the avalanche journal

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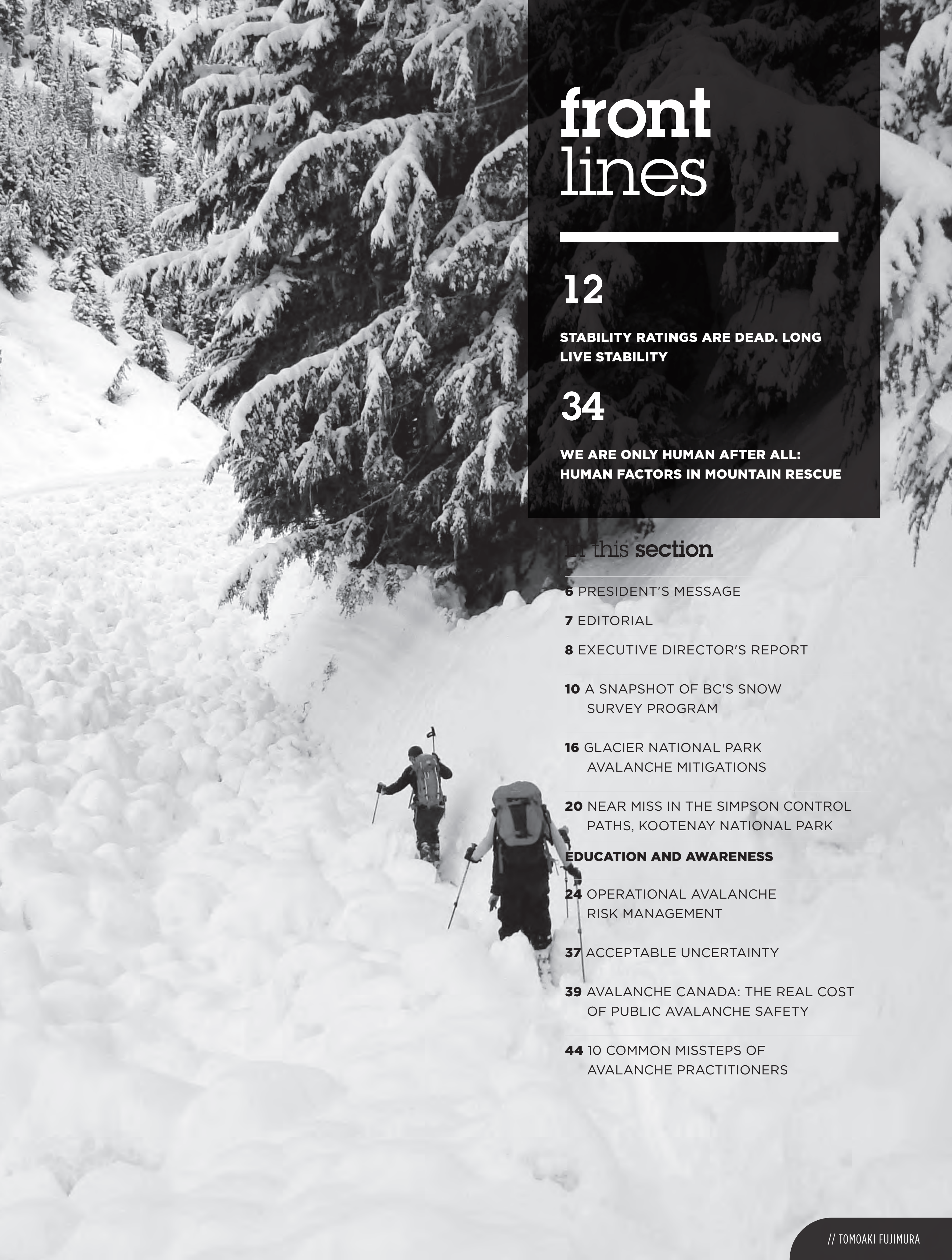

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President's Message

Walter Bruns
CAA President

THANK YOU FOR READING this winter issue. The season is well underway, and you are likely in the thick of it with little time to spare. Hopefully the Rockies contingent (and some coastal types) have warmed up a bit, and everyone made it through the holidays (and their after-effects) in good fashion.

Let me start with some reflections from the ISSW in Breckenridge, Colorado last October. Joe Obad, Kristin Anthony-Malone, Emily Grady and I attended on behalf of the CAA. We networked, attended meetings, and talked to people from all over the world at our booth. What struck me was the consistent admiration for the Canadian avalanche community. From the public services provided by Avalanche Canada, to our culture of collaboration as exemplified by InfoEx, to our Industry Training Programs which so many attend or emulate, to the many talented practitioners and researchers who are pushing the frontiers of our understanding, there is a universal respect for what we do and how we do it in Canada.

Karl Klassen discusses the demise of stability ratings on page 12. Cam Campbell and the TASARM team continue to outline new standards of practice in the second of a series of articles on page 24. Todd Guyn's impressive presentation from the ISSW is included in article form on page 44. These, along with other great articles in this issue, are just a few examples of the many insightful developments and ground-breaking progress in our field.

As members of this community, we can be very proud indeed. And to put the icing on the cake, Steve Kujit and Christine Grimble secured ISSW 2020 for Fernie, BC with their excellent presentation. Congratuations!

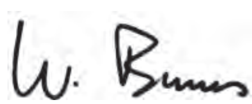
In November, I attended the Avalanche Canada and Avalanche Canada Foundation AGMs in Vancouver. The take-home point was that while we at the CAA strive for fiscal sustainability (in member services, ITP and InfoEx, all of which are on pretty solid ground), our colleagues at AvCAN are essentially living hand-to-mouth from government funds which are far from assured, while demands for public services are ever-increasing. Folks at the Foundation are working hard to raise funds to plug the holes. Mary Clayton provides a comprehensive summary of the challenges on page 39. In conversation with my counterparts Kevin Seel of AvCAN and Gord Ritchie of ACF, I offered support on behalf of the CAA to assist their efforts, wherever we can, to solidify oong-term government funding.

And speaking of national scope, we can indulge in another brief moment of self-congratulation as the CAA is now formally registered as a federal society. For those of you who followed the rationale leading up to this event, it may have appeared fairly straightforward: federal makes the most sense, so incorporate federally, dissolve provincially—done deal. Well, as is so often the case, the devil emerged in the details. I would like to thank Joe, Kristin and Janis Borden primarily, with a special thanks to board member John Martland, for the substantial effort they put in to get this done. And thank you to all the members who voted online in advance, which gave us a quorum for the required special general meeting (at a very disadvantageous time of year), and which thereby satisfied the technical requirements of the process and passed the motion.

A further thanks goes to CAA staff Brent Strand, Luke Norman and Stuart Smith for their efforts in setting everything up online and in real-time for the meeting. The dreaded "techno-moment" did not arise; everything worked seamlessly. Perhaps this can serve as a template for future opportunities for member engagement and participation?

Please read on to Joe's report, where he covers the CAA's transition to a federally incorporated not-for-profit, the upcoming work associated with the competency profile, which include training and assessment. Stay tuned for more information at the AGM in May.

Finally, let me wish you a continued safe and successful season.



Walter Bruns, CAA President

Generating **Discussion**

Karilyn Kempton
Managing Editor

WELCOME TO THE WINTER issue of *The Avalanche Journal*. Thank you for reading. Over the years, it's been gratifying to see more and more articles dedicated to examining human factors as they pertain to decision making, guiding, rescues and teaching. This issue alone features a handful relating to the topic that may generate some good discussion in workplaces.

Todd Guyn's "10 Common Missteps of Avalanche Practitioners" presentation at ISSW was highly recommended as an inclusion in the Journal, and I'm pleased to include it here for you. It's a compilation of survey data from CMH guides and outlines ten common mistakes that guides indicated. It should give you pause. It's likely that all of us will benefit from keeping that list in our mental back pocket.

Here's something else to think about. Ian Jackson's article on a near miss in Kootenay National Park last season ends with an important question: can avalanche professionals do a better job at reporting and archiving professional near misses so that the community can learn from and see trends in the data? And if so, where should that kind of information live? InfoEx? I'd love to hear from you on what you think of that.

Mike Innis' piece on human factors in mountain rescue is also a good reminder of the importance of situational awareness, teamwork, communications, and knowledge of one's own abilities. As he gently reminds us, it's not unlikely that you'll be forced into a rescue scenario (if it's not already a regular occurrence for you).

This year I've worked on consciously slowing down some of my processes in the mountains to increase my situational awareness as much as I can. I ask more questions out loud, and more frequently. I have a history of being a scaredy cat and so I have focused on managing fear by more realistically examining my exposure so that I am thinking and acting more clearly. As Innis mentions and which bears reminding, slow is steady and steady is fast.

And on a personal note, this is my last issue at the helm of the publication. I've been around for seventeen issues and am consistently impressed with the work submitted by CAA members. Taking the time to write a thoughtful article in the midst of avalanche season (or mid summer!) is not an easy task, and you do it for free. It's truly appreciated by your peers. I started under the keen mentorship of former editor Mary Clayton, to whom I owe a huge debt of a gratitude. The CAA has vision and integrity, and it's got strength in numbers—you fine folks!

Your connection to the Journal is still editor@avalancheassociation.ca, so please send along your articles, photos, near-misses, successes, comments and ideas. There's a steep learning curve for the new editor, so I urge you to help out by sending along any ideas and articles you have percolating. Thanks again for reading, and for sharing.

Have a great rest of the season. See you on the snow.

Karilyn Kempton

Joe Obad
CAA Executive Director

CAA Executive Director's Report

FIRST OFF LET ME WISH ALL MEMBERS and CAA stakeholders a great 2017! As we head towards printing this issue, it is good to see most of our members are facing a better snowpack this year than last year, especially the coast. Hopefully things in parts of the Rockies turn around.

As Walter mentioned in his presidential address, federal re-incorporation was no small task. Without many hands from board, staff and members this would not have been possible. Thank you to everyone who pitched in. For all the work to operate under a new non-profit jurisdiction, our direction remains the same. We have thrown on a new coat by registering as a federal non-profit, but we are still the same CAA. Our path is the same and our boots (capacity) to walk that path remain the same. Let's take a look at that new jacket and where those boots are headed.

Like the modern stretchy fabric you traded your 1980s fleece in for, our new jacket allows some added movement and flexibility. The change to federal incorporations allowed us to easily change our fiscal year to December 1 to November 30. This cycle gives us much more time to sort out finances prior to the AGM in May.

We also have a fresh start with our financial statements. Comptroller Janis Borden and I sat down with our accountants at BDO to discuss making the statements more reader-friendly to members. We also talked about trying to display the capital value of intellectual property like ITP curriculum on our books. We have a fresh opportunity to do this as a "new" organization (we looked at doing it in the old organization and were told we would have to redo the books back to 1981 or not do it at all).

Lastly, the full audit required under the Canada Not-for-profit Corporations Act ensures a third party looks at our books and provides a "reasonable assurance" that the financial statements are free of material misstatement and are in accordance with Canadian accounting standards for not-for-profit organizations. This provides assurance to members and other stakeholders that the CAA is being a fair broker about our finances and how we use them to pursue our mandate for members, InfoEx subscribers, students and others.

While a lot of progress has been made on some fronts like producing *Technical Aspects of Snow Avalanche Risk Management: Resources and Guidelines for Avalanche Practitioners in Canada* (TASARM), we have played catch up on fulfilling the promises associated with the competency profile.

The competency profile (available in the main menu of the members only section of the website) is a bit like a lighthouse—it lights the way, but it isn't the destination itself. The competency profile for future active and professional members describes the ability to perform specific workplace tasks at a predetermined proficiency. The related proficiency scales address the independence of practitioners to perform with or without supervision.

Our main tasks now are to build a robust training environment and assessment procedures for entrance to CAA membership.

On the assessment front, the working group is working towards presenting a draft set of assessment procedures to the membership at the 2017 AGM. We have applied for a grant from the National Search and Rescue Secretariat for funds to overhaul ITP to train towards the competency profile. We are also looking at alternative methods to finance this work if our application is unsuccessful. Look forward to more news on these fronts at the AGM.

Members should also be paying attention to the terrain working group addressing use of terrain by avalanche educators. Last spring, we presented a framework that enabled instructors and protected students. It was well received at the AGM and we are now working on draft guidelines to present to the membership. Any rollout will depend on board and member buy-in.

Nevertheless, diligent AST instructors should be getting ahead of the curve on a couple of fronts. For one, dive into TASARM. It offers a scalable model for looking at avalanche risk assessment from both planning and operational perspectives—and yes, it scales down to teaching recreational avalanche courses. The CAA and Avalanche Canada are likely to provide tools down the road for instructors, but the wise instructor should be getting to know TASARM now, and thinking about how it applies to AST instruction.

The terrain working group looked particularly closely at terrain identification and mapping. Instructors may want to begin building their own terrain atlases now to get ahead of the game. Again, stay tuned for more as we head into spring.

As this issue goes to press let me express a big thank you to *The Avalanche Journal* managing editor Karilyn Kempton, who is leaving the CAA for a great new opportunity in Revelstoke. For over five years Karilyn has worked tirelessly and with boundless enthusiasm for the CAA. She and designer Brent Strand moved the publication into the colour era with great content begged and borrowed from many of you. She later took over organizing presenters for the spring technical sessions. Karilyn has been a rock of positivity and reliability. We are sorry to see her energy and skills go, but we wish her the very best in her new endeavour.

Joe Obad, CAA Executive Director

Membership Changes

Kristin Anthony-Malone
CAA Operations Manager

AS THE OPERATIONS MANAGER working with the CAA Board of Directors and the Executive Director, there are two membership changes that we would like to make sure every member is aware of. The first is under way and the second you will see implemented December 2017.

As you can see from Fig. 1, we have tightened up the membership renewal process. The time had come to shorten the gap between when we ask for dues and when members pay those dues. In the past, it often took up to 12 months before payment was sorted, which can be confusing for members and time consuming for staff. We hope the new plan you see here makes the payment process more seamless for all.

The second change is that beginning December 1 we will be changing our membership year to match the financial year. Our new year end is now November 30, and we are taking this opportunity to synchronize our membership year with our financial year. In addition, it means that the membership year falls in line with more of the winter season.

All our members play a vital role in supporting the CAA through membership dues. I'd like to extend a thank you to all of those who have already paid their 2017 dues. For a reminder of the benefits of membership, please visit our website at avalancheassociation.ca/page/benefits_of_membersh.

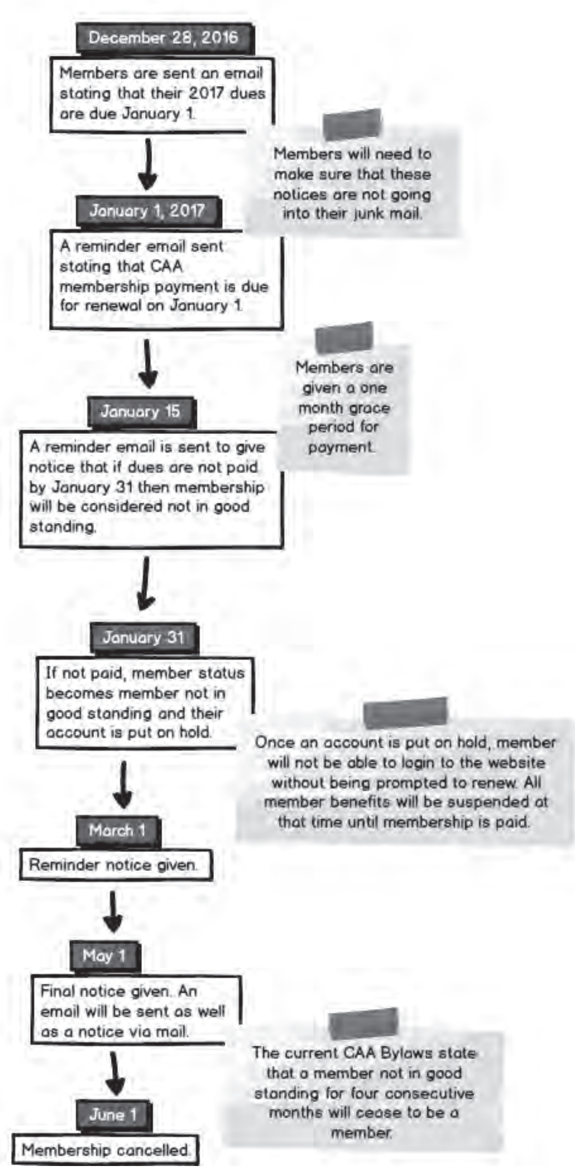


FIG. 1: MEMBERSHIP RENEWAL PROCESS FOR 2017

A Snapshot of BC's **Snow Survey Program**

Author and Photo Tony Litke

Alongside many weather monitoring networks and avalanche specific weather monitoring activities CAA members are aware of is a lesser known provincial snow monitoring program. We caught up the current snow survey program coordinator Tony Litke to ask what the program is about and how it can benefit avalanche professionals.

TAJ: What is the British Columbia Snow Survey Program (SSP) and how did it come to be?
LITKE: The BC Snow Survey Program was established in 1935 in response to a prolonged drought to monitor snow packs in BC, and is one of the longest running environmental monitoring programs in the province. It has largely been a cooperative program with federal, provincial and local governments contributing in different capacities over the 80+ years that formal snow surveying has been occurring in BC. Today the major agencies involved are the Ministry of Environment, Ministry of Forests, Lands and Natural Resource Operations and BC Hydro. The program also receives monitoring assistance from some local governments and a few private sector companies.

TAJ: So in a nutshell, what is snow surveying?
LITKE: A snow survey is extremely simple in its nature: a surveyor travels to a site and inserts a specifically designed long aluminum pipe into the snow pack at five to 10 set locations. The pipes are weighed and the average snow depth and snow water equivalent (SWE) recorded. This is performed on predetermined schedules one to eight times per year. Traditionally this data is then correlated to downstream rivers to model and predict water flows and assist with water management.

TAJ: Where are the SSP monitoring sites?
LITKE: Manual snow courses and automated snow weather stations are usually at higher elevation locations, typically between 1,000m and 2,300m. They're found around the entire province from the northern Rockies to the coast to the Kootenays to the Okanagan and everywhere in between. Often they are strategically positioned to correspond with specific drainages and watersheds.

TAJ: How has technology changed the snow survey program?
LITKE: The advent of computers, weather monitoring instrumentation and satellite telemetry has slowly but drastically changed the way we survey snow, starting in 1969 when the first snow pillow and automated data collection platform was installed at Mission Creek near Kelowna. Despite the early start, widespread automation of manual snow survey sites really didn't really gather momentum until the mid-90s and has been ongoing ever since.

Nowadays most automated sites measure and report temperature, cumulative precipitation, snow depth and snow water equivalent on hourly intervals, 24 hours a day, 365 days a year. The most recent development has been the emergence of snow scales as a viable alternative to fluid filled snow pillows, which has made construction and deployment of new sites far less cumbersome.

TAJ: What are some problems involved with trying to keep track of how much snow there is across BC?
LITKE: Where to begin! I always tell people snow surveys are the hardest simple thing you will ever do. First of all, as we all know snow packs can be extremely variable over very small geographic areas. With manual surveys, human and site specific factors greatly influence the results, and these are extremely hard to control for. Given the remote location of most of the sites you never know what you are going to get until you get there. When it comes to the automated weather stations, lightning, wildfires, snow creep, falling trees, critters, bears and vandalism all conspire to push stations off the air. It's definitely more challenging than maintaining a weather plot in a resort or roadside setting, because due to their far flung locations we can't easily visit the sites to see what is going on and often only get to visit them a couple times a year. Thankfully, as time has progressed monitoring technology and reliability have greatly improved to the point where the electronics typically operate problem free.

TAJ: Can you give us a snapshot of the program today?
LITKE: After a few years hiatus there has been a push in recent years to continue to automate manual snow courses resulting in the construction of six new automated snow weather stations this past summer. That brings the total number of automated sites to 76 across the province, in addition to manual snow surveys happening at 158 active sites. This season over one million discrete snow measurements will be recorded across the SSP.

TAJ: How can CAA Members use make use of the SSP data?
LITKE: All the data the snow survey program produces is publicly available, including the historical archives dating back to 1935, and ongoing hourly near-real-time data. Some of the sites are already replicating data into the InfoEx or various other enthusiast-maintained websites.

The snow survey program is in the process of creating a new map-based platform to share data that should hopefully go live in early 2017. In the meantime the data is available through the river forecast centers webpage in tabular format at bcrfc.env.gov.bc.ca/data/index.htm. The snow weather stations all broadcast hourly data, so it is useful for any sort of weather reconnaissance you might need, from determining how a weather system moved through a mountain range to whether or not there is some fresh powder at your favorite touring haunt. We receive all sorts of enquiries from around the world, from power traders in the states betting on the markets that depend on water supply, to the strangest call I remember which was an RCMP detachment looking to find out whether it snowed in a certain area on the day a robbery occurred to aid an investigation. In summer time people are often interested in when the snow has disappeared so they can decide if it is mountain biking season. One advantage of the snow survey program weather station data is that it is year-round, so when the ski hills and backcountry lodges stop updating their websites and submitting to InfoEx, our data keeps rolling in.

TAJ: What does a typical day for you look like?
LITKE: A typical day…is there such a thing? It really depends on the time of year and what is going on. Normally the first thing I do on any given day is take a look at all of the snow weather stations to check that everything is functioning correctly. We aim to visit each site a minimum of twice a year, so a lot of planning and effort goes into those logistics. In the summer once the snow is gone we do all our repair work and any new installations, so depending on the year there might only be a few snow-free months to accomplish a lot of work. In the winter we like to stop in and make sure everything is functioning like we expect based on what we see on site. I also receive a lot of emails everyday, so I spend a good chunk of my time in the office working with the more than two dozen different cooperating groups that operationally help us deliver the program. My favorite days are the ones in the winter where it's snowing heavily, time slows down a bit, and everything just seems to be quiet and serene on site. One thing is for sure, every day is different, and every day has a new challenge.

TAJ: Why has this been one of the longest running monitoring programs and how is the data being used for decision making?
LITKE: Water supply forecasting is the primary driver for the program and the impacts range from public safety to economics. From power generation forecasting, flood forecasting, drought monitoring or irrigation planning, decision makers need to know how much snow is in the mountains because it will eventually become water in our lakes and rivers. The more information, and the more accurate the information is, the better the decision making will be. This has been important for decades and will continue to be, which explains why the program has had such a long and healthy life. Of course climate change is another big driver and being able to keep tabs on what is going on in remote mountainous regions over the long term will become more and more important on the horizon There is not yet technology on the horizon that is immediately able to take over in-situ weather monitoring, so it is likely the snow survey program will still be around for some time.

// SNOW DYNAMICS

Stability Ratings Are Dead. **Long Live Stability.**

Karl Klassen

AS OF THE 2016-17 SEASON, STABILITY RATINGS have been removed as an input field from InfoEx. Historical stability ratings can be viewed in tables as an optional column. The decision to remove stability ratings was made at the InfoEx subscriber meeting in May 2015, but implementation was held up; the decision was subsequently revisited and reconfirmed at the May 2016 meeting. Stability ratings were removed because they are inconsistent with current best practice for avalanche hazard assessment in Canada, which is based on the Conceptual Model of Avalanche Hazard (CMAH).

