

Case studies are instructive in an analysis of avalanche risk. Several of the following summaries were produced in conjunction with an avalanche workshop held in Revelstoke in 1996 (Stethem et al. 1996). Examples cover a range of incidents in varied terrain and conditions. In Case Study 6.7, the incidents described resulted in a heightened avalanche awareness and in the development of a set of safe work procedures.



6.1 WARDANCE SLOPE AT BIG SKY, MONTANA

A 35–40° (70–80%) slope was logged for a ski run in the 1980s, creating a 1-ha start zone (Figure 141). Avalanches threatened four lots in a subdivision downslope and legal action ensued.

The range of mitigation measures proposed included:

- deflecting or arresting dams;
- incorporating protective structures into the buildings;
- using zoning to prohibit the use of the buildings during the winter; and
- constructing snow-supporting structures in the start zone to promote reforestation of the slope.

A snow support structure was chosen, designed, and constructed with the help of American and European avalanche consultants. The structure and its foundation had to be designed to cope with snow creep and glide pressures, which can be significant.



FIGURE 141
High consequence: a slope logged to create a ski run has potential to generate avalanches that might run out into high-value buildings below.

This design was based, in part, on a 20-year reforestation period (Figure 142). Since its construction in 1990, several small avalanches have initiated below the structure. One larger, full-depth release occurred to the right of the structure, but did not come close to the remaining trees below the slope. It did not pose a threat to the subdivision.



FIGURE 142 Supporting structures in start zone designed to inhibit avalanches, thus protecting buildings and people in the runout zone.

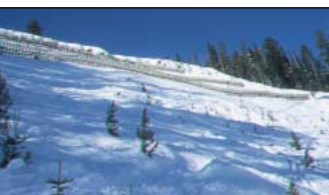


FIGURE 143 Ten-year-old trees, 1.5–2 m in height, offer little protection in a 1.25-m-deep snowpack.

The support structure and reforestation, though expensive, were considered the best solution for long-term mitigation of the hazard to the lots. Reforestation of the avalanche path was seen to be the most practicable and effective means of reducing the avalanche risk. Reforestation now depends on the successful functioning of the engineered snow support structures (Figure 143).

6.2 PROTECTION ROLE OF FORESTS ABOVE THE COQUIHALLA HIGHWAY, B.C.

Forests adjacent to the Coquihalla Highway contain valuable timber. Areas of forest adjacent to the highway have also been identified as having a “protection” function; logging these areas would increase the avalanche hazard on the highway. The B.C. Ministry of Transportation has long been concerned that logging of the slopes adjacent to the highway could increase the avalanche and debris torrent hazard.

The value of timber that could be harvested from these protection forests over 25 years was compared with the cost of additional avalanche hazard mitigation under four different scenarios (Lister et al. 1986):

1. No logging
2. Logging using conventional clearcut techniques
3. Logging with some restricted areas
4. Logging with careful controls

Option 4, involving intensive forest management prescriptions, was recommended based on a cost-benefit analysis. This option was expected to increase harvesting costs by 60%, but would not require additional measures to mitigate the avalanche hazard to the highway.

Lister's report provides a cost-benefit analysis based on harvesting and mitigating avalanche hazards and an example of designation of European-style "protection forests" in British Columbia. This concept is developed in the proposed Canadian national avalanche mapping and zoning standards (CAA 2002; McClung et al. 2002).

6.3 AVALANCHE TRIGGERED IN CUTBLOCK KILLS RECREATIONIST NEAR SALMO, B.C.

In January 1994, a snowmobiler was killed in an avalanche in a clearcut near Salmo, B.C. Because many forests are too dense to be used for winter recreation, logged areas inevitably attract recreationists. Accidental triggering of avalanches is likely in some areas, especially where extensive surface hoar development is common (e.g., in the Columbia Mountains).

Forest development on public lands is undertaken differently in British Columbia compared with the U.S. Pacific Northwest. In British Columbia, the timber licensee locates and lays out cutblocks on Crown lands. Similar accidents have occurred in the United States where the U.S. Forest Service is responsible for locating and laying out cutblocks in National Forests, which are federal land. If a new block proved to be avalanche-prone, then the responsibility would lie with the government, not the timber company (S. Bones, U.S. Forest Service, pers. comm.).

As a general rule, the U.S. Forest Service does not place signage on forest roads to warn of avalanche hazards. Unploughed roads and unmaintained areas are not signed in any way during the winter. Avalanches are treated no differently than any other backcountry hazard situation. Backcountry users recreate at their own risk in U.S. National Forests. The situation is less clear where roads are groomed for over-snow winter use.

6.4 RANCH RIDGE, NEAR HILLS, B.C.

On February 12, 1988, a snow avalanche from a steep clearcut in an area known as the Ranch Ridge ran into a steep gully (Figure 144). The avalanche contributed to a mixed snow avalanche and debris flow,



FIGURE 144 Two wet snow avalanches originated in adjacent clearcuts in the same period. One of these reached Highway 6.

which then ran out onto Highway 6, 3 km south of the community of Hills in the Slocan Valley. The deposit at the highway was a mixture of snow, log debris, soil, and rock.

Reports from the time of the incident indicate that the event originated in the clearcut as a wet snow avalanche, which then knocked down trees below the block. The avalanche entrained both timber and soil in the gully and ran out at the highway as a mixed deposit. A second avalanche ran in an adjacent clearcut and gully, but did not reach the highway, probably because benched terrain in the runout zone caused the event to stop above the highway (Figures 145 and 146).



FIGURE 145 *The first of two snow avalanches originating in a clearcut stopped just before Highway 6. A second event blocked both the road and railway. (A berm has subsequently been constructed in the runout to protect the highway.)*

A debris flow followed down the avalanche path in April 1988 when a landing failed. The flow probably entrained some of the avalanche debris already in the gully. The highway was again blocked and fine sediment was discharged into Slocan Lake. Further snow avalanches and debris flows have since occurred in the gully.

6.5 AIRY CREEK IN THE SLOCAN VALLEY, B.C.

At Airy Creek in British Columbia's Slocan Valley, a large, high-elevation clearcut (Cutting Permit 72, Block 6 in Tree Farm Licence 3) was logged in terrain that contained a shallow bowl and a small gully that extended downslope below the clearcut. Prior to logging, the potential for snow avalanches was limited to small, non-destructive events in the natural gully feature. After being harvested, the clearcut became prone to wind loading.

In February 1994, a large avalanche originated in the bowl within the clearcut. The avalanche entrained timber along the gully, breaking trees of up to 40 cm dbh. Midway down the track, mature cedar trees were ripped out of the ground in an area about 3 m wide by 10 m long (Figure 147).

One nearby cedar tree was flagged to a height of 15 m. The debris ran to the creek below, blocking the stream. Intakes on the community water supply were put at risk.



FIGURE 146 *Mixed deposit of snow, trees, and colluvium.*

Regeneration of the forest cover in this new avalanche start zone and track is considered critical to the protection of downstream values.

Timber, soils, and surficial materials entrained in snow avalanches that run into creeks may affect both the water quality and supply of downstream communities. This site in the Slokan Valley has high scenic values.

