# GUIDELINES FOR AVALANCHE CONTROL SERVICES: ORGANIZATION, HAZARD ASSESSMENT AND DOCUMENTATION – AN EXAMPLE FROM SWITZERLAND

Lukas Stoffel* and Jürg Schweizer
WSL Institute for Snow and Avalanche Research (SLF), CH-7260 Davos Dorf, Switzerland

ABSTRACT: Whereas for the stability evaluation process in backcountry skiing many tools have been developed in the last twenty years to simplify the decision making process, nothing comparable exists for services that are responsible for avalanche safety on highways or in residential areas. After the catastrophic avalanche winter 1998-99, the need arose to structure the documentation process of avalanche control services since the documentation is of particular importance if things go wrong and the service has to prove good diligence. However, as there was no written guidance on the decision making process, this had to be established first. In consultation with some leading Swiss avalanche control services standards were developed for the organization, the hazard assessment and the subsequent documentation of the decision making process. The guidelines suggest a three-step approach for assessing and mitigating avalanche risk: (1) Evaluating the local weather and snow situation, (2) Assessing the hazard for one or more specific avalanche path, (3) Deciding on the control measures to be taken (e.g. closures, evacuations). An electronic tool to facilitate the documentation process has been developed that also helps to structure the decision making process.

KEYWORDS: snow avalanche, avalanche forecasting, avalanche control, avalanche protection, risk management

## 1. INTRODUCTION

The extraordinary avalanche winter of 1998-99 clearly demonstrated the importance of temporary avalanche protection measures. Many accidents were prevented by the evacuation of endangered settlements, preventive road closures or artificial release of avalanches (SLF, 2000; Wilhelm et al., 2001).

However, the event analysis showed deficiencies in the safety concepts and decision-making process of several communal and road administration avalanche services (Bründl et al., 2004). In particular, some of the legal procedures following the fatal avalanche accidents that occurred in the winter 1998-99, showed that documenting the analysis and decision making process is a key element in the work of an avalanche service. In addition, it strongly helps to keep the knowledge about avalanche situations from the past.

The legal procedures also caused substantial uncertainty in regard to the required standards for avalanche control services. Whereas there exist well established guidelines for avalanche control services in ski areas that have been developed by the professionals themselves and are nowadays accepted by the courts as the relevant standards (SBS, 2006; SKUS, 2006), similar comprehensive guidelines for control services responsible for the avalanche safety on roads or in residential areas were lacking. Some basics for the evaluation of avalanche danger on roads were previously described (VSS, 1988).

Also, for backcountry skiing tools have been developed since the mid 1990s to help recreationists to structure their decision making process (e.g. Munter, 1997).

When a working group was established to provide guidance on documentation, it soon realized that first of all guidelines for the analysis and decision making process were required. The working group was initiated by the Swiss Syndicate of Avalanche Warning Systems (SILS), consisted of a number of avalanche professionals and was lead by SLF. After extensive consultation the guidelines were adopted by SILS (Stoffel and Schweizer, 2007). They are available in German, French and Italian.

The guidelines were established for control services responsible for the avalanche safety on roads or in residential areas (partly also called avalanche commissions). They describe (1) the principles, (2) some organizational requirements, (3) the working basis, (4) a generic scheme for the hazard evaluation and decision

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*Corresponding author address:* Lukas Stoffel, WSL Institute for Snow and Avalanche Research SLF, Flüelastrasse 11,
CH-7260 Davos Dorf, Switzerland;
tel: +41 81 4170126; fax: +41 81 4170110;
email: stoffell@slf.ch

making process, and (5) suggestions on how to document the evaluation and decision making process.

In the following, we will present the guidelines and provide examples on how it might be applied by an avalanche control service.

## 2. PRINCIPLES

The 5-degree European avalanche danger scale was designed in 1994 to cover all avalanche situations from low danger for recreationists to very high danger for residential areas (Meister, 1995). Accordingly, the public bulletin issued daily in Switzerland, also contains warnings about the avalanche danger for transportation lines and in residential areas. However, these forecast are general and valid for relatively large areas in the Swiss Alps. They are of limited use for local avalanche control services since the local conditions are decisive, though they provide some guidance and certainly have to be considered by local services. On the other hand, the avalanche forecasting service at SLF cannot make detailed recommendations for local problems. For that purpose, the communities, for example, have to establish their own local control service.