Concerns have been raised about this change. This is understandable, especially for anyone who has not attended a CAA Avalanche Operations Level 3 course, or for those who have not yet fully embraced the conceptual model. Having participated in the development of the Level 3 course and, as both a guide and public avalanche forecaster having made the transition to the CMAH years ago, I offer my personal opinions about the two primary concerns I've heard against removing stability from InfoEx, and then summarize my support for the new paradigm.

CONCERN #1: "I WANT STABILITY BECAUSE IT'S RAW DATA."

Raw data can be defined as "…data (e.g., numbers, instrument readings, figures, etc.) collected from a source. … Raw data has not been subjected to processing, … or any analysis…. As well, raw data has not been subject to any other manipulation by a software program or a human researcher, analyst or technician. …"[1]

By this definition, a stability rating is clearly not raw data. A stability rating is a one word summarization of a qualitative assessment that's based on judgement and experience. A stability rating is *derived* from raw data, some of which is quantitative (e.g. a stability test result or an observed avalanche occurrence), some of which is quasi-quantitative (e.g. a size 2 avalanche in which the size is derived from estimates of width, depth, and destructive potential), and some of which is qualitative (e.g. "numerous" avalanches associated with an estimated occurrence time observed in a single drainage on a foggy day).

I suspect that "raw data" is not the real issue here. I think people feel that by removing stability ratings from InfoEx, something important is missing and there's no longer a way to quickly and easily see others opinions about snowpack stability. I'll address this in my response to Concern #2 below and in my summary.

[1] *Excerpts from Raw Data, Wikipedia. https://en.wikipedia.org/wiki/Raw_data*

CONCERN #2: "WITHOUT STABILITY WE'RE MISSING A KEY PIECE OF INFORMATION RELATED TO HAZARD AND RISK."

This is a valid concern, but I think it's unwarranted. Clearly, any avalanche hazard analysis, assessment, and forecasting process must take into account the stability of the snow. But a stability rating is only one means of doing that, and in my opinion is an outdated method. Let's compare the old and the new.

Stability is described in OGRS (2014) as follows:

> "Stability refers to the chance that avalanches will not initiate. Stability is analysed in space and time relative to **sensitivity to triggers and spatial distribution**" (emphasis added).

The CMAH process includes determining "Likelihood of Triggering," the components of which are **sensitivity to triggering** and **spatial distribution.** The old stability rating system had five levels: Very Good, Good, Fair, Poor, Very Poor.

Likelihood of triggering in the conceptual model has five levels: Almost Certain, Very Likely, Likely, Possible, Unlikely. And, bonus! with likelihood it's acceptable, encouraged even, to choose a range such as "Possible to Unlikely" instead of being forced to pick a single term. Those arguments about "Fair to Poor" are gone for good in likelihood.

The old stability rating system had a table that provided guidance for choosing a stability rating. The CMAH contains two tables providing guidance for assessing sensitivity to triggers and spatial distribution, which are then taken into account when assigning a likelihood rating:

G.1.2 SNOW STABILITY RATING SYSTEM

Stability rating	Observation or Triggering of Avalanches		Stability test results	
	Natural avalanches	Triggered avalanches	Test score	Fracture character
Very Good (VG)	No natural avalanches expected.	Avalanches may be triggered by very heavy loads, such as large cornice falls, in isolated terrain features.	Generally no results.	No fracture or non-planar break fractures.
Good (G)	No natural avalanches expected.	Avalanches may be triggered by heavy loads in isolated terrain features.	Generally moderate to hard results.	Generally resistant or non-planar break fractures.
Fair (F)	Isolated natural avalanches are expected on specific terrain only.	Avalanches may be triggered by light loads in areas with specific terrain features or certain snowpack characteristics.	Generally easy to moderate results.	Resistant or sudden fractures.
Poor (P)	Natural avalanches are expected in areas with specific terrain features or certain snowpack characteristics.	Avalanches may be triggered by light loads in many areas. Ski cuts or skier remotes possible.	Generally easy results.	Generally sudden fractures.
Very Poor (VP)	Widespread natural avalanches are expected.	Widespread triggering of avalanches by light loads.	Very easy to easy results.	Sudden fractures.

FIG. 1: SNOW STABILITY RATING SYSTEM TABLE. OGRS 2014, 88.

SENSITIVITY TO TRIGGERS

Determine the sensitivity to triggers based on what kind of triggering will initiate avalanches of any size within the defined location.

Sensitivity	Natural Triggers	Human Triggers	Explosive Triggers		Cornice Triggers
			Size	Result	
Unreactive	No avalanches	No avalanche	Very large explosives	No slab	No slab from very large cornice fall
Stubborn	Few	Difficult to trigger	Large explosives & air blasts	Some	Large
Reactive	Several	Easy to trigger with light loads	Single hand charge	Many	Medium
Touchy	Numerous	Triggering almost certain	Any size	Numerous	Any size
Description of observation	Natural avalanche occurrences	Ease of triggering by a single human	Size of explosive and effect		Size of cornice fall that will trigger a slab

FIG. 2: CONCEPTUAL MODEL OF AVALANCHE HAZARD, LIKELIHOOD OF TRIGGERING TABLE.

SPATIAL DISTRIBUTION

Determine the density and distribution of the instability within the defined location.

Distribution	Density	Evidence
Isolated	The instability is spotty and found in few locations.	Evidence is rare and hard to find.
Specific	The instability exists in portions of terrain.	Evidence exists but is not always obvious.
Widespread	The instability is found in many locations.	Evidence is everywhere and easy to find.
Comment	How is the evidence distributed within the location identified?	How hard is it to find?

FIG. 3: CONCEPTUAL MODEL OF AVALANCHE HAZARD, SPATIAL DISTRIBUTION TABLE.

IN SUMMARY: MEET THE NEW BOSS. SAME AS THE OLD BOSS.

Okay, that's a bit of a stretch. Likelihood of triggering is not exactly the same as the stability ratings were. Likelihood introduces new (and I'd venture more clear) terms. It approaches the issue from a slightly different angle. But fundamentally, likelihood closely follows the old methodology used to determine a stability rating.

The display used in InfoEx to look at the components of the CMAH is a rich mix of words and graphics. It's highly effective way to visualize the full context of avalanche hazard, including likelihood. In Fig. 4 one can easily see that it's Unlikely to Possible that size 1 to 1.5 windslab avalanches will occur on north-east and east aspects in the alpine. And, for those who still prefer text, the words and abbreviations remain available in the avalanche problems column of the avalanche hazard table.

So, while the old words and method are no longer used, the assessing and rating likelihood ensures that snowpack stability remains an integral part of the avalanche hazard assessment process, and the tools provided in InfoEx make effective visualization of likelihood (in addition to the larger context) easy and fast.

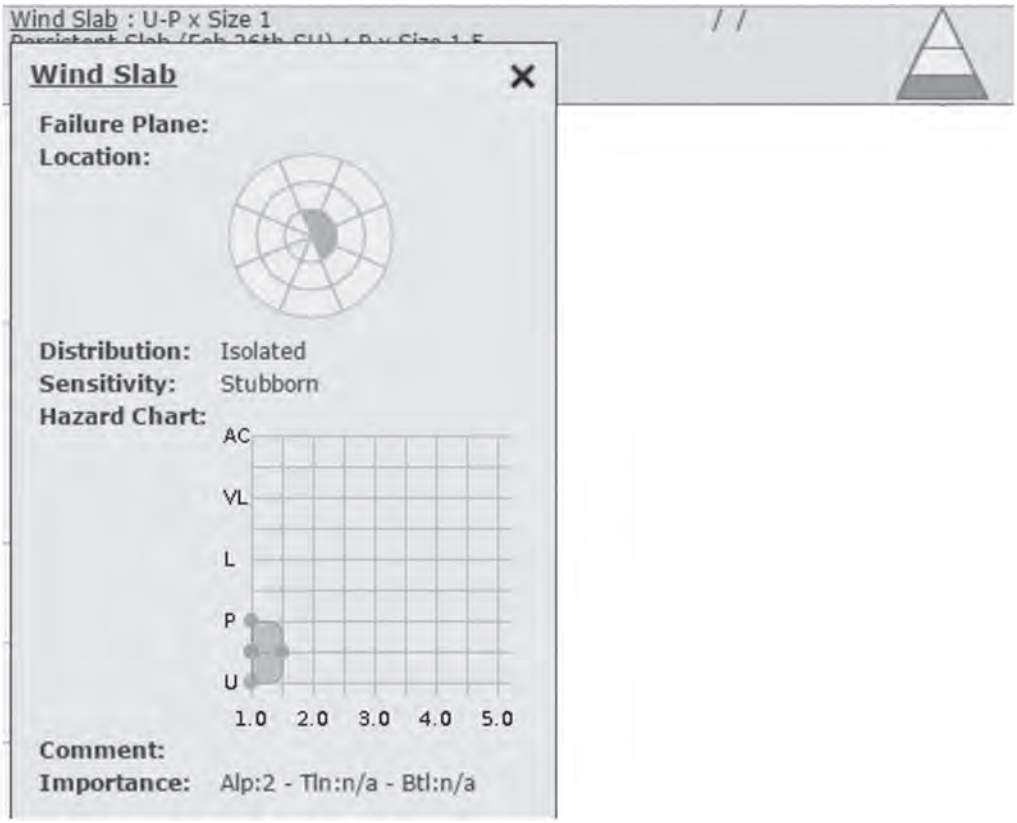


FIG. 4: GRAPHICAL DISPLAY OF AVALANCHE PROBLEM AND AVALANCHE HAZARD IN AN INFOEX REPORT.

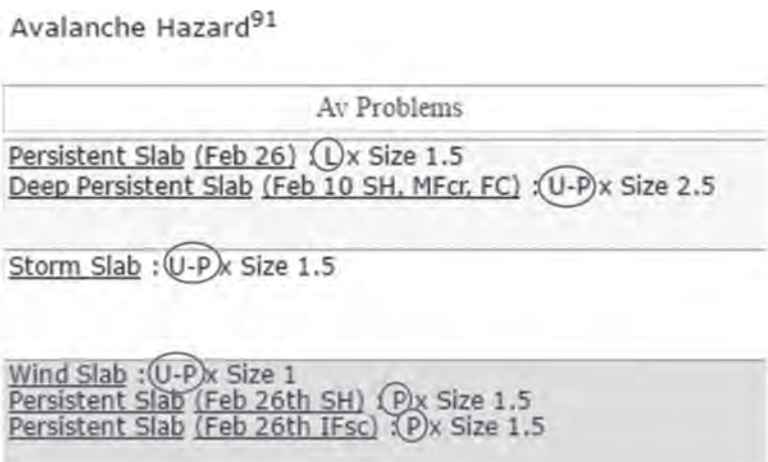


FIG. 5: TEXTUAL DISPLAY OF AVALANCHE PROBLEMS IN AN INFOEX REPORT. LIKELIHOOD CIRCLED

SNOW NET PROJECT FACTS

TOTAL NUMBER OF SNOW NET ANCHORS DRILLED AND INSTALLED: 1,275 of 1,506 (85% of project total)

TOTAL METRES OF SNOW NETS INSTALLED: 953 of 1,930m (49% of project total)

NUMBER OF CREW LOADS/ PASSENGER FLIGHTS: 670

NUMBER OF EXTERNAL/LONG LINE LOADS: 695

APPROXIMATE WEIGHT FLOWN EXTERNALLY: 1,531,000kg

GEOBRUGG SPIDER SNOW NETS PROJECT CONTRACTOR: BAT Construction Ltd.

DETAILED DESIGN AND LAYOUT ASSISTANCE: Alpine Solutions Avalanche Services

PRIME CONSULTANT: McElhanney Consulting Services Ltd.

RACS PROJECT FACTS

NUMBER OF AVALANCHE GUARD TOWERS INSTALLED IN 2016: Three on Mount Fidelity and two on Mount Fortitude

WEIGHT OF INDIVIDUAL LOADS FLOWN EXTERNALLY VIA K-MAX HELICOPTER WITH INTERMESHING ROTORS: 2,400kg

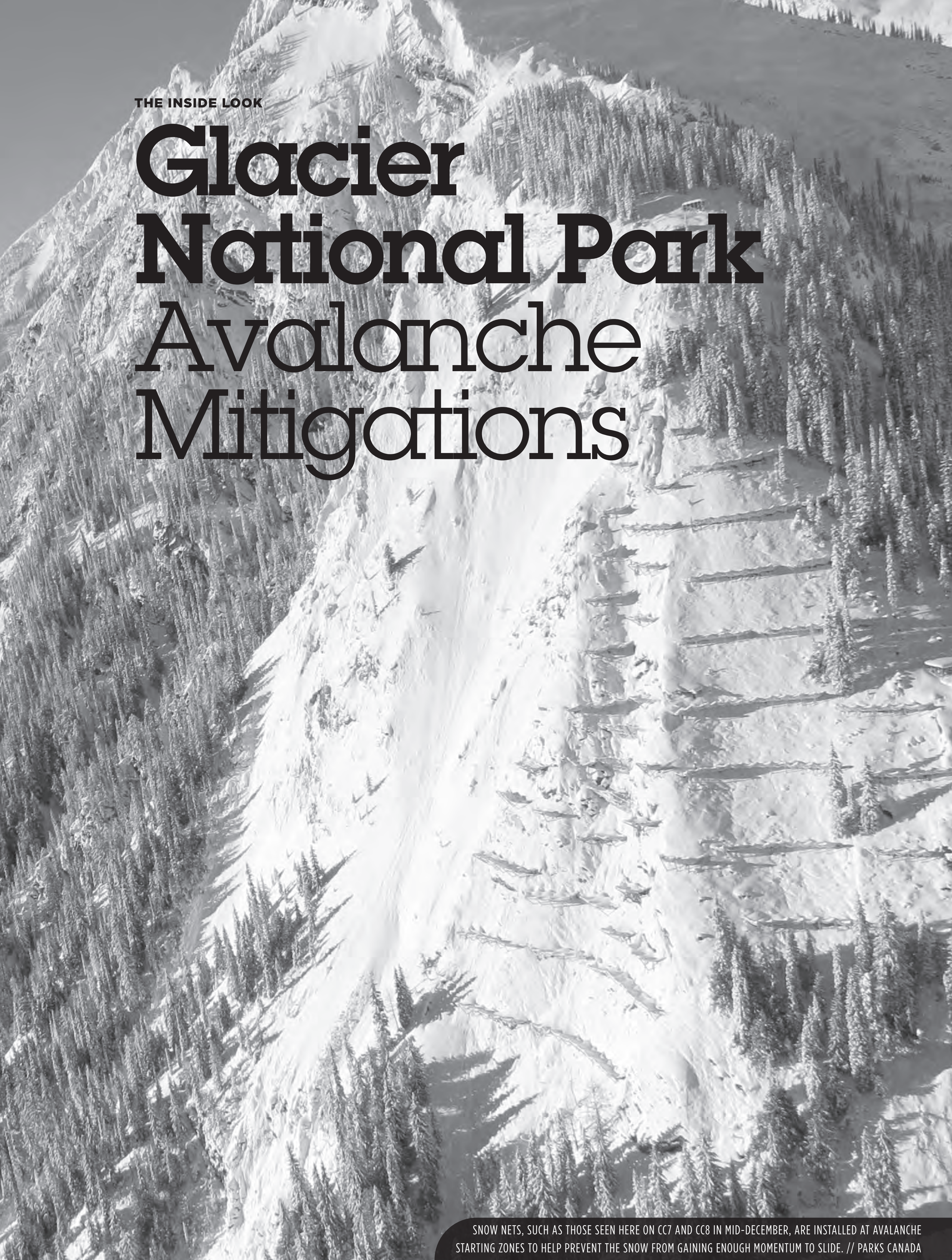
RACS PROJECT CONTRACTOR: CIL Explosives

PRIME CONSULTANT: McElhanney Consulting Services Ltd.

ROWS OF GEOBRUGG SPIDER SNOW NETS ARE INSTALLED ON COUGAR CORNER SLIDE PATH #8 (CC8) IN ROGERS PASS, AT A TOP ELEVATION OF 1,675 M AND AVERAGE SLOPE ANGLE OF 50 DEGREES. TO THE LEFT, SLIDE PATHS CC7 AND CC6 AWAIT INSTALLATION OF SNOW NETS. // PARKS CANADA

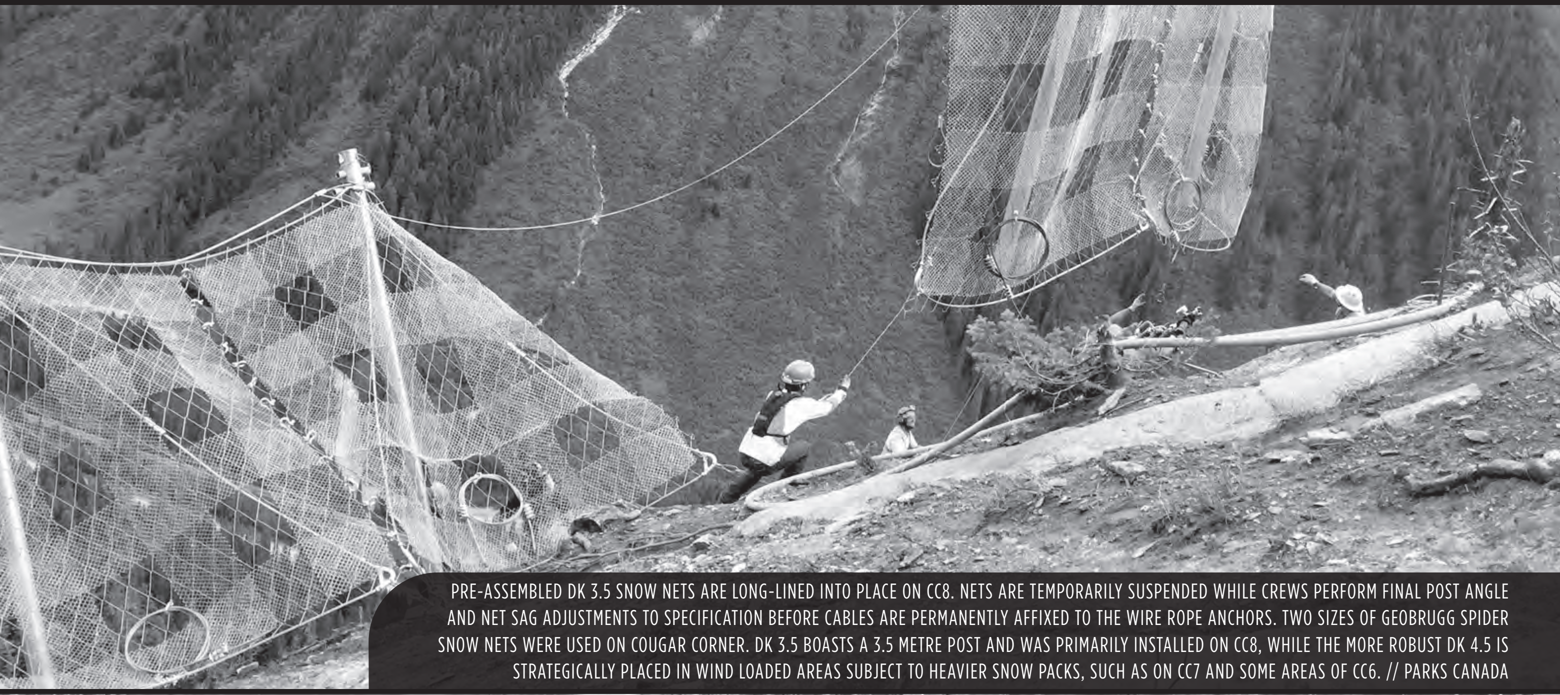
THE INSIDE LOOK

Glacier National Park Avalanche Mitigations

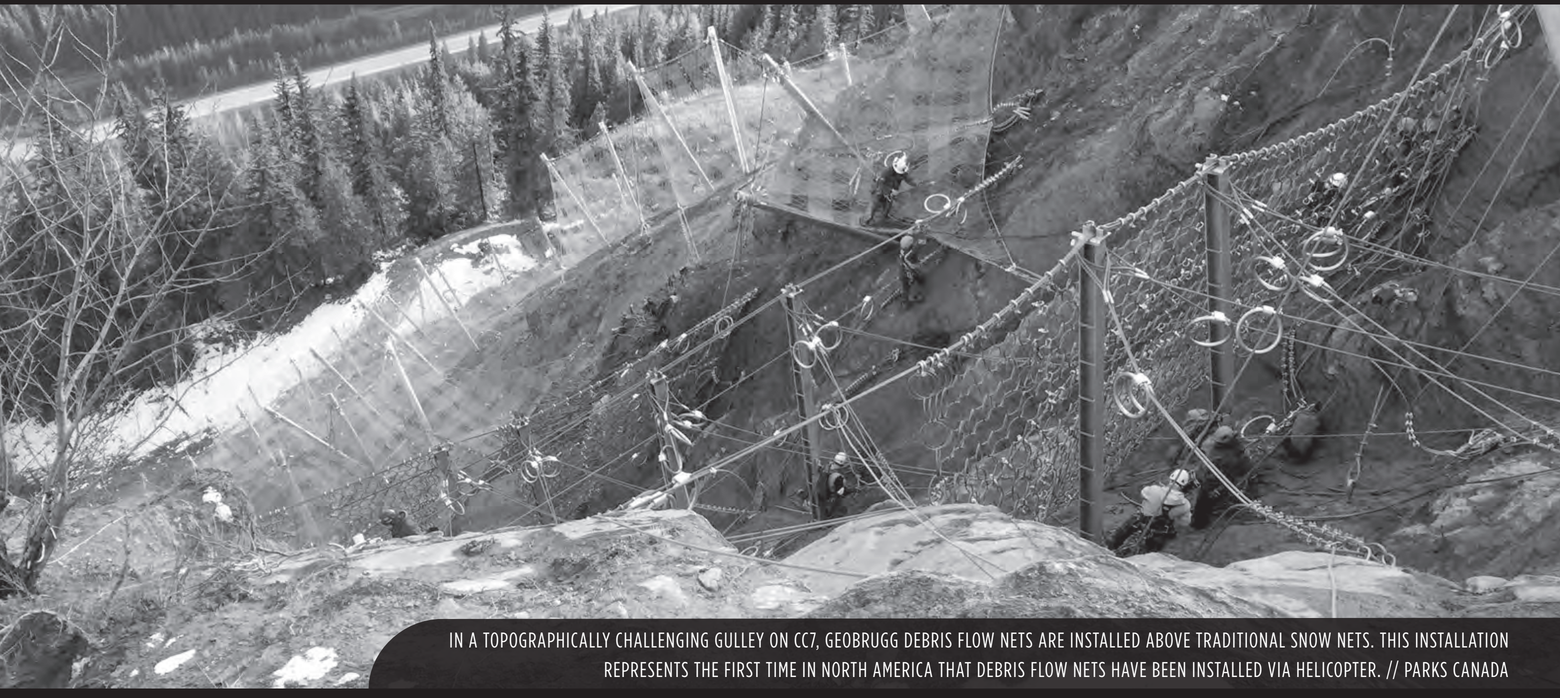


SNOW NETS, SUCH AS THOSE SEEN HERE ON CC7 AND CC8 IN MID-DECEMBER, ARE INSTALLED AT AVALANCHE STARTING ZONES TO HELP PREVENT THE SNOW FROM GAINING ENOUGH MOMENTUM TO SLIDE. // PARKS CANADA