6.6 NAGLE CREEK CUTBLOCKS, NEAR MICA CREEK, B.C.

A series of clearcuts on a steep valley side were harvested in 1988 at Nagle Creek, near the Mica Dam, B.C. Replanting occurred in 1990. On March 14, 1996, a large (Size 4.5), wet avalanche released in Block 83D007-27, ran into standing timber below, and destroyed 12.5 ha of forest, a significant resource. Two adjacent blocks in near-identical topography did not avalanche (Figure 148).

Cutblock 83D007-27 measures approximately 500 m along the contour and has a maximum downslope length of about 500 m. It spans an elevation range of 950–1270 m (300 m vertical). The block has a slight convex profile with a narrow, gently sloping bench at the top. Below the bench, the slope is uniformly steep and has a number of shallow linear depressions and a few rock outcrops. Neither the bench nor the gullies are identified on 1:20 000 scale TRIM mapping.

Tree stumps of 0.2–0.8 m diameter and 0.3–1.0 m in height remained on the slope after harvest. Below the block, a continuous band of mature timber existed from 950 to 750 m elevation. A young plantation existed below 750 m (also see Figures 3, 17, and 85).

The avalanche fractured on a slope of 33–42° (65–90%), across a width of 500 m below a convex break in the slope where stumps were cut off near ground level to optimize deflection for cable yarding. A second, full-depth fracture extended across a steep section of road fill (Figure 149).



FIGURE 147 Airy Creek avalanche originated in a clearcut and ran into a community watershed.



FIGURE 148 The block in the foreground avalanched, but the two adjacent clearcuts, which have similar topography, were not affected. The affected block had been broadcast burned, which reduced the surface roughness compared with the unaffected blocks.



FIGURE 149 Fracture occurred at upper convex slope change and below the road. A subtle concavity exists in a gully to the left.

The moving avalanche mass was partly channelled by shallow depressions on the slope, which increased its destructive potential. Some surface materials and soils were removed below the cutblock by the moving avalanche (Figure 150). Avalanches stripped the bark and limbs on the uphill side of the standing trees (Figure 151).



FIGURE 150 *Timber damage and soil erosion represent substantial resource losses.*



FIGURE 151 *Damage to immature trees in the start zone (snowshoe for scale).*



FIGURE 152 *LANDSAT image of the area surrounding Mica Dam showing forest damaged by avalanches at Nagle Creek (arrow). Note: An avalanche occurred in the block in March 2000.*

Similar destructive events also initiated in clearcuts at nearby Pat Creek, near Mica, and in the Akolkolex River south of Revelstoke during the same warm weather.

The Ministry of Forests retained an avalanche consultant to investigate the release. A snow profile investigation was undertaken above the fracture line and the snowpack was determined to be isothermal at 0°C. A hard melt–freeze crust at the surface was found to overlay a relatively low-strength snowpack.

A Ministry of Transportation remote weather station sited at a similar elevation and aspect approximately 5 km away showed a maximum air temperature of 13°C on the day of the event, up from the preceding day’s maximums of 6 and 7°C. It is likely that rapidly rising air temperatures and strong inputs of solar radiation produced snowmelt. The avalanche release was attributed to liquid water percolating down to a series of crusts deep in the pack, producing a lubricated sliding surface.

The road through the block has subsequently been deactivated and the slope profile restored. Removal of the over-steepened fillslope is likely to have reduced the avalanche susceptibility in that part of the block.

The potential for forest regeneration has been compromised in parts of the block where soil was scoured. The affected area remains clearly visible from space in medium-resolution satellite images (Figure 152).

6.7 AVALANCHE IN A BLOCK WITH ACTIVE LOGGING, SOUTHERN INTERIOR, B.C.

Two avalanche incidents that occurred in an active harvest area in the Southern Interior of British Columbia in February 1999 provide insight into workplace hazards encountered during winter logging. Fortunately, no one was injured in the incidents. Avalanche awareness was much heightened and a set of safe work procedures developed. This case study is both real and highly instructive. After scrutinizing it in detail, one might be able to assess how other operations would manage in a similar scenario.

After a series of snowfalls and a natural avalanche in an adjacent cutblock, two avalanche technicians were contracted by a timber company to assess the snow stability in a block where winter timber harvesting was approximately two-thirds complete (Figure 153). Their plan was to use explosives to release unstable snow if they assessed the snowpack to be unstable and the workplace hazardous.

Day One – Accidental Triggering

Winter harvesting with partial suspension cable yarding was complete in the western half of a steep cutblock. The logged portion was separated from an access road approaching from the north by a 100–150 m long strip of immature forest. The eastern portion of the block had a forwarding trail crossing through standing forest to a cable yarder that was situated mid-slope in a partially harvested area. Harvesting and yarding in the upper portion of the block were complete. Both felled and standing timber were located below and adjacent to the yarder.

The logging crew consisted of five people in the harvest area and one on a landing. In the harvest area, one person was operating a cable yarder, and two were shovelling snow and felling and hooking trees onto the aerial cable. One person was unhooking trees at the yarder and another was skidding the logs down the forwarding trail to the landing. The person on the landing was bucking and loading logs onto trucks. Their employer was operating a grader a few kilometres away, ploughing snow from forest roads.

Two avalanche technicians arrived onsite to undertake a snow stability assessment. They determined that the yarder and crew were at risk if the slope above was to avalanche and recommended that the crew postpone



FIGURE 153 A natural avalanche occurred in the cutblock at the right. Two avalanches were triggered in the cutblock in the foreground, one of which ran down to the creek in the valley floor.

work until the snowpack stability could be assessed and, if need be, avalanches could be triggered with explosives. The contractor and logging foreman felt that, because of the recent yarding activities on the cutblock, snow accumulations would be inadequate to produce a substantial avalanche. The logging contractor and foreman decided that they would remove the crew from the work area if it were established that there was a potential instability in the snowpack. The avalanche technicians set out to make this determination through snowpack investigation. They had no clear authority to recommend that the logging operations be temporarily suspended.

Using skis fitted with climbing skins, the avalanche technicians climbed through the area of standing timber within the block. Their route proceeded westward towards an area where the slope broke into a stream gully and the standing timber met the uphill cable-harvested section. The size of the open slope (harvested area) between the climbing trail in the timber and the top road was considered to be sufficient to generate a large avalanche. The technicians decided that the rib forming the gully break to the west would make a safe climbing route so they continued their ascent to access the upper road.

When the avalanche technicians reached the upper road, they stopped to select a site to excavate a snow profile. The snowpack settled under their weight with a characteristic “whumpf.” Immediately following the settlement, most of the snowpack on the harvested area on the eastern portion of the cutblock was set in motion. The settlement triggered a slab avalanche with a 30–40 cm deep crown extending from the technicians’ climbing track to the gully near the eastern boundary, a distance of approximately 300 m. The fracture propagated across the entire area above the logging crew.

The avalanche ran through a stand of hemlock (age class 8, greater than 140 years old), burying the forwarding trail to a maximum depth of 4 m. It then ran out into the gully near the eastern boundary, burying much of the downed timber, then continued through standing forest, knocking down several large hemlock and pushing several trees down to the trail.

