AVALANCHE FORECASTING FOR ICE CLIMBERS: ESTIMATING EXPOSURE AND MANAGING OPERATIONAL UNCERTAINTY

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ABSTRACT: Avalanche bulletins give us the regional picture, but ice-climbing decisions are made at one climb, one start zone, one runout, and often one short section of terrain. This paper looks at how Yamnuska Mountain Adventures (YMA) guides make that translation in day-to-day operations using End-of-Day Program Summaries and Daily Hazard Evaluations from calendar years 2023-2025. We identified 773 waterfall-ice guide-group records on 372 operating dates, representing 640 venue-days and 2,713 client participations. In a manually reviewed subset with standard five-level danger ratings, the Public Bulletin and YMA Localized Forecast agreed in 65 of 69 alpine pairs (94.2%), 70 of 71 treeline pairs (98.6%), and 63 of 68 below-treeline pairs (92.6%). We then applied practitioner estimates of typical avalanche exposure time to 707 records (91.5%). These records represent approximately 380 guide-group exposure hours and 1,180 person-exposure hours. The venues we used most were not necessarily where exposure accumulated: Junkyards accounted for 327 records but was assigned 0 h of routine sustained exposure under normal use, while Louise Falls accounted for 50 records and about 200 guide-group exposure hours. These estimates are not a risk score; they show where operational time in avalanche terrain accumulates. We describe the decision process as Hazard -> Uncertainty -> Terrain -> Exposure: start with the bulletin, identify what is uncertain, connect the problem to the terrain, then decide how much exposure to accept.

KEYWORDS: avalanche forecasting, ice climbing, spatial scale, uncertainty, exposure, operational risk

1. INTRODUCTION

Public avalanche forecasts are built to describe a region. That is exactly what they need to do, but it is not the same scale at which an ice-climbing guide makes a decision. Banff National Park covers 6,641 km², while the decision on a given morning may come down to one drainage, one overhead start zone, or a few minutes spent crossing or standing in a runout (Parks Canada, 2026a; Parks Canada, 2026b).

This difference in scale is especially obvious in waterfall ice climbing. The climbs do not move. We often return to the same objectives throughout the winter, and clients may spend long periods climbing or belaying below the same overhead terrain. Parks Canada's waterfall-ice guidance notes that avalanche bulletins cover large areas, local variation is common, and climbers still need to assess the conditions at the climb itself (Parks Canada, 2010). ATES v.2 also recognizes waterfall ice climbing as its own terrain-use context and highlights how terrain changes as we look at it from different spatial scales (Statham and Campbell, 2025).

This paper looks at how that translation happens in a working guide operation. Using YMA records, we followed four parts of the decision: Hazard -> Uncertainty -> Terrain -> Exposure. We wanted to answer three practical questions: where and how often are we operating in waterfall-ice terrain; how often does our localized assessment line up with the public bulletin; and what information are we still missing if we want to understand our cumulative exposure over time?

2. DATA AND METHODS

2.1 Operational data sources

Our two main operational sources were the YMA End-of-Day Program Summary and the YMA Daily Hazard Evaluation, both exported on 26 August 2026. The End-of-Day file contained 14,740 records and 101 fields; the Daily Hazard Evaluation contained 10,538 records and 114 fields. We focused on calendar years 2023-2025, which gave us 4,417 end-of-day submissions across all YMA activities and the hazard records used for the regional-to-local comparison. The datasets were analyzed as complementary operational sources. Because the forms do not share a consistent trip identifier, we did not link every Daily Hazard Evaluation one-to-one with

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an End-of-Day record. We also reviewed the archived YMA schedules for program names and seasonal context, but did not use the planning calendars as the main count of completed operations.

2.2 Ice climbing classification

We counted a record as waterfall ice climbing when the location was a named ice-climbing venue in the YMA records or when the program name clearly identified an ice-climbing course or camp. We left out glacier, icefield, ski, Wapta, snow-and-ice, mountaineering, and crevasse-rescue records unless the listed location was clearly a waterfall-ice venue. We removed exact duplicates based on date, program, location, leader, and client count. Eleven duplicates were removed, leaving 773 guide-group records.

Each record represents one guide group's end-of-day submission. It is not necessarily one unique booking or one unique person. 'Client participations' therefore means the total number of clients recorded across those submissions; the same client can appear on more than one day. We treated one normalized venue used on one date as a venue-day. If several YMA groups were at the same venue on the same day, that counted as one venue-day but several guide-group records. The paper reports only aggregate results; no guide or client identities are presented.