For a few years now early warnings are issued (jointly prepared by the Swiss weather service and the Swiss avalanche forecasting service at SLF) to alert the local services in case that about 100 cm of new snow are expected possibly resulting in a danger level of very high.

Therefore, the work of a local avalanche control service has to be defined in the context of regional avalanche forecasts issue by the Swiss avalanche forecasting service at SLF. A local avalanche service, typically established by a mountain community or a highway department, has to assess the hazard to people and infrastructure and make recommendations to the authorities on how to best protect people and infrastructure. In particular, the local service has to

(a) evaluate the local danger relevant for the avalanche problem under consideration. This local danger forecast can be different from the regional forecast as described in the public bulletin issued by SLF. When assessing the hazard to people and infrastructure in one or more avalanche paths, the service has to be familiar with the avalanche hazard map and is supposed to consider the possibility of extreme events.

(b) suggest measures that correspond to the local hazard as assessed. At a given regional forecast, a variety of protection measures might be adequate for the local problem under consideration depending on the actually prevailing local hazard. In other words, if a starting zone is not loaded due to wind effect or a previous release, no protection measures might be needed in the run out zone of that specific avalanche path, although the regional danger level as described in the public bulletin is high. On the other hand, if, for example, the local hazard is evaluated as “very high”, the closures must reflect this forecast and be extensive: an extraordinary situation requires extraordinary measures.

(c) document its evaluation and decision making process and justify protection measures (why taken or not, or why cancelled).

## 3. ORGANIZATION

The position, the rights and duties etc. of a local control service within the parent organization (e.g. a community or highway department) have to be defined and corresponding job descriptions have to be established. To provide guidance, a checklist was established some years ago (Bründl et al., 2004). The relevant points include the purpose, the description of the avalanche problem, the duties, the organisation, responsibilities and rights, liability and insurance, and finances.

As mentioned above, local avalanche control services in Switzerland typically suggest temporary protection measures that are than carried out by others, e.g. the fire department or some road maintenance personnel. However, some measures might be taken by the control service itself, e.g. the artificial release by explosives. Still, the necessary closures will typically be carried out and supervised by another organisation. Hence, it is very essential to define the responsibilities and interfaces. The head of the service (or his/her deputy) has to be reachable at any time. Decisions are usually taken as a group, but any member of the service should be entitled to immediately take action if required.

This seemingly unnecessary complicated structure follows from the fact that the avalanche problems local services deal with, are relatively infrequent – unlike in a ski area where the hazard is frequent and a professional control service is usually responsible for all aspects of avalanche control, often including the rescue.

Finally, it needs to be defined how the communication works, for example, how local warnings to residents are issued, or who is communicating with the mass media in case of, for example, an accident.

Of course, members of local avalanche control services should be well educated and from time to time should follow continuing education courses. Such courses are organized by SLF (Bründl et al., 2004).

## 4. WORKING BASIS

In order that a local avalanche control service can successfully follow his duties, a number of basic documents have to be available (or need to be established). These include:

- avalanche map (or atlas): map with avalanche paths (starting zones and avalanche flow directions), avalanche protection measures (e.g. supporting structures); possibly complemented with a table describing terrain characteristics (e.g. starting zones: altitude, inclination, aspect, topography, area), photographs; if available terrain inclination map.
- avalanche history: date of large events (incl. run-out, damage); possibly map with area affected by large events.
- avalanche hazard map.
- endangered objects and potential damage: as table (e.g. number and type of buildings) or GIS based.

Furthermore, it is helpful to establish a general safety concept that includes, among other things, specific guidelines on the local hazard assessment based, e.g. on local automatic weather stations (AWS), a plan of various standard protection measures to be taken at a given local hazard scenario (see example of closure plan in section 6.3), and if applicable a report describing procedures for the artificial triggering by explosives (avalanche paths, release method, blasting locations, closures, communication).

## 5. HAZARD ASSESSMENT

In the following, a possible scheme is described to be followed for avalanche forecasting for residential areas and rather infrequently endangered transportation lines.