The logging contractor was notified of the situation by radio. He immediately made his way to the landing where the loader operator was working alone. The avalanche technicians made their way towards the yarder, prepared to initiate an avalanche rescue. They were extremely relieved to find four of the crew standing by the machine. One worker, who

sought refuge below the yarder, was partly buried as the moving snow flowed around the machine.

After establishing that the harvesting crew was safe, attention was turned to the skidder operator who had been forwarding logs down the trail at the time. The avalanche had travelled through the standing hemlock and over the forwarding trail. The technicians and harvesting crew followed the trail down to the landing, looking for signs of the machine. The operator had just reached the landing when the avalanche struck and was, fortunately, out of harm's way. It was quickly established that all workers were present and accounted for and that no injuries had occurred.

Some equipment (chainsaws, pulley blocks, and cables) was lost or damaged. The upper side of the yarder was buried to half the height of the cab and the operator had to climb out through the hatch in the top. The faller and shoveller working below the yarder were protected from the avalanche by the machine and the forwarding trail, which had absorbed some of the momentum of the moving avalanche mass.

After the event, a test snow profile was undertaken and the snowpack was found to contain a thin weak layer of surface hoar grains on top of the old snow surface, even though harvesting activities had disturbed the surface. The slope had been cross-loaded with new snow by winds from the west and southwest. Table 25 describes the avalanche start zone geometry and dimensions of the avalanche that released.

Day Two – Equipment Damaged during Avalanche Control

Given that the previous day's avalanche indicated very poor snowpack stability and that the avalanche technicians had found buried surface hoar, avalanche control work was planned.

The key area of concern was where a haul road crossed through a stream gully just before reaching a log landing. The gully showed evidence of previous avalanche activity: there was thick brush and only a few trees within 2–3 m of the stream banks. A reserve patch extended from the haul road, approximately 150 m up the stream gully, and was contiguous with standing timber on the east side of the gully. The reserve

TABLE 25 *First avalanche start zone: geometry and dimensions*

Cutblock elevation	1450 m
Cutblock aspect	Northeast
Cutblock slope angle	53–70% (28–35°)
Avalanche crown width	300 m
Mass (estimated)	2400 t
Avalanche size	3.0
Avalanche trigger	Person, accidental

timber and a strip of immature forest below the western portion of the block were presumed to be providing protection to the haul road where it entered the block from the north. In the harvested area above the reserve, wind-deposited snow had accumulated below a convex slope break. Because vegetation in the stream gully showed signs of past avalanche activity, the avalanche technicians decided to use explosives in an attempt to release the unstable snow at the gully to eliminate the hazard posed to the haul road.

A 25-kg explosive charge was delivered by helicopter to a cross-loaded slope above the reserve area with the aim of initiating an avalanche that would be confined by the gully. The fracture propagated more widely than anticipated and a Size 3 avalanche released. The slab pulled out most of the slope above the gully, but the avalanche did not become confined to the stream gully until below the haul road. The avalanche moved slowly as it ran through the reserve timber above the road, but rapidly gained speed within the gully. The avalanche track was widened as mature timber was broken along the flanks and the runout extended into a recently spaced juvenile stand. The avalanche ran to the edge of the creek below the gully, but did not enter it (Figure 154).



FIGURE 154 *New path resulting from slab avalanche triggered by explosives in clearcut above. The avalanche ran through the standing timber into the gully in the foreground.*

The contractor's emergency transport vehicle (ETV) was parked on an inactive forwarding trail, within the reserve timber patch, approximately 40 m west from the stream gully. There was approximately 30 m of standing timber above the vehicle. It was incorrectly presumed to be in a safe location.

When the avalanche ran through the patch of timber above the ETV, it buried the vehicle. The force of the snow then picked up the vehicle, spun it around through 90°, and deposited it wheel-side down on the main haul road approximately 10 m below. The avalanche continued down the gully to the edge of the creek, leaving the ETV on the road above. The vehicle suffered considerable external body damage including a broken window. It was excavated from the debris and driven away for repairs the next day. Had the road not stopped the vehicle, damage and retrieval efforts would have

been far more severe. Table 26 describes the start zone geometry and dimensions of the second avalanche.

Incident Review

No weather records were available. The avalanche technicians were not informed of the natural avalanche in an adjacent cutblock. Perhaps no one working onsite noted it.

When the snowpack stability in an area is unknown, it is better to work from the hypothesis that the area is highly unstable and take all practicable precautions. The assumption that recent partial suspension logging had disturbed the snowpack enough to obliterate any weak layers proved incorrect.

Clear lines of responsibility and command must be defined before an external contractor is called in to an existing work site.

None of the forest workers was wearing an avalanche transceiver. Workers must be provided with avalanche rescue beacons if they are exposed to a moderate level of risk, as discussed in Chapter 3, “Avalanche Risk Assessment.”

Communications are all-important. The loggers were not on the same radio frequency as the avalanche technicians, forestry company office, or contractor, who was several kilometres away in a grader.

Development of Safe Work Procedures for Snow Stability Assessment in Active Harvest Areas

After the event, the avalanche technicians worked together with the WCB and the forestry company to establish safe work procedures, a summary of which follows:

Rationale and Recommendations

Snow avalanches may pose a threat to logging crews working in active and inactive timber harvest areas in steep snow-covered terrain throughout the winter and spring. Avalanche likelihood is related to snow stability and the presence of a trigger. Snowpack observations enable

TABLE 26 *Second avalanche start zone: geometry and dimensions*

Cutblock elevation	1450 m
Cutblock aspect	North to northeast
Cutblock slope angle	53–70 % 28–35°
Avalanche crown width	200 m
Avalanche fracture depth	40 cm
Avalanche size	3.0
Avalanche trigger	Explosives, by helicopter

snow stability to be assessed so that safe risk management decisions can be made.

It is strongly recommended that logging crews be adequately trained and supplied with appropriate safety equipment when working in potential avalanche terrain. Training should include an annual one-day avalanche course that addresses specific issues encountered by loggers in avalanche-prone terrain. Personal protective equipment should include avalanche transceivers for everyone onsite and easily accessible rescue caches containing avalanche probes and shovels positioned outside the avalanche-prone area.

The following summary of safe work procedures is intended to minimize the exposure of logging crews and related workers to avalanches while snow stability is being assessed.

Safe Work Procedures

Snow stability assessment must be undertaken by a minimum of two people, one of whom will have a CAA Level 2 qualification and avalanche forecasting experience. Both of these people will be equipped with, and competent in the use of, avalanche transceivers and standard rescue equipment (probes and shovels). The assessment team will have a minimum of two radios capable of communication with workers and equipment in the vicinity.

Depending on the local terrain within the harvest and work area, workers, other than those on the assessment team, may be restricted to a “safe area” not potentially exposed to any avalanche that may initiate in the area being assessed. These “safe areas” will be determined by the avalanche technician in charge and communicated to the logging foreperson.

The possibility that traditional “presumed areas of safety” may no longer offer protection from avalanches if the upslope forest cover has changed must be factored into decisions. Depending on the size of the logged opening and the terrain configuration, snow avalanches may occur in areas where none have occurred before. Avalanche tracks and runout zones may yet be created or extended. This must be considered when safe areas are being defined.