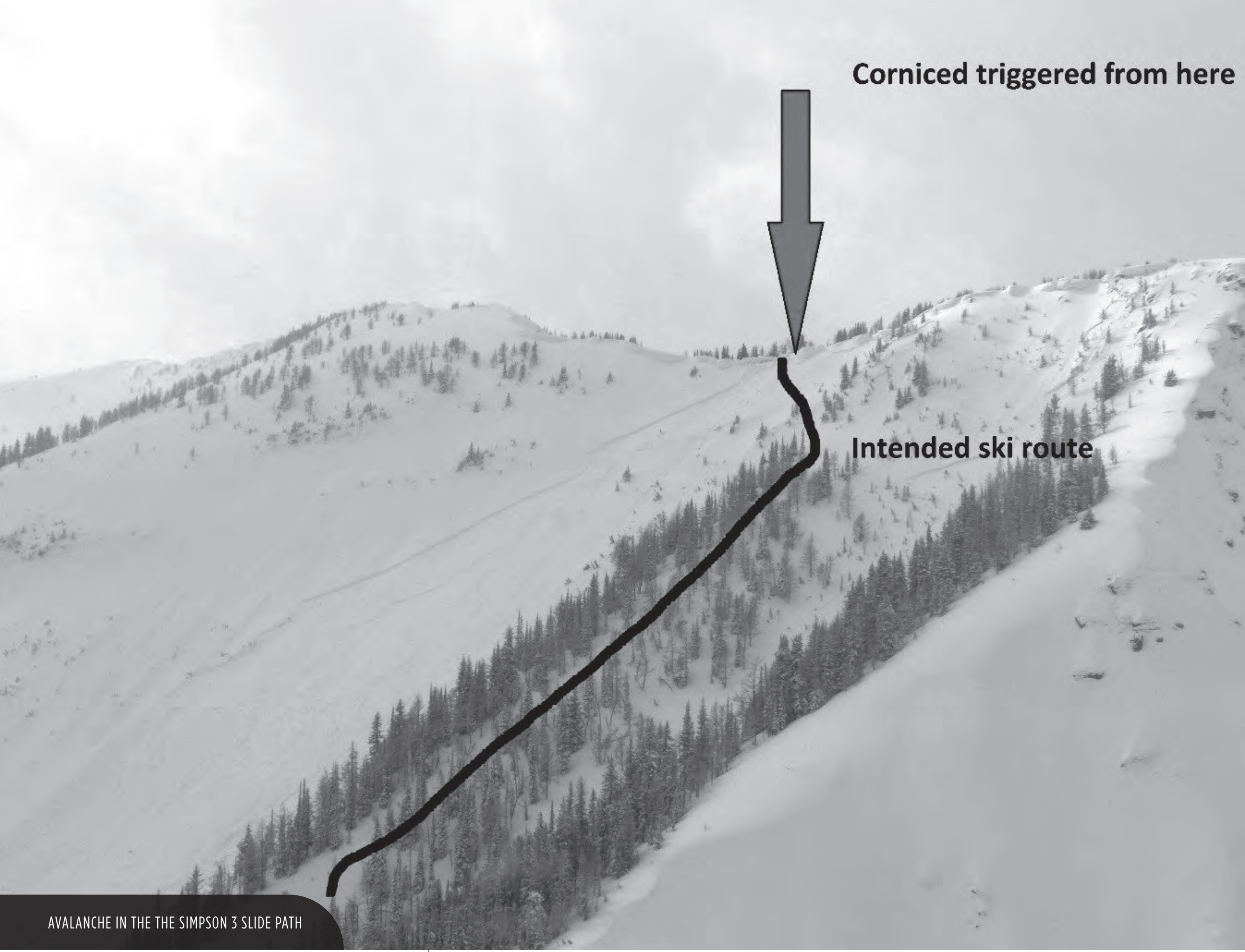
LOCATED AT 2,260M ON MOUNT FIDELITY'S SOUTH RIDGE, THIS AVALANCHE GUARD TOWER DIRECTS CHARGES AT FIDELITY SLIDE PATH TARGETS 2 AND 3. EACH TOWER CONTAINS ONE OR TWO BOXES, EACH HOUSING 10 4KG CHARGES AND EACH BOX AIMED AT ONE TARGET. // PARKS CANADA



PRE-ASSEMBLED DK 3.5 SNOW NETS ARE LONG-LINED INTO PLACE ON CC8. NETS ARE TEMPORARILY SUSPENDED WHILE CREWS PERFORM FINAL POST ANGLE AND NET SAG ADJUSTMENTS TO SPECIFICATION BEFORE CABLES ARE PERMANENTLY AFFIXED TO THE WIRE ROPE ANCHORS. TWO SIZES OF GEOBRUGG SPIDER SNOW NETS WERE USED ON COUGAR CORNER. DK 3.5 BOASTS A 3.5 METRE POST AND WAS PRIMARILY INSTALLED ON CC8, WHILE THE MORE ROBUST DK 4.5 IS STRATEGICALLY PLACED IN WIND LOADED AREAS SUBJECT TO HEAVIER SNOW PACKS, SUCH AS ON CC7 AND SOME AREAS OF CC6. // PARKS CANADA



IN A TOPOGRAPHICALLY CHALLENGING GULLEY ON CC7, GEOBRUGG DEBRIS FLOW NETS ARE INSTALLED ABOVE TRADITIONAL SNOW NETS. THIS INSTALLATION REPRESENTS THE FIRST TIME IN NORTH AMERICA THAT DEBRIS FLOW NETS HAVE BEEN INSTALLED VIA HELICOPTER. // PARKS CANADA



AVALANCHE IN THE THE SIMPSON 3 SLIDE PATH

Near Miss in the Simpson Control Paths, Kootenay National Park, March 14th, 2016

Story and Photos by Ian Jackson,
Visitor Safety Technician, Banff, Yoho & Kootenay National Parks, CAA Professional Member and ACMG Mountain Guide

NEAR HIT?

On March 14, 2016, my colleague Grant Statham and I were on a forecasting field trip to the Simpson study plot near Vermillion Crossing in Kootenay National Park. This area is adjacent to the Simpson control paths, which are regularly monitored as part of the Banff, Yoho and Kootenay (BYK) avalanche control program. We followed the regular uptrack through the trees, to the established study plot at ~2,050m. We did a full profile at the study plot and got no alarming results. We decided to ski to the ridgeline and investigate a loop skiing down Simpson 3 (one of the highway control paths) and onto the ridge between Simpson 3 and 4.

We did some ski testing with small cornices on the way up Simpson 1 and got no results, and then skied a short steep north facing run into the hanging valley above Simpson 3. We uptracked onto the ridge and skied along the corniced ridgeline towards the entrance to our proposed run to do some more testing with cornices when I triggered a truck-sized cornice at my ski tips.

The cornice landed on the slope below and triggered a size 3 avalanche in the Simpson 3 slide path (Fig. 1). This failed on a suncrust layer down 50–100cm, which was not a layer we were tracking. The fracture line was approximately 200-300m wide and ran for about 1,200m, taking out much of our intended ski route. Nobody was involved in the avalanche. We were obviously surprised by this and momentarily concerned about the open highway below. Upon further investigation, the avalanche had stopped ~400m from the road.

ANALYSIS

This event was significant as it was a near miss with a large avalanche that was not forecast by our hazard assessment, and occurred in terrain that we were planning on skiing that day. Additionally, this avalanche occurred in a path above an open highway. It identified an avalanche problem that was not being tracked and showed that our forecasting team was more out of touch with the conditions than we thought. The following factors contributed to our near miss:

1. OPERATIONAL PRESSURES

The morning forecasters' meeting was rushed to get out the door for a bigger field day. We didn't spend much time discussing current conditions or looking at the terrain we were planning on going to as we were busy getting out the door and on the road. The field day was rushed as we had to move quickly to make it back for a forecaster meeting planned for the end of the day.

2. SNOWPACK OBSERVATION GAPS

- Both forecasters felt out of touch with the snowpack as they had not been in the field much recently, especially in the Simpson area.
- No surface instabilities were noticed with ski testing while uptracking, and variable but not alarming results in the snow profile gave us confidence and confirmed our incorrect hazard assessment.
- We were not tracking the February suncrust layer well, and its presence was not known in the Simpson paths. This layer did not show up in the study plot profile, and we had not seen many avalanches failing on buried sun crusts; it caught us by surprise. In hindsight, it seems obvious that a sun crust would have formed during the warm weather of the preceding weeks. We had been intentionally staying off of solar aspects due to ski quality, so didn't have direct observations of this crust.
- We talked about cornice growth since previous visits multiple times, but the uptrack wasn't adjusted enough to give the cornices an extra margin and we didn't make the connection to the wind-loading of new snow into the start zone.

3. BIASES

- We hadn't solidified our trip plans in the morning, but had the trip in the back of our minds as a possibility if conditions looked favourable at the study plot and on the tour up. The ski quality was excellent, the tour made for a good loop with fall-line skiing in terrain that we didn't visit often, and we had pre-placed a bike shuttle on the highway. These factors created a motivational bias to complete the more aggressive loop.
- I had done the same trip three times earlier that year and was familiar with the terrain. I felt that the deep persistent problem was not present as it had been cleaned out by avalanche control earlier in the year, and the wind slab would be no bigger than size 2 and manageable with cornice testing from the ridgeline. This familiarity with the terrain from earlier in the year became a bias pushing me into more aggressive terrain than I otherwise would have been comfortable with.

Despite all of this, we made a critical snowpack observation that influenced the decision to do avalanche control in the following days. Forecasters added a layer to the avalanche hazard assessment and triggered many large avalanches during control over the next three days.

SUMMARY

Near-miss incidents are often the result of many small errors that alone would be inconsequential, but when added together create an accident or a near miss. In the case of Simpson 3, the biggest of these errors was that the forecasting team that day never had a good discussion about the terrain they were planning on travelling into before they were there. The group terrain discussion which occurs in the form of a run list discussion at most ski guiding operations was not present and may have prevented this near miss. Given the geography and operational constraints of the BYK Visitor Safety program, it is improbable to use a run list for all the possible terrain that we may access as in a typical guiding operation. However, we have identified this lack of group terrain discussion as a gap in our risk assessment and are working on ways to improve on this. New approaches include adopting the strategic mindset as a tool to guide a generalized terrain discussion, creating a modified run lis of popular areas, and working on ways to streamline the rest of our morning meeting tasks to enable us to spend more time on the important terrain discussions. Additionally, we have decided to adopt a new study plot location near the Simpson control paths that will better represent suncrust problems and help fill the gap in our snowpack observations there.

Given that we accidentally triggered a large avalanche in a path above an open road, our team had a discussion on whether we should implement a protocol to guide when and how we access terrain above open roads. After some discussion, and given that many of our paths have a long runout before they affect the road, we decided the benefits of gaining information from field trips to the start zones outweighed the potential risks of triggering an avalanche onto the open road and didn't create any new policies. Instead, we are using this incident as a reminder to our team of the high consequences of terrain above the highway.

Reflecting on this near miss, and reading near miss reports from other operations, it seemed that there were a higher than usual number of professional near misses and incidents in 2015-16. This raises some important questions: Are professionals having more near misses now than in the past? Is there a trend? Is this season's high number of professional near misses due to unique snowpack conditions? Is there just a better culture to share these events? Or am I simply biased by my recent near miss? Many of these near misses were shared openly amongst the professional community. Whether through the InfoEx, Informalex or a company's internal email system, it was great to see that professionals were open to sharing and learning from each other's mistakes. Often there is not a big difference in actions and decisions between a near miss and an accident, so sharing and learning from these near misses is critical.

Based on the near misses of winter 2015-16, we decided to make some changes to the way we keep track of and share near miss incidents in BYK Visitor Safety. We gathered approximately 10 years of historical near miss data to create a baseline database of incidents in our program and improved recording protocols going forward to ensure all future near misses are recorded and shared amongst the entire Mountain Parks Visitor Safety Program. These changes will allow us to share notable events and track trends more easily.

I think near miss tracking and recording is a critical step to increasing the safety of avalanche professionals and I hope that my sharing this incident inspires other CAA members to share their near misses going forward. Many near misses are shared openly on the InfoEx, in this publication and at the CAA spring meetings, and we generally have an open culture about promoting these reports and learning from them. However, to my knowledge, we don't record and archive professional near misses anywhere. Can we do a better job at this so that we can learn from and see trends in the data? Is the InfoEx a suitable platform? I think these are worthwhile questions for all avalanche professionals to consider as we continue to improve our risk management systems going forward.

Have a safe winter and share those near misses so we can all learn from them.

DEPARTING MANAGING EDITOR KARILYN KEMPTON ENJOYING THE GOODS // JACOB HANSON

Operational Avalanche **Risk Management**

Cam Campbell, Steve Conger,
Brian Gould,
Bruce Jamieson,
Grant Statham
Canadian Avalanche Association,
Revelstoke, BC

THIS ARTICLE IS THE SECOND IN A SERIES EXPLORING TECHNICAL ASPECTS OF SNOW AVALANCHE RISK MANAGEMENT.

PREAMBLE

In its first year of publication, The CAA's Technical *Aspects of Snow Avalanche Risk Management - Resources and Guidelines for Avalanche Practitioners in Canada* (TASARM) is beginning to gain acceptance, with both new and existing risk management concepts and terminology being incorporated into several operations. The following article is intended to help provide linkages from current practice to operational risk management as described in TASARM. The CAA ITP is also beginning to incorporate TASARM, with the goal of having it as an established reference document for all professional avalanche practice in Canada.

1 INTRODUCTION

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. This article draws on material from TASARM and the upcoming *A Land Managers Guide to Law, Ethics and Human Resources for Addressing Snow Avalanche Risk in Canada* to outline the operational avalanche risk management process from hazard or risk identification through to mitigation. In this article, operational avalanche risk management is described in terms of how it applies to a typical day of work for an avalanche practitioner (e.g., technician, forecaster or guide). This typically involves two distinct risk assessments:

1 Office-based avalanche risk assessment and forecast in the morning prior to the upcoming day of outside work, which usually relies on avalanche, snowpack and weather data from a variety of sources.
2 Real-time avalanche risk assessment often in the immediate proximity of the avalanche hazard. This is generally an assessment of current risk, with "now forecasting", and relies on the results of the morning risk assessment as well as any data collected from the field, up until the time of the assessment.

2 BACKGROUND

This section reviews background concepts found in TASARM and the *Land Managers Guide* that assist in understanding the underlying foundation for operational avalanche risk management.

2.1 Risk Tolerance and Acceptance

In order to effectively manage avalanche risk, it is important to understand societal risk tolerance and how that relates to the acceptable risk of an operation, and an individual.

2.1.1 Risk Tolerance

Risk tolerance is an organization's or society's readiness to accept the uncertainty and potential outcomes after the mitigation in order to achieve objectives (after CSA, 2011; ISO, 2009). Risk tolerance is a condition in that it represents expectations. Factors affecting Canadian tolerance to snow avalanche risks include:

- History of similar events: has it happened before and been deemed preventable?
- Multiple fatalities: as shown in an F-N plot of societal risk tolerances (Section 2.1.1.1, Fig. 1).
- Vulnerable victims (e.g., society is less tolerant of avalanche risk if minors are involved).
- Perceived ineptitude: where the public perceives the event was caused by ineptness, whether this is true or not.
- Role of government: where the government is seen as being responsible for public safety and when the public is not safe the government is asked to react (e.g., cost recovery for Search and Rescue groups or government funding for public avalanche safety programs).

• Voluntary or involuntary risk (e.g., societal avalanche risk tolerance for workers (involuntary) is much lower than recreationists (voluntary)).

2.1.1.1 F-N Plot

Societal risk tolerance can be represented as a two-dimensional relationship between frequency and cumulative severity of outcome, called an F-N plot (Kendall et al., 1977) (Fig. 1). F-N plots typically define societal tolerance of risk in terms of the annual frequency (F) of events with number (N) or more fatalities. Based on the premise that society tends to be more concerned about multiple fatalities in a single event, as the number of fatalities per event as well as frequency increases, societal tolerance for the risk decreases.

On the F-N plot, societal risk tolerance can be divided into three zones:

- Intolerable.
- Tolerable if *as low as reasonably practical* (ALARP) (Section 2.1.1.2).
- Broadly tolerable.

The borders between these zones are typically plotted as a straight line on a logarithmic graph (Fig. 2).

2.1.1.2 ALARP

When risk tolerance is not provided by regulations, standards or the organization conducting the risk planning, it is often appropriate to develop a risk evaluation system that measures and ranks each risk scenario to help prioritize them. One strategy is to use the *as low as reasonably practical* (ALARP) criteria as outlined in Fig. 2. Under ALARP, high risks for potential harm must be reduced to a sliding scale where costs and benefits can be directly compared (CSA, 1997; Weir, 2002). Risks are as low as reasonably practical when the mitigation efforts result in a tolerable level of risk that cannot be reduced further without resources and costs being disproportionate to benefit gained, or where the solution is impractical to implement. This includes costs of not meeting the operational objectives (e.g., good skiing or keeping the road open).

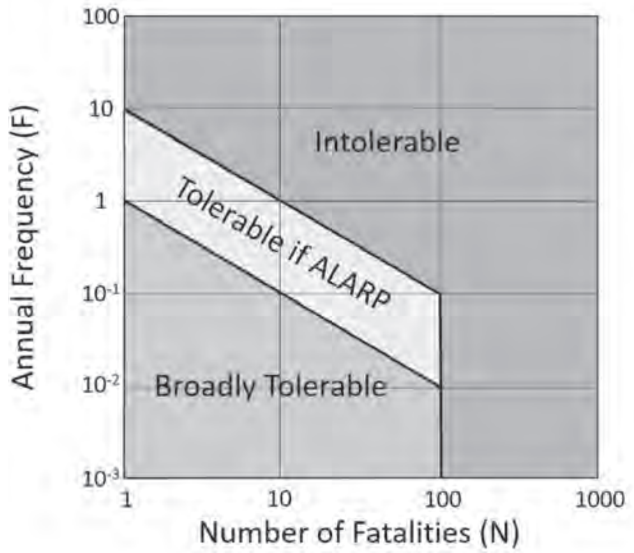


FIG. 1: THE AVALANCHE RISK MANAGEMENT PROCESS. THE CENTRE OF THE DIAGRAM ILLUSTRATES THE PARALLEL PATHS THAT FOCUS ON EITHER PLANNING OR OPERATIONAL ACTIVITIES AND IDENTIFIES HOW THIS STRUCTURE ALIGNS UNDER THE ISO 31000 UMBRELLA.

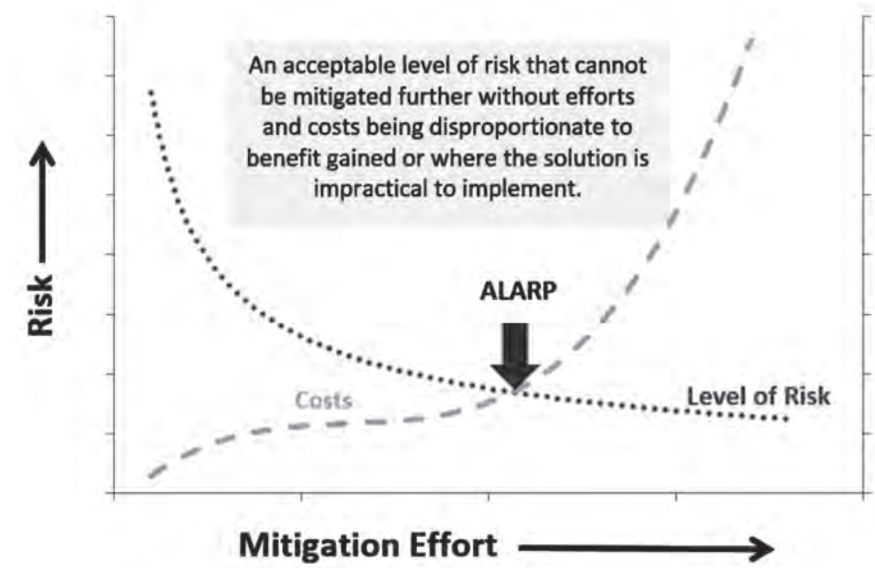


FIG. 2: EXAMPLE OF "AS LOW AS REASONABLY PRACTICAL" (ALARP) RISK EVALUATION STRATEGY. AS SHOWN IN THE FIGURE, RISK IS MITIGATED TO A LEVEL AS LOW AS REASONABLY PRACTICAL WHEN THE RESIDUAL RISK IS ACCEPTABLE AND ANY ADDITIONAL RISK REDUCTION COMES AT A DISPROPORTIONATE MITIGATION COST OR EFFORT, OR IS IMPRACTICAL TO IMPLEMENT.

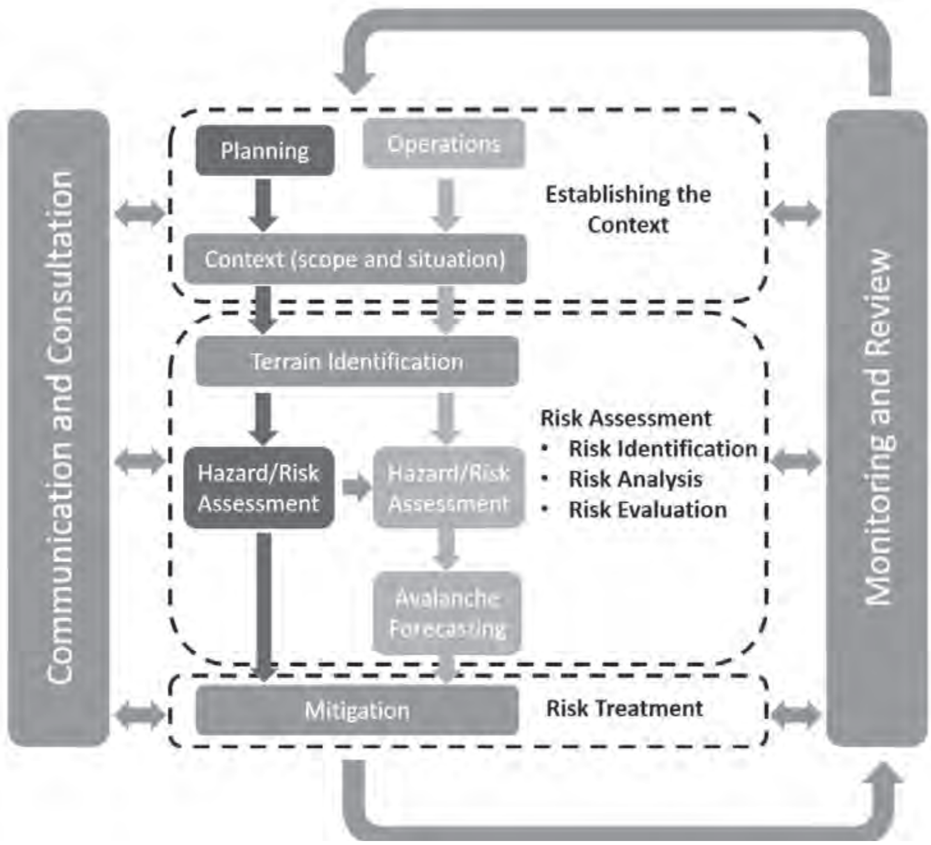


FIG. 2: THE AVALANCHE RISK MANAGEMENT PROCESS (CAA, 2016B). THE CENTER OF THE DIAGRAM ILLUSTRATES THE PARALLEL PATHS THAT FOCUS ON EITHER PLANNING OR OPERATIONAL ACTIVITIES AND IDENTIFIES HOW THIS STRUCTURE ALIGNS UNDER THE ISO 31000 UMBRELLA (CSA, 2010).

