THE AVALANCHE IMPACT SCALE: A QUALITATIVE FRAMEWORK FOR FORECASTING AND RECORDING IMPACTS ON INFRASTRUCTURE, COMMUNITIES AND WORKSITE SAFETY

Bree Stefanson[1]*, and Ryan Boyle[1]

1 BC Ministry of Transportation and Transit, Bear Pass Avalanche Program, Stewart, BC, Canada

ABSTRACT: Effective risk management in avalanche-prone terrain requires a clear understanding of how avalanche activity interacts with specific elements at risk, such as worksites, infrastructure, and defence structures. This presentation introduces the Avalanche Impact Scale (AIS), a qualitative forecasting and recording tool designed to categorize potential and observed impacts on a six-level scale (0–5).

The scale moves beyond traditional hazard ratings by directly linking avalanche impacts on operational outcomes and mitigation requirements. Levels range from Level 0 (No Risk), where activity is below the threshold for impact, to Level 5 (Historically Significant), representing catastrophic events that exceed engineered designs and require large-scale emergency responses like evacuations. Intermediate levels provide specific criteria for exposure controls and the impacts on avalanche defence structures. They also outline the implementation of safety measures such as training, Personal Protective Equipment (PPE), worksite signage, safe locations, closure points, and personnel sweeps.

By utilizing this structured framework, avalanche practitioners can improve the consistency of risk communication, better manage vulnerability and exposure at worksites, and streamline the decision-making process for mitigation strategies. This presentation will detail the operational definitions of each level and discuss the practical application of the scale in protecting industrial and community assets. It is the opinion of the forecasting team in the Bear Pass Avalanche Program (BPAP) that forecasting for expected avalanche activity and recording avalanche occurrences based on this scale closes the forecasting feedback loop. This allows practitioners the ability to compare actual avalanche occurrences observed to their forecast and learn where they were correct or when it is time to reevaluate. Forecasting and recording this way can also help to train artificial intelligence, especially in programs that use automated devices such as avalanche radar detection.

The BPAP has four seasons of forecasting and recording for each avalanche path utilizing the AIS with examples that can be used to showcase practical application of this scale.

KEYWORDS: Forecasting, Recording, Communication, Risk, Management, Standardization

1. INTRODUCTION

For years the Ministry of Transportation and Transit's (MOTT) BPAP has been working to improve their communication in forecasting for natural avalanches, recording avalanche observations, and documenting risk management decisions in relation to static worksites, infrastructure, avalanche defence structures and/or community assets. In speaking with colleagues who work in highways and industrial operations such as mining, it has been determined that using a standardized scale to communicate anticipated avalanche impacts and record avalanche observations relative to the element at risk would benefit Avalanche Professionals, workers, stakeholders, and clients.

* *Corresponding author address:*
Bree Stefanson, Bear Pass Avalanche Program,
Stewart, BC, V0T 1W0;
tel: +1 250-842-8689;
email: bree.stefanson@gmail.com

https://doi.org/10.15788/1790098560

2. LOCATION AND CLIMATE

The BPAP is based in Stewart, British Columbia, Canada (Figure 1). This remote industrial community lies on the Canada-United States border adjacent to Hyder, Alaska, and is situated on the delta formed where the Bear River enters the Pacific Ocean. The area is geographically constrained by the steep terrain of the North Coast Mountains, which rise directly from the head of the Portland Canal and provide a narrow corridor for transportation and development.

Stewart is at sea level and experiences severe winter weather and heavy snowfall from October to April. Proximity to the Pacific Ocean combined with steep coastal terrain causes orographic lifting, which delivers steady maritime precipitation. Between October and April, the area receives an average of 1300 mm of precipitation. This results in peak winter snowpacks averaging 1 to 2 meters at sea level and 3 to 8 meters in the alpine.