When possible, snow observations will be scheduled on days when no logging crews are working in the vicinity of the area being assessed. If such scheduling is not feasible, the logging crew will be required to allow

the snow observation crew adequate time to gather the information necessary to make the snow stability assessment. During this time, workers will be required to vacate the vicinity of the area of potential hazard as determined by the avalanche technician. This restriction will be cancelled if the avalanche technician determines the risk of avalanche initiation to be low.

In an active harvest area, there may be anomalies in the snowpack structure when it is compared with surrounding undisturbed snow. This possibility will be investigated and considered as a part of the snow stability assessment.

Upon the completion of the fieldwork, but before departure from the potential hazard area, the assessment team will contact the client (forest licensee) and the logging contractor (if onsite) and supply an interim stability assessment. A full report, including plotted snow profiles, snow stability assessment, and recommendations, will then be submitted to the client.

(Source: Workers' Compensation Board [wcb], current as of March 2000, subject to periodic review)

Snow avalanches can constitute a workplace hazard if logging or other operations are undertaken on or below steep terrain where an unstable snowpack creates avalanche danger in winter or spring.

The *Workers' Compensation (Occupational Health and Safety) Amendment Act 1998* came into force on October 1, 1999. Section 115 sets out general duties of employers as follows:

Section 115 (1) of the Act requires that every employer must:

- (a) ensure the health and safety of
 - (i) all workers working for that employer, and
 - (ii) any other workers present at a workplace at which that employer's work is being carried out, and
 - (b) comply with this Part, the regulations and any applicable orders.
- (2) Without limiting subsection (1), an employer must:
- (a) remedy any workplace conditions that are hazardous to the health or safety of the employer's workers,
 - (b) ensure that the employer's workers
 - (i) are made aware of all known or reasonably foreseeable health or safety hazards to which they are likely to be exposed by their work,
 - (ii) comply with this Part, the regulations and any applicable orders, and
 - (iii) are made aware of their rights and duties under this Part and the regulations,
 - (c) establish occupational health and safety policies and programs in accordance with the regulations,
 - (d) provide and maintain in good condition protective equipment, devices and clothing as required by regulation and ensure that these are used by the employer's workers,
 - (e) provide to the employer's workers the information, instruction, training and supervision necessary to ensure the health and safety of those workers in carrying out their work and to ensure the health and safety of other workers at the workplace.

Section 119 requires that every owner of a workplace must:

- (b) give to the employer or prime contractor at the workplace the information known to the owner that is necessary to identify and eliminate or control hazards to the health or safety of persons at the workplace.

Blasting Operations

Part 21.85 of the Occupational Health and Safety Regulations

(B.C. Regulation 296/97) **relates to blasting operations used in snow avalanche control.**

21.85 Snow Avalanche Control

- (1) Explosive charges must not be dropped from a helicopter or other aircraft, placed manually on site by workers, or projected by any means for the purpose of avalanche control, until the proposed work procedures have been submitted to and accepted by the board.
- (2) Explosives must not be primed until the last most practicable moment, which means that point in time when the explosives are as close to the control route as possible, in a safe, sheltered location excluded from public access.
- (3) The pull-wire lighter must not be placed on the safety fuse assembly until immediately before placing the charge.
- (4) The employer must ensure that procedures are reviewed annually and that proposed changes to the procedures are submitted to the board for approval before implementation.

The Canadian Avalanche Association has consulted with the WCB to establish safe work procedures for the priming of explosives at “the last most practicable moment.” Consultation on other matters is ongoing.

Forestry Operations

Part 26.17 of the Occupational Health and Safety Regulations

(B.C. Regulation 296/97) **relates specifically to weather conditions as they may affect snow avalanches while 26.18 relates to landslides and/or snow avalanches in forestry operations.**

26.17 Weather Conditions

When weather conditions create hazards to workers, additional precautions must be taken as necessary for the safe conduct of the work.

26.18 Landslides/Avalanches

In a forestry operation where there may be a risk of a landslide or avalanche,

- (a) the risk must be assessed in accordance with a standard acceptable to the board,
- (b) if a risk is found to be present, written safe work procedures must be developed meeting the requirements of the standard, and
- (c) workers must be educated in the safe work procedures.

A 2.1 Safe Work Procedures

(Adapted from B.C. Ministry of Transportation's Snow Avalanche Program)

The following example is intended to serve as a template for safe work procedures. It should be adapted to suit the scale of operation and degree of hazard encountered in an area.

This management system assumes that:

- a) *there will be one person responsible for avalanche hazard management. That officer will have specialist training in snow stability evaluation (i.e., CAA Level 2). The snow stability will be rated on a scale from Very Good to Very Poor (see Appendix 6). That person will make a daily formal assessment of the avalanche danger in winter (Low, Moderate, or High) for various elevations and aspects.*
- b) *a written avalanche search and rescue plan exists.*
- c) *all potential avalanche paths are identified and mapped in an avalanche atlas, and an overall risk rating is produced for the operating areas (Low, Moderate, High, or Very High). See Section 3.2, "Avalanche Risk Classification," and Table 12.*
- d) *signage is in place at all ploughed major forest roads intersected by avalanches.*
- e) *all proposed cutblocks are rated for avalanche initiation or runout.*

Field personnel must:

- a) *be able to recognize avalanche terrain and the safe areas within the operating area;*
- b) *understand the importance of having warm clothing available inside machinery in case of burial;*
- c) *know the correct procedures to follow when buried by an avalanche, whether inside or outside a vehicle or machinery;*
- d) *know the correct procedures to follow when an avalanche is on a forest road;*
- e) *know where all other personnel working in an avalanche area are during hazardous periods;*
- f) *know the correct procedures to follow regarding the use of heavy equipment in avalanche areas;*
- g) *know the basic indicators of changes in snowpack stability and the need to report them to an officer for avalanche risk management; and*

- h) know the location of rescue caches and have access to emergency avalanche transceivers, probes, radios, and first aid kits.

Rescue Procedures

All field personnel must know the procedures for:

- a) reporting the accident
- b) locating and using rescue equipment
- c) using avalanche rescue beacons
- d) using the *Avalanche Search and Rescue Plan*; including:
 - initiating the rescue operation
 - following the line of command for rescue
- e) carrying out an avalanche rescue.

Avalanche Awareness and Safety Training

Snow avalanche paths that affect operating areas throughout the forest should be identified on waterproofed maps and orthophotos. Workers operating in these areas require a specific level of avalanche safety training that depends on:

- a) the severity of avalanche terrain and frequency and magnitude of avalanches expected in the area (risk);
- b) the location of the area (i.e., if the area is remote and/or radio communications are poor, then more extensive training is required);
- c) the position of the person and his or her possible involvement in an avalanche rescue; and
- d) the regularity with which staff are expected to work in the area (i.e., road maintenance or logging personnel working in moderate or high-hazard areas will require a higher level of training than personnel working in low-hazard areas on an irregular basis).

Assessment of Avalanche Danger

At the beginning of winter, the officer responsible for avalanche risk management will begin monitoring the snowpack to establish when avalanche thresholds are attained (largely a function of surface roughness). Thereafter, the avalanche danger, as assessed at each work site, will be broadcast by radio to all workers at the start of each working week, and written notice provided to all contractors. Contractors will advise all workers of the avalanche danger and modify work procedures accordingly. The officer will be advised of rate of harvest at various operations. New clearcuts above roads may create potential paths that did not exist at the start of the winter.