2.1.2 Acceptable Risk

Risk acceptance is the informed decision to take a particular risk (ISO, 2009). Risk acceptance is an action in that it represents a decision, which for operations is often in the form of an operational risk band (Section 6). The operational risk band is described as the area between an upper and lower limit of acceptable risk. Decisions that, in hindsight, are above the upper limit (e.g., allowing too much uncertainty or exposure to harm) can lead to incidents that are intolerable. Decisions below the lower limit represent excessive conservatism and likely missed opportunity or unnecessary failure of meeting objectives. Excessive costs (e.g., death or economic loss) characterize errors of decisions outside either limit (McClung and Schaerer, 2006).

2.2 The Process

Fig. 3 illustrates the overall risk management process including both the planning and operations stages (CAA, 2016b). 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.

In general terms, hazard can be defined as the potential for harm or loss and risk is the exposure of something of value to the hazard. In operations hazard is expressed in terms of likelihood of triggering and destructive size, while risk is often expressed in terms of probability and consequence, or hazard and the exposure and vulnerability of the element at risk (Section 6.2).

In this process, the risk assessment is treated separately from hazard assessment. This is because avalanche risk management can conclude with a hazard assessment, which is often the case when producing avalanche hazard bulletins, or in the event that there is no hazard, there's no need to carry on with a risk assessment. However, a risk assessment is typically based on an initial hazard assessment, and the exposure and vulnerability of the element at risk is then factored in.

Although this article focuses primarily on the risk assessment and mitigation steps of operational avalanche risk management, it is important to remember that successful operational avalanche risk management is based on sound planning and includes mechanisms for ongoing monitoring and review as well as communication and consultation.

2.2.1 Monitoring and Review

In an operational setting, ongoing *monitoring and review* of avalanche risk, forecasting and mitigation effectiveness is used to revise the risk assessment, avalanche forecast and mitigation strategies in a real-time continuous feedback loop. Furthermore, daily review of the risk assessment, avalanche forecast and mitigation (e.g. during an evening guides meeting) helps inform the baseline risk assessment for the following day by summarizing the current hazard and confidence levels, and identifying knowledge gaps.

2.2.2 Communication and Consultation

Ongoing internal communication and consultation throughout the risk management process helps to support and encourage accountability and ownership of risk within an organization (CSA, 2010). This includes an open and transparent risk management system that contains processes to consolidate information from a variety of sources. This could also include mechanisms that encourage team decision-making, as well as reporting of "near-misses", which can be valuable to validate the effectiveness of a risk management program.

3 ESTABLISHING THE CONTEXT

3.1 Scope

The scope of operational avalanche risk management identifies objectives, hazard/risk criteria, relevant factors (internal and external) of the activities, or parts of the organization where the risk management process is applied. Defining the scope of the assessment (and resulting mitigation, if required) includes the clear statement of the operational objectives. The recognition of factors (internal and external) relevant to the organization or activities is also necessary to define the scope. Examples of scope of risk assessment for avalanche operations include:

- Complete a morning hazard evaluation for a helicopter-skiing operation and assess daily risk with the guiding team on a run-by-run basis.
- Conduct explosives control on a slope adjacent to a ski run in order to test instability and determine whether to open the area.
- Analyze regional snowpack data in order to determine if threshold snowpack depths have been reached for a remote site.
- The completion of a site-specific snowpack test to build upon an earlier desktop analysis in order to determine whether to ski a slope.

3.2 Situation

A situation is described by the intersection of three factors: element(s) at risk, scale and avalanche risk scenario(s). An element at risk describes the population, properties, environmental elements, economic activities and services in the area affected by the avalanche(s) (after IUGS, 1997). Scale refers to the physical extent of terrain or geographic area (i.e. spatial scale) of the hazard, as well as the time span (i.e. temporal scale) over which the element at risk is exposed. Scenarios are a hypothetical sequence of events that answer the question "What could go wrong (or right) during the exposure of the element(s) at risk to the hazard?"

Outlining the situation for an operational avalanche risk assessment begins with identifying the element(s) at risk and determining the physical (spatial) extent of terrain or geographic area where operations will occur. This may be specifically described in a risk-control plan or may be recognized and acknowledged as part of daily practice procedures. The temporal scale and associated risk scenarios are then formulated based on the scope.

4 TERRAIN IDENTIFICATION

Operational avalanche terrain identification is an ongoing recognition of the extent of the geographic area where avalanche hazard may exist. It typically occurs at various times and locations during an operational period, and is often part of a continuous search for terrain-correlated patterns of instability (Section 5.1). It may include a visual review of terrain atlas or mapping during the pre-field trip meeting. It also occurs in the field through the direct recognition of terrain configuration, steepness and other characteristics associated with avalanche initiation, flow and runout areas.

The terrain identification can be summarized in these sequential questions as the operational day progresses:

- Where can an avalanche occur?
- Can this terrain produce an avalanche?
- What is the severity of the terrain? (E.g. what is the scale of potential exposure; are there terrain traps?)
- What is my position relative to the boundaries or parts of the path?

Operational terrain identification for the current day is applied to base maps or photos prepared at the planning stage to visualize topography, as well as review of reports from other avalanche operations to determine specific terrain characteristics of particular avalanche problems. Subsequent aerial reconnaissance and/or ground-based observations may occur in conjunction with ongoing operational hazard/risk assessment as a component of both hazard and risk identification.

5 HAZARD ASSESSMENT

An operational avalanche hazard assessment is a series of activities undertaken to:

1. Describe the avalanche problem.
2. Recognize the potential for a harmful avalanche.
3. Monitor and analyze the environmental conditions that contribute to the hazard.

4. Estimate the likelihood and magnitude of a harmful avalanche.

These activities fall within the general steps of identification, analysis and evaluation.

5.1 Hazard Identification

The first step of hazard identification is accomplished in the terrain identification. The next step applies the snowpack to the terrain. Here the first question is about thresholds, i.e. has the snow cover reached the threshold where ground roughness has been smoothed? This is followed by questioning whether threshold amounts of snow to produce a slab or instability have been reached or might be reached during the current weather conditions. This information relates to the consequence component of the hazard, i.e., what is the destructive size?

Hazard can also be identified through information regarding its likelihood, e.g. reports of Class I data from neighbouring operations, observed instabilities through testing or natural activity, or local avalanche problems described in prior operational meetings.

5.2 Hazard Analysis

Avalanche hazard analysis involves the systematic observation, monitoring and investigation of avalanche activity, and snowpack and weather conditions. In addition to emphasizing relevant measurement values, analysis considers the strength, weight and associated uncertainties of the gathered evidence. The careful observation and systematic recording of these factors supports the feedback loop for operational avalanche hazard analysis.

5.2.1 *Avalanche Activity*

Observation of avalanche activity is direct evidence of snow cover instability and considered the strongest supporting information when undertaking the hazard analysis. An important analysis tool is discovery through patterns of avalanche activity. The compilation of this information (or the identification of a lack of it) from both local and near-by operations is a vital step in the pre-field trip operational meeting and should be included in structured hazard and risk assessments (e.g. AM Hazard & Risk Assessment Worksheet).

5.2.2 Snowpack

Hazardous avalanches typically require a threshold snow depth of 30 to 60cm beyond the amount required to smooth ground roughness or irregularities. Upon nearing this threshold, regular observation and recording of snowpack structure and instability is necessary. Since it is not feasible to assess every slope, extrapolation of this information across the spatial scale of the situation is essential. Temporal change of this information necessitates monitoring on an appropriate interval to minimize uncertainty. Understanding the distribution of snow structure and characteristics of weak layers across the terrain is an ongoing requirement in avalanche operations.

5.2.3 *Weather*

Weather factors have a direct influence on the snowpack, which in turn directly influence the avalanche hazard. Typical observations include sky cover and solar radiation, precipitation type and intensity, air temperature ranges, relative humidity, recent snowfall and total snowpack depth, wind direction and speed, and blowing snow (CAA, 2016a). Spatial redundancy of observations helps to reduce uncertainty.

5.3 Hazard Evaluation

Operational hazard evaluation consists of comparing the results of the analysis against benchmarks such as an ordinal set of descriptors. The Canadian Avalanche Association's hazard rating scale used for InfoEx hazard assessments (Table 1) is an example of operational hazard evaluation. Its primary objective is to accompany an InfoEx hazard assessment

TABLE 1: CANADIAN AVALANCHE ASSOCIATION'S AVALANCHE HAZARD RATING SCALE USED FOR INFOEX HAZARD ASSESSMENTS

Hazard level	Likelihood of triggering	Size and distribution
5 (Black)	Natural and artificially triggered avalanches almost certain.	> Size 3 avalanches are widespread.
4 (Red)	Natural avalanches likely; artificially triggered avalanches very likely.	Size 2-3 avalanches are widespread; or > size 3 avalanches in specific areas.
3 (Orange)	Natural avalanches possible; artificially triggered avalanches likely.	< Size 2 avalanches are widespread; or size 2-3 avalanches in specific areas; or > size 3 avalanches in isolated areas.
2 (Yellow)	Natural avalanches unlikely; artificially triggered avalanches possible.	< Size 2 avalanches in specific areas; or size 2-3 avalanches in isolated areas.
1 (Green)	Natural and artificially triggered avalanches unlikely.	< Size 2 avalanches in isolated areas or extreme terrain.

and provide a relative measure of avalanche hazard that corresponds to a set of definitions for each of the five levels. Operational hazard evaluation is an ongoing process that occurs in real-time and typically leads to forecasts within time scales of 12 to 72 hours.

5.3.1 *Avalanche Problem*

Operational hazard evaluation integrates weather, snowpack and avalanche analysis with local terrain factors and weather forecasts. The avalanche hazard evaluation determines the character (Atkins, 2004), elevation and aspect, likelihood, and size of potential avalanche events based on the analysis. This construct of the avalanche problem describes the avalanche hazard and regularly includes the degree of confidence and representation of uncertainties associated with the estimation.

5.3.2 Conceptual Model of Avalanche Hazard

The conceptual model of avalanche hazard (Statham et al., in prep) is a series of independent concepts and components that when linked together in a stepwise fashion, provide an organizing framework for the process of avalanche hazard assessment (Fig. 4). Starting from an initial state (operational objectives, scale) the model proceeds through a succession of analytical steps (avalanche character, location, likelihood of triggering, avalanche size) before concluding with a rating of avalanche hazard.

Avalanche character (Atkins, 2004) describes different types of avalanche regimes, each of which presents a general, repeatable pattern of potential or observed avalanche activity that suggests a distinct approach to risk treatment (Statham et al., in prep). An avalanche character (e.g. wind slab, storm slab, persistent slab, deep persistent slab, wet slab, loose wet, loose dry, cornice fall and glide avalanche) is attributed to specific locations by aspect, elevation, vegetation bands, operating zones or terrain features. Likelihood of triggering is a function of the spatial density and distribution of the instability and the sensitivity to triggers of various sizes by natural or artificial means. Destructive size is typically represented by the avalanche size classification system (CAA, 2016a). The uncertainty in likelihood and magnitude (based on the uncertainty in the inputs) should be described/displayed and communicated.

6 RISK ASSESSMENT

A risk assessment provides evidence-based information and analyses to support informed decisions on how to treat particular risks and how to select between mitigation options (after ISO, 2009). An operational avalanche risk assessment is grounded in standardized methods along with the expertise and competence of the individuals performing the assessment. It is a continuous and iterative process that occurs on an ongoing basis, and may or may not be recorded in a variety of formats (e.g. notebooks, forms and/or databases).

An operational avalanche risk assessment builds on the hazard assessment results with these additional efforts:

1 Find, recognize and describe the element at risk.
2 Analyze its exposure and vulnerability to the hazard.
3 Determine the level of risk.
4 Compare the results to a given criteria to determine whether the risk meets the identified risk tolerance.

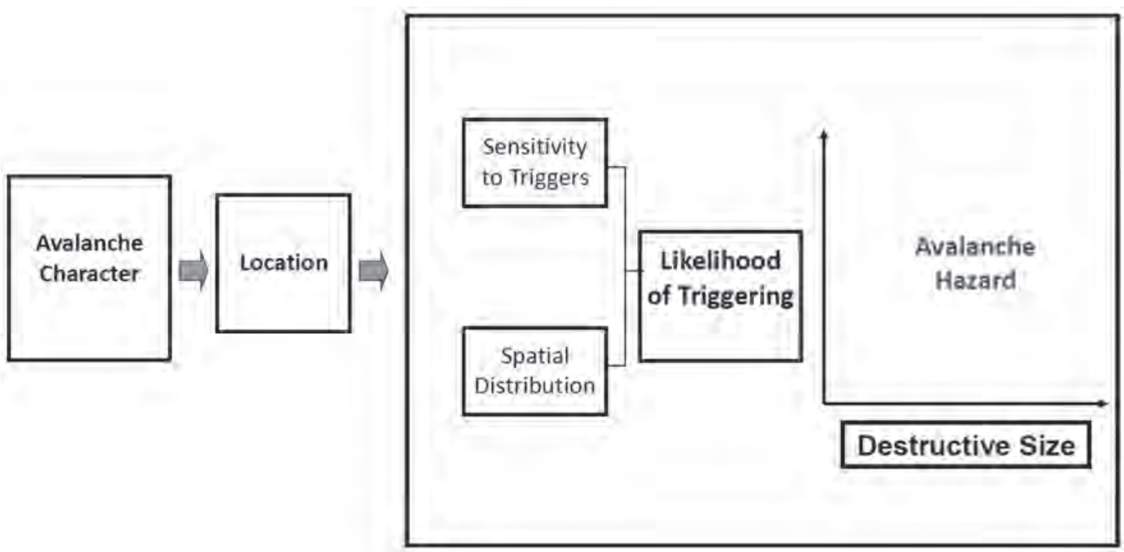


FIG. 4: THE CONCEPTUAL MODEL OF AVALANCHE HAZARD (STATHAM ET AL., IN PREP) IS USED TO CONSTRUCT THE AVALANCHE PROBLEM. FOR EACH AVALANCHE CHARACTER AT A SPECIFIC LOCATION, AVALANCHE HAZARD IS DETERMINED THROUGH EVALUATING THE RELATIONSHIP BETWEEN LIKELIHOOD OF TRIGGERING (A FUNCTION OF THE SENSITIVITY TO TRIGGERS AND SPATIAL DISTRIBUTION OF A WEAKNESS) AND THE EXPECTED AVALANCHE SIZE. AVALANCHE HAZARD IS OFTEN REPRESENTED AS A RANGE OF VALUES FOR BOTH LIKELIHOOD OF TRIGGERING AND DESTRUCTIVE SIZE, REPRESENTING VARIABILITY AND UNCERTAINTY.

These activities fall in the general steps of identification, analysis and evaluation. An example of a commonly used operational avalanche risk assessment method is the CAA's morning (AM) and afternoon (PM) Hazard and Risk Worksheets.

6.1 Risk Identification Through Scenarios
The risk identification step connects the hazard assessment to the element at risk through use of risk scenarios. The hazard assessment result provides a location, an estimation of the likelihood of occurrence, and magnitude for the potential avalanche hazard. This potential event is then combined with an element at risk.

In an operational setting, scenarios are typically mental visualizations of the planned activities and objectives that may occur in the area subject to the hazard. This step involves answering the question "Given the avalanche forecast and the locally observed conditions, what can happen?" This question serves both as an identifier of scenarios and supports the constant consideration aspect of maintaining situational awareness.

Visualizing scenarios allows consideration of various outcomes based on changes to the hazard or application of mitigation measures. Envisioning multiple scenarios assists the subjective judgment of event likelihood, consequences and level of uncertainty.

6.1.1 Element at Risk
The element at risk is determined by the operational setting and objectives. Within this parameter, elements at risk can be identified through answering the question "What or who is vulnerable to a potential avalanche?"

In operational risk assessment, the element at risk is typically people, but may include other elements as determined by the operational setting and specific objectives. For example, an avalanche risk manager for a highway might consider people as the primary element at risk, and vehicles and commerce as secondary.

6.1.2 Exposure
Each scenario typically involves different exposure levels of the element at risk to the avalanche hazard. Exposure is the extent to which the element(s) at risk is (are) subject to potential avalanche hazards. It is a function of the time period and position the element is present within an avalanche path. Controlling or managing exposure has a vital effect on the uncertainties associated with potential avalanche hazard.

6.1.3 Vulnerability
Each element at risk has an associated vulnerability, which is defined by the fraction of loss given that the element at risk is hit by or caught in an avalanche with specified magnitude. When people are affected by avalanches, vulnerability is the probability of death (after IUGS, 1997). Vulnerability of people is a function of:

- The personal protective equipment they are wearing or carrying (e.g. transceiver, airbag and helmet).
- Whether the person is in and protected by a building or vehicle, or whether they are outside and fully exposed to the avalanche.
- The ability of the person to free themselves from an avalanche if caught, which depends on, for example, their strength, ability and mode of travel (e.g. in a vehicle or on skis, snowmobile or foot).
- The ability of the person to be rescued in a timely manner if buried, which depends on, for example, the proximity, number and ability of rescuers, as well as the rescue equipment available to them.

6.2 Risk Analysis
Risk analysis is a series of actions undertaken to comprehend the uncertainties associated with the visualized scenarios. Operational avalanche risk analysis typically follows different approaches depending on whether the risk analysis is taking place in the office on the morning of a field day, or in in the field in real-time. A risk analysis approach for the first situation is presented by Statham and Gould (2016), where the exposure and vulnerability of the element at risk is systematically combined with the avalanche hazard to determine risk. This approach breaks risk into the components onto which mitigation can be applied (i.e. direct mitigation acts on the hazard, whereas indirect mitigation acts on the exposure and/or vulnerability of the element at risk), and, therefore helps to streamline the choice between mitigation options (Section 8).

However, in real-time in-situ situations, a more intuitive risk analysis model that helps to maintain situational awareness through repetitive consideration is typically used. This model is based on Kaplan and Garrick's (1981) probability and consequence risk definition, where probability is a function of the likelihood of an avalanche occurring and the exposure of the element at risk, and consequence is a function of the expected avalanche size and the vulnerability of the element(s) at risk. Answering the following questions guides the analysis:

1 How likely is it that a specific scenario will happen?
2 If it does happen, what would be the consequences?
3 What uncertainties can be reduced?

6.3 Risk Evaluation
Avalanche risk evaluation compares the results of risk analysis with risk criteria to determine whether the risk is acceptable. The amount of uncertainty associated with the likelihood of the hazardous event or the potential consequence is also

considered in risk evaluation. In an operational setting, risk evaluation is often conducted in tandem with risk analysis where both are part of the same step in the risk assessment process. Typical strategies for operational risk evaluation use the operational risk band concept outlined in Section 2.1.2 as the evaluation criteria.

At a fundamental level, risk evaluation works through the questions:

1 What is tolerable? (Section 2.1.1)
2 How safe is safe enough? That is, what is acceptable? (Section 2.1.2)
3 What needs to be done?

What is tolerable is a prerequisite drawn from establishing the context. What is acceptable is the basis for the decisions of:

- Whether an activity should be commenced.
- Whether a risk requires mitigation.
- Mitigation prioritization.
- Which of a number of options should be chosen.

Implicit in the question of "how safe is safe enough" is the critical continuous feedback that occurs in operational avalanche risk assessment. This feedback comes in the evaluation of whether the chosen method of mitigation is effective and has altered the risk level to within what is acceptable. For example, the continued analysis and re-evaluation of hazard following explosive avalanche triggering efforts to determine if the avalanche forecast has changed substantially from the previous one. This reflects a return trip through the assessment steps prior to deciding to remove the mitigation measure of temporary closure and evacuation.

7 UNCERTAINTY AND DECISION AIDS

Uncertainty and confidence in the assessment are inversely related, where the lower the uncertainty, the greater the degree of confidence in the estimate of risk (Willow & Connell, 2003). One way to reduce epistemic, or knowledge-source uncertainty, is to use independent methods in the same assessment (e.g. decision aids). Fig. 5a shows the risk spectrum from low to high, with the operational risk band (ORB) somewhere in the middle. In this case the risk assessed with an aid is in fairly good agreement, with the risk assessed by an expert using judgement, so the assessment aid reduces uncertainty and increases confidence.

In Fig. 5b the decision aid indicated that the risk level is well above the ORB, but expert judgement suggests it is well within it. Again, assessment aids are often conservative and we need expert judgement to determine the true risk levels; however, this situation should raise some red flags. It may lead us to apply additional mitigation, just to be on the safe side. Or we may seek more targeted information to reduce uncertainty, and reassess to make sure we didn't miss anything. In these sorts of situations, we can often look at the underlying components of the assessment aid and find specific parameters that were perhaps weighted higher than what our judgement suggests, and we can adjust our assessment accordingly. Or upon further consideration, we may recognize that the assumptions or dataset limitations behind the decision aid limit its applicability to the risk being considered.

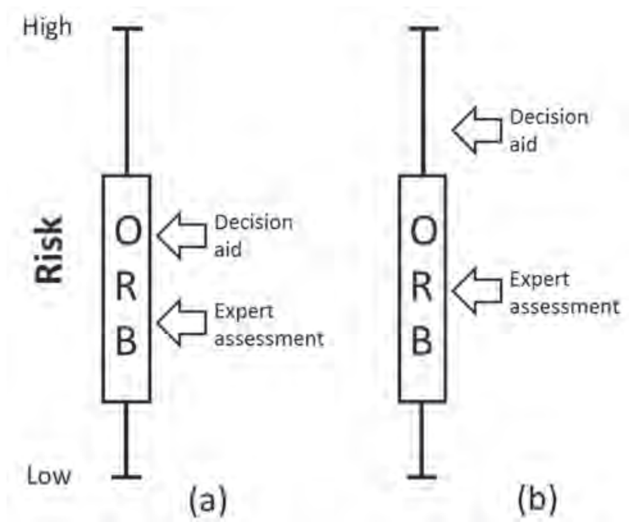


FIG. 5: HYPOTHETICAL RISK SPECTRUMS FROM LOW TO HIGH RISK WITH THE OPERATIONAL RISK BAND (ORB) SHOWN (MCCLUNG AND SCHAERER, 2006). TWO DIFFERENT CASES ARE SHOWN WERE (A) BOTH THE EXPERT ASSESSMENT AND THE DECISION AID INDICATE RISK IS WITHIN THE ORB, AND (B) THE EXPERT ASSESSMENT INDICATES THE RISK IS WITHIN THE ORB; HOWEVER, THE DECISION AID SUGGESTS THAT RISK IS HIGHER THAN THE UPPER LIMIT OF THE ORB.

8 OPERATIONAL RISK MITIGATION

Operational avalanche risk mitigation typically involves short-term measures that are effective for hours to days depending on the context. These mitigation can provide either direct intervention (i.e. act on the hazard) or indirect intervention (i.e. adjust the exposure and/or vulnerability of the element at risk).

