NGI

Snow Avalanche Forecasting in Iceland and Norway

Proposal of guidelines for implementation and operation of local avalanche forecasting

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Summary

This document describes local avalanche warning and forecasting operations in Iceland and Norway, with the focus on forecasting as a preventive measure for communities with threatened habitations. The objective of an avalanche forecasting program in this context is to provide the basis for specific decision making on the local level in avalanche hazard situations.

Although the legislation differs in the two countries, recommendations are given concerning the implementation of local avalanche forecasting programs in the future. In addition, recommendations regarding observation and evaluation procedures are given.

It is recommended that the procedure of implementing local avalanche forecasting programs in Iceland and Norway should follow the outline below:

- Local avalanche forecasting programs for habitations should either be carried out or supervised by the official avalanche institute, which in Iceland is the Icelandic Meteorological Office and in Norway the Norwegian Geotechnical Institute. A project quality plan should be prepared for each program.
- Avalanche forecasting programs should be implemented at a specific site after an avalanche mapping, a risk and vulnerability analysis, and preferably a cost/benefit analysis of alternative safety measures have been performed.
- The decision making should be performed by committees with the necessary legal authorisation and political support in co-operation with the official avalanche institute, in Iceland the Icelandic Meteorological Office and in Norway the Norwegian Geotechnical Institute. The legal and economic responsibility of the committees should be determined.
- Training programs for avalanche observers and avalanche committee members should be established. A yearly workshop should be held, where the experiences from the previous winter are discussed. The workshop could be held nationally or as an Icelandic-Norwegian avalanche forecasting workshop.
- It is recommended that an observation handbook complete, complete with observation guidelines and recording standards for weather, snow and avalanches is prepared in the Norwegian and Icelandic languages during the coming year.
- The work involved in forecasting can be done as a public service financed through government funds or on a contract basis where the client finances the operation.

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1 INTRODUCTION

In connection with the serious avalanche accidents in the north-western part of Iceland in 1995, contacts were established between the Icelandic Meteorological Office (IMO) and the Norwegian Geotechnical Institute (NGI). Such contacts had also been established before, for example in 1974 when there was a serious snow avalanche accident at Neskaupstaður in Iceland. In view of the situation in Iceland, an interest was expressed to establish a more formalised co-operation between agencies involved in avalanche prevention. In the spring of 1995 the Nordic Ministerial Council decided to support a proposal of research and development co-operation between Iceland and Norway.

The co-operation was divided into four sub-projects. The present report is the first report in the avalanche forecasting sub-project.

At a meeting between representatives from the Icelandic Meteorological Office and the Norwegian Geotechnical Institute during the ANENA Avalanche Symposium in Chamonix, France on June 1, 1995, the content of the Icelandic-Norwegian Avalanche Forecasting Project was defined. It was agreed upon that the general framework of the project should be avalanche forecasting with at degree of detail to be useful for local communities, specific road stretches and so on (local level avalanche forecasting). At the meeting it was decided to formulate two separate objectives:

For the first project period the goal will be to work out guidelines for implementing local level forecasting. A draft of the guidelines should be presented by the end of the first project year.

The second project period should have the objective to improve existing methods for forecasting. This part of the project is perceived as a 2-year project.

2 LOCAL AVALANCHE FORECASTING

2.1 Objectives

Local avalanche forecasting in this context means forecasting of avalanche hazard in specific avalanche paths or runout zones, where a high degree of accuracy of the forecast is important. The objective of a local level avalanche forecasting program is to provide the basis for specific decisions in avalanche hazard situations as, for example, the evacuation of housing areas or closure of important roads.

The avalanche forecasts should give information on the release probability in specific avalanche paths and what the expected magnitude of avalanches will be. The evaluation should be based as much as possible on objective and quantifiable observations and the professional skills of the observer/forecaster and the methods used should be updated continuously to the current state of the art.

2.2 Possibilities and limitations of avalanche forecasting

At present, no generally accepted procedures for avalanche forecasting exist. Avalanche forecasting is traditionally done by experts acting on their knowledge of snow stability and their experience with avalanche situations. They use quantitative data, as well as several observations that have no formal data collection procedures, to arrive at conclusions about the avalanche hazard. However, the exact manner in which information is utilised in this process is not well established.