Assessments are to be updated each working day if conditions change or are expected to change.

Low Avalanche Danger

During periods of low danger, workers and contractors may proceed with normal forest operations. The officer responsible for avalanche risk management will:

- a) Ensure that avalanche rescue equipment is maintained and ready for use.
- b) Ensure that turnarounds on forest roads are free of snow. Pullouts in designated avalanche areas must not be cleared of snow once avalanche thresholds are attained.
- c) Ensure that correct avalanche safety measures are practised. This includes not stopping, re-fuelling, or parking vehicles and equipment in designated avalanche areas on forest roads.
- d) Monitor and record changes in:
 - avalanche occurrence observations
 - basic indicators of snowpack stability
 - current weather observations.

Functions outlined in d) may be delegated to a contractor or other worker, provided the information is transmitted by radio in a timely manner.

Moderate Avalanche Danger

During periods of moderate danger, all workers and contractors will:

- a) Maintain communication with the officer responsible for avalanche risk management and immediately give notice of any apparent changes in the snow avalanche danger.
- b) Immediately notify the officer responsible for avalanche risk management if avalanche activity is increasing or affecting any forest road or harvest area.
- c) If working outside of vehicles or machines in potential avalanche areas, move to safe areas when instructed.
- d) Monitor and report to the officer responsible for avalanche risk management on:
 - avalanche occurrences
 - basic indicators of snowpack stability
 - current weather.
- e) Take additional observations if requested by the officer responsible for avalanche risk management.
- f) Call by radio upon entering and leaving avalanche areas and when travelling through signed avalanche paths on forest roads.
- g) Ensure that equipment and resources are available for working in pairs, should the avalanche danger warrant. Working in tandem shall

occur at the discretion of the officer responsible for avalanche risk management.

- h) Not operate stationary equipment (e.g., yarders) within potential avalanche areas unless the officer responsible for avalanche risk management has been consulted and given approval. If stationary equipment is allowed in the avalanche area, an off-site spotter may be required. Machines can work in separate, but adjacent, areas if the operators have visual contact, thus eliminating the need for a spotter.
- i) Ensure that one person regularly monitors the location of road maintenance staff such as grader operators. All persons working alone shall check in at 30-minute intervals.
- j) Monitor weather forecasts and avalanche bulletins.
- k) Conduct road closures to allow for avalanche control (helibombing) programs as directed by the officer responsible for avalanche risk management.

High Avalanche Danger

During periods of high danger, the officer responsible for avalanche risk management will:

- a) Advise the contractor to close work sites in potential avalanche areas that may be affected by snow avalanches.
- b) Ensure that there is no travel by any personnel in or through avalanche areas except where personnel are needed to carry out:
 - a post-closure sweep of the area
 - avalanche and weather observations
 - avalanche control operations
 - any other task as approved by the officer responsible for avalanche risk management.
- c) Ensure that no travel or work occurs at night in the avalanche area.
- d) Ensure that correct avalanche safety procedures are practised.
- e) Ensure that no other regular forest and harvest activities are conducted inside the affected avalanche area.

During periods of high danger, contractors and workers operating outside of potential avalanche areas will:

- a) Monitor and report to the officer responsible for avalanche risk management:
 - avalanche occurrences
 - basic indicators of snowpack stability
 - current weather.
- b) Take additional observations as necessary or as requested by the officer responsible for avalanche risk management.

- c) Monitor weather forecasts and avalanche bulletins.
- d) Continue forest road maintenance as required within safe areas, in consultation with the officer responsible for avalanche risk management. Machine operators must work in tandem in potential avalanche areas and schedule radio checks at 15-minute intervals.

A 2.2 Response – Avalanche on Road

(Adapted from Crestbook Forest Industries)

A card with the following information is to be carried in all vehicles (the card should be plastic laminated to a forest road map).

If you encounter an avalanche on a road:

- a) Stay in the vehicle.
- b) Radio the supervisor or area office (or whomever you can contact if the former are not accessible) and specify the location and avalanche size (kilometre point on road, length of road covered, and maximum depth on road).
- c) Try to determine if anyone might be caught. (Is the avalanche large enough? Is anyone missing?)

If someone might be caught, then initiate a rescue immediately:

- a) Evaluate the upslope danger. (Do multiple start zones exist? Could more avalanches occur?) Do not proceed into the path if you are alone and if the avalanche danger persists.
- b) Determine an escape route. Appoint a spotter if possible. Expose only a minimum number of people to potential hazards.
- c) Ensure that your avalanche transceiver is on. Take a portable radio with you. If that is not possible, tell someone that you are going onto the deposit and that you will call back in 5 minutes.
- d) Conduct a quick search of the entire deposit, looking for visual clues, and check for an avalanche transceiver signal. If no signal is apparent, probe the likely burial spots.

If you are certain that nobody is caught:

- a) Do not venture onto the deposit.
- b) Move to a safe location, notify the officer responsible for avalanche risk management, and await instructions.

If your vehicle gets caught in an avalanche or stuck in avalanche debris:

- a) Stay in the vehicle.

- b) Shut off the engine and lights (to avoid the risk of carbon monoxide poisoning and to conserve the battery) and do not smoke.
- c) Radio the supervisor or area office (or whomever you can contact if the former are not accessible). Describe the location and size of the avalanche (give the road kilometre point, length of road covered, and maximum depth on road). Leave the radio on.
- d) Try to determine if anyone else might be caught and radio out this information.
- e) Ensure that your avalanche transceiver is in “transmit” mode.
- f) Only if you are certain that no further danger exists and that you can move to a safe location should you leave the vehicle.
- g) If the vehicle is buried, push a probe out through the window and up to estimate the depth of burial. Leave the probe in place to mark your position for the rescue party and to provide an air path.
- h) Do not start the vehicle. Put on extra clothes for warmth.

A 2.3 Avalanche Search and Rescue Plan – Office Procedures

(Adapted from Crestbook Forest Industries)

The following summarizes the key elements of an avalanche rescue plan for office staff who will need to co-ordinate the rescue effort. The plan should be modified to suit the local operating environment. See Chapter 8 of the Avalanche Handbook (McClung and Schaerer 1993) and Backcountry Avalanche Awareness (Jamieson 1997) for further information.

Time is of the essence. Keep a log of persons and agencies that have been contacted, noting arrangements, estimated times of arrival, etc. The office must function as a central dispatch and rescue co-ordination centre. Having two or more people share the contacting duties will speed the rescue effort. Appoint a person who is not involved in the rescue to deal with inquiries from the media.

1. **Dispatch the first rescue party to the site** with basic rescue equipment. Obtain probes and shovels from caches on the way to the site (refer to the emergency caches map).
2. **Contact Search and Rescue (SAR) or nearest Canadian avalanche rescue dog handler (CARD A).** Use whoever can most quickly access the site by helicopter (see dog team list below). **Arrange a helicopter pick-up location with the dog master.** If leaving the message on a pager, report the incident, give a contact phone number and explain that helicopter transport is being arranged and you will call back with the pick-up location. Even after leaving a pager message, contact a second or third dog team and make transport arrangements. If

weather may prevent helicopter access to the site, arrange to **fly in as far as possible** and arrange for vehicle pick-up and transport from there.