8.1 Precautionary Evacuation and Restricted Access

The simplest short-term measure is precautionary evacuation and restricted access, as the risk is effectively eliminated while the measure is applied. Since precautionary evacuation and restricted access is a form of exposure control, the measure can be effective for people and any object that is mobile (e.g. a person on foot or in a vehicle), but cannot protect fixed property or infrastructure. Examples are provided in CAA (2016b), and they include:

- Evacuation of buildings.
- Curfew, if buildings are designed to withstand the effects of an extreme avalanche.
- Temporary closure, traffic delays or seasonal closures in the case of transportation corridors.

- Daily or temporary ski run or zone closures in the case of ski areas, and mechanized ski operations.
- Restricted access for personnel with limited training and experience (e.g., only those with CAA Level 2, and/or professional CAA membership allowed to access complex terrain during high hazard). This would normally be outlined in specific procedures and policies in an operation's avalanche risk management plan (Section 8.3).

8.2 Route Selection and Group Management

Route selection (or route finding) and group management is a form of exposure control used in all backcountry travel (i.e., for recreational, commercial and industrial purposes). It involves actively managing the movement of people through areas of avalanche hazard. Deliberate adjustments to the exposure of individuals or groups is routinely practiced in the daily operations of avalanche professionals travelling in the backcountry. Similarly, in a transportation setting, convoys are occasionally used to manage the exposure of traffic.

In real-time, the slope-scale risk mitigation practiced by avalanche professionals relies on an intimate understanding of the nature of avalanche formation, and the nuanced interaction between snowpack, terrain and people. Its critical function is the ability to make micro-adjustments to people's position and time spent in avalanche terrain that reduces their risk by limiting their exposure to the hazard. At its core level, it can be processed as probability and consequence; however, the tools to mitigate the risk generally involve adjusting the hazard, the exposure, or the vulnerability (Section 6.2).

8.3 Policy and Procedure

Risk control based on procedure and policy (P&P) involves the use of a structured operating procedure (e.g., risk matrix) to restrict or enable access to hazard areas based on forecasted hazard levels, terrain classification and level of training of the user. These systems are normally employed in an environment where there may be an array of field-based activities occurring at a large scale, and there is potentially a spectrum of staff training levels. They may also be used by a guiding or field team to restrict or enable specific routes (e.g., a run list). Details regarding the procedures and policies would normally be described in an avalanche safety plan.

Terrain classification used within the scope of P&P-based risk control is often determined in advance during the planning stage. Hazard ratings may be provided by a forecasting program within the organization, outside contract services, or from publicly available sources. However, it is important to note that P&P-based risk control should be guided by hazard assessments specific to the element at risk. If non-specific or inappropriate sources are used, it must be understood that there are often more restrictions than with risk control based on hazard and guidance provided by a forecasting program within the organization (or from contract services), due to potential differences in spatial and temporal scale, intended audience and element-at-risk characteristics.

The risk control procedure (risk reduction parameters and access decisions) are typically provided in a table or matrix format, an example of which can be found in Campbell et al., (2016).

EXAMPLE OF EVIDENCE GATHERING TO SUPPORT OPERATIONAL HAZARD ANALYSIS // M. BOISSONNEAULT

Avalanche safety equipment and training are standard requirements for all exposure to avalanche terrain, whether in a recreational or professional setting. These requirements, as well as an emergency response plan, are all normal components of P&P-based risk control. For workplaces, these are normally outlined in the organization's avalanche safety plan (ASP), along with maps and other procedures and policies (e.g., risk matrices).

8.4 Artificial Triggering and Snowpack Compaction

Artificial triggering reduces the hazard by releasing unstable snow at controlled times (during evacuations) and/or reduces the subsequent likelihood of triggering large avalanches. Triggering measures range from ski cutting and hand charging with explosives to sophisticated remote avalanche control systems utilizing either explosives or gas. The level and sophistication of triggering technique or system is normally based on cost-benefit evaluation and worker safety considerations. Often a combination of systems will be employed for a particular control program (e.g., ski area control routes that use ski cutting and hand charging).

The intent of snowpack compaction is to disrupt layers in the snowpack in order to reduce future instability. The snowpack can be compacted using intentional boot or ski packing, or as a corollary of public recreational ski or snowmobile traffic. The impact of compaction on hazard reduction, and resulting success as avalanche risk mitigation measure, depends on the snow and weather conditions that develop subsequent to compaction (generally over weeks to months).

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We Are Only Human After All: Human Factors in Mountain Rescue

Article and photo by Mike Inniss, MD, DiMM (ICAR)

THE MORE TIME WE SPEND IN THE MOUNTAINS, the more likely we are to find ourselves assisting fellow mountain folk in times of distress. Whether we are responding as organized professionals or because we happen to be in a certain place at a certain time, hopefully we can safely act in an efficient, effective manner to make someone's bad day a whole lot better. Unfortunately, to err is human nature. This article reviews the most common human factors that interfere with the safe operations of a rescue mission, at times with tragic results.

The mountain environment contains certain inherent elements of risk. At the end of the day we all want to go home to our loved ones in one piece—physically and mentally. A mantra of mountain rescue states that the priority of care is yourself first, your team next, and then your subject. Being mindful of the human factors that can interfere with an operation and potentially lead to an accident helps us to follow that sage advice. By identifying and minimizing the most common human factors that could contribute to a potential chain of negative events during a rescue operation, we can explore ways to lessen their potential impact.

Much of the work in this field comes from within the aviation industry, where the impact of human error can be immediate and drastic. Similarly in the field of medicine, medical error has now been established as a major cause of illness and death. Studies have shown that in Canada more people die from medical error than motor vehicle accidents each year. In the mountain environment, estimates are that upwards of 60 percent and perhaps as high as 80 percent of all accidents during mountain rescue are human error.

SITUATIONAL AWARENESS

At its roots we are all striving to maintain situational awareness and mitigate the human factors that can so easily sabotage it. The ability to maintain situational awareness is a critical and extremely valuable skill required on rescue teams. We have all likely experienced a momentary loss of situational awareness, often during stressful situations, and perhaps suffered consequences as a result. The cost to yourself and/or your team members can be too great in the mountain environment to allow a lapse to happen. Only with the maintenance of situational awareness can we maintain the critical shared mental model with our teammates that will enhance and ensure successful outcomes.

HUMAN FACTORS IN MOUNTAIN RESCUE

Communication

We are all aware how a frustrating communication breakdown such as lost radio contact can impact a rescue. Miscommunication affects the flow and safety of a rescue mission. Timely, clear and concise communication is a learned skill. The art of closed loop communication (e.g. "heli eta 15 mins" followed by "copy that, heli in 15") is a skill effective teams practice and promote to reduce communication errors.

The effectiveness of a calm approach to communication cannot be overstated. At times assertiveness may be essential. For example, saying something like "double check that knot; it doesn't look right to me for some reason" could save a life.

Fatigue

It is no surprise to anyone that fatigue as an isolated factor is a common culprit leading to human error during mountain rescue. Professions like pilots, truck drivers and medical residents in training now follow strict guidelines regarding work day length. Many of the world's most notorious accidents, perhaps most famously Chernobyl, revealed operator fatigue as the major factor when analyzed. Individual team members must be aware of their fatigue level and teams must have protocols in place to identify and prevent fatigue-related errors.

Stress

Stress has a negative effect on a person's ability to think and act clearly. Both personal, chronic stress and acute stress in the moment will impact a rescuer's performance. Fear is also a form of stress and can be severely distracting to the point of immobilization. Physiologically, stress results in the release of stress hormones, most notoriously

adrenalin, which actually diverts blood away from the brain to the muscles and cardiovascular system. It is challenging to think straight during a fight-or-flight response. The ability to slow things down at critical stressful moments is an invaluable skill. It's a common tactical adage that "slow is steady, and steady is fast."

Complacency
"That's the way we've always done it" is a defining statement and red flag for complacency. Those in the avalanche industry are well aware of the dangers of complacency within a fixed group mindset and the trap of familiarization, both of which are common heuristic traps found when avalanche incidents are analyzed.

Teamwork
Lack of effective teamwork can be a troubling human factor in mountain rescue. Being a good team member takes work and doesn't necessarily come naturally. Effective communication and the willingness to put the success of the team over personal gain are keys to effective teamwork. There is no role for the individual hero in mountain rescue response. Effective teams make rescue work look downright routine and matter of fact.

Knowledge and Skill
Individuals have to be willing to admit when they may not have the necessary knowledge, experience or skill set to be safe and effective on a rescue mission, no matter how much they may want to help. A rescue mission is no time to test one's personal limits when an entire team is depending on surefooted, steadfast work. There should be zero tolerance for jumping in over one's head as the consequences could be too great.

Self-awareness
A healthy dose of self-awareness goes a long way in mountain rescue. It can feel uncomfortable to depend on an overconfident team member who lacks self-awareness about their limits. Blindly pressing on, perhaps even in the face of deteriorating operational or personal factors, is a surprisingly common phenomenon in mountain rescue and reveals how easy it can be to lose situation and self-awareness.

MITIGATING HUMAN FACTORS

Mitigating the human factors that can negatively impact mountain rescue occurs is necessary on both personal and team levels, and should be a continual work in progress during training and throughout a rescue effort. On a personal level, it is necessary to maintain a healthy body and mind. A high level of physical fitness is desirable to reduce the physical stress of mountain rescue work. A clear, positive mindset allows for clarity of thought. And we are becoming more and more aware of the risk of lasting emotional effect of traumatic rescues and how it can interfere with performance.

Regular training and skill maintenance clearly helps team members work as effectively as possible. The development and use of clear operational guidelines and memory aids (e.g., colour-coded ropes, laminated knot cards) can be of great benefit. From a team perspective, communication workshops, rules regarding time on task, and operational debriefs immediately after tasks can all be fruitful exercises when trying to minimize or eliminate human factors that may negatively affect any mountain rescue scenario.

Within the challenging and dynamic mountain environment it will never be possible to completely eliminate individual human factors that could potentially contribute to human error. However, with awareness it is possible for individuals and teams alike to identify these factors, both prior to and during a rescue mission, and to intervene in a timely manner to thereby minimize the impact of those human factors, leading to better outcomes for all involved. After all, someone is already having a bad day and they are counting on you not to have one yourself.

Acceptable Uncertainty

Steve Conger

Stupid risks are what make life worth living. Now your mother, she's the steady type and that's fine in small doses, but me, I'm a risk taker. That's why I have so many adventures! -- Homer Simpson *(episode 24: season 9), The Simpsons (1998)*

YOU CAN GET INTO MURKY WATER when conveying to novices the type of decision making that's necessary for avalanche risk management. This is especially accurate in a culture where risk is frequently linked to reward and opportunity. This article describes a strategy to impart an appropriate feeling of risk to a vulnerable individual when faced with exposure to avalanche hazard.

There have been a phenomenal number of advancements in the avalanche field over the past couple of decades, many of which have translated directly into how we teach and train both recreationists and professionals. We've been honing in on ways to identify and describe likelihood and triggering, propagation, human factors, and avalanche risk management. Can all of these be combined to provide an effective answer to the silver bullet question of how to decide whether or not to ski fill-in-the-blank?

I suggest the answer is yes, and a simple decision-making framework will assist to make "expert" judgements. Let's take a look at the steps to this framework.

The first step is to remove what bias you can from the discussion. Dave McClung's rule and suggestion number 16 on avalanche forecasting and decisions is to "discard your ego" (McClung & Schaerer, 2006). We can do this by taking terms that are strongly influenced by ego or emotion out of our answer. Risk is just such a term; the many perspectives and competing definitions of risk make it difficult to begin a fundamental and pragmatic discussion or offer an answer to the question. Removing loaded words like this will help avoid explanations of rationality such as "we calculated the risk." The term risk is not used in the balance of this framework or its description.

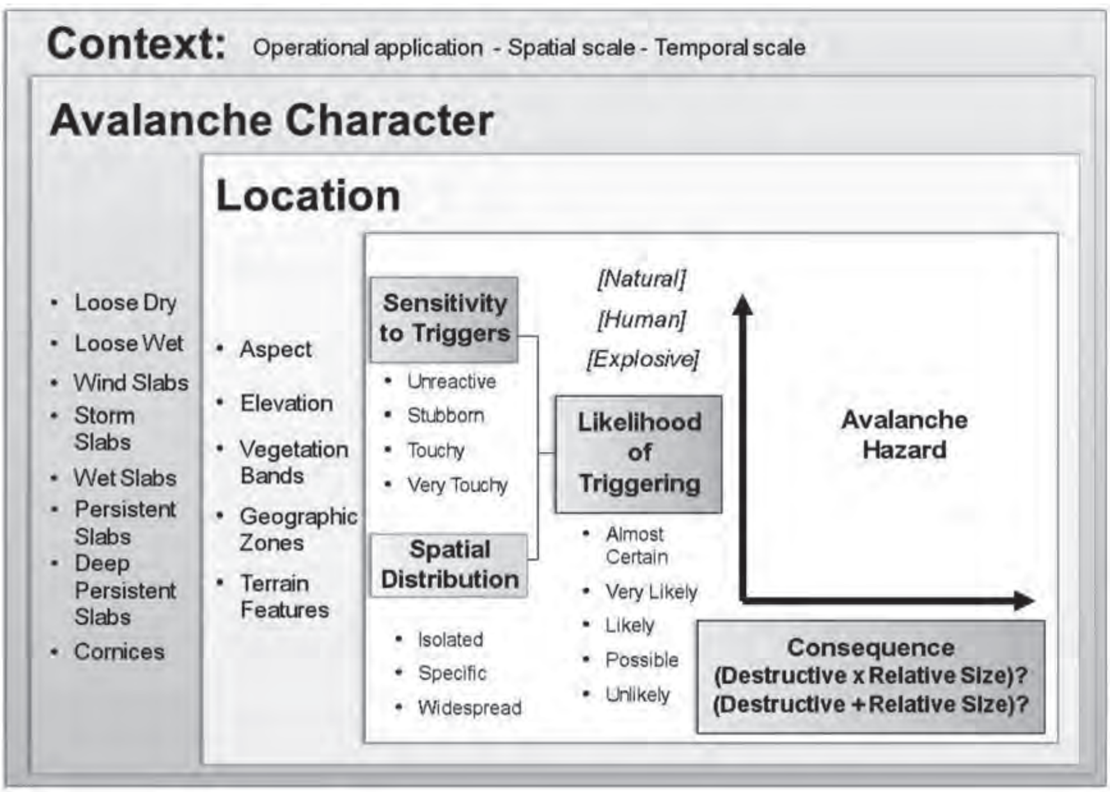

FIG. 1: SUMMARY GRAPHIC AND ADAPTATION OF THE CONCEPTUAL MODEL OF AVALANCHE HAZARD (AFTER STATHAM, ET AL., 2010).

The second step in the framework is to give students relevant context. My answer to the silver bullet question usually starts with another question: "Would you like a robust decision-making framework that will work for you at all stages of your learning and practice with avalanches? One that seasoned pros use intuitively and novices can easily follow?"

The third step invokes a commonality currently followed in the avalanche community. Every day we make decisions about avalanche hazard in our work; every day we gauge the exposure to hazard faced by something of value. The Conceptual Model of Avalanche Hazard (Statham, et al., 2010) offers a framework for inputs to decision making (Fig. 1). Once a basic understanding of the conceptual model is achieved, the model can point towards most of the information needed for this decision making framework. For example, a result from a compression test may provide evidence about the sensitivity of triggering for a particular layer or interface, but what about its spatial distribution and location? What avalanche character is this result connected to? An avalanche hazard assessment in an operational setting is made by defining an avalanche problem using the components of the conceptual model.

The fourth step uses a single filter to identify where to focus. This is where we ask, "What part of the hazard assessment are you most uncertain about?" For example, are you most uncertain about the likelihood of triggering or the propagation (which may relate to its expected relative size)? With this we arrive at the key input for a decision.

Focussing on uncertainty goes a long way towards removing ego and emotion from the decision process. We know that uncertainty is a defining characteristic of the avalanche hazard discipline (LaChapelle, 1980). It is inherent in avalanche risk management and cannot be eliminated, but it can be accommodated. An excellent strategy that has been recommended includes acknowledging uncertainty's existence, decreasing it when practical, communicating the irreducible uncertainty and embedding it in decisions (Jamieson, Haegeli, & Statham, 2015).

Answering the silver bullet question is about conveying how and where to draw your safety margin. So in step five, you draw your safety margin according to what you are most uncertain about in the assessment (e.g., avalanche character, aspect, elevation band, terrain feature, sensitivity to human triggering, sensitivity to natural triggering, spatial distribution of instability, propagation/relative size, destructive size). Then you do what you can to change your relationship to the uncertainty (e.g., change the hazard with explosives, change your exposure in space and or time, change the objective to one unaffected by the uncertainties). Altering your efforts to gather more information is an example of changing the objective.

Once your preferred choice of change has been achieved, there is one final filter to the decision before acting: **Is the remaining uncertainty acceptable?**

> You might be on the wrong side of your safety margin.

The bottom line is if you do not feel okay about the remaining uncertainty—if you haven't honestly acknowledged it, done what you can to reduce it, and communicated it with your peers—then you haven't accommodated that uncertainty in your decision making. You might be on the wrong side of your safety margin.

Imparting this tool to your avalanche assessment tool box will hopefully help to limit treacherous biases associated with the *affect heuristic* described by Finucane (Slovic, 2010) and lead to better avalanche risk management decisions.

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THE SOUTH ROCKIES FIELD TEAM REMAINS SUCCESSFUL THANKS TO SUPPORT FROM TECK. MARTINA HALIK HARD AT WORK. // JEN COULTER

Avalanche Canada: **The Real Cost of Public Avalanche Safety**

Mary Clayton

PROVIDING PUBLIC AVALANCHE FORECASTING in Canada is a unique challenge that is met with unique solutions. The sheer size of the country is one of the biggest hurdles but thanks to the CAA's InfoEx, Avalanche Canada has access to professional, daily data from regions hundreds of kilometres away from our office in Revelstoke. Other alpine nations are green with envy of the InfoEx system—and the database it generates—and we're all rightfully proud of and grateful for it.

But one of our long-standing issues is providing avalanche safety programs for data-sparse regions—areas where InfoEx subscribers are few or nonexistent. The South Rockies is one of those areas. Its neighbouring region, the Lizard Range and Flathead, are fairly well served with InfoEx subscribers but the South Rockies region, comprising the Crowsnest Pass and Elkford area, is not.

INSTALLING A WEATHER STATION IN THE KAKWA WILDERNESS AREA, WITH THE HELP OF THE SWAN CITY SNOWMOBILE CLUB OUT OF GRANDE PRAIRIE, AB //RYAN BUHLER

Fortunately, we have a generous sponsor in Teck that allows us to support a three-person field team for the South Rockies. This field team has been in place since 2011 and provides our forecasters with the data required to produce a daily forecast for that region. This team also does some great outreach work and has made a significant contribution to building a local culture of backcountry safety and avalanche awareness. Not to jinx the program, but there hasn't been a fatality in the South Rockies since our field team started.

Field teams are a really good solution to our data-sparse problem but they're expensive, requiring trained staff, vehicles, trailers, snowmobiles, etc. Since 2011, AvCan has partnered with the Yukon Avalanche Association (YAA) to provide a twice-weekly avalanche forecast for backcountry users in the Klondike region, where there are no InfoEx subscribers. This program was initially funded by a three-year federal grant but when the grant expired in the spring of 2014, the product suffered.

In 2015, last-minute funding was scraped together and the forecast ran from February to May. In 2016 the forecast season was even shorter, from early March to late April. This season, there is no field team and no regular forecast for the Yukon region.

The North Rockies region is probably the poster child for the data-sparse issue, containing well-used recreational areas with an alarming history of fatal accidents and no daily forecasts. This is a massive region and would require at least two field teams, if not three. Unfortunately, despite our efforts, no corporate "angels" have come forward to support an avalanche safety program for the region.

Providing services for these data-sparse regions is one of our primary concerns and one that we've spent a lot of time and energy in trying to address. In the past few years we've been working on a new approach that we've called "hot zone reports." This season, thanks to funding from Recreation Sites & Trails BC (RSTBC), we're trying it out as a pilot project in five areas—the Kakwa and the Renshaw in the North Rockies, the Hankin-Evelyn and Telkwa areas of the Northwest Inland, and the Yukon's Klondike region.

Hot zone reports will be based largely on Mountain Information Network (MIN) submissions, along with data from local weather stations and our snowpack modelling program. Reluctantly, we've had to get into the weather station business for this project, gathering donated and purchased parts, and assembling the stations at our office in Revelstoke. We're then delivering and installing the stations with the help of local stakeholders.

Hot zone reports aren't equivalent to a daily avalanche forecast. Instead, they will be general summaries of local conditions with some risk management advice. Hot zones are depicted as fuzzy grey balls on the front page map at avalanche.ca. We wanted the boundaries fuzzy to indicate the geography of this product isn't strictly defined. The grey colour will change to blue when sufficient information has been submitted to allow a report to be produced.

The key to the project's success is MIN submissions. The focus of our outreach in these regions will be on promoting the MIN and, in some areas, even providing field training for MIN submissions. Our hopes are high for this project and it will be interesting to see how it gets used in the different regions.

The North Rockies is primarily a snowmobiling area, while the NW Inland is primarily backcountry skiing. The Yukon is a mix of both user groups. These five areas also represent varying levels of user engagement. All these factors and more will play a role in whether this experiment will work. However, even if it's a roaring success, this is still a pilot project and at the moment, we don't have operational funding to continue after this season.

App development is not for the faint of heart, nor the faint of wallet.

As we look ahead to this season and beyond, adequate and sustainable funding continues to be one of our challenges. The Avalanche Canada Foundation is a charity that raises money with various fundraising events and through donations. Founded in 1999, the foundation predates the national public avalanche safety organization by five years. They've been strong contributors over the years and their volunteer board works very hard, but keeping up with the growing demand for our services is an uphill battle.

We've also had many great projects funded through grants and sponsorships over the years. Some of these projects have yielded internationally recognized, seminal work that continues to contribute significantly to public avalanche safety. The Avaluator is a prime example, but so are the *Throttle Decisions* video series, the microsite *Rescue at Cherry Bowl*, and the ATES mapping of all of BC's managed snowmobile areas and many of its provincial parks.

That last example is a good one because it identifies the main drawback of project funding—lack of sustainability. With this project, which was funded by RSTBC, we created KMZ files for thousands of square kilometres of terrain, all mapped with the three-point avalanche terrain exposure scale. This data made some great maps and beautiful trailhead signs across the province. But to be really effective, we need to get this information online.

This data could be the foundation for a really effective online trip planning tool that would allow users to easily select terrain according to the current conditions. But we don't have the resources to build this project out to its full potential and sustain it. That's just one example but there are plenty more. Users expect online services and as backcountry use explodes, the demand for more and better products just increases and we're not keeping up.

We were very excited to hire a web developer halfway through 2016, growing our IT department to two very dedicated and talented people. But even our wonder duo can't keep up with what we could, and should, be doing. Take our app, for example.

THE YUKON FIELD TEAM AT WORK LAST YEAR. THIS YEAR, DUE TO LACK OF FUNDING, THERE IS NO FIELD TEAM IN THIS REGION. // RYAN BUHLER

Mobile phone technology moves ridiculously fast and when you have an app, you have to ensure it functions on the latest iteration. “Old” technology (younger than a kid in kindergarten) gets left behind pretty quickly. That means your ancient iPhone 4 is no longer supported. App development is not for the faint of heart, nor the faint of wallet.