Figure 1: Location Map of Stewart

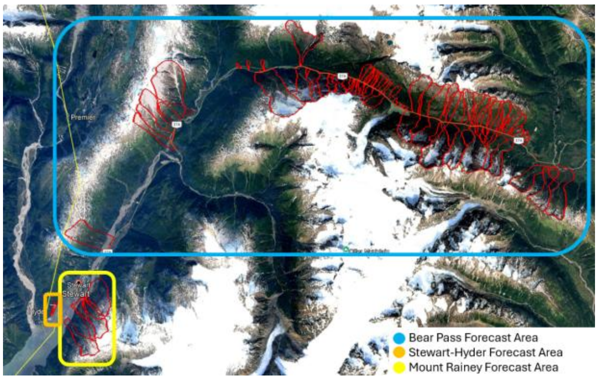

Figure 2: Bear Pass Avalanche Program Map

3. PROGRAM DESCRIPTION

The BPAP is responsible for managing avalanche risk to workers and the travelling public along Highway 37A, a provincial highway. In addition, the program operates under a formal agreement with the District of Stewart to provide avalanche risk assessments and risk management suggestions for an industrial bypass route and the townsite of Stewart. The program encompasses three forecast areas: Bear Pass, Stewart-Hyder, and Mount Rainey (Figure 2). Avalanche-related road closures can isolate the communities of Stewart, BC, Canada, and Hyder, Alaska, USA.

Avalanche paths within the program area vary considerably in scale, ranging from small paths with start zones approximately 200 m above the highway to large paths that can travel up to 4 km ground length before reaching the highway. Many paths contain glaciated terrain, where serac entrainment can significantly increase avalanche volume and deposit mass. Several paths also feature steep, plunging terrain that can cause avalanche debris to become airborne. The resulting powder-clouds can have minimal concerns limited to visibility obstructions or the associated air blasts can be highly destructive, with frontal velocities exceeding 55 m/s.

To aid with avalanche forecasting, the program has eight remote weather stations at various elevations and five automated radar units continuously monitoring 19 avalanche paths. The George Copper radar site was presented at ISSW 2023 (Whalen et al, 2023).

4. PROGRAM CHALLENGE

Due to the complexity and number of avalanche paths within the BPAP, maintaining effective and consistent communication among forecasters remained an ongoing challenge, particularly during prolonged avalanche cycles and periods of scheduled leave.

5. SOLUTION

Instead of listing each path, stating the destructive size class of the avalanche and describing any impact that it had at highway level or to the defence structures, the BPAP team began summarizing avalanche occurrences using the same risk scale it uses to forecast - initially the MOTT's Avalanche Hazard Levels and Specific Operational Procedures (BC MOTT, 2026). This approach proved successful, allowing forecasters to compare forecast avalanche activity directly against observed occurrences. Building on that success, the team saw an opportunity to streamline the language of the MOTT scale and craft a scale that could standardize how all highways and industrial avalanche programs forecast and record the impacts to an element at risk, the AIS. A table with the AIS levels and corresponding safe work procedures can be found at the end of the document (Table 1). Structuring the scale this way links each forecast level directly to the safe work procedures, closures and worker training required under section 4.1.1 of British Columbia's Occupational Health and Safety Regulation (WorkSafeBC, 2015), which obliges employers to document these measures in a written avalanche safety plans. Notably, the AIS is aligned with the six MOTT Avalanche Hazard Levels and corresponding Specific Operational Procedures and is used operationally within this framework.

5.1 <u>The Avalanche Impact Scale</u>

The AIS is a six-level scale which ranges from no risk to a historically significant avalanche cycle. Instead of speaking to the size and likelihood of expected avalanche activity, which is completed in the Avalanche Hazard Assessment, using the conceptual model (Statham, et al, 2018), each level of this scale expresses the potential significance the possible avalanche occurrence(s) may have to the avalanche program, including the maximum expected impact to the static element at risk, and corresponding worksite safety procedures. While avalanche size and termination distances are important metrics, they do not always present a clear picture of the actual impact an avalanche had on the element at risk, especially in cases of dustings and air-blasts. Below are the definitions of each level of the AIS with photo examples.

Avalanche Impact: 0 – Avalanche activity not possible or is insignificant. Area is below threshold to impact worksite(s), infrastructure and/or avalanche defence structure(s). No risk (Figure 3).

Figure 3: Example of Avalanche Impact Scale Level 0

Avalanche Impact: 1 – Avalanche activity insignificant. Area is at threshold. No significant impacts on worksite(s), infrastructure and/or avalanche defence structure(s). Risk mitigated through education, signage and PPE (Figures 4 and 5).