3. **Establish communication with field rescue leader**, specify the channel to use, and attempt to clear other radio users. Note the Frequency in use _____, or the Channel _____.
4. If no member of the team is trained in avalanche rescue, assign one person to advise the most suitable team member on the procedures that a field rescue leader should follow. Have a staff member with snow safety training use the manual's *Avalanche Response*, *Probe Searches*, and *Transceiver Search* sections to talk the rescue team through the basics.
5. Determine a location suitable for **landing a helicopter** with field personnel. Be prepared to give an accurate description of the location and landing site to the pilot; obtain GPS co-ordinates if the pilot is coming from out of the area.
6. Determine the location of a suitable site for ground crew access (e.g., kilometre point on the road, other directions to site).
7. **Contact a helicopter to transport the dog team** to the site. (See helicopter list below.)
8. Contact the Provincial Emergency Program at 1-800-663-3456.
9. Contact the local RCMP detachment (see RCMP list attached). Have them send an ambulance.
10. Contact _____ or _____ at head office (local _____).
11. Contact the forest officer responsible for avalanche risk management (local _____ at head office or _____ [home]).
12. Stop all logging-related traffic on the roads as soon as possible. Send some pilot vehicles out to the road head to lead rescuers arriving by road to the accident site.

Contact numbers:

RCMP

SAR / CARDA **dog teams**

Helicopter pilots

Heliski companies

Note: Heliski companies may be able to bring trained rescue personnel to some sites quickly.

(Procedures updated and contact numbers checked: ____/____/20____)

A 2.4 Avalanche Rescue Equipment

(Adapted from B.C. Ministry of Transportation Snow Avalanche Programs)

FIRST PARTY Rescue Pack	
Rescue pack labelled FIRST PARTY with tag listing the following contents:	
1	Rescue plan (applicable section) and pencil
4	Collapsible probes
2	Shovels with short "D" handles
30	Marking wands with bright red, blue, and orange flagging
1 (roll)	Flagging tape
1	WCB basic first aid kit in weatherproof case
2	Heat packs
1	Blankets – disposable
1	Blankets – space, re-usable
1	"Fox 40" rescue whistle or air warning horn
4	Headlamps with new batteries each winter (remove batteries each spring)
1	Hand lantern with new batteries each winter (remove batteries each spring)
1	Flagging vest, labelled "Avalanche Rescue"
5	"Cyalume" light sticks or similar

Rescue equipment must be maintained in good order and be ready to go at all times.

Rescuers should also have ready access to one or more portable radios. One first party pack must be kept in the Emergency Transport Vehicle (ETV).

One pack must be available at a designated permanent rescue cache and ready to be transported by helicopter.

SECOND RESCUE PARTY Equipment

Pack labelled SECOND PARTY with tag listing the following contents:

20	One-piece probes
10	Shovels with short "D" handles
150	Marking wands with bright red, blue, and orange flagging
1	WCB Level 1 first aid kit
10	Heat packs
2	Blankets – disposable
2	Blankets – space, re-usable
4	Rope (30 m lengths of 12 mm diameter)
1	Loud hailer
1	"Fox 40" rescue whistle or air warning horn
6 (pair)	Snowshoes
10	Headlamps with new batteries each winter (remove batteries each spring)
5	Hand lantern with new batteries each winter (remove batteries each spring)
1	Toboggan kit, with back board and cervical collar
1	Portable lighting and generator (need not be part of kit but location documented)
1	Oxygen set

Second party equipment should be stored at a designated rescue cache (e.g., on a forest mainline road or at camp) and be readily transportable by helicopter.

Internet URLs (world wide web sites) current as of December 2002.
(Links are indicated by blue text.)

Canadian Sites

Canadian Avalanche Association

www.avalanche.ca

Site offers an assessment of current avalanche conditions in western Canada. Information is drawn from an extensive reporting network. Intended for recreationists. Limited prediction. The CAA issues avalanche bulletins for the North Columbia Mountains, South Columbia Mountains, South Coast Mountains, and the Canadian Rockies. An example is given on pages 156–157. Recordings of the bulletins are available at 1-800-667-1105.

UBC Avalanche Group

www.geog.ubc.ca/avalanche

Includes FRBC-funded research outputs.

University of Calgary Applied Snow and Avalanche Research Group

www.eng.ucalgary.ca/Civil/Avalanche/

Division of Engineers and Geoscientists in the Forest Sector

www.degifs.com

Includes a skill set for qualified registered professionals undertaking snow avalanche assessments.

Provincial Emergency Program

www.pep.bc.ca

Canadian Avalanche Rescue Dog Association

www.carda.bc.ca

Precipitation and snow accumulation data—British Columbia

www.weatheroffice.ec.gc.ca/forecast/Maps/bc_e.html or

www.msc-smc.ec.gc.ca/climate/index_e.cfm or

srmwww.gov.bc.ca/aib/wat/rfc/archive/index.html or

eww.bchydro.bc.ca/info/res_hydromet/res_hydromet825.html

United States Sites

West Wide Avalanche Network, Colorado

www.avalanche.org

An online library of selected papers from the biannual International Snow Science Workshops.

www.avalanche.org/~moonstone

North West Avalanche Centre

www.nwac.noaa.gov

Mountain meteorologists provide avalanche forecasts for Northern Cascades. Includes hourly weather data from Mt. Baker and other sites.

Idaho Panhandle Nation Forest

www.fs.fed.us/ipnf/visit/conditions/backcountry/index.html

North West Montana Glacier Country Avalanche Centre

www.glacieravalanche.org

An informal online discussion group that operates under the banner of the Cyberspace Avalanche Centre (CSAC). The site provides an open forum for discussion.

www.csac.org/Canada

Other Sites

International Snow Science Workshop (ISSW)

www.issworkshop.org

Swiss Federal Research Institute (SLF; English)

www.wsl.ch/welcome-en.ehtml

Link to proceedings of International Union of Forest Research Organisations (IUFRO) workshops on mountain forests.

www.wsl.ch/forest/waldman/mfe/welcome-en.ehtml

PC software used to plot and store snow profile records, initially developed by the B.C. Ministry of Transportation's Snow Avalanche Program, is marketed by Gasman Industries of Victoria, B.C. as "SnowPro."

www.gasman.com

Example of a Canadian Avalanche Association Public Bulletin

South Columbia Mountains February 8, 2001

NOTICE OF UNUSUAL AVALANCHE CONDITIONS: Valid until further notice.

This season, avalanche professionals between the Inner Coast Mountains and the Rocky Mountains have observed snowpacks that are unusually weak. The combination of below-normal snow depth and low temperatures has produced layers of faceted grains and surface hoar with a low strength. These types of weak layers can persist for a long time, and the avalanche danger will increase with every load of new snow onto this weak base. The present snowpack is less stable than in most other years and remarkably different from the snowpack at the same time last winter. Backcountry users will have to pay much attention to snowpack structure and strength during this winter.