Theoretically it may be possible to make quantitative local avalanche hazard evaluation based on deterministic relationships. However, only a few simple mechanical and physical features of snow that are relevant to avalanche release, are well understood. Consequently deterministic models are not very successful in avalanche hazard evaluation and they will probably not be in the near future.

The highest success-rate in avalanche hazard evaluation seems to be obtained by experienced forecasters using statistics to support their more or less subjective expert opinion. The development of the 'nearest-neighbour' and other statistical models for pattern recognition in weather and snow data, have improved the possibilities for the forecaster to use previous experiences and to base the evaluation on objective facts. This also makes it easier to document the basis for the evaluation.

The measured parameters should have some relevance to the snow stability in the avalanche starting zone. As there are no well developed methods for direct measurement of the stresses or the propagation of fractures in the snowpack prior to avalanche release, the parameters used have only an indirect relationship to the processes in the snowpack in the avalanche starting zone. In addition, the measurements usually have to be done at some distance from the avalanche starting zones.

The strategy of many local forecasting operations is therefore to measure what parameters seem most relevant, and that are also possible to measure in practice. The avalanche activity is then closely monitored. After a period of time, a statistical relationship between these measurements and the release of avalanches can be established. With the use of artificial intelligence systems now under development, computer programs can also be trained to use several types of information without any assumptions on the form of the relationships between the different input variables. Nevertheless, long term databases of high quality are critical to all non-deterministic forecasting techniques.

The verification of avalanche forecasts is often difficult. The reason for this being that the stability of the snowpack in the starting zone cannot be readily determined, unless an avalanche actually is released. It is possible that the strain rates in the snowpack in the starting zone can be nearly critical, but does not quite reach the point where a fracture propagation starts and an avalanche is released. The general snow stability can then only be inferred from stability tests and avalanche occurrences elsewhere.

It is important to acknowledge that in every assessment of avalanche hazard there will always be a degree of uncertainty. Some causes of avalanche release may not be within what is practically possible to observe or predict. In addition it is not always possible to guarantee the quality of the data used. Thus, even the best avalanche forecasting operation is not perfect, and the success rate in predicting avalanches will not be 100%. Given the residual uncertainty in the avalanche forecasting problem in general, an error rate of 20% is often considered normal.

When one considers large catastrophic avalanches, which are the type that usually has to be considered when habitations are threatened, the return interval of actual accidents may be very long. This is because the avalanches themselves often have a long recurrence interval, often 100 years or more. In some climatic regions it may be reasonable to assume that avalanches of this type are more predictable than avalanches with shorter recurrence interval. However, the low frequency can also mean that only a limited amount of data, or no data at all, connected to the release of these extreme avalanches exist. If one assumes that the error rate is 20% for the forecasting program, the average return period for an unforecasted, catastrophic avalanches can be in the order of 500 years (the assumption being that 80% of avalanches with a recurrence interval of 100 years are correctly predicted).

Thus, in certain cases, an avalanche forecasting program can reduce the risk to individuals to acceptable levels. In many cases one also has to consider that the collective risk, or the sum of individual risks endangered by the same event, may not be acceptable. In such cases, and in cases where the potential material damage is great, a forecasting program should be seen only as a temporary measure until permanent measures can be implemented.

2.3 System failures

To ensure the long term quality of local level avalanche forecasting program, it is important to identify the ways in which the program can fail to reach its objective. When one disregards the inherent uncertainty in the avalanche forecasting problem, the overall reliability of the system will depend mainly on:

- the ability to acquire reliable snow and weather data on a continuos basis
- the ability to acquire reliable weather forecasts
- the ability to analyse the data and the forecasts
- the reliability of the communication lines
- the ability of the decision makers to respond correctly and at the right time to the avalanche forecasts

Failure in any of these parts may in the end seriously affect the outcome of an avalanche occuring in the area for which the forecasting program has been implemented. To identify problems and weak links in a forecasting operation, the system could be tested regularly with simulated avalanche situations.