2.3 Hazard, uncertainty, terrain, and exposure variables

We used the two YMA datasets to look at different parts of the operational decision. The End-of-Day Program Summary tells us where we went, how often we went there, the guide group, and the number of clients. The Daily Hazard Evaluation gives us the forecasting side: the Public Bulletin and YMA Localized Forecast danger ratings by elevation band, confidence, stability trend, avalanche problems, observations, proposed terrain, expected hazards, human factors, risk treatment/mitigation, and strategic mindset. For the danger-rating comparison, we manually reviewed records and retained operations where the plan or location showed a waterfall-ice objective or ice-climbing instruction. Avalanche-training and ski records were excluded even when they occurred near an ice venue. We compared only pairs where both fields contained one of the five standard danger ratings. N/A, Below Threshold, Spring Diurnal, blank, and other non-standard entries were kept outside that comparison. N/A was not used consistently: it may mean the hazard was below an operational threshold, or that no avalanche hazard applied because the program was in non-avalanche terrain. We therefore did not convert N/A to Low or treat it as one danger category.

We also added practitioner-derived estimates of typical avalanche exposure time for the most-used venues. These estimates describe a normal operational day at the venue, not measured exposure time for each individual trip. A value of 0 h means there is normally no sustained avalanche exposure in the way we use that venue; it does not mean an avalanche can never reach it. Several 0 h venues can become exposed during extreme events or when critical loading or other thresholds are met. Exposure estimates were assigned to 17 venue groups covering 707 of 773 guide-group records (91.5%). Person-exposure hours were estimated as the typical venue exposure time multiplied by one guide plus the recorded clients, so the estimate may be a minimum on days with additional guides. These values show where operational time accumulates; they are not a risk score and should not be read as precise measurements of time beneath avalanche paths.

3. RESULTS

3.1 Operational frequency

From calendar years 2023-2025 we identified 773 waterfall-ice guide-group records on 372 unique operating dates. Those records represented 640 venue-days and 2,713 client participations. The number of guide-group records dropped from 302 in 2023 to 240 in 2024 and 231 in 2025, while the number of days we were operating on ice stayed fairly steady.

Annual summary: 2023 - 302 guide-group records, 128 unique dates, 1,061 client participations; 2024 - 240 records, 117 dates, 860 client participations; 2025 - 231 records, 127 dates, 792 client participations. Three-year total: 773 records, 372 dates, 2,713 client participations.

3.2 Concentration by venue

A large part of our ice operation happens at a relatively small number of venues. Cleaning the raw location text resolved many of the 77 records that had previously been left as 'venue not explicit.' The updated counts include 327 Junkyards records, 102 Haffner Creek, 50 Louise Falls, 44 King Creek, 29

Grotto Canyon/Falls, 28 Johnston Canyon, 22 Wedge Smear, 22 Weeping Wall, 21 Chantilly/Moonlight, and 16 Bear Spirit records. The remaining less-common or one-off objectives are kept separate rather than forcing an exposure assumption onto sparse records.

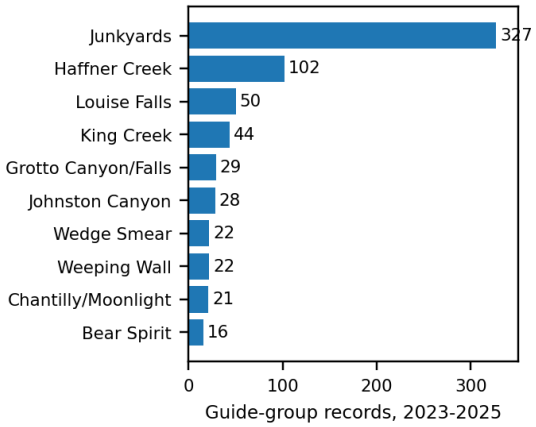

Figure 1: Ten most frequently recorded named waterfall-ice venues in the YMA End-of-Day dataset, calendar years 2023-2025.

3.3 Regional-to-local danger translation

Among the manually reviewed records with standard paired danger ratings, the Public Bulletin and YMA Localized Forecast usually told the same broad story. They matched in 65 of 69 alpine pairs (94.2%), 70 of 71 treeline pairs (98.6%), and 63 of 68 below-treeline pairs (92.6%). The localized rating was lower four times in the alpine, once at treeline, and five times below treeline; it was not higher in this cleaned comparison. Confidence was most often Moderate in the alpine (49 of 69), while High confidence was more common below treeline (40 of 68). We do not treat the differences as public forecast errors. They may represent the guide adjusting the regional picture to the terrain scale that mattered that day.