WEATHER: Last weekend's storm cycle ended on Monday and was followed by a shift to northerly winds and a significant drop in temperature. Northern parts of this region reached -25°C , while the Kootenays dropped to -15 . Look for a slight moderation of temperatures into this weekend, and light snowfall amounts giving minor accumulations.

SNOWPACK: 60–80 cm of last week's storm snow sits on a buried layer of surface hoar and sun crust in some locations. Along with another new snow instability down about 30 cm from the top, surface slabs are a significant concern and can be triggered easily on these layers. Primary concern remains with the weak facets and depth hoar near the base of the snowpack. This layer has shown little improvement and is still incredibly weak. Combined with a near-critical load above it, the potential for large, destructive avalanches is quite real.

AVALANCHES: Numerous avalanches were triggered by humans and explosives all week. Often the triggers were from a long distance away from where the actual avalanche happened. In one case a skier triggered a Size 3.5 avalanche from a slope nearby. **Several avalanches in clearcuts were also noted.** Many observers are reporting avalanches occurring on slopes that released earlier in the season but have now become reloaded.

(continued)

**Forecast Of Avalanche Danger Up To Monday Evening
(Feb 12)**

Alpine – Considerable

Treeline – Considerable

Below Treeline – Moderate

TRAVEL ADVISORY: Avalanche conditions in this region are extremely touchy right now. Backcountry ski guides across the area are nervous and on their toes constantly. Conditions like this are complicated and very difficult to predict. Safe route finding and good terrain skills are essential components of travelling safely through the backcountry right now.

APPENDIX 4 AVALANCHE SITE IDENTIFICATION FORM

Observer _____ Site _____ Date _____ Weather _____

1. Field Evidence of Avalanche Activity Enter: Yes No ? Unknown

	Start Zone	Track	Runout Zone
A Normal erect vegetation for site is			
A1 Missing			
A2 Unusually sparse and scattered			
A3 Replaced by other species			
A4 Broken off near ground			
A5 Pushed over but not broken			
B Damage to standing trees and brush			
B1 Entire plant bent or deformed			
B2 Tops broken out			
B3 Limbs, twigs, or needles missing			
B4 Trunks or tree limbs scarred			
C Debris and Colluvium			
C1 Snow abnormally deep or persistent			
C2 Tree trunks, limbs in debris			
C3 Branches, needles, brush			
C4 Colluvium as cones or mounds, etc. *			
C5 Other debris (specify)			

* Not due to glacial or fluvial processes.
(After Martinelli 1975)

2. Surface Cover (percent of total area in each component of the avalanche path)

	Start Zone	Track	Runout Zone
Dense timber			
Scattered timber			
Brush above 2 m			
Brush under 2 m			
Grass and shrubs			
Bare ground			
Large blocks and boulders >1 m in height			
Blocks and boulders >256 mm diameter (b axis)			
Rubble 2–256 mm diameter (b axis)			
Bedrock (relatively smooth)			
Other (specify)			
	100 %	100 %	100 %

3. Detailed Site Investigation (features often not mapped at 1:20 000 scale)

Locate features on an orthophoto or oblique air photo.

Enter: ✓ Yes ✗ No ? Unknown

Feature	✓ ✗?	Map location	Comment if present
Convex terrain in starting points			
Cliffs in start zone			
Gully headwalls in start zone			
Timber in start zone			
Multiple tracks			
Cliff band in track(s)			
Benches in track(s)			
Channelized track(s)			
Sinuous track(s)			
Potential for avalanche to leave track			
Snow roll in start zone			
Cornice			
Elements at risk in or near track			
Elements at risk in or near runout zone			

Note: Colour photographs and photo-documentation should be provided where appropriate.

4. Snow and Weather Data

Nearest weather station _____ (Elev. ____ m, Year's record ____)

Nearest snow course _____ (Elev. ____ m, Year's record ____)

Direction from which most snow drifting occurs _____

Snow depths expected (30-year average) _____ cm and water equivalent _____ mm

5. Verbal or Written Accounts of Avalanche Activity

Avalanche runout reaches	Frequency	Information		Comment
		Source	Reliability	
Lower end of track				
End of current runout zone				

6. Specific Avalanche Events

Date	Runout reached	Damage or Injury	Information		Comment
			Source	Reliability	
1.					
2.					
3.					
4.					

APPENDIX 5 AVALANCHE ASSESSMENT CHECKLIST

Potential for avalanche initiation within cutblock (Type 1 avalanche)

Guidance: Refer to Figures 23 and 24 and Tables 11–13

Observer _____ Site _____ Date _____ Weather _____

Evaluation Factor	Observations / Data	Contribution to Avalanche Risk		
		Likely	Possible	Unlikely
Incline in harvest area				
Incline below harvest area				
Surface roughness				
30 year snow supply				
Threshold snow supply				
Snow climate				
Wind				
Remaining vegetation				
Cross-slope shape				
Down-slope shape				
Terrain features				
Potential start zone area				
Avalanche obs. (relevant)				
Aspect				
Conclusion				

Checklist from Canadian Avalanche Association/FCSN Forestry Risk Mapping course material, 2002 (methodology under development).

**Potential for extension of avalanche runout into cutblock
(Type II avalanche)**

Guidance: Refer to Figures 23 and 24 and Tables 11 and 12

Observer _____ Site _____ Date _____ Weather _____

Evaluation Factor	Observations / Data			
Start zone incline				
Wind				
Start zone feature				
Aspect				
Start zone area				
Track incline above harvest				
Track configuration				
Path width				
30 year snow supply				
Threshold snow supply				
Snow climate				
History				
Frequency/Magnitude	Contribution to Increased Avalanche Risk <input checked="" type="checkbox"/>			
	Likely	Possible	Unlikely	
Harvest area incline				
Down-slope shape				
Cross-slope shape				
Surficial materials				
Terrain features below				
Incline below				
Conclusion				

Checklist from Canadian Avalanche Association/FCSN Forestry Risk Mapping course material, 2002 (methodology under development).

APPENDIX 6 SNOW STABILITY RATING SYSTEM

Code	Term	Definition
VG	Very Good	Very large triggers, such as cornice falls or explosives, produce only sluffs. Stability tests generally produce little or no results.
G	Good	Natural avalanches are not expected. Avalanches may be triggered by heavy loads in isolated terrain features. Stability tests generally produce moderate to hard results.
F	Fair	Natural avalanches can be expected in isolated terrain features. Avalanches may be triggered by light loads in areas that have specific terrain features or certain snowpack characteristics. Stability tests generally produce easy to moderate results.
P	Poor	Natural avalanches can be expected in areas with terrain that has specific features or certain snowpack characteristics. Stability tests generally produce easy results.
VP	Very Poor	Natural avalanches can be expected on a widespread basis. Stability tests generally produce very easy to easy results.
U	Unknown	

(CAA 1995, revised 1996)

Definitions:

Heavy load: a snowmobile or explosives

Light load: one person on snowshoes, skis, or foot

Isolated terrain features: extremely steep terrain, steep convex rolls

Specific terrain features: lee slopes, sun-exposed aspects

Certain snowpack characteristics: shallow-faceted grains, persistent weaknesses

When applying the snow stability rating system:

- specify the stability for three elevation bands: alpine, timberline, below timberline
- give the expected stability trend for the next 12–24 hours (when possible)
- use the following terms: improving, steady, decreasing
- specify a confidence level in the ratings when appropriate

Experienced observers may qualify the rating based on:

- topography (aspect, slope, elevation)
- spatial extent (localized or widespread)
- time of day
- level of the unstable layer in the snowpack (e.g., near surface, mid level, deep)

See Appendix F of the *Avalanche Handbook* (McClung and Schaerer 1993) for a discussion of the merits of this and other snow stability and hazard rating systems.