We have had, and continue to have, the support of some very generous corporations. As noted earlier, Teck plays a major role in ensuring our South Rockies program continues its success. MEC is a long-time partner, supporting our training programs, partnering with TECTERRA to build our app, and helping to fund the *Rescue at Cherry Bowl* project. The Columbia Basin Trust is another long-time sponsor and Toyota BC recently came on board, supplying us with two new Tundra trucks for two years.

But overall, corporate funding is declining. CP has been the title sponsor of Avalanche Awareness Days since the early 2000s but has told us this will be the last season of their sponsorship. This is the final season of the RBC Foundation’s support for our youth program. In fact, this season is the end of a number of corporate sponsorship deals and we don’t know how many will be renewed.

Donor fatigue is certainly an issue and some corporations simply wish to move on. They give to one cause for a few years, then move on to the next recipient. It’s a tough world and there are many worthy organizations vying for the same corporate purse.

In 2012 we gave it our best shot, hiring a professional fundraiser who had raised millions for universities and the Red Cross in his career. We tried for three years to get closer to the goal of sustainable funding through corporate donations but that vision never materialized. In general, corporations are more interested in funding projects rather than operations. The message from the private sector is clear—sustained operational funding for public avalanche safety should be the responsibility of government.

> The message from the private sector is clear—sustained operational funding for public avalanche safety should be the responsibility of government.

Government funding has always been part of the funding model for our organization and we have received funding from the federal government and the provinces of BC and Alberta since our inception. However, we have written agreements for less than half of the total and, by the same token, less than half of government funding is in multi-year commitments. Generally, it feels pretty tenuous.

There are many models in other alpine nations where avalanche forecasting programs are primarily a government-funded service. Some, such as Switzerland, are funded very well. Others, such as those in the mountainous states of the US, are not. Here in Canada we’re somewhere in the middle. We’re grateful for the commitment from multiple layers of government but unfortunately, the amount of funding has not changed appreciably for a number of years.

Avalanche Canada is at a tipping point. With fewer corporate donations and government funding static at best, we are not able to sustain the current level of services. This season we are dipping into our reserves, which is clearly not sustainable. Programs will be cut next year if this situation doesn’t change.

This hasn’t taken us by surprise. We’ve long recognized that push is coming to shove and we’ve been actively strategizing to achieve long-term sustainability. We’re in contact with all current and many prospective funding bodies and we’ve had a number of promising face-to-face meetings.

We have a lot to brag about at those meetings. Each year, some 7-8,000 people take an AST course, and our youth program reaches over 7,000 K–12 students. Our website is viewed over one million times each winter and our app has been downloaded over 12,400 times. And despite the exploding use of the winter backcountry, the average annual number of fatalities has stayed relatively steady.

We know we provide a fundamental service, integral to our identity as Canadians. Canada has a proud reputation for leadership in public avalanche safety and we’re not giving that up easily.

// CANDIAN MOUNTAIN HOLIDAYS

10 Common Missteps of Avalanche Practitioners

Article and photos by Todd Guyn, Canadian Mountain Holidays

AVALANCHE PRACTITIONERS WORK in a hazardous environment, characterized by a large degree of uncertainty. While extensive operational efforts are undertaken to minimize uncertainty, it cannot be eliminated. As a consequence, accidents and incidents will continue to befall this challenging workplace. There are often many different contributing factors to any avalanche incident, but the one constant is the presence of people.

The purpose of this article is to outline and discuss 10 common missteps or errors avalanche practitioners and winter mountain travelers make in the course of their career or life. To identify the most common missteps, a short questionnaire was distributed among 70 IFMGA mountain guides or ACMG ski guides with 10 or more years working in a production helicopter skiing company in a team environment. The company averages 6,000-7,000 guests in a guided wilderness skiing setting per season spread over 11 different operations. It has been operating 52 years with an annual guiding staff of 125 certified guides. None of the factors discussed fall exclusively within the snow science area, but are rather the results of the interaction between the avalanche hazard and the people working and traveling in the mountain environment. Although the discussion of bias is not new in the social science realm of the avalanche world, it is insightful to review and reflect on observations of the seasoned practitioners themselves.

INTRODUCTION

Working with a large group of mountain guides for the past 21 years has provided valuable insight to the day-to-day operations of an occupation in an uncertain and high risk environment. For the last five years, I have been the mountain safety manager for 12 operations, with the main focus being on snow science, hazard and risk.

This has given me the opportunity to discuss the hazards and risk with some of the most experienced guides in the world. The paper began with an interview request from Wagner skis to highlight "Mistakes Even Experienced Backcountry Skiers Make." It was written by Krista Crabtree and can be found in the Wagner Custom Skis Journal. It was a worthwhile piece and I felt it could be expanded to be directed at operating professionals in the avalanche industry.

The intent of this paper is for practitioners to stop and give thought to some common human factors we all face and all have within us, regardless of experience.

SETTING AND METHODOLOGY

Canadian Mountain Holidays (CMH) is one of the oldest adventure travel companies in North America and the most experienced and biggest heli-skiing operator in the world.

CMH operates in the Purcell, Selkirk, Monashee and Cariboo mountains of eastern BC from eight backcountry lodges and three town-based hotels: Adamants, Bobbie Burns, Bugaboos, Cariboos, Galena, Valemount, McBride, Revelstoke, K2 Nakusp, Gothics and Monashees. We have recently added a Nomads package which operates from Halcyon Lodge. Our operating area encompasses approximately 15,000 square kilometres of terrain, granted under Licenses of Occupation from the British Columbia government.

CMH hosts between 4,500 and 6,500 heli-ski guests on mainly week-long trips every year, which also makes it the largest heli-ski operator worldwide in terms of guest skier days.

CMH has a winter guiding staff of 125 guides, all certified and qualified with the following

- ACMG or other IFMGA member associations, including CAA level two certification
- Annual CMH pre-season guides training (three days)
- Annual CPR and AED recertification (four hours)
- Annual CMH area training/set up (five days)
- Professional CPD requirements for ACMG/IFMGA and CAA members
- Advanced first aid recertification (40 hours every three years)
- WSBC Avalanche Blasting Recertification, if applicable

The Mountain Safety Manager (MSM) role was first incorporated into CMH in 1991. The role was established to focus solely on all aspects of snow stability evaluation, hazard assessment, and risk management procedures for CMH skiing operations.

During the winters of 2012-13 and 2015-16, questionnaires were sent out to all the guiding staff with 10 or more years of heli skiing experience. The total number of guides who replied was about 70 - 80 between the two surveys. The results were compiled and sent to all the winter guiding staff. The positive feedback indicated it was an interesting and successful project for the guides.

10 COMMON MISSTEPS OF AVALANCHE PRACTITIONERS

Misapplication of Terrain

There are constants in the formulation of avalanche hazard on any given day and one of the main elements is the terrain itself. It changes little over time and before decisions are made it can be studied and interpreted. As competent professionals we all know the physical factors involved in identifying avalanche terrain but we continue to falter in our mitigation of the risk by not adjusting location to meet the hazard at the time. The snowpack lies over the terrain but it is not a constant and can be unpredictable and therefore uncertain, leading to the importance of interpretation of physical terrain. You can solve most avalanche hazard issues by choosing the right terrain for specific conditions. Competent practitioners often underestimate the complex uncontrolled nature of the environment. The cultural trend of our society and industry often views our terrain as an amusement park. This can have an influence on our respect and caution towards mountain travel and terrain interpretation. We cannot change the snowpack, the terrain or the weather but we can change where we are and how we travel in the mountain environment. To quote one of the guides, "Even more fundamental than hazard assessment, decision making, and safety equipment, our most effective tool to manage the inherent hazards we encounter is how we manage our movement through the terrain."

Bigger margins of safety in terms of terrain have made a difference to many experienced guides. Remember the basics: size, angle and shape. Respect the terrain.

Being Impatient With Conditions

Humans are not particularly patient. How many people have switched lanes in traffic or flipped through the TV channels only to get back to exactly where you started—or worse? When we have goals we are trying to reach, be it guest satisfaction or opening un-skied terrain, we often view time as a hurdle to achieve those goals. This naturally leads to impatience. What has cost you more in your life, being patient or impatience? A common comment from the guides was doing too much, too fast with a given avalanche problem. For example:

"One of the continued things I see is too much trust in a surface hoar layer gaining strength. Time and time again, I see and hear that 'blank layer' is now not a problem or that it is no longer a concern. I will make decisions on a SH layer after some weeks or longer until I can justify to myself the layer is no longer a concern with direct observations or tests to back up my actions. If I think about it, the more time I give a layer the better I feel, and that can be months later."

It was also noted that sometimes not acting on short term feedback (e.g., ski cutting) but deliberately slowing down and letting time pass would eventually lead to opportunities presenting themselves.

Practicing patience and waiting out conditions was viewed as a positive trait among the guides, and in the end led to a less stressful work environment and a higher level of certainly about prediction of avalanches. The key to everything is patience.

"You get the chicken by hatching the egg, not by smashing it open." – Arnold Glasow, American humourist

Trying Too Hard to Outwit the Avalanche Hazard

As a general rule, thinking is a good thing. Having a logical and methodical approach in your decision making is highly valued. However, quite often avalanche professionals try to seek a way around a problem using analytical skills when the problem is just too widespread or uncertain in nature. We do our damnedest to get to the solution using our conscious analytical brain; unfortunately due to our cognitive bias we fail to see the blind spots we missed along the way. Quite often we just try too hard, when waiting out the problem is the best solution.

'For every complex problem, there is a solution that is simple, neat and wrong" H.L. Mencken

Acting Too Much on Emotion

Understanding how your brain works in decision making is an important element for a safe and successful career in a high risk workplace. Your brain works in two ways: the rational part gathers information to help you make an informed decision and the emotional part (the feeling) tries to have a good time. But you really have to keep yourself in check and balance between the feeling and the rational process. You need the emotion to have a fulfilling life but we must not be controlled by it. Just because you want to have a good time and ski the slope, conditions might not be right. The rational part needs to say, "all the info says it's bad, so I'm not going to ski it."

Information Overload

These days the excuse for not being informed is usually not valid. With the technical age we live in, having access to current conditions is easier than ever. One of the issues facing an avalanche professional is the sheer volume of information available and the time and resources required to process that information in a meaningful way. It is important to understand what is essential to your decision making on a said problem and then remove what is not. Getting more information is not always the correct answer. The challenge lies in getting the data that is most relevant to your issue. We need to ask, is more really better? "Most of what exists in the universe–our actions and all other forces, resources and ideas—has little result; on the other hand, a few things work fantastically well and have tremendous impact." Richard Kock

Not Being Vigilant to Changes in the Environment

The weather and the snowpack are closely related. Awareness of changes in both these elements is highly valued. These changes can be quite subtle in nature, but among the guides it was noted that a failure to recognize these environmental changes led to a inconsistency in predicting avalanche behaviour. Making a conscious effort to ask oneself "What I am missing out on here?" is worth adding to your internal dialogue.

Letting Familiarity Influence Your Mindset

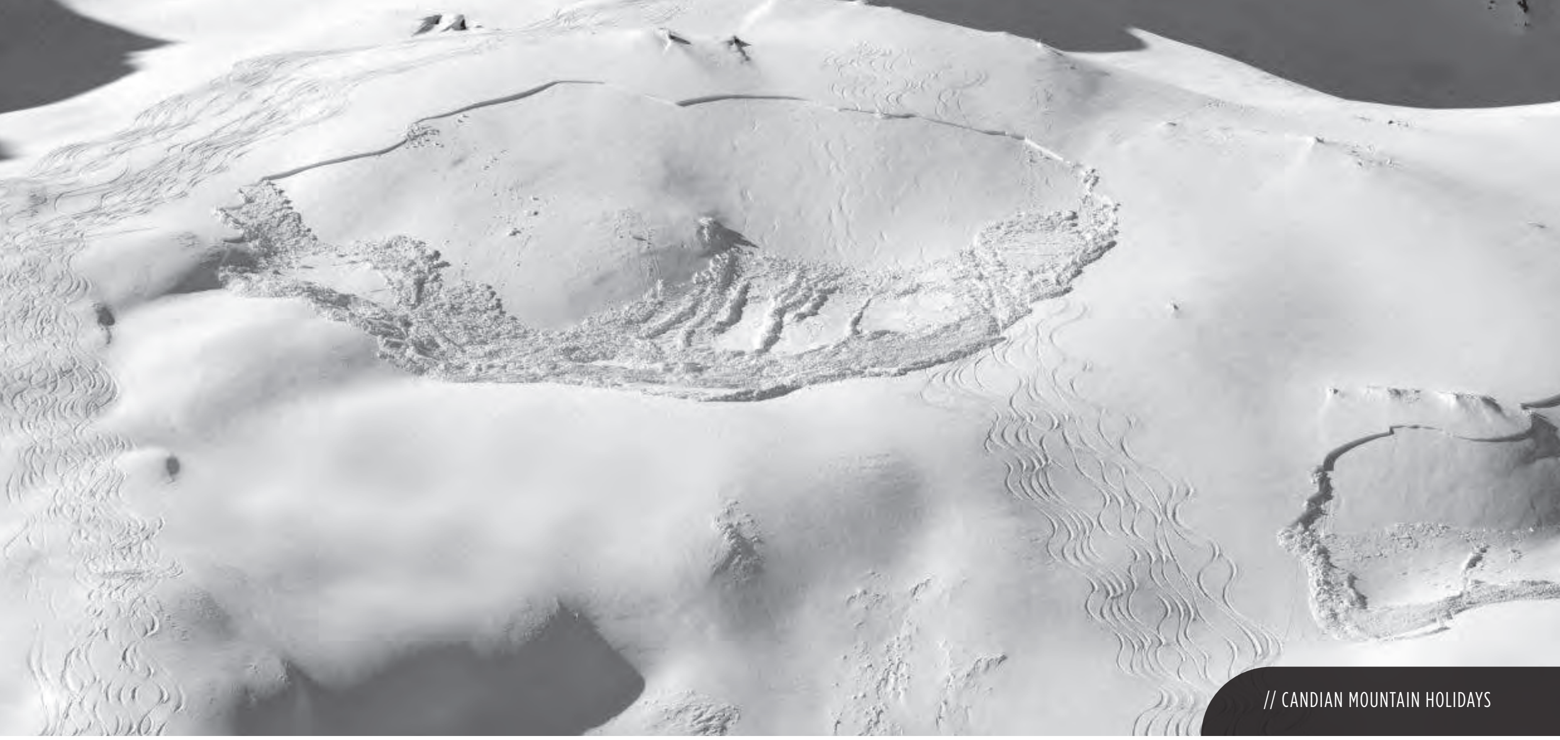
The familiarity heuristic is one of the most cognitive embedded biases we carry in our decision making process, and much of the time it serves us well. We generally equate the familiar with safety and knowns. However, the "gut feel" we have about a familiar piece of terrain can be quite misleading and may lead to a underestimation of risk. When we return to the same areas often, we usually get in a positive reinforcement loop, get complacent and often lose the perspective of potential risk. The duality of working in familiar terrain and snowpacks remains a challenge. Keeping an open mindset and fresh eyes was something to be remembered and strived for.

Underestimating Consequence

We are constantly surprised by the magnitude of avalanches. We underestimate the destructive size the terrain and snowpack can produce. The failure to make necessary adjustments in terrain choice can be based on the lack of understanding of the magnitude and intensity of an event, making this a human error. Because events may not be everyday occurrences, people diminish the relevance of past experiences.

Lack of Communication

The main misstep noted by the guides had to do with a lack of communication. It was the single biggest factor involved in events of consequence. Communication could be on a larger scale amongst teams, or person-to-person giving directions. It also came in many forms including not being transparent, choosing the wrong communication style, not knowing your audience, incorrect tone, and not speaking up when doubt lingered. There are many reasons why communication may be an issue, but the bottom line is a lack of information in one form or another. If we have



a workplace where we work with other people, we must continue to seek ways to facilitate open and meaningful dialogue about the essential tasks at hand.

Underplaying of Uncertainty

The current definition of uncertainty in the Canadian avalanche industry is: "the state (even partial) of the deficiency of information related to the understanding or knowledge of an event, its consequence or likelihood" (ISO, 2009).

Due to the spatial variability and the physical environment of the mountains, we often work in a highly uncertain state. It is important to recognize this element in our entire decision making process. We often overestimate what we know or what we think we know due to past success in our field, which can lead to overconfidence. Overconfidence and a failure to recognize the level of uncertainly in the physical environment we work in leads to faulty decisions based on incorrect premises.

More targeted information gathering, understanding the uncertainly and differentiating between what we actually know and what we think we know can all help reduce the uncertainly and, in the end, our overall risk in our field.

CONCLUSION

As science slowly grinds away explaining the uncertainties in nature, we are left to live and work within an environment carrying risk. Although all the above missteps fit into some heuristic bias or other, the interesting point is not the box or name of the bias but rather how these are actually manifested and communicated by real practitioners. There is nothing new in our failings; they seem very common and familiar to all of us, but perhaps in being cognitive of the mistakes of others we can see them in ourselves.

Remember these common missteps the next time you head into the backcountry, and remember to stay safe out there.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank CMH, all the winter guides, and managers past and present for their time, thoughts, discussions and mentorship, with special mention to Roger Atkins and Dr. Pascal Haegeli. Without their dedication to providing a safe and enjoyable mountain experience for CMH staff and guests we would not have the opportunity to partake in a wonderful pursuit.

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avalanche community

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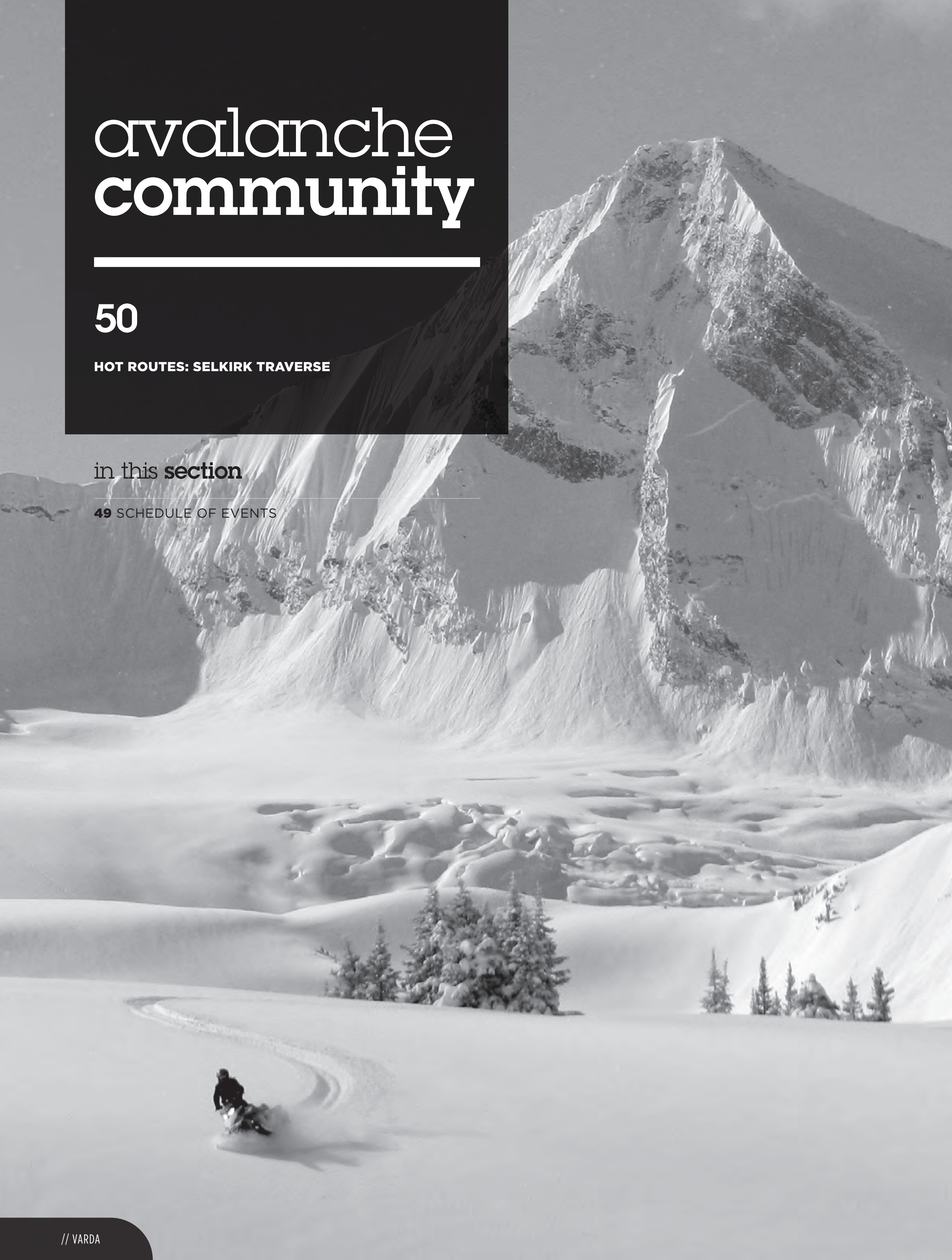
HOT ROUTES: SELKIRK TRAVERSE

in this **section**

49 SCHEDULE OF EVENTS



// VARDA

Schedule of Upcoming **Events**

WILDERNESS MEDICAL SOCIETY'S 25TH WILDERNESS & MOUNTAIN MEDICINE CONFERENCE

February 16 - 22, 2017
Park City, Utah
Leading-edge information in avalanche rescue, cold injuries, high-altitude illnesses, expedition/travel medicine and more.
For more information: wms.org/conferences/parkcity17

85TH ANNUAL WESTERN SNOW CONFERENCE

April 17 - 20, 2017
Boise, Idaho
This year the conference is combined with the Weather Modification Association.
For more information: westernsnowconference.org/meetings/2017

CAA SPRING CONFERENCE AND ANNUAL GENERAL MEETING

May 1-5, 2017
Ramada Inn & Suites and Penticton Trade & Convention Centre, Penticton, BC
Join us for the AGM, meetings, case study and research presentations and discussions about the Canadian avalanche industry.
For more information: avalancheassociation.ca

HELICAT CANADA ANNUAL GENERAL MEETING

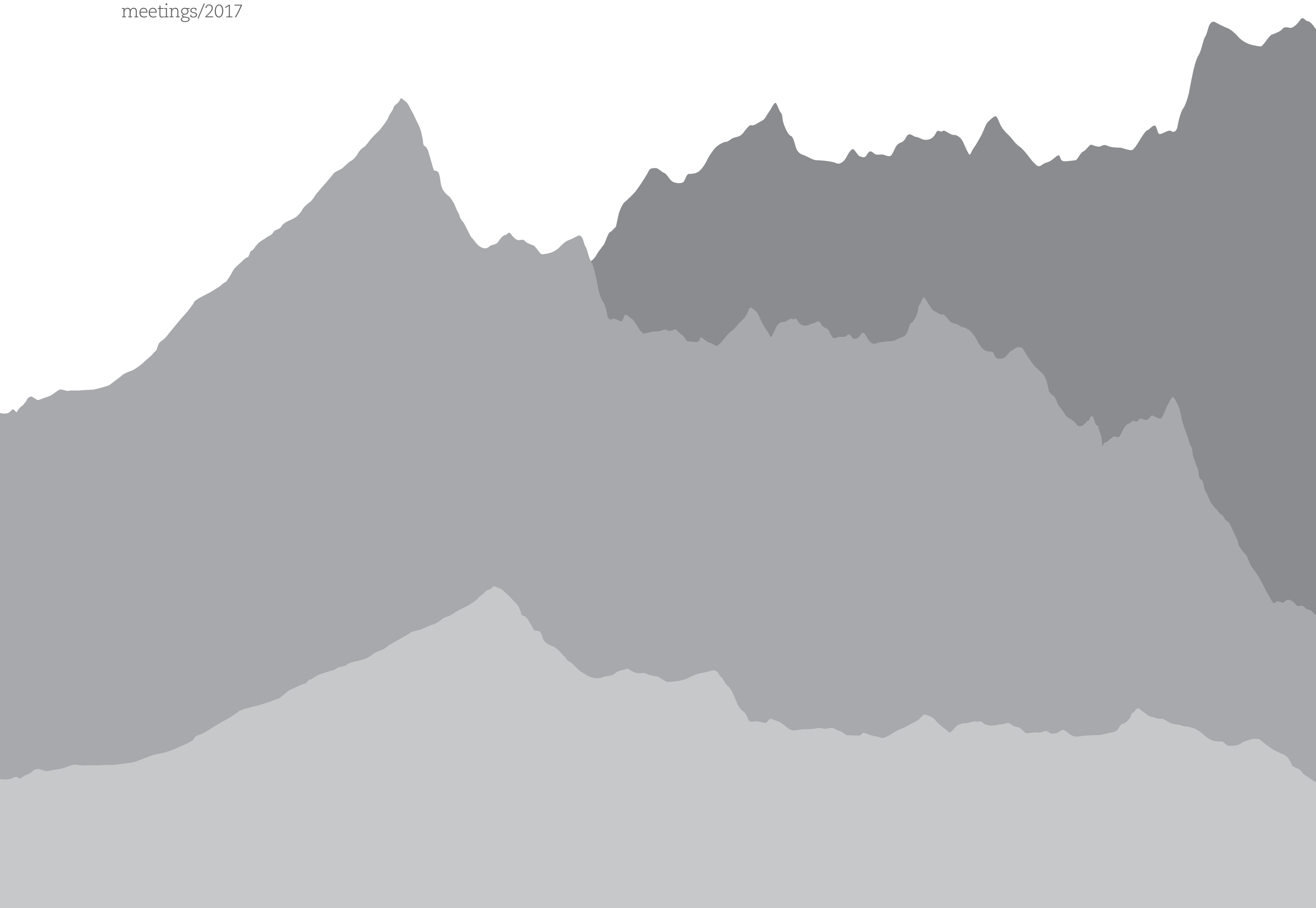
May 1, 2017
Penticton, BC
For more information: helicat.org

CANADA WEST SKI AREAS ASSOCIATION 2017 SPRING CONFERENCE

April 25 – 27, 2017
Lake Louise, AB
For more information: cwsaa.org

GEO-RISK 2017: GEOTECHNICAL RISK FROM THEORY TO PRACTICE

June 4 – 7, 2017
Denver, Colorado
For more information: georiskconference.org



HOT ROUTES

Selkirks Traverse

All done during one of the hottest springs in recent memory.