Of course, avalanche forecasting procedures are in general well established (e.g. (McClung and Schaerer, 2006) and the primary contributing factors are known, in particular for back-country operations or highly exposed and vital transportation corridors (e.g. Schweizer et al., 1998).

In general, the procedures when assessing the danger to residential areas or roads are similar, except that the hazard due to a particular path has to be assessed – typically from the valley bottom. The evaluation is based on weather and snowpack information from nearby sites. In contrast to the hazard assessment in ski areas, valuable Class I instability information (McClung and Schaerer, 2006) from avalanche control by explosives is usually not available. Furthermore, another principle difference between the forecasting for residential areas and roads, and the forecasting in ski areas, is the return period of the avalanches under consideration. Whereas in ski areas the avalanche return period *T* is on the order of 0.1-2 years, it is typically about 1-20 years, commonly also higher, for avalanches reaching the valley bottom and endangering roads or settlements. Table 1 summarizes some of the differences.

Table 1: Differences between avalanche forecasting in ski areas and for residential areas and transportation lines in the valley bottom.

| | Ski areas | Residential areas and transportation lines |
|---|---|---|
| Number and return period *T* | many paths with $T$<1-2 yr | a few paths with T≈5-50 yr |
| Contributing factors | minor snowfall, snow drift, wet snow | snow loading due to major snow storm |
| Observations, data | personal observations at elevation of starting zones | observations at and from the valley bottom, data from AWS |
| Key data in evaluation process | critical depth of snow loading (new snow and /or snow drift), artificial avalanche activity | Critical new snow depth, avalanche activity |
| Frequency of evaluation | (almost) daily | ~5-25 days per winter, for pass roads >50 days |
| Protection measures | explosive control, preventive closures | closures, evacuation (or curfew), possibly explosive control |

Table 2: Three-step scheme suggested for hazard assessment by local avalanche control services (responsible for residential areas and roads)

| | |
|---|---|
| Step 1 | Detailed data analysis and evaluation of avalanche situation (danger level) based on:<br>- snow and weather data, own observations<br>- forecasts: weather, new snow |
| Step 2 | Hazard assessment for the avalanche paths under consideration in view of potential damage to people and infrastructure based on:<br>- avalanche path characteristics<br>- previous avalanche activity in the path during the winter or the present cycle<br>- effectiveness of permanent protection measures (if available)<br>- snow conditions in avalanche path |
| Step 3 | Decision on temporary protection measures based on hazard assessment (step 2) either<br>- no measures needed, or<br>- measure needed: preventive closure or evacuation (or curfew), possibly explosive control, or<br>- previously taken measures can be cancelled. |

We propose to assess the avalanche hazard for residential areas and roads in three steps. If the situation is not critical, a level that needs to be defined depending on the local avalanche problem, the consultation of the weather forecast and the public bulletin is usually sufficient (step 0).

If the avalanche danger increases, or maybe even an early warning was issued, the weather and snowpack development should be followed more closely. Then, the 3-step approach can be applied (Table 2). Depending on the severity of the situation not all steps need to be followed. In particular, at the beginning of a storm, step 1 might be sufficient, and the service decides to re-assess the situation in, for example, 8 hours. In general, the assessment is a continuous process, the various steps are repeatedly examined during a severe storm.

*5.1 Step 1: Data analysis and danger evaluation*

In step 1, based on snow and weather data of the region, own observations (e.g. on the snowpack) and forecast of weather and new snow (if available), the avalanche situation is assessed (Table 3) and usually expressed in terms of the locally prevailing degree of avalanche danger. The danger may be further described in terms of release probability, expected avalanche size and type. Based on the danger assessment, the service has to decide whether people or infrastructure might be endangered, and if so, a detailed assessment by avalanche path (step 2) is required.