GLOSSARY

(After B. Jamieson. A more comprehensive illustrated glossary is available at the CAA web site.)

Avalanche transceiver An electronic device worn by people in avalanche terrain. In “transmit mode,” it constantly transmits a radio signal that becomes stronger at close range. If someone with a transmitting transceiver is buried, the other members of the group can switch their transceivers into “receive” mode and follow a search pattern that locates the strongest signal. Probing and shovelling are then used to find the victim.

Bed surface The surface on which an avalanche runs. Not to be confused with failure plane.

Cornice An overhanging build-up of snow, usually on the lee side of a ridge.

Cross-loading Occurs when wind blows across a slope, picking up snow from the windward face and depositing it in the lee of convexities, surface depressions, and other terrain features.

Crust A hard, usually thin, snow layer, either one or a few grains in thickness, and consisting of uniform, well-bonded material.

Depth hoar An advanced, generally larger, form of faceted grain. Depth hoar grains are striated and, in later stages, often form hollow shapes. Cup-shaped grains are a common form of depth hoar. This type of grain can form at any level in the snowpack, but is most commonly found near the base of shallow snowpacks following periods of cold weather.

Facets (also called **faceted grains**) A grain form that develops in response to a strong temperature gradient within the snowpack. Grains grow flat faces through a process known as “kinetic growth” or, simply, “faceting.” Facets commonly form near the snow surface or where the snowpack is shallow during periods of cold clear weather (see also **depth hoar**).

Failure plane The plane in a snowpack along which a fracture spreads, releasing a slab avalanche. The bed surface usually lies immediately below the failure plane.

- Melt-freeze crust** A layer of snow that has been warmed until liquid water forms between the grains and then refreezes to form a relatively strong layer. Crusts sometimes form the bed surface for avalanches.
- Propagation** The spreading of a fracture or crack. The shear fractures that spread along weak layers and release slab avalanches tend to propagate farther under thicker, harder slabs than under thinner, softer slabs.
- Rime** A deposit of ice from supercooled water droplets. Rime can accumulate on the windward side of rocks, trees, or structures or on falling crystals of snow. When snow crystals cannot be recognized because of rime, the grains are called “graupel.”
- Rounded grains (rounds)** Under weak temperature gradients or uniform temperatures, branched and angular grains decompose into more rounded shapes called “rounds.” This process occurs in dry snow and involves the sublimation of ice from convex parts of grains into hollows. Rounding also tends to build bonds between grains (a process termed “sintering”). Consequently, layers of rounded grains are often stronger than layers of faceted grains of similar density.
- Slab** One or more cohesive layers of snow that may start to slide together, creating a slab avalanche.
- Sluff** A small avalanche usually made up of loose snow.
- Snowboard** A solid, flat, white-painted square of plywood, approximately 600 × 600 mm square with a vertical rule projecting upward. Laid on the ground or on the snow surface, it is used by observers to measure the new snow depth and equivalent water content.
- Stepped down** A feature of a slab avalanche when the motion of the initial slab causes lower layers to slide, resulting in a second bed surface deeper in the snowpack. A step in the bed surface is usually visible.
- Storm snow** The snow that falls during a period of continuous or almost continuous snowfall. By definition, a storm terminates after a day when new snow accumulation is less than 1 cm.
- Sun crust** A term used to refer to a melt-freeze crust that is more noticeable on sunny slopes than on shady slopes. According to the International Classification for Seasonal Snow on the Ground (Colbeck et al. 1990), a sun crust (also called “firnspiegel”) refers to

a thin transparent layer caused by partial melting and refreezing of the surface layer.

Surface hoar Crystals, often shaped like feathers, spikes, or wedges, that grow upward from the snow surface when air just above the snow surface is cooled to the dew point. This is the winter equivalent of dew. Surface hoar grows most often when the wind is calm or light on cold, relatively clear nights. These crystals can also grow during the day on shady slopes. Once buried, layers of surface hoar are slow to gain strength, sometimes persisting for a month or more as potential failure planes for slab avalanches.

Temperature gradient The change in temperature with depth in the snowpack. For example, if the temperature 20 cm below the surface is 3°C warmer than the surface, then the temperature gradient in the top 20 cm averages 1.5°C per 10 cm. Gradients greater than 1°C per 10 cm are often associated with faceting of grains and weakening of layers, whereas lower gradients are usually associated with rounding of grains and strengthening of layers. However, the transition between faceting and rounding also depends on factors other than the temperature gradient. (Note that even though the centimetre is not a standard SI unit, its convenience makes it the preferred unit of length in snow avalanche work.)

Terrain trap A terrain feature that worsens the consequences should a person get caught in an avalanche. For example, gullies and road cuts increase the odds of a deep burial; treed areas increase the odds of traumatic injuries.

Water equivalent The depth of water (in millimetres) obtained by melting a core of snow (or by other techniques).

Whumpf The sound of a fracture propagating along a weak layer within the snowpack. “Whumpfung” sounds are indicators of local instability. In terrain steep enough to avalanche, whumpfs often occur simultaneously with slab avalanche release.

Wind-loaded Terrain on which the wind has deposited additional snow. Slopes on the lee sides of ridges are often wind-loaded.

Wind-slab One or more stiff layers of wind-deposited snow. Wind slabs usually consist of snow crystals broken into small particles by the wind and packed together.

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Fig. 73, p. 49

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Fig.18, p.16



Fig. 21, p. 18



Fig. 30, p. 23



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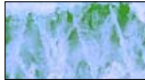


Fig. 8b, p. 10



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Fig. 120, p. 104

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Fig. 39, p. 27



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Fig. 3, p. 6



Fig. 6, p. 9



Fig. 17, p. 16



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Fig. 145, p. 132



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Fig. 68, p. 46



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Fig. 1, p. 5



Fig. 26, p. 22



Fig. 61, p. 37

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Fig. 60, p. 37

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Fig. 131, p. 118

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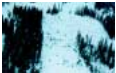


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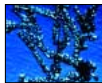


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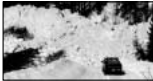


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Snow avalanches in recently harvested areas can damage new forest plantations, destroy downslope resources, and endanger public safety. This Land Management Handbook reviews snow avalanche science as it applies to forestry. It presents risk assessment methods for use in forestry planning, outlines harvest designs, and describes

silviculture strategies to reduce the risk of snow avalanches. Approaches for managing avalanche risks to forest workers are also summarized. With an extensive bibliography and list of Internet resources, this publication will be a valuable reference for natural resource managers, recreation planners, land developers, and anyone who manages work sites in winter.

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