3 LEGISLATION

3.1 Legislation in Iceland

During the compilation of this report the law relating to snow and avalanche protection in Iceland, was significantly altered. The Law now gives the responsibility of all aspects of avalanche safety to the **Ministry of the Environment** and one of its institutes, the **Icelandic Meteorological Office (IMO).**

Now, all planning procedures shall take into account the possibility of slides of any kind (avalanches, debris flows and landslides etc.). The Icelandic Meteorological Office shall supervise the production of hazard maps and base them on expert knowledge of the nature and effect of avalanches. The regulation regarding the use, classification of hazard zones and their use, as well as the building of defence structures shall be issued by the ministry in collaboration with the IMO.

The **Civil Defence** shall produce emergency plans and guidelines and provide public education on the hazard of slides, also in conjunction with the IMO. When the IMO in conjunction with the chief of police and the local civil defence committees, issues a warning on localised avalanche hazard and declares an emergency, people shall be evacuated from all buildings in the zones that are named in the IMO's warning, in accordance with an existing emergency plan. These zones shall be depicted on special maps which the IMO shall supervise the production of and are based on expert knowledge of the nature and effect of avalanches. Those maps shall be notarised by the minister of the environment and shall be introduced to the Civil Defence and the appropriate civil defence committees.

The chief of police and the local civil defence committee shall implement the evacuation and are permitted to use force if deemed necessary. While an emergency situation persists, all traffic shall be forbidden in the area declared a hazard zone except by special permission of the chief of police. The IMO shall decide when a hazard situation shall be lifted and do so in collaboration with the chief of police and the local civil defence committee.

The IMO shall collect data on avalanches and avalanche danger and analyse that data. It shall supervise the measuring of snow stratigraphy and perform research on them with special emphasis the threat of avalanches and shall issue warnings thereof. The IMO shall hire personnel to investigate and monitor topographical and meteorological conditions with respect to avalanches and/or debris flow and landslides where it is deemed necessary. The IMO shall do the hiring in collaboration with the respective chiefs of police.

The **Building Regulation** stipulates, that the erection of new buildings is forbidden, where it is known that damage has occurred as a result of a snow avalanche, debris flow, landslides, floods or other natural disasters.

The **Planning Regulation** stipulates that maps and reports shall be compiled on areas where there is a threat of disaster caused by weather conditions, floods, snow avalanches, debris flows, wind gusts or earthquakes.

3.2 Legislation in Norway

In Norway there are at present no laws specifically demanding the implementation local avalanche warning and forecasting operations. According to the **Report to the Parliament** (Stortingsmelding) **no. 9, 1972**, the responsibility for doing avalanche research and being able to provide specific advice on avalanche hazard (such as local forecasting) is given to the Norwegian Geotechnical Institute (NGI). NGI is a non-profit research and consulting institute and it undertakes work according to NGI's General Conditions (which specifies validity, payment, liability, etc.). NGI is committed to operate a quality management system that complies to the requirements of the international standard ISO 9001.

Following the **Report to the Parliament** (Stortingsmelding) **no. 24, 1992-93** the **Directorate for the Civil Defence and Emergency Planning** (Direktoratet for sivilt beredskap) has made a **Guidelines for Municipal Risk and Vulnerability Analyses** (Rettleiar for kommunale risiko- og sårbarhetsanalysar). Although they are not required by law to do so, some municipalities have started working on such analyses. In areas where potential avalanche hazard exists, this is also considered in the analyses.

The Ministry of Justice and the Police is responsible for rescue and public safety in Norway. In the new proposal for §28 in **the Police Law**, the Police is also responsible for reducing hazard and to limit damage. The Police can requisition avalanche hazard evaluation by professional avalanche experts as required. The Police has also the legal authorisation to order the evacuation of hazardous areas, closure of public roads, etc. The ordering of specific measures, may lead to demands for economic compensation. In cases where the Police only advises measures, economic compensation is as a rule denied.

It can be asserted that legal demands on avalanche hazard evaluation exist in pursuance of the Building and Planning Act (Bygningsloven), the Act Relating to Worker Protection and Environment (Arbeidsmiljøloven) and the Act Relating to the Regulation of Water Resources:

The Building and Planning Act (Bygningsloven) concerns land use planning and the design of structures, but the safety requirements are related to individual risk. The general clause of the Building Regulation states that:

> *"Buildings and directly adjacent external areas in use shall be situated, dimensioned and constructed so that there is reasonable safety against personal injury occurring because of such loads which may be foreseen."*

The acceptable risk level has been quantified in the regulations in three different classes of buildings according to the consequences of structural failure:

Table 1. Norwegian safety requirements for the location of buildings

Safety Class	Consequences of Structural Failure	Highest Nominal, Annual Probability of Natural Hazards	Categories of Buildings
1	Less serious	10^{-2}	• Garages for max. 2 cars, boat houses etc. • Storage sheds occasionally in use • Halls of plastic-based fabrics • Agricultural buildings etc., if frequently used class 2 or 3
2	Serious	10^{-3}	• Buildings not exceeding two storeys of moderate span and in normal use • Industrial and storage buildings of one storey not accessible to general public, with ≤ 5 persons per 100 m^2. Distance to other buildings, roads etc ≥ height of the facade • Tall masts, independent towers, silos and chimneys outside developed area
3	Extremely serious	$< 10^{-3}$	• Buildings not included in class 1 & 2

The Municipal Building Committees are responsible for evaluating the risk level and the Municipality is liable for their decisions. During the last ten years, a number of court cases have been tried in Norway where municipalities have been found guilty of compensatory negligence.

The Act Relating to Worker Protection and Environment (Arbeidsmiljøloven) relates to the safety of employees. In cases where workers could be subject to avalanche hazard, the employer is responsible for the safety of the workers and could be required by the Directorate of Labour Inspection (Arbeidstilsynet) to monitor the avalanche hazard.

Instructions on avalanche safety are also established in pursuance of the **Act Relating to the Regulation of Water Resources.** In case of application for a concession in accordance with the Water Resources Act there is a premise that the potential avalanche hazard of the actual areas shall be evaluated by an expert during the planning stage. At this stage the builder or his consultant is responsible for ensuring that the appropriate steps are taken. The evaluation document should be enclosed with the application.

The **Headquarters Defence Command Norway/Army Staff** recommends in its **Manual for Winter Service UD 6-81-9** that an avalanche forecasting service is implemented during larger military exercises. This has been the practise for the annual NATO field training exercise in Northern Norway, during which two experts from the Norwegian Geotechnical Institute have been joining the military avalanche forecasting team. The **Security Manual for the Army UD 2-1** is currently under revision and will include recommendations for avalanche forecasting for other operations also.

In Norway, private consultants have also undertaken avalanche hazard evaluation and forecasting for clients. Although no cases have been tried so far, it is likely that any contractor can be made legally responsible for accidents or damage following the use of avalanche forecasts if it can be proven in court that the contractor or any of his employees have shown gross negligence in work.

3.3 Implementation

An avalanche forecasting operation should preferably be implemented at a specific site after an avalanche mapping, a risk analysis, and preferably a cost/benefit analysis of alternative safety measures have been performed.

It is suggested that local level avalanche forecasting programs for habitations should either be carried out or supervised by the official avalanche institute, which in Iceland would be the Icelandic Meteorological Office and in Norway the Norwegian Geotechnical Institute.

The work involved in forecasting can be done as a public service financed through government funds or on a contract basis where the client finances the operation.

Guidelines for data collection, data treatment, procedures for hazard evaluation and quality assurance should follow the outline drawn in the following chapters.

4 SNOW STABILITY AND AVALANCHE HAZARD EVALUATION

4.1 Type of Measurements

For local avalanche hazard evaluation, a certain minimum amount of snow and weather data is required. It is recommended that the following data be available:

Representative weather data in near real time with a maximum measuring interval of one hour. This means that automatic weather stations will have to be used.

- air temperature
- wind direction
- wind speed
- precipitation and new snow accumulation

In addition, periodic and intermittent data from manual/visual observations done by a trained snow observer is needed. The observations should be done as often as required depending on the weather and snow stability situation:

- snow stratification profiles
- snow stability tests
- avalanche activity
- snow distribution in the starting zone(s)

Additional observations outside the formal data collection procedures can be carried out as required.

4.2 Observation Standards

Since complete guidelines for observers are not yet available in Icelandic and Norwegian it is referred to other international guidelines at this time.