STATS	
SKIERS Madeleine Martin-Preney, Stephen Senecal, Sam McKoy, Mark Grist and Douglas Noblet	
DISTANCE	520+ km
ELEVATION GAIN	43,000m
DAYS	36
BROKEN BINDINGS	2
BROKEN SKIIS	2
BROKEN POLES	3
START	Kootenay Pass
FINISH	Monashee Lodge

// DOUGLAS NOBLET

FOR ME, THE SELKIRK TRAVERSE was most definitely an exploration of the term "commitment." The idea for this journey first came up in spring 2012. Stephen Senecal and I were on our way to Mt. Logan and it was during the long drive from Revelstoke to Whitehorse that the conversation turned to other dream trips. Somehow, we had a similar idea to connect the various traverses through the Canadian Selkirk range into one continuous mega-traverse. It seemed the ultimate exploration and journey through the mountain range we both lived and worked in.

Three years later, while driving back to Squamish from the Duffy, Steve resurrected the dream of a complete Selkirk Traverse. “So… remember that idea we had of traversing the entire Selkirks? I think I want to do it next spring.”

I whipped around in my seat and stared at him intently. “Steve,” I exclaimed, “you can’t do that traverse without me!”

He grinned and replied, “Good! I was hoping you would say so because I think the biggest challenge will be finding other people who actually want to do something like that!”

From that moment forward, we were both committed and 16 months of sporadic planning ensued. Carving out time to talk about route, logistics, food caches, trip partners, gear and grant applications between both of our erratic and busy schedules proved to be a minor miracle.

We recruited three more trip partners--Sam McKoy, Mark Grist and Douglas Noblet--to join us and we quickly became a strong, cohesive team, probably in great part because of our shared sense of humour and penchant for endurance adventures.

We started our journey at Kootenay Pass on April 3, 2016 and were joined by coastal friends Lena Rowat and Nick Matwyuck for the first 11 days. Fast travel and awesome stability were the hallmarks of our first leg, with soft and squishy spring snow as opposed to light and fluffy. One and a half days of demoralizing drizzle while slogging it out on logging roads brought us to the first hut of our trip, Ymir Lodge. We took full advantage of the space and woodstove to dry out sopping gear while we played foosball and ate as much as we could to lighten our loads since we were two days ahead of schedule.

The next day we experienced a mini winter revival below Ymir peak as we skied through Whitewater Ski Resort’s terrain. We took this as a good omen that the snowpack would stay healthy as we made our way north over the next several weeks. But as we got closer to Nelson and descended the final slopes and cut blocks to the town limits, it was apparent that in the valley things had changed drastically in the four days we had been in the mountains. We arrived to summer-like temperatures and foliage looking like mid-May: alarming given it was only the first week of April.

As we resupplied our bags for second leg, we checked our weather resources and learned that we would be expecting a significant heat wave for our next leg from Nelson to Retallack. More fast travel? Well, as long as we had decent overnight freezing…

Steve and I chose to bike from Nelson up the Kokanee Park FSR as far as we could make it, which ended up being about 9km. The others met us with all of our gear, and we were soon skinning up the logging road in our long underwear, wondering if we had made a mistake by even bringing Gore-Tex and down layers given the heat and incredibly clear forecast.

When we arrived at the Gibson Lake shelter, we were greeted by a steady stream of water dripping from the roof. It filled our 10L pot in about 15 minutes; at least we weren't wasting fuel by melting snow, right?

We went for a short ski over the lake and up the slope opposite our next day's ascent route to get a view of what we would be getting into. We found isothermal snow and severe suction hampering our glide as we tried to ski down back to the lake. What happened to our April powder? It was probably at Durrand…

The second leg was characterized by super sunburns and more fast travel aided by a great melt-freeze cycle as we zoomed our way through Kokanee Provincial Park. We were able to put in long days and average ~1,800m and 18km a day with big packs. Our bodies were adjusting to the new rhythm, and snow conditions and terrain allowed us to start early and end late despite the warming. The snowpack was still holding on, but we were all aware that unless the heat wave ended, we would be racing against time to stay on snow. And soon we would start seeing a significant spring avalanche cycle as we headed into increasingly complex terrain.

Arriving in Retallack ahead of schedule, we were relieved to find out that freezing levels were forecast to drop again, which meant that we could count on the snowpack lasting a while longer. At this third resupply Douglas joined us and Nick and Lena left us after two more days. Cindy Walker, owner of the Hazel Hut in Retallack, joined us for the Goat Range.

The terrain was now more serious than what we had spent the previous 11 days travelling through. Characterized by significant vertical relief, deep valleys and some of the biggest avalanche paths we would see in the Kootenays, the Goat Range is a beautifully rugged and secluded section of the Selkirks. As we travelled through this seldom-frequented area, we saw evidence of the spring cycle kicked off by the recent warming event. The biggest debris piles we would see on the trip were found in Poplar and Mobbs Creeks, with average chunks about the size of a grown person. Again we made quicker time than anticipated and finished the Goat Range in five days instead of the planned nine. There was a minor hiccup as one of my skis, which had cracked on our second day from Retallack (I guess light skis aren't meant to withstand hard sun cups, frozen tree bombs and a heavy pack) completely broke two days later.

Mark, Cindy and I decided to exit via Poplar Creek to get to Trout Lake, where friends brought me another pair of skis. Meanwhile Steve, Sam and Douglas fought their way down Mobbs Creek and met us the next day. They could all attest that there is a good reason why Mobbs Creek is NOT the regular exit from the Goat Range. Alder rappelling, anyone?

Our trip's fourth leg took us from Trout Lake to Battle Abbey, where we had our fifth food cache. This was when things got quite interesting from a snowpack, terrain and avalanche perspective. We were now into mid-April, which really felt more like late May. The snowpack was being decimated by the high daytime temperatures and freezing levels had soared to 3,800m, and several nights had no re-freeze. We had a real wake-up call one morning when we were forced to cross a small bench underneath a large face that had started to shed loose wet avalanches with increasing frequency. It was only 9:00 a.m.

After that, we decided we would have to travel at night in order to minimize our exposure to any sort of sun effect on the snow. On our first midnight wake up, we were awoken at 11:59pm by the sound of a monstrous avalanche—likely a cornice failure--from the peaks above our camp below tree line. For the next five days, we woke at midnight and skied until anytime between 9:00 a.m. and 11:00 a.m. depending on sun. The mental and physical adjustment required to completely ignore our natural circadian rhythm was one of the bigger challenges of the trip. Almost all of us would start to go loopy by about 4:00 a.m., and we relied on each other to keep ourselves in check.

Travelling through the Badshot and into the Battle Range sleep deprived and by moonlight, there were several tense moments realizing that the only way through was to ascend headwalls with enormous glide cracks exposing wet, smooth rock and running water lubricating the precariously hanging snow slabs. Pole probing only confirmed our fears that the snowpack was rapidly degrading and almost completely isothermal. I was slightly sick with fear and apprehension on many of those ascents, and yet we somehow managed to make our way through the terrain without incident.

We were all aware that our personal levels of risk tolerance were going to be challenged by different things on this journey, and fortunately we trusted each other enough to follow and lead with relative fluidity. Pulling the pin on the whole thing crossed our minds on more than one occasion, but in general it always seemed that to continue on was no worse than turning around.

When we arrived at Battle Abbey at 8:00 a.m., we were invited in to spend the night and eat and drink the leftovers from a group of guests who had just left on a chartered early heli ride out due to the sub-optimal (read: terrible) ski conditions.

We found out that the lodge had lost a metre of snow in the last week, numerous parties had bailed on even starting the Bugs-Rogers and other traverses in the Selkirks, and at least one group had opted to fly out partway through their traverse. It seemed our graveyard shift ski tactic was perhaps not too drastic after all.

That afternoon we sat in the lodge at about 2,200m discussing our options and watching as the rain poured outside, saturating the already-soaked snowpack.

Had we just been rolling the dice and getting lucky every single time for the past week? Was continuing on for the next few weeks even a good idea?

The weather models suggested a cooling period on the horizon, and if we could make it onto the ice fields of Glacier National Park, we would probably be fine. It had to get better; we were barely over halfway through April! Somehow, we were all committed to continuing on. We hadn't yet reached a situation that felt unmanageable and we wanted to see this thing through—or at least give it our very best shot.

Declining Roger Laurilla's offers of a free helicopter ride to Golden the next day ("It's empty anyhow; it would be no trouble at all!"), we skied away from the lodge at 5:00 a.m and made it to Revelstoke two days later for our one planned rest day of the trip and sixth resupply.

Revelstoke was in full bloom. It looked and felt like June, and everyone around town kept repeating that things were "five weeks ahead." We traded our ski boots for flip flops and soaked in the sun with pleasure instead of fear for a change, while re-gluing skins and devouring ice cream.

Claude Duchesne generously gave us all a ride back to Rogers Pass the next day, and after he had driven away we looked at each other laughing and exclaiming, “What the hell are we doing?”

Leg six of our traverse—Rogers Pass to Sorcerer Lodge—was only three days long. However, it was one of the cruxes of the trip. Mountain Creek (ahem, RIVER) proved much more intimidating to cross when swollen by an unusually large spring freshet and no possibility of a snow bridge to be found. Our group was also split at this crossing, as Douglas had broken his ski on the north side of Bruins Pass which made for a truly spectacular effort by him and Steve as they skied back to Rogers Pass and hitchhiked to Revelstoke while Douglas' father (a pilot) flew another pair of his skis from Nelson to Revelstoke and met them. They then borrowed my car to drive back up to the Pass and began skinning at 7:00 p.m. back up and over Bruins Pass. They somehow managed to follow our tracks (for better or worse) by headlamp until they came to the log crossing that we had found. Douglas was smart enough to refuse to cross the log at 2:00 a.m. after such a monster day, and Steve reluctantly acquiesced. We were reunited by 10:00 a.m. the next morning, recounting how each of us had to find our inner Zen to cross the log above turbulence just inches from our boots.

Our seventh food cache was at Sorcerer Lodge. We were greeted by Eric Oxner and Colin Bakker, who were on their own at the lodge for a week. With high fives all around and lots of stories to swap, we spent another cozy afternoon repacking our bags in the hut as it drizzled.

The next day found us boot packing up Iconoclast in a whiteout, and despite waiting for an hour at the summit for the weather to improve for our descent, we eventually had to feel-ski our way back down, hand-railing our boot pack.

It was a relief to feel like we could trust the snowpack again in the alpine, and we reverted back to a normal sleep schedule, which left us all functioning a little better.

The Northern Selkirks were undoubtedly the most spectacular section of the traverse. The high alpine camps (like the one perched on Pyrite ridge watching the light of the sunrise and sunset on Sir Sandford) are not something I will forget anytime soon. It was a welcome reminder about why we go to such lengths to access places like these and experience them in such a profound way.

The last leg of our journey was from Fairy Meadows to Mica via Fred Laing ridge. These were five strenuous days which had all of us wondering at one moment or another whether or not we would make it. Windy Creek was another mental crux and sketchy log crossing, requiring much more of that inner Zen than Mountain Creek. Scratching our way along crumbling river banks while whitewater raged inches from our feet was not what we had envisioned, nor the soul crushing alder jungle-gym on rock slab that we were forced to navigate to gain access to the glacier below Neptune Peak. It was truly a testament to how warm the previous weeks had been, completely annihilating the snowpack below 1,200m. It's unfortunate but true that sometimes spring traverses are not all about the skiing.

On May 5, we made our way over Fred Laing Ridge, through the cut blocks that still held snow, and then walked the final five kilometres down the logging road that spit us out onto Highway 23 North. We were once again greeted by summer-time temperatures and trees in full foliage as we walked down the road to the Monashee Lodge where Rooster, who we had met at Battle Abbey, had left us a "Congratulations" note taped to a case of beer. My dad drove up from Nelson and met us at the lodge where we sat in a stunned and happy stupor. We actually pulled it off!

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MEASURING SNOW SURFACE TEMPERATURE: WHY, WHY NOT, AND HOW?

// RAY MASON

Measuring Snow Surface Temperature: **Why, Why Not, and How?**

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Avalanche forecasting operations measure snow surface temperature, Tss, for up to three objectives: 1) to infer near surface faceting (NSF) from Tss and the snow temperature 10cm below the surface; 2) to measure change in the snow surface temperature over time (e.g., days) usually at study plots; and 3) to determine the point-in-time surface temperature. We review the surface properties of snow and the energy exchange at the snow surface and identify the low albedo of contact thermometers as problematic for measuring snow surface temperature. Using field studies with contact thermometers, hand-held IR thermometers and an IR camera, we show that a contact thermometer on a shaded part of the snow surface can be up to 6 °C above the surface temperature. While hand-held IR thermometers are promising for measuring Tss, some units are more accurate than others and some units are slow to adjust to the ambient temperature. Since the true snow surface temperature varies widely within hours and the near surface temperature gradient usually reverses twice per day, a point-in-time measurement of the surface temperature—even with an accurate handheld IR thermometer—is less indicative of NSF than observations of the sky cover. We suggest observations or measurement methods for each of the three objectives of avalanche forecasting operations.

1. INTRODUCTION

1.1. Why avalanche forecasting operations measure the snow surface temperature

Avalanche forecasting operations measure the snow surface temperature for at least three different objectives:

1. To estimate the temperature gradient (TG) in the top 10 or 20 centimeters and hence infer whether current faceting (weakening) of near surface layers is likely. The temperature gradient is calculated from the surface temperature and a snow temperature usually 10cm below the surface, T10, respectively.
2. To determine the change in the snow surface temperature over time in a study plot from readings taken once or twice per day. This is used to infer the change in temperature of near surface snow layers over time, e.g., days. When warmed, creep increases in near surface layers, which weakly contributes to instability (Schweizer et al., 2013)
3. To determine the point-in-time surface temperature for (a) estimating the amount of warming required to bring the surface of similar slopes to the melting point, and (b) validating the reading from a downward facing infrared (IR) sensor on a tower at a nearby weather station, or from a snowpack evolution model.

Surface temperature measurements for objectives 2 and 3b are made only at fixed sites, usually study plots (Greene et al., 2010; CAA, 2016). Traditionally, shaded contact thermometers (alcohol, bi-metal or electronic thermometers) have been used to measure snow surface temperature.

1.2 The energy exchange at the snow surface

To understand the advantages and limitations of contact and infrared (hand-held or tower-mounted) thermometers, we briefly review the energy exchange at the snow surface, emphasizing the radiation exchange (Fig. 1).

Short-wave (SW) radiation from the sun enters the upper atmosphere. The fraction that is not absorbed by particles, water droplets in clouds, etc., or blocked by terrain or vegetation reaches the surface as direct SW. Indirect SW radiation is the fraction of incoming SW radiation that is scattered by the atmosphere, especially clouds, or reflected by surrounding terrain.

Snow reflects most SW radiation. The fraction of reflected radiation is known as the albedo, which can range from less than 50 % for dirty old wet snow to over 90% for fresh dry snow (Male and Gray, 1980). Since as recreationists and avalanche practitioners, we often move around on top of fresh dry—snow that reflects most SW radiation—we sometimes get sunburns on the underside of our chins (if we didn't apply sun cream) and wear sun glasses (or squint). The fraction of SW that enters the snow is called absorbed SW. It partly reflects off snow grains, bouncing around within the upper snowpack, and is increasingly absorbed with depth. Little SW radiation reaches more than 30cm into the snowpack, which is why you know if you cut the roof of your snow cave thinner than about 30cm. The absorption results in fast warming, which decreases strongly with depth.

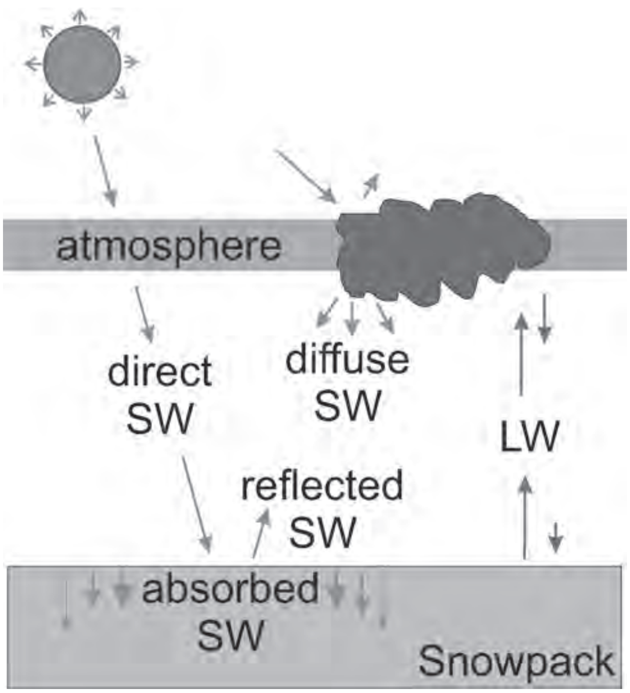

FIG. 1: RADIATION EXCHANGE AT THE SNOW SURFACE. THE HEAT TRANSFERRED BY WIND, PRECIPITATION, EVAPORATION, SUBLIMATION AND DEPOSITION OF SURFACE HOAR OR RIME IS NOT SHOWN.

Everything, including the snow surface, emits radiation according to its temperature and emissivity. Emissivity is a measure of how efficiently a surface radiates, and ranges between 0 and 1. Snow is a very efficient radiator; many snow surfaces have an emissivity between 0.98 and 1.0 (Dozier and Warren, 1982). Given the range of snow surface temperature, the snow surface emits long wave radiation. This upward radiation is partly absorbed by atmospheric particles, water droplets in clouds, as well as greenhouse gasses such as water vapor, carbon dioxide and methane. These particles and molecules are warmed and re-emit diffuse LW radiation in all directions. The downward portion of this LW radiation warms the earth's surface, including the snow surface. (This greenhouse effect favours life in the lower atmosphere at most places on Earth.) Vegetation, as well as exposed rock and earth, also emit LW radiation, some of which reaches and adds energy to the snow surface.

While the radiation exchange often dominates the heat exchange at the snow surface, there are other mechanisms. Although diffusion from still air has little effect on the energy exchange, warm wind can supply heat to the snow surface, or a cool wind can draw heat from the surface. Deposition of surface hoar or rime will release heat at or near the snow surface. Sublimation and evaporation will absorb heat from at or near the snow surface. Rain can add heat to the upper snowpack and contribute to melting. Snowfall can also be warmer or cooler than the previous snow surface and thus contribute to the heat exchange.

Adding heat can warm the snow at and near the surface, OR it can contribute to melting (provide latent heat with no temperature change). Also, a loss of heat from the snow surface can result in cooling OR freezing of liquid water in the snow at and near the snow surface with no temperature change.

Ok, now let's talk about thermometers. Like snow, contact thermometers emit LW radiation efficiently but they have lower albedo, that is, they absorb more incoming SW radiation than the snow surface. For example, the stainless steel shaft of a dial stem thermometer likely has an albedo around 70%. So, when placed on the snow surface or in the top 30cm of the snowpack, contact thermometers give temperatures higher than the snow they are supposed to be measuring (e.g., Morstad et al., 2007). Shading of contact thermometers is discussed in Section 3.2.

IR thermometers are passive sensors of the IR radiation emitted by the surface they are measuring. They can measure the temperature of a surface whether it is in the sun or shade. The emissivity of the surface, often 0.98 to 1.0 for snow, must be entered into the sensor to get an accurate reading.

1.3 Effect of terrain on snow surface temperature

Slope angle and aspect can have strong effects on the radiation exchange when the sky is clear. On a sunny day, a steep south-facing slope, inclined at, say, 30 to 40°, with clear view of the sky absorbs more SW than it emits LW. In contrast, a steep north-facing slope with a clear view of the sky emits more LW than it absorbs SW. Under a clear sky with little wind the surface temperature on the steep north-facing slope will be cooler than the steep south-facing slope (which might be at its melting temperature). This difference in the radiation exchange will be reduced on less steep slopes, say,10 to 20°. Under common conditions, near surface warming of dry snow can be predicted for the coming day with the SWarm model (Bakermans and Jamieson, 2009).