Paired Public Bulletin vs. Localized Forecast: Alpine n=69 - 65 same, 4 localized lower, 0 higher; Treeline n=71 - 70 same, 1 lower, 0 higher; Below treeline n=68 - 63 same, 5 lower, 0 higher.

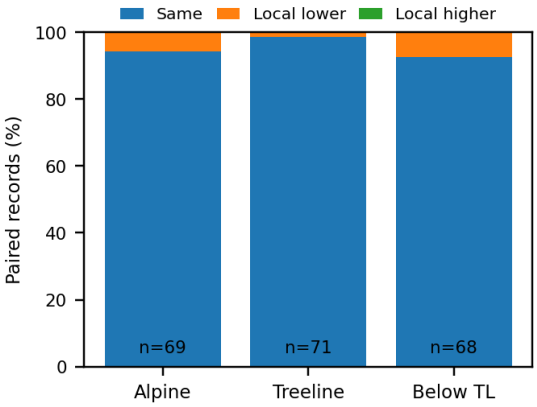

Figure 2: Agreement between paired standard Public Bulletin and YMA Localized Forecast danger ratings in manually reviewed waterfall-ice Daily Hazard Evaluations, calendar years 2023-2025. Differences may represent terrain-scale operational adjustments and are not interpreted as public forecast errors.

4. DISCUSSION

4.1 Hazard -> Uncertainty -> Terrain -> Exposure

For us, the paired records help clarify what the spatial-scale issue really is. Most of the time, the regional bulletin and our recorded localized danger rating agree. That suggests the bulletin often provided the same broad hazard picture recorded in the localized assessment. But that is not the end of the guide's job, and agreement alone does not prove that an independent local assessment occurred. We still need

to ask whether the forecast avalanche problems are actually connected to the start zones, tracks, runouts, aspect, elevation, loading pattern, and timing of the climb we are considering. When the information is incomplete, confidence matters. It is better to make that uncertainty visible than to hide it inside a single danger rating.

We have found it useful to think of the process as Hazard -> Uncertainty -> Terrain -> Exposure. The regional bulletin gives us the hazard picture. We then look at what we know and what we do not know from weather, observations, avalanche activity, and confidence. Next comes the terrain: does the problem actually connect to the climb, approach, belay, or runout? Only then do we decide how to manage exposure through objective choice, timing, positioning, group movement, substitution, or simply not going there. This keeps the regional bulletin in its proper role while making the guide's terrain-scale reasoning easier to talk about and review as a team.

4.2 Exposure is easier to see when we count it over time

Adding typical exposure time changes the venue picture. High use does not automatically mean high avalanche exposure. Junkyards accounted for 327 records, or 42.3% of all guide-group records, but was assigned 0 h of routine sustained exposure under normal use. Louise Falls accounted for only 50 records, or 6.5% of the operation, but its estimated 200 guide-group exposure hours represent 52.8% of the approximately 380 h estimated across covered records. The Weeping Wall adds 88 h, King Creek 44 h, Wedge Smear 22 h, Bear Spirit 16 h, Shades of Beauty 8 h, and Cable Gullies 1 h.

Using one guide plus recorded clients, those same records represent approximately 1,180 person-exposure hours: about 504 at Louise Falls, 224 at the Weeping Wall, 203 at King Creek, 132 at Wedge Smear, 72 at Bear Spirit, 36 at Shades of Beauty, and 5.5 at Cable Gullies. Because we counted one guide per record, this may be a minimum on days with additional guides. These exposure estimates are not a risk score. They show where operational time accumulates; the level of risk still depends on the day's hazard, expected avalanche size, group vulnerability, and the controls used.

Table 1: Selected venues showing how operational frequency and estimated avalanche exposure can diverge.

Venue	***Visits***	***h/visit***	***Group h***	***Pers. h****
Junkyards	327	0	0	0
Louise Falls	50	4	200	504
Weeping Wall	22	4	88	224
King Creek	44	1	44	203
Wedge Smear	22	1	22	132

* Person-hours assume one guide plus recorded clients. Values are practitioner-derived typical exposure estimates, not measured risk. A 0 h value means no routine sustained exposure under normal use, not that avalanche involvement is impossible under exceptional loading or threshold conditions.