Table 3: Step 1: Data analysis and danger evaluation

| | |
|---|---|
| Data and observations | - public avalanche bulletin<br>- new snow (storm snow)<br>- snow depth<br>- wind<br>- temperature (air, snow)<br>- snowpack stratigraphy (existence of weak layers)<br>- avalanche activity (natural activity and results of explosive control)<br>- possibly information from neighbouring services or ski areas |
| Forecasts (for the next hours) | - weather<br>- public avalanche bulletin (development of danger and danger level)<br>- new snow amount (snow fall limit)<br>- wind (direction and speed)<br>- air temperature trend |
| Conclusion | → estimate of locally prevailing avalanche danger and its trend<br>→ people or infrastructure endangered?<br>- If yes, proceed to step 2.<br>- If no, time of next evaluation (repeating step 1), or possibly explosive control to prevent large avalanches. |

*5.2 Step 2: Assessing the danger to people or infrastructure*

After assessing the danger in the region in general, the focus in step 2 shifts to the specific avalanche problems. For one or more avalanche paths an estimate is made whether an avalanche has to be expected and whether its size might endanger people or infrastructure. Estimates about the release probability and avalanche size for on individual path generally have a high uncertainty. This uncertainty needs to be considered when subsequently in step 3 decisions on temporary measures are taken.

Table 4: Step 2: Assessing the danger to people and infrastructure

| | |
|---|---|
| Terrain characteristics | - starting zone (inclination, aspect, exposure to wind etc.)<br>- track (e.g. gully, roughness)<br>- run-out zone |
| Previous avalanche activity | - release during the winter<br>- release during the current snow fall period<br>- possibly result of artificial release |
| Effectiveness of protection measures | - starting zone<br>- run-out (e.g. dam with avalanche deposit) |
| Current snow conditions | - in comparison to local AWS<br>- situation in starting zone and track |
| Conclusion | → Probability of an avalanche causing harm or damage<br>- If probability not negligibly small, proceed to step 3.<br>- If release is unlikely and/or expected size not critical, time of next evaluation, or possibly preventive explosive control (provided expected avalanche size is not too large). |

The hazard assessment for the avalanche path at hand (Table 4) is based on (1) the terrain characteristics of the path, e.g. the inclination in the starting zone, (2) previous avalanche activity which might influence the avalanche extent in the run-out zone (due to e.g. a decreased fracture depth or a smoothed-out track), (3) the effectiveness of permanent protection works (e.g. supporting structures buried, or a dam backfilled with deposit from a previous release), and (4) the current snow conditions in the starting zone, the track and the run-out zone. The conditions in the specific starting zone need to be extrapolated based on the data evaluation in step 1. Assessing the present conditions in a specific avalanche path during a storm is often hindered by poor visibility – so that no direct observation is possible; this contributes to the uncertainty.

When assessing release probability and avalanche size, the comparison of the present new snow depth with a critical value that has previously been established based on past events, has proved to be useful. This critical value of new snow depth has to be adapted depending on the actual conditions (e.g. wind speed and direction, snowpack stratigraphy).

Before coming to a conclusion in step 2, the possibility of a rare or extreme event has to be taken into account. This is best done by consulting the avalanche hazard map. The extreme avalanche extent outlined in the hazard map, may not have been seen by the members of the local avalanche control service in the last couple decades, but in an extreme situation an avalanche as large as outlined in the hazard map cannot be ruled out.

### *5.3 Step 3: Decision on preventive measures*

Based on the estimated probability and size of an avalanche in the path under consideration a decision needs to be taken on whether preventive measures are necessary. Possible measures are road closures, curfew or evacuation.

If in a residential area the buildings in the runout zone are properly reinforced it might be appropriate to restrict the movement of people (on foot or in cars) by closures and recommend the residents to stay in their house (curfew). Often residents will then prefer to move out of their house anyway. Curfew can easier be carried out than a full evacuation. However, it requires that the service knows whether the houses are really reinforced. If it is foreseeable that the avalanche situation will deteriorate and finally require an evacuation, it is not recommended to first request a curfew since the evacuation will then have to occur at a very unfavourable, hazardous time. An evacuation plan has to exist, and residents need to be informed in advance about what to do in case of an evacuation, so that the evacuation goes smoothly and quickly without putting people at unnecessary risk.