- Weather data: Weather observations, manual or automatic, as far as possible in accordance with *World Meteorological Organisation standards.*
- Snow stratigraphy: Full snow profile procedure in accordance with *Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches*[1] and *the International Classification for Seasonal Snow on the Ground*[2]
- Snow stability: Rutschblock tests in accordance with *Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches*[1]. Other information about the snowpack stability could also be added using qualitative descriptions.
- Avalanche occurrences: Avalanche observations in accordance with the *IMO avalanche database*[2] template and the *Avalanche Atlas*[3]

4.3 Data Storage

The weather data from the automatic stations should be stored in computer files, preferably in ASCII-format for easy retrieval. The data stored should be measured with an interval of no more than 3 hours.

Data of snow stability and stratification can be stored on paper or as a computer file.

The avalanche observations should be stored in the *IMO avalanche database* format.

4.4 Instrument Standards

- Weather and snow height data: Instruments should as far as possible be in accordance the with specifications of the *World Meteorological Organisation standards.* Automatic stations are recommended.
- Snow stratigraphy: Equipment in accordance with *Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches*
- Snow stability: Equipment in accordance with *Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches*
- Avalanche activity monitoring and observation of snow distribution in the starting zone(s) is done by visual inspection. This can be aided by using binoculars, possibly infra red for night vision, and continuous video camera surveillance. Permanent snow stakes close to the starting zone make it possible to estimate snow distribution. Ultrasonic snow depth

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[1] Canadian Avalanche Association, 1995
[2] International Commision on Snow and Ice of the International Commision of Hydrological Sciences, 1990

[2] Icelandic Meteorological Office, 1994
[3] International Commision on Snow and Ice of the International Commision of Hydrological Sciences, 1981

gauges can also be used to monitor snow accumulation continuously regardless of visibility.

It is also possible to monitor a dry snow cover continuously in selected areas of an avalanche starting zone by the use of microwave snow stratigraphy radars (FMCV) buried in the ground.

The instrumentation should be upgraded as the technology advances.

4.5 Localisation

The selection of instrument sites is important with regard to the representativeness of the measurements. Ideally, the observations should be made in or very close to the starting zone itself. In general wind and snow transport should be measured on wind exposed sites, while snow accumulation/precipitation should be measured on sites representative of the starting zone.

A study plot should be established, where regular snow stratigraphy and certain snow stability evaluations take place. An effort should be made to correlate additional snow pit data to the results obtained form the study plot. All study plot sites should be at a safe location and have a safe access route, even during bad weather conditions.

5 AVALANCHE HAZARD FORECASTING

5.1 Basic Requirements

The available data sources should consist of those mentioned above. In addition a detailed and frequently updated local weather forecast valid for at least 24 hours ahead should be available. The available tools for data treatment should consist of industry standard computers and software.

For distribution of forecasts and data collection, phone, fax and modem should be available.

In addition, avalanche maps of the area and a collection of previous weather, snow and avalanche data should be available.

5.2 Principles

As mentioned above there are at present no generally accepted standard procedures for avalanche forecasting. When no statistical data are available, only very general criteria for new snow accumulation and wind speed can be utilised. In such cases it may to some extent be possible to work out initial avalanche criteria based on analyses of the synoptic situations during previous avalanche occurrences.

The general procedure of avalanche forecasting can be described as in the chart below:

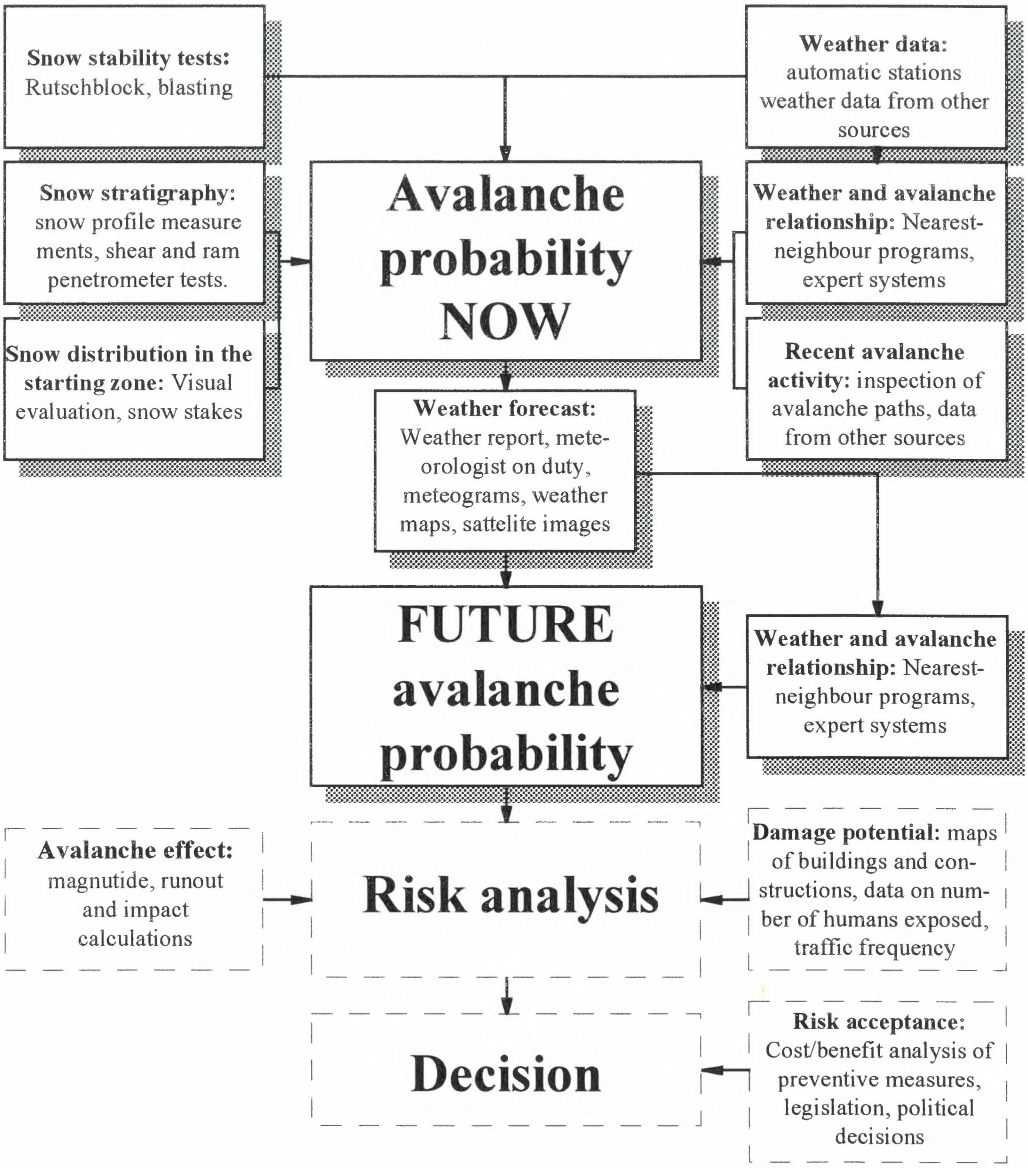

Figure 1 *Outline of an avalanche forecasting procedure with input data and their possible sources. The risk analysis and the decision making are normally not within the domain of the forecasting operation.*

5.3 Presentation

The avalanche hazard should generally be described in terms of release probability and the magnitude of the avalanches expected.

A message of the estimated avalanche hazard should include

- the location and time span which the message concerns
- a main message which refers to the European Avalanche Hazard Scale

- background weather and snow data
- the avalanche probability now and in the near future
- the level of confidence in the forecast (or an estimation of the uncertainty)

When specific objects are considered, such as buildings or groups of buildings, constructions, roads, etc., the probability for each of the objects to become involved in an avalanche should be estimated specifically.

5.4 Verification

Verification of the hazard evaluation has to be based on observation of avalanche occurrences and snow stability evaluations. Information should if possible also be obtained from outside sources like road maintenance personnel and the public. After each winter, the forecasts, together with an evaluation of the correctness, should be reported.

When each forecast period is over, it should be given an a posteriori rating of the avalanche hazard based on the observed snow stability and actual avalanche activity in and near the forecasting area. This rating is important for the continuos improvement of the statistical relationship between the measurements and the avalanche hazard.

5.5 Distribution

The avalanche warnings and forecasts can be distributed through a number of channels. The main requirements are listed below

- channels should be reliable and there must be a backup channel
- recipients should be required to acknowledge that the message has been received
- the messages must be in writing and stored in paper file
- the forecast should be signed by the forecaster responsible and a reviewer

5.6 Quality Assurance

A project quality plan should be prepared for each program. The planning, implementation and operation of the avalanche forecasting program should be in accordance with the International Standard ISO 9001.