4.3 Lower-exposure terrain as an operational control

The Parks Canada waterfall-ice guidance is useful here because it separates terrain from the day's hazard. It notes that bulletins cover large regions, local variation is common, and terrain ratings and daily bulletins need to be used together. Its ice-climbing ATES list also shows why a 0 h operational estimate should not be confused with a permanent statement about hazard. Some venues are identified as not exposed to avalanche hazards in the terrain rating, while others are Simple, Challenging, or Complex terrain. For YMA, lower-exposure terrain is an important operational control: when uncertainty or loading changes the picture, change terrain, change timing, reduce exposure, or choose another objective rather than forcing the original plan.

5. YAMNUSKA OPERATIONAL IMPLICATIONS

For YMA, the value in this work is not another forecasting system. It is making the reasoning we already use easier to see, share, and learn from. Our Daily Hazard Evaluation already records the Public Bulletin, our Localized Forecast, confidence, stability trend, avalanche problems, proposed terrain, expected hazards, human factors, mitigation, and strategic mindset. The End-of-Day Program Summary tells us

where we actually ended up. At present, we can compare those sources at an aggregate level but cannot reliably link every trip one-to-one. A shared trip identifier would let us connect the forecast, terrain choice, exposure, and outcome for the same operation.

For waterfall ice, a useful minimum record would include the regional danger ratings and avalanche problems, our local assessment and confidence, the venue, number of people exposed, approximate minutes in avalanche terrain, any terrain substitution or mitigation, and the outcome. It would also help to prompt the guide to record what is different locally from the bulletin, what remains uncertain, and the strategic mindset for the day. That makes it harder for the localized forecast to become a simple copy of the bulletin and gives the guide team something useful to review later.

6. LIMITATIONS AND NEXT STEPS

There are limits to what these records can tell us. They were built for running a guide operation, not for research. We classified ice-climbing days from program names, plans, and named venues, so some generic private or custom days may have been missed and some ambiguous records remain. Client participations are not unique clients. The two forms do not share a consistent trip identifier, so the hazard and end-of-day datasets were analyzed as complementary sources rather than linked one-to-one for every trip. Exposure times are practitioner-derived typical values rather than measured times for each trip, and conditions can make actual exposure shorter or longer. The person-hour estimate assumes one guide and may undercount days with additional staff. A 0 h estimate means no routine sustained exposure under normal use, not zero avalanche possibility during extreme events or when critical loading/threshold conditions are met. N/A was also used inconsistently and can mean either below threshold or no applicable hazard in non-avalanche terrain, so it was kept separate rather than interpreted as Low.

The paired danger-rating sample is small, operational, and not random. Repeated records may involve the same guide, venue, or operating day, so the percentages describe the completed and interpretable records rather than all YMA ice days or the accuracy of the public forecast. There is also potential guide bias and anchoring. A guide may carry the published bulletin rating into the localized field without fully documenting an independent thought process. The form does not necessarily capture the conversations, observations, uncertainty, or strategic mindset that led to the day's decision. High agreement between the Public Bulletin and Localized Forecast therefore does not prove that an independent terrain-scale assessment happened in every case. Better prompts for local differences, uncertainty, strategic mindset, and actual exposure minutes would make the record more useful both operationally and for future analysis.

7. CONCLUSION

For waterfall ice climbing, the challenge is not choosing between a regional forecast and a local assessment. It is taking the regional picture and applying it to the terrain and exposure in front of us. YMA's calendar-year 2023-2025 records show that the recorded Localized Forecast usually agreed with the Public Bulletin, but the exposure analysis shows why the terrain step matters. The venues we used most were not necessarily where avalanche exposure accumulated. Junkyards represented about 42% of all guide-group records but was assigned 0 h of routine sustained exposure under normal use. Louise Falls represented about 6% of records but contributed roughly 53% of the approximately 380 guide-group exposure hours estimated across covered records. Those hours are not a risk score; they show where operational time in avalanche terrain accumulated.

Hazard -> Uncertainty -> Terrain -> Exposure is a simple way for us to describe the process. The bulletin gives us the regional hazard picture. Local observations and confidence tell us how certain we are. Terrain tells us whether the problem matters to the climb in front of us. Exposure tells us how long and how many people we are putting into that terrain. The important next step is not a more complicated forecasting system; it is clearer documentation of the guide's local reasoning, strategic mindset, and actual exposure time so we can learn from repeated decisions over many seasons.

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