1.4 Diurnal surface temperature and the near surface temperature gradient

Fig. 2 shows a common fluctuation in the near surface temperature gradient. Four profiles of the upper snowpack were taken within 15 hours (Fierz, 2011) during which the sky was initially clear. As is common, the near surface temperature gradient reversed in the morning and afternoon. In the four profiles, the strongest temperature gradients (favourable to faceting) were in the top 2 to 6 centimeters. Temperature gradients based on the difference in temperature between Tss and T10 often miss or underestimate the strongest gradients. The profile at 00:30 is the clearest example since the temperature difference across the top 10cm is near 0 °C (suggesting no faceting) whereas the magnitude of the temperature gradient in the top 3cm is greater than 150 °C/m (suggesting rapid faceting).

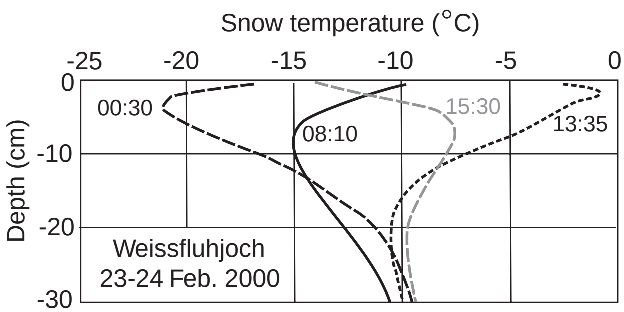

FIG. 2: TEMPERATURE PROFILE IN TOP 30 CM OF SNOWPACK AT FOUR TIMES DURING 15 H UNDER INITIALLY CLEAR SKY. AFTER FIERZ (2011).

1.5 Objectives of this study

The objectives of this paper are:

- to identify advantages and limitations of contact and handheld IR thermometers, and
- to stimulate discussion regarding which type of thermometer or observation is preferable for each of the operational objectives stated at the start of this paper.

Recommending specific models of IR thermometers is not an objective of this study.

2. INSTRUMENTS

We used two contact thermometers: a Bios dial stem thermometer (~US$30) and a Oakton Series 5 Acorn (accuracy 0.1 °C, ~US$250), as well as five IR thermometers, which ranged in price from approximately US$30 to US$250 (Fig. 3). As a reference temperature for some of the experiments we used a IR camera (FLIR B300, about US$9,000, accuracy of ±2%).

The stated accuracy of the hand-held IR thermometers varied between ± 1.5 to 2 °C, or 1 to 2% (whichever is greater) typically over the approximate range of -50 to +400 °C. The range of interest to avalanche practitioners is a small part of the range of most IR thermometers as shown in

FIG. 3: CONTACT THERMOMETERS (BIOS IN BOTTOM LEFT, OAKTON ACORN IN BOTTOM RIGHT) AND FIVE IR THERMOMETERS (ABOVE), FOUR OF WHICH ARE PISTOL-SHAPED.

Fig. 4. According to the manufacturers, each of the tested thermometers was temperature compensated, meaning the reading should not be affected by the ambient air temperature. However, temperature compensation takes time. The instructions for one IR thermometer stated compensation could require at least 30 minutes.

The emissivity of each IR thermometers was set to 0.98, although values up to 1.0 are reasonable. Fortunately, for IR thermometers held within a metre of the snow surface, emissivity values within between 0.98 and 1.0 are unlikely to shift the temperature measurement by more than 0.2 °C (Shea and Jamieson, 2011).

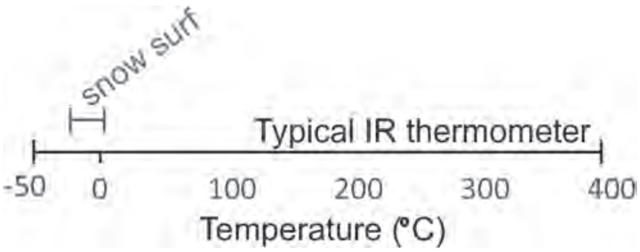

FIG. 4: THE RANGE SNOW SURFACE TEMPERATURE OF INTEREST FOR AVALANCHE FORECASTING ALONG WITH THE WIDER RANGE OF MANY HAND-HELD IR THERMOMETERS

3. METHODS

3.1. Accuracy of various IR thermometers for wet snow

The accuracy of the IR thermometers for a wet snow surface was tested on 2016-04-04 at a shaded valley bottom site where the snowpack was isothermal. Several centimeters of dirty wet snow were scraped away to expose an apparently clean wet snow surface. One at a time, each of the IR thermometers was pointed at 90° to the cleaned snow surface, held within 50cm of the surface, at least 40cm away from the operator's pant legs, and moved in small circles. To reduce heating of the snow surface by the operator, insulated clothing including gloves should be worn, and the operator should not have been with a few metres of the measurement site for more than a minute or so (Shea and Jamieson, 2011).

The average temperature over five seconds was recorded for each IR thermometer. To test the temperature compensation these measurements were made:

- promptly after the units were removed from the operator's jacket, and
- at several times while the units were exposed to the ambient air temperature for approximately 20 minutes in the shade.

3.2 Shading of the snow surface

As is common in avalanche forecasting operations, an area of the snow surface was shaded with the blade of an inverted snow shovel (Fig. 5). The dark shovel blade was 30 to 50cm from the snow surface to allow for unimpeded convective heat exchange at the snow surface and reduce LW radiation from the shovel reaching the snow surface.

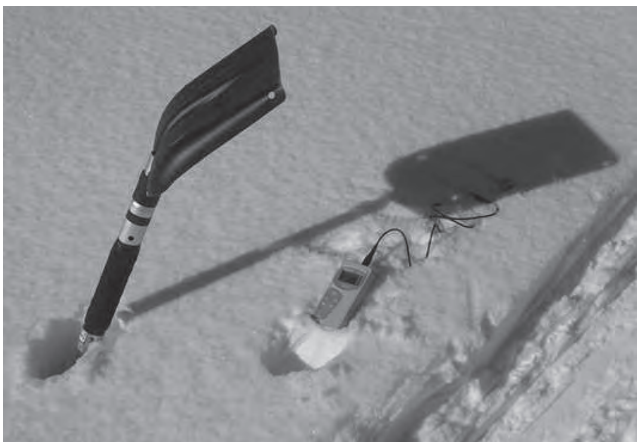

FIG. 5A: SHADING OF THE SNOW SURFACE BY A SHOVEL BLADE ON A CLEAR DAY. THE TEMPERATURE IN THE SHADE IS BEING MEASURED WITH THE TWO CONTACT THERMOMETERS.

On sunny days as shown in Fig. 5a, the shovel blade—especially the back—will absorb SW radiation, and all surfaces will radiate LW radiation. The snow surface and thermometers in shade of the blade can be warmed by LW radiation from the lifting surface of the blade. Increasing the distance of the blade from the snow surface will decrease this effect but reduce the effect of shading on cloudy days when most SW radiation is diffuse, i.e., when the boundary of the blade's shadow is not sharp. We did not experiment with varying distance between the shovel blade and the snow surface, nor with different colors of shovel blades.

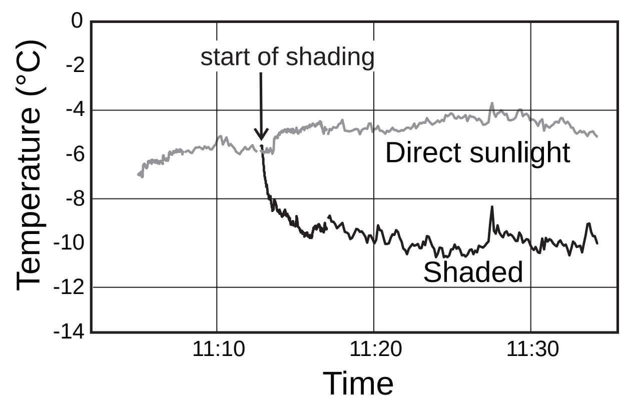

FIG. 5BA: SNOW SURFACE TEMPERATURE FROM THE IR CAMERA IN A PIXEL SHADED BY THE SHOVEL AND AN UNSHADED PIXEL.

3.3 Comparison of contact and IR thermometers under clear and cloudy skies

To compare the readings from two contact thermometers (Oakton Acorn and Bios) and three IR pistol thermometers, measurements were taken in the shade of a shovel on a sunny day (Fig. 6) and a day with broken sky. On both days, the IR camera recorded the surface temperature in the shade of the shovel and outside the shaded area. The readings from the various thermometers were taken prior to shading (when the contact thermometers are expected to be warmer than the snow surface) and at various times after the shading shovel was placed.

FIG. 6: EXPERIMENT IN 2014 TO COMPARE THE READINGS FROM TWO CONTACT THERMOMETERS IN THE SHADE OF THE SHOVEL AND AN IR THERMOMETER (NOT SHOWN).

4. RESULTS AND DISCUSSION

4.1 Accuracy of three handheld IR thermometers

As described in Section 3.1, on 2016-04-04 under cloudy skies in the shade of a tree, four readings were taken over 17 minutes (about four minutes apart) of a cleaned wet snow surface with three IR pistol thermometers, labelled IR 1, IR 2 and IR 3. Fig. 7 shows the distribution of the four readings as box plots for each thermometer. Readings from IR 1 ranged from -2.6 to -3.4 °C. The readings from IR 2 and IR 3 each averaged -0.9 °C and had a narrower range.

The readings from IR 2 and IR 3 were within the stated accuracy of ±1.5 to 2 °C of the melting point. The averages from these two IR thermometers were below 0 °C. Readings from IR 1 averaged -2.9 °C, which is outside its stated accuracy.

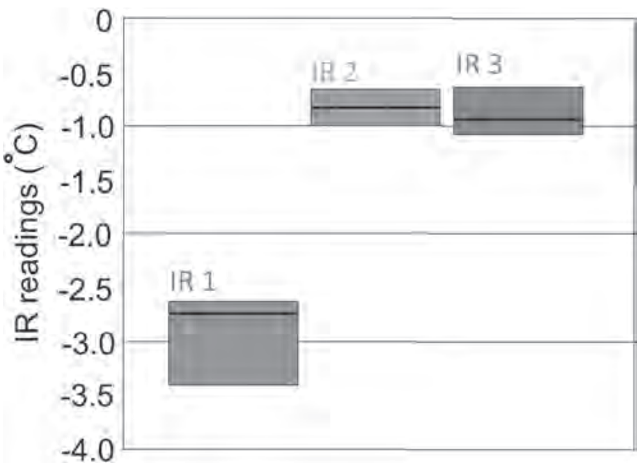

FIG. 7: BOX PLOTS SHOWING THE RANGE AND MEDIAN (THICK LINE) OF FOUR READINGS OF A WET SNOW SURFACE BY THREE IR THERMOMETERS SHORTLY AFTER REMOVAL FROM THE OPERATOR'S JACKET.

4.2 Effect of exposing the sensors to ambient spring air temperature

Fig. 8 shows the wet snow readings of three IR thermometers shortly after removal from the operator's jacket and four to five more times over 23 minutes. Between readings the thermometers were placed in the shade where the air temperature was 5.5 °C. The first readings for each IR thermometer are comparable to the readings in Fig. 7. Readings from thermometers IR 1 and IR 2 decreased in the first five minutes. After five minutes, all thermometers showed an increasing trend. IR 3 showed the most stable readings, increasing from -1 °C to +0.1 °C. For all six readings, IR 1 was outside its stated accuracy during the exposure to ambient air temperature. For three of four readings after more than a minute of exposure to ambient air, IR 2 was also outside its stated accuracy. For IR 2 and IR 3, the most consistent readings were obtained promptly after removal from the operator's jacket.

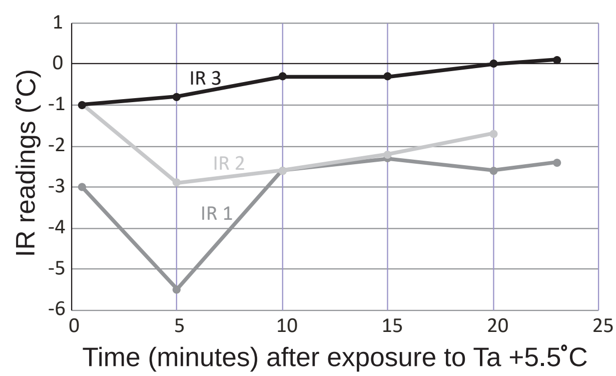

FIG. 8: TIME SERIES OF READINGS OF A WET SNOW SURFACE FROM THREE IR THERMOMETERS OVER 23 MINUTES AFTER REMOVAL FROM THE OPERATOR'S JACKET.

4.3 Comparing contact and IR thermometers

On a sunny day with the IR camera providing the reference snow surface temperature in the shade of a shovel and adjacent to the shaded area, readings were taken with two contact thermometers in the shade (Fig. 9). Prior to the start of shovel shading at 11:13, both contact thermometers displayed temperatures near the melting point, which was approximately 6 °C above the surface temperature recorded by the IR camera. After the start of shovel shading, the IR camera shows that the snow surface took about eight minutes to cool. The contact thermometers required a similar time to cool but the Acorn and Bios thermometers were approximately 4 and 5 °C, respectively, above the surface temperature as recorded by the IR camera. The contact thermometers in the shade were reading close to the surface temperature in the sun, but this was a coincidence.

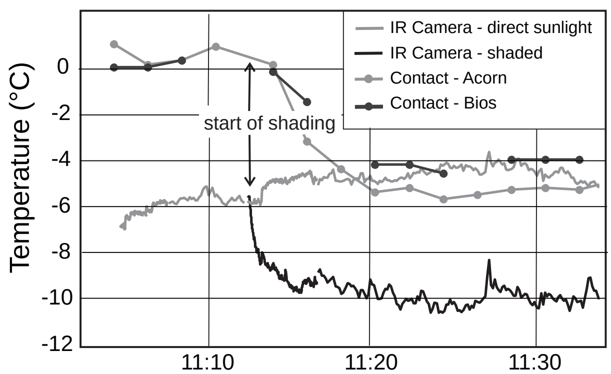

FIG. 9: SURFACE TEMPERATURE MEASURED WITH TWO CONTACT THERMOMETERS BEFORE AND AFTER SHOVEL SHADING AT 11:13 UNDER CLEAR SKY COMPARED TO REFERENCE TEMPERATURE FROM AN IR CAMERA.

Fig. 10 shows the readings from the IR camera, a handheld IR thermometer (pistol) and the same two contact thermometers when the sky was broken. Prior to shovel shading, the contact thermometers were reading about 6.5 °C too high. After shovel shading, which started at 10:13, the contact thermometers were reading about 6 °C above the reference temperature. These errors are primarily due to the lower albedo of the contact thermometers compared to the snow surface.

Prior to shovel shading (Fig. 10), the IR pistol was twice within its stated accuracy, which is about ±2 °C, and once about 7 °C below the reference temperature. After shovel shading the IR pistol was higher than the reference temperature by 1 °C or less for seven measurements and 2 to 3 °C higher than the reference temperature for four measurements. Only for two of the 11 measurements in the shade was the IR pistol error greater than the stated accuracy of 2 °C. These experiments were conducted in 2014. With different and newer IR thermometers in 2016 we found the accuracy of IR 2, IR 3 to be within specification (Fig. 7).

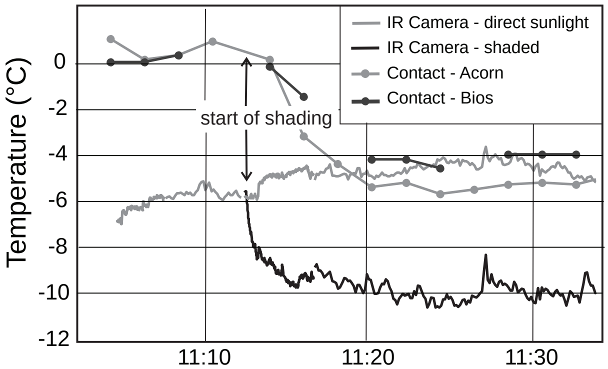

FIG. 10: SURFACE TEMPERATURE MEASURED WITH TWO CONTACT THERMOMETERS BEFORE AND AFTER SHOVEL SHADING STARTED AT 10:13 COMPARED TO A REFERENCE TEMPERATURE FROM AN IR CAMERA. THE SKY WAS BROKEN.

5. CONCLUSIONS AND RECOMMENDATIONS

The snow surface temperature is difficult to measure accurately with any technology. Since the albedo of contact thermometers is substantially lower than the albedo of snow, readings from contact thermometers can be substantially higher, e.g., up to 6 °C higher, than the snow surface temperature even in the shade. Handheld IR or tower mounted IR thermometers are preferable for measuring snow surface temperature. (Unfortunately, hand-held IR thermometers are not suited to measure the temperature profile on snow pit walls partly due to the typical exposure time of the pit wall as well as the effect of hollows, grooves, bumps and ridges in the pit wall (Schirmer and Jamieson, 2014)).

Before multiple units of the same make and model of inexpensive IR thermometers are purchased, the accuracy of a sample unit should be tested for the temperature range of interest or, at least, for slush (°C),

Our limited data suggest that temperature measurements with inexpensive IR thermometers should be done shortly after removal from a person's jacket. In the coming winter, we plan on testing IR thermometers shortly after removal from a backpack.

Some avalanche operations may choose to measure Tss in artificial shade. After shading by an object such as a shove blade, a sunny snow surface can cool for at least eight minutes before reaching its shaded temperature. After shading begins, a contact thermometer on the surface will cool partly because it is absorbing less SW and partly because it is in contact with snow that is cooling.

Inferring the near surface faceting from a point-in-time surface temperature measurement (even with an IR thermometer) and a snow temperature measurement 10cm below the snow surface is inferior to a few observations of the sky condition (J. Schweizer, pers. comm., 2016). When the sky is relatively clear for at least a few hours, faceting of near surface layers is more likely at night or on north quadrant slopes. Near surface faceting is best observed manually with a loupe and crystal screen. When manual field observations are impractical, snowpack evolution models such as SNOWPACK or CROCUS are useful.

Traditionally, at least in Canada (CAA, 2016, p. 4), shaded contact thermometers have been used to measure Tss once or twice a day in study plots. One reason for this measurement may be to track the change in surface temperature from day to day. However, the value of tracking Tss in a study plot is debatable, and Greene et al. (2010, p. 4) do not include this measurement in standard study plot observations. If an operation chooses to measure Tss in a study plot, then an IR thermometer is preferable because of the large errors associated with contact thermometers.

Based on results and arguments presented above, Table 1 shows our suggestions for the type of observation or measurement for the three objectives of avalanche forecasting operations.

TABLE 1: SUGGESTED TYPE OF THERMOMETER OR OBSERVATION FOR THE THREE TYPICAL OBJECTIVES OF AVALANCHE FORECASTING OPERATIONS RELATED TO SURFACE TEMPERATURE

	Objective		
	1.Near surface faceting	2. Tss change over days	3. Tss current
Reg. obs. in study plot	Sky	IR[a,b]	IR
Roving profile	Sky	n/a	IR

[a] same time each day
[b] in most study plots, surface exposure to sun/shade varies during the winter.

Especially in a roving snow profile in which the time required for measuring Tss takes away from other observations, we see little forecasting value in measuring Tss with a contact thermometer.

Reasons for continuing to measure snow surface temperature with contact thermometers in a study plot include: consistency with operational datasets, consistency with observation guidelines such as CAA's OGRS or with training programs. For operations concerned that switching to IR thermometers would compromise interpretation of their historical datasets for Tss, we suggest numerous, say 100, measurements with both types of thermometers under varied weather and snow surface conditions. This might facilitate a conversion for historical Tss measurements in level study plots, and might further clarify the limitations of contact and IR thermometers.

Even considering the 2 °C accuracy and limitations of inexpensive hand-held IR thermometers, they are more accurate than contact thermometers for measuring Tss. Also, IR thermometers can measure Tss when the snow surface is directly in the sun. For more on the science behind IR thermometers, see Shea and Jamieson (2011).

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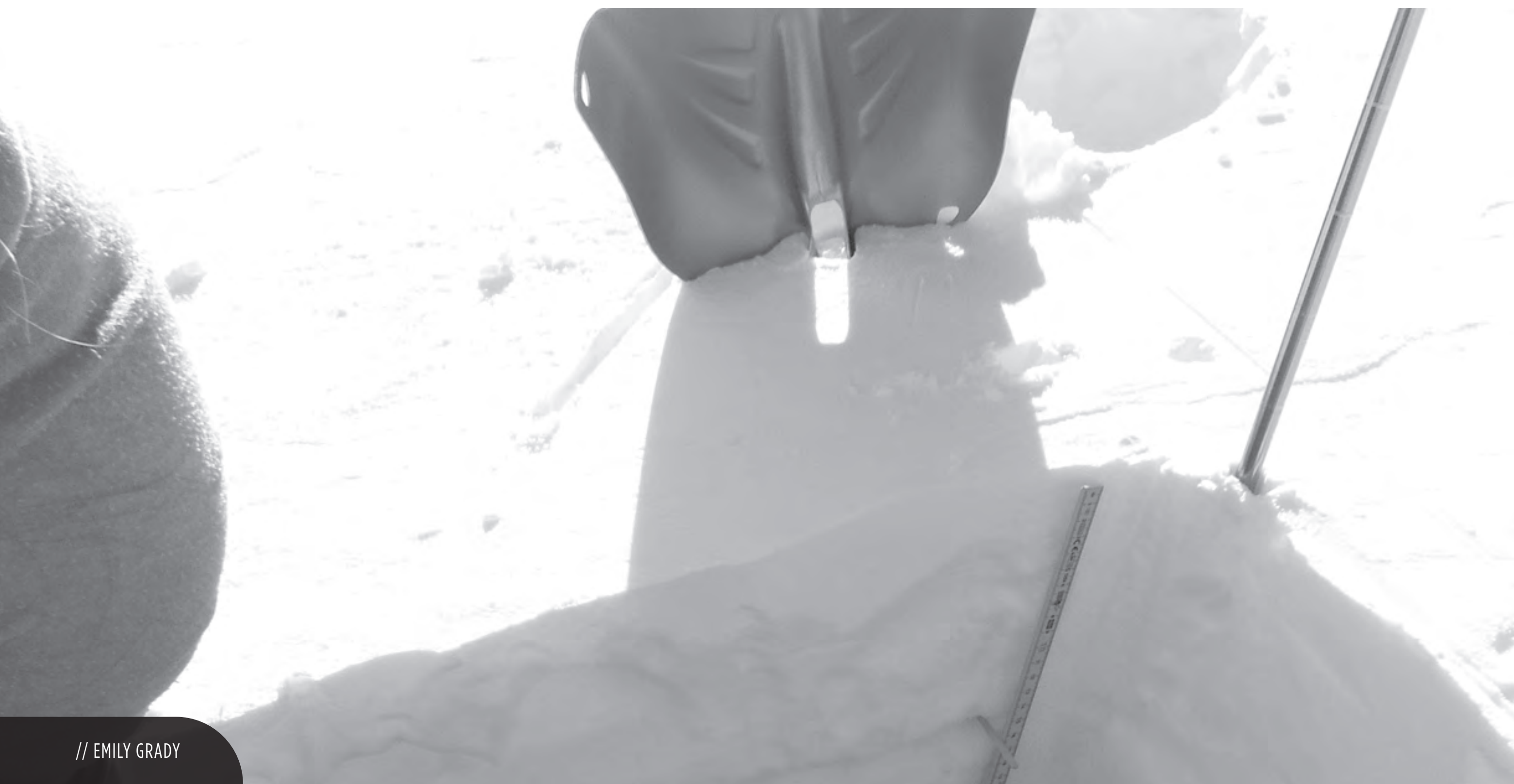

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