As in the case of an evacuation, a plan is recommended that describes – depending on the avalanche situation – the areas to be closed and the locations of the temporary closure barriers. The material such as signs (“avalanche danger, no entry”) has to be available. An example of a closure plan (or concept) established in advance is shown in Table 5 and Figure 1. A closure plan is also required if artificial release is an option as preventive measure. Explosive control as a preventive protection measure in residential areas requires particularly high safety standards which may even prevent its application. In the closure concept as shown in Table 5 artificial release is considered and requires a larger area to be closed (larger margin of safety) since fatalities due to explosive control have to be avoided as much as possible. Plan A to D in Table 5 correspond to scenarios with increasing avalanche danger and require increasingly larger areas to be closed off.

It can be helpful to develop scenarios for the measures to be taken based on the current situation and its forecasted development (as evaluated in step 2). For example, an avalanche control service evaluates the situation in the evening of the first day of major storm and concludes that no preventive measures are required yet, but might be needed the next morning. The service can take a decision what to do the next morning depending on how much snow will have accumulated by the next morning, e.g. with another 30 cm of new snow the road from A to B needs to be closed. This preventive measure can then be carried out the next morning at 5 pm without delay as no further consultation among the control service is required.

Table 5: Example of a closure concept for a residential area (Stoffel, unpublished course lecture notes).

| | Closure | Closure during explosive control |
|---|---|---|
| Intermediate snowfall, every 1-2 years (e.g. <50 cm in 2 days) | - | Plan A |
| Large snowfall, every 2-4 yr | Plan A | Plan B |
| Very large snowfall Every 4-10 yr | Plan B | Plan C |
| Extraordinary situation Every 10-20 yr | Plan C, evacuation possible | If explosive control is still possible: C or D |
| Extreme situation (e.g. >120 cm in 2-4 days) | Plan D, evacuation required | Explosive control in general not possible |

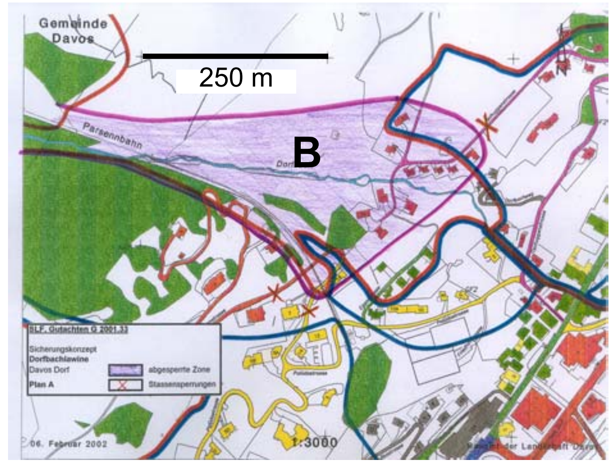


Figure 1: Closure for the residential area in Davos (Switzerland) endangered by the Dorfbach avalanche. The red line indicates the border of the red zone (area of high hazard). The blue area (B) shows the part of the residential area that is "closed" under plan (or scenario) B; it includes most of the red zone. Crosses (x) denote the locations of temporary road closure barriers (Stoffel, unpublished report).

## 6. DOCUMENTATION

Snow and weather data, observations and decisions on measures shall be recorded. It is recommended to justify the decisions why or why not a certain preventive measures has been suggested. This might be done be either writing down a few notes, or by simply following step 2 and making notes on the relevant points.

If explosive control is applied, the documentation consists of a table with, for example, date, location, method, and result of blasting.

To facilitate the documentation, an online web-based documentation form was worked out. Data from AWS and routine manual observations are automatically filled in the form. Notes can then be made on the current snowpack stratigraphy, recent avalanche activity, forecasted snow and weather trends etc. After the evaluation of the danger situation, the decision on measures can be recorded.

## 7. CONCLUSIONS

Following the catastrophic avalanche winter 1998-1999 in the Swiss Alps the need emerged to provide education and guidance for local avalanche control services that are responsible for avalanche safety of residential areas or on roads. Guidelines were developed that should help local control services to structure their evaluation and decision making process and facilitate the corresponding documentation. A three-step approach was proposed: (1) Data analysis and danger evaluation, (2) Assessing the hazard to people and infrastructure, and (3) Decision on preventive measures. The guidelines were developed in close collaboration with some heads of local control services and were well received. The guidelines represent the first ever developed standards for this group of avalanche professionals. In addition, a web-based documentation tool has been designed and preliminary tests in winter 2007-2008 confirmed its usefulness.

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