Figures 4 and 5: Examples of Avalanche Impact Scale Level 1

Avalanche Impact: 2 – Avalanche activity with significance in mass reduction. No impacts on worksite(s) or infrastructure other than defence-structure worksites. May impact but not override avalanche defence structure(s). Risk mitigated through education, signage and PPE with exposure control in place for specific defence-structure worksites (Figures 6 and 7).

Figures 6 and 7: Examples of Avalanche Impact Scale Level 2

Avalanche Impact: 3 – Significant avalanche activity with manageable* impacts on worksite(s) or infrastructure. May have minor impacts, including a manageable amount of deposit mass and/or light dusting(s) which create visibility impairment. May impact, fill or override avalanche defence structure(s). Risk can successfully be mitigated to an acceptable level through education, signage and PPE with an elevated level of layered exposure and vulnerability controls at all worksites. Additional personnel and equipment may be required to remove minor avalanche impacts and/or monitor avalanche activity (Figures 8 and 9).

Figures 8 and 9: Examples of Avalanche Impact Scale Level 3

Avalanche Impact: 4 – Significant avalanche activity with major impacts on the worksite(s) or infrastructure that are not safe to manage. Major impacts include critical depth deposit mass and/or violent air-blast(s). Expected to fill and override avalanche defence structure(s). Risk mitigated through exposure controls only, closure and sweep. No work in area of concern, specific work within Avalanche Area under the direction of an Avalanche Professional (Figures 10 to 12).

Figures 10 to 12: Examples of Avalanche Impact Scale Level 4

Avalanche Impact: 5 – Historically significant, catastrophic impacts on the worksite(s) or infrastructure that are not safe to manage. Avalanche impacts may exceed trimlines and/or engineered design of infrastructure. Expected to fill, override, and may damage avalanche defence structure(s). Impacts have a longer timeline to recovery and/or compound, block or back up water courses, isolate communities/workcamps, possible state of emergency. Risk mitigated through exposure controls only, closure and sweep, evacuations, shelter in place (Figures 13 and 14).

Figures 13 and 14: Examples of Avalanche Impact Scale Level 5

* The term “Manageable” will depend on the operational risk band identified within the avalanche program, and mitigation measures available. As the intersection of where each avalanche path meets an element at risk (AES) is unique, mitigations must account for each site’s unique risk profile and how risks can be reduced with exposure and vulnerability controls. A potential AIS Level 3 mitigation plan could include limiting exposure and reducing vulnerability of personnel by requiring them to travel through the area in a moving vehicle (no stopping), positioning traffic control personnel and snow removal equipment to remove manageable amounts of debris as it impacts a highway. These mitigation measures may not work at all sites due to traffic volumes, site complexities, or risk tolerances, but layered with other mitigations and controls it may work to keep worksites functioning inside the identified operational risk band.

5.2 Forecasting

Due to the complexity of this area, the BPAP team created the Path Hazard and Risk Table (PHART) an internal forecasting tool adapted from the Association of Canadian Mountain Guides “Run-List”, (ACMG, 2023). This formal process was designed to document specific risk management decisions throughout each forecast area. This form started as an excel spreadsheet in which the forecaster assigns a value to each path or group of like paths, initially based off of the MOTT’s Avalanche Hazard Levels and Specific Operational Procedures (BC MOTT, 2026). Over the years, the spreadsheet evolved into a geospatial mapping tool with defined polygons representing the anticipated spatial extent of impacts associated with each of the six AIS levels for individual avalanche paths. An early version of the map was presented at ISSW 2018 (Zhecheva, 2018). The current version is built as a Google sheet which syncs to an ESRI map (Figure 15). The map is attached to risk management documentation for forecasters and workers. As of this year, the Canadian Avalanche Association’s (CAA) Information Exchange (InfoEx) can now produce this risk management list and path map through the Run-List Extension (Figure 16). The use of this tool was presented at the CAA’s InfoEx Subscribers Meeting, May 2026.

