---|---|---|---|
| 5 | Extreme | AVALANCHE TECHNICIAN APPROVAL REQUIRED | ON-SITE GUIDANCE REQUIRED | ON-SITE GUIDANCE REQUIRED |
| 4 | High | AVALANCHE TECHNICIAN APPROVAL REQUIRED | ON-SITE GUIDANCE REQUIRED | ON-SITE GUIDANCE REQUIRED |
| 3 | Considerable | NO RESTRICTIONS IF TRAINED | AVALANCHE TECHNICIAN APPROVAL REQUIRED | ON-SITE GUIDANCE REQUIRED |
| 2 | Moderate | NO RESTRICTIONS IF TRAINED | AVALANCHE TECHNICIAN APPROVAL REQUIRED | ON-SITE GUIDANCE REQUIRED |
| 1 | Low | NO RESTRICTIONS IF TRAINED | NO RESTRICTIONS IF TRAINED | AVALANCHE TECHNICIAN APPROVAL REQUIRED |
| ATES Class | | Class 1 | Class 2 | Class 3 |

Figure 6. Example of risk planning matrix for daily field work in avalanche terrain

Table 2. Model for zoning with the Avalanche Terrain Exposure Scale (Campbell & Gould, 2013).

<table>
<tr><th colspan="2"></th><th>Class 0 (optional)</th><th>Class 1</th><th>Class 2</th><th>Class 3</th></tr>
<tr><td rowspan="3">Slope Incline[1] and Forest Density[2]</td><td>Open</td><td>99% ≤ 20°</td><td>90% ≤ 20°<br>99% ≤ 25°</td><td>90% ≤ 30°<br>99% ≤ 40°</td><td rowspan="3">< 20% ≤ 25°<br>45% > 35°</td></tr>
<tr><td>Mixed</td><td>99% ≤ 25°</td><td>90% ≤ 25°<br>99% ≤ 35°</td><td>90% ≤ 35°<br>99% ≤ 45°</td></tr>
<tr><td>Forest</td><td>99% ≤ 30°</td><td>99% ≤ 35°</td><td>99% ≤ 45°</td></tr>
<tr><td colspan="2">Start Zone Density</td><td>No start zones.</td><td>No start zones with ≥ Size 2 potential.<br>Isolated start zones with < Size 2 potential.</td><td>No start zones with > Size 3 potential.<br>Isolated start zones with ≤ Size 3 potential, or<br>Several start zones with ≤ Size 2 potential.</td><td>Numerous start zones of any size, containing several potential release zones.</td></tr>
<tr><td colspan="2">Interaction with Avalanche Paths[3]</td><td>No exposure to avalanche paths.</td><td>Beyond 10-year runout extent for paths with ≥ Size 2 potential.</td><td>Single path or paths with separation.<br>Beyond annual runout extent for paths with > Size 3 potential.</td><td>Numerous and overlapping paths of any size.<br>Any position within path.</td></tr>
<tr><td colspan="2">Terrain Traps[4]</td><td>No potential for partial burial or any injury.</td><td>No potential for complete burial or fatal injury.</td><td>Potential for complete burial but not fatal injury.</td><td>Potential for complete burial and fatal injury.</td></tr>
<tr><td colspan="2">Slope Shape</td><td>Uniform or concave</td><td>Uniform</td><td>Convex</td><td>Convoluted</td></tr>
</table>

[1] Slope inclines are averaged over a fall-line distance of 20 - 30 m.
[2] Open: < 100 stems/ha or > 10.0 m tree spacing on average. Mixed: 100 – 1000 stems/ha or 3.2 – 10.0 m tree spacing on average. Forest: > 1000 stems/ha or < 3.2 m tree spacing on average.
[3] Position within paths based on the runout extent for avalanches with a specified return period.
[4] Terrain traps are features in tracks or runouts that increase the consequences of being caught in an avalanche. Thresholds are based on the potential increased consequences they would add to an otherwise harmless avalanche. For this purpose, terrain traps can be thought of as either trauma-type (e.g., cliffs, trees, boulders, etc.) or burial-type (e.g., depressions, abrupt transitions, open water, gullies, ravines, etc.). Degrees of burial used in this model are based on Canadian standard avalanche involvement definitions (Canadian Avalanche Association, 2009).

## 5 DISCUSSION AND SUMMARY TABLE

Table 3 provides a summary of modern snow avalanche terrain mapping for industrial projects in Canada. All types of mapping presented in this paper are useful for indicating potential hazard to elements at risk at various project stages. Sometimes a combination, or a hybrid, of mapping types may be suitable in specific circumstances. For example, initial mapping for a project may include ATES zone mapping combined with locator mapping for early reconnaissance where roving field workers are accessing a potential project area using remote access roads. As another example, during site planning a hybrid map that indicates high frequency (annual), low frequency (> 100 year) and zero frequency areas may be created for a specific site area that has multiple constraints (e.g. environmental, topographical, geotechnical, etc.) in order to optimize location planning of facilities. Highly vulnerable risk elements can be placed completely outside of all avalanche terrain (zero frequency) while less vulnerable facilities (such as access roads and temporary worksites) can be located within areas of low frequency exposure as much as possible. A forecasting and control program can account for the residual risk that remains from exposure to high and low frequency avalanches.

Although these mapping types are useful in the reconnaissance stages of a large project, once regular project sites and transportation are routes are established (e.g. during construction and operation), atlas mapping (combined with an avalanche atlas) generally supersedes ATES and any hybrid mapping as primary mapping tools for mitigation.

Table 3. Summary of avalanche mapping types for industrial projects

| Type of Mapping | Description | Analysis | Typical Purpose | Stage of Project |
|---|---|---|---|---|
| **Locator Mapping** | Path arrows showing location and flow direction. | Desktop with potential field checking. | Mapping of access routes and planned facilities, especially linear energy corridors. | Early – typically during scoping phase |
| **Atlas Mapping** | Polygon mapping of individual paths showing maximum extent of avalanche paths, May be high resolution for locating buildings or other vulnerable facilities. | Desktop with field checking, Extensive field survey and numerical modelling for high resolution or risk zone mapping. | General location planning of facilities around specific avalanche paths, or for an avalanche atlas. | When greater detail is required for general siting of facilities, or longer term work site safety. |
| **ATES zone Mapping** | Class 0, 1, 2, 3 zones within a predetermined study area. | Desktop with potential field checking. | Roving worker guidance. Generally not for facilities or access routes. | Early, scoping, when roving fieldwork is being completed. |

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