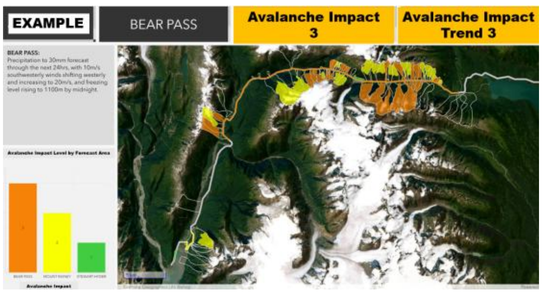

Figure 15: BPAP Risk Management Map Example

Figure 16: BPAP Risk Management Map InfoEx

5.3 Recording

After several years of describing observed avalanche impacts using the AIS and summarizing those impacts within their daily risk assessment, the team began recording the AIS rating for each avalanche observation within the comments field of their operational recording tools four years ago. Over the past two seasons, the BPAP has further advanced this practice by recording both natural and controlled avalanches geospatially within an internal database and mapping platform (Figure 17). An early version of this work was presented at the 2019 CAA Spring Conference (Bishop, 2019). This season the BPAP team was grateful to collaborate with the CAA's InfoEx development team and for the first time, daily forecast AIS ratings and observed AIS ratings (captured in the comment box) can be displayed together geospatially on the InfoEx map. This powerful visualization integrates forecasting and observational data, enabling users to quickly assess forecast performance, identify spatial patterns, and better understand the relationship between expected and observed avalanche impacts (Figure 18).

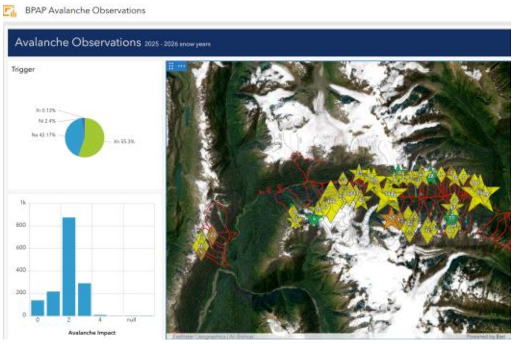

Figure 17: BPAP Avalanche Observation Map

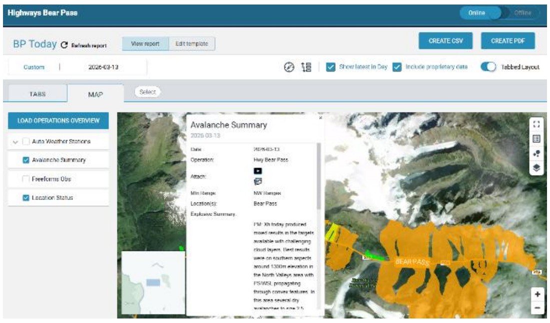

Figure 18: BPAP Forecasting and Observations InfoEx

6. OUTCOME

After four seasons of using this scale to record avalanches as they are forecasted for, the BPAP has streamlined communication within their team. When forecasting and recording avalanches using this scale, forecasters can accurately compare their predictions against actual occurrences and continually reassess, therefore, closing the "feedback loop". The team believes that this has improved the accuracy of their forecasts, their skills as forecasters, their communication to workers, and their reliability to stakeholders.

7. FUTURE WORK

While the AIS has proved to work well within the BPAP, the use of the scale and its wording should be proved by other highway and industrial avalanche programs. The BPAP is working to have a place built to record the AIS level for forecasting and recording avalanche occurrences within, the CAA's InfoEx, the BC MOTT's SAWSx database and the GravX avalanche radar database they use. By building these spaces to forecast and record AIS within avalanche programs daily workflows, it is our hope that operational value is recognized. Eventually the goal is to see a standardized version of the scale and its use included into the Canadian Avalanche Association's Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches (ORGS).

Identify worksites (infrastructure, road, rail, industry, communities) as Avalanche Exposure Sites (AES).

8. CONCLUSION

Based on the successful implementation of the AIS within the BPAP, the team believes this scale would provide significant value to any avalanche program responsible for managing risk to fixed worksite locations and/or static infrastructure. In addition to streamlining internal communication and supporting more consistent forecasting within a program, adopting a standardized scale would improve communication across all programs. Avalanche professionals moving between organizations would only need to learn the unique operational nuances of a program, rather than developing or adapting to new scales. Furthermore, a common scale would provide a shared understanding of the significance and impact of each avalanche occurrence, improve the interpretation of reports and facilitate more effective information exchanges between programs.

Additionally, adding this qualifier to avalanche occurrence observations in programs that use automated avalanche detection systems, such as radar, would provide valuable context for machine learning and artificial intelligence applications. By associating each recorded occurrence with its corresponding level of significance and impact on the element at risk, intelligence applications systems could learn from historical events, leading to improved analytical capabilities, and greater forecasting predictions.

Table 1: A Table Showing the Avalanche Impact Scale and Corresponding Safe Work Procedures

Avalanche Impact Level	Avalanche Activity	Worksite / Infrastructure Impact	Static Defence Structures	Risk Mitigation	Worksite Status
0	Not possible or insignificant.	No impact.	No impact.	No risk. No mitigation required.	Worksite open.
1	Insignificant.	No significant impacts.	No significant impacts.	Risk mitigated through education, signage and PPE.	Worksite open.
2	Significance limited to mass reduction.	No impacts on worksite(s) or infrastructure other than defence-structure worksites.	May impact but not override avalanche defence structure(s).	Risk mitigated through education, signage and PPE with exposure control in place for specific defence structure worksites.	Worksite open outside of defence structure worksites.
3	Significant with manageable impacts on worksite(s) or infrastructure.	May have minor impact, including a manageable amount of deposit mass and/or light dusting(s) which create visibility impairment.	May impact, fill or override avalanche defence structure(s).	Risk can successfully be mitigated to an acceptable level through education, signage and PPE with an elevated level of layered exposure and vulnerability controls at worksite. Additional personnel and readied equipment may be required to remove minor impacts.	Worksite open with increased controls outside of defence structure worksites.
4	Significant impact(s) on the worksite(s) or infrastructure that are not safe to work in.	May have major impact including critical depth deposit mass and/or violent air-blast(s).	Expected to fill and override avalanche defence structure(s).	Risk mitigated through exposure controls only, closure and sweep.	Worksite closed, or specific site(s) within an area closed under the direction of an Avalanche Professional.
5	Historical, catastrophic avalanche impacts.	Major impacts that may exceed trimlines and/or engineered design of infrastructure. Impacts have a longer timeline to recovery and/or compound, block or back up water courses, isolate communities/workcamps, possible state of emergency.	Expected to fill, override, and may damage avalanche defence structure(s).	Risk mitigated through exposure controls only, closure and sweep, evacuations, shelter in place.	Worksite closed.

REFERENCES

Association of Canadian Mountain Guides (ACMG), 2023. Ski Guide Manual, Chapter 22 – Mechanized Ski Guiding, Ski Guiding Skills, Guiding Challenges, 243.

Bishop, A., 2019. GIS Interface for Avalanche Hazard Management (CAA Case Studies 2019), YouTube. htwww.youtube.com/watch?v=8l9NKBWlIt0

British Columbia Ministry of Transportation and Transit (BC MOTT), 2026. Snow Avalanche Safety Measures for Highways Manual, Appendix F – Avalanche Hazard Levels and Specific Operational Procedures, 49-50. https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/highway-bridge-maintenance/avalanche/snow_avalanche_safety_measures-hwys.pdf

Canadian Avalanche Association (CAA), 2024. Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches. Canadian Avalanche Association, Revelstoke, BC, Canada.

Statham, G., Haegeli, P., Greene, E., Birkeland, K., Israelson, C., Tremper, B., Stethem, C., McMahon, B., White, B. and Kelly, J.: A conceptual model of avalanche hazard, Nat Hazards, 90, 663-691, https://link.springer.com/article/10.1007/s11069-017-3070-5, 2018.

Whalen, S., Boyle, R., Schmid, L., 2023. AADS Bear Pass: From Pilot to Daily Use of the Radar-Based Automated Avalanche Detection System for Improved Road Management of Highway 37, Proceedings, International Snow Science Workshop, Bend, Oregon, 2023, https://arc.lib.montana.edu/snow-science/objects/ISSW2023_P3.50.pdf

WorkSafeBC, 2015. Occupational Health and Safety Regulation, Part 4 – General Conditions, Sections 4.1.1 and 4.1.2, Snow Avalanche Assessment. WorkSafeBC, Richmond, BC, Canada. https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable-ohs-regulation/ohs-regulation/part-04-general-conditions

Zhecheva, L., 2018. Developing Applications: Avalanche Path Hazard Assessment, Proceedings International Snow Science Workshop, Innsbruck, Austria, 2018, https://arc.lib.montana.edu/snow-science/objects/ISSW2018_O09.1.pdf