6 DECISION MAKING

6.1 Risk Analysis

Risk can be split into three basic factors; 1. the hazard, or the probability for a certain event, 2. the probability of damage in case of the event, and 3. the extent of damage. The residual risk is the product of the three factors after they have been minimised as far as possible. The collective risk is the sum of all individual risks of all threatened persons or objects.

An avalanche forecasting program in connection with habitations will not affect the first factor, the probability of an avalanche release. It can, however, reduce the probability and the extent of damage in case of an avalanche, mainly in terms of human lives spared, if the appropriate measures are taken.

In a risk analysis, one also has to consider what the ability to make accurate avalanche hazard evaluations is. To keep the risk permanently low, it must be possible to forecast avalanches continuously with a high degree of precision and to use a sufficient safety margin when decisions are made.

However, there will always be a certain residual risk. To find out whether this residual risk will be within what is tolerable, one will usually refer to the accident statistics of other, similar aspects of life. The residual risk will in the long run have to match this.

6.2 Decision Making

In all cases when different options exist, the decision should be based on a cost/benefit analysis to compare the justification of the measures.

When a forecasting program is the main preventive measure against avalanches, the risk to humans lives, can only be reduced if appropriate measures are taken at the right time. In the case of habitations this will mean the evacuation of the threatened areas. Evacuation of people can cause considerable logistic problems and can be time consuming. It is often desirable to use a safety margin, and an evacuation should preferably be in effect before a dangerous situation has developed. However, if the evacuation has to be in effect for too long a time or if there are too many unnecessary evacuations, the decision makers may lose credibility among the public and the media.

This will put the decision makers in difficult situations and give them a great responsibility. The decision making should therefore be performed by authorities with the necessary legal authorisation and political support. Public education will also be important.

Because of the possibility of considerable pressure put on the decision makers, it is recommended that a plan that determines what specific precautions are to be taken during the different levels of hazard, is worked out when a forecasting program is implemented. Procedures for how and when such a plan could be circumvented should also be established.

7 RECOMMENDATIONS

It is recommended that a local avalanche forecasting handbook, complete with observation guidelines and recording standards for weather, snow and avalanches is prepared in the Norwegian and Icelandic languages during the coming year. The handbook should contain the translations of the international classification schemes for snow and avalanches. It is also recommended that the handbook is made in co-operation with the International Workgroup of Avalanche Warning Services. The handbook should be updated regularly.

7.1 Implementation

It is recommended that the procedure of implementing an avalanche forecasting program in Iceland and Norway should follow the outline below:

- The sites should be determined by an avalanche hazard survey mapping and risk analysis. After a priority site has been chosen, an avalanche map and a data base of previous weather, snow and avalanche data for the location should be constructed.
- A survey of the avalanche history for the location and an analysis of the synoptic situations connected to previous avalanche situations should be done. On the basis of this, initial avalanche hazard criteria are worked out for use during the first winters of operation. The criteria could contain threshold values for when the situation should be investigated more closely and be evaluated by experts from the official avalanche institute (In Iceland: the IMO, in Norway: the NGI). A project quality plan should be prepared.
- A snow and avalanche observation program should be established and automatic weather stations installed. A computer with the necessary software for performing statistical analyses, storing data and forecast should be installed. A work instruction for the observer/forecaster is prepared.
- A local avalanche committee with the necessary legal authorisation and political support should be established. The committee, in co-operation with the official avalanche institute (in Iceland: the IMO, in Norway: the NGI), should be responsible for the decision making based on the avalanche forecasts. An evacuation and closure plan should be established. The legal and economic responsibility of the commission is determined.
- A plan that determines the specific actions and precautions that are to be taken during the different levels of hazard should be worked out. Procedures for how and when such a plan could be circumvented should also be established.
- After each winter a report of the forecasting operation should be written.
- Training programs for avalanche observers and avalanche committee members should be established.
- It is recommended that a yearly workshop is held where experiences from forecasting operations and new ideas are exchanged. The workshop could be held nationally or possibly as an Icelandic-Norwegian avalanche forecasting workshop.

7.2 Observation Program

The following observation program is suggested:

Hourly measurements (minimum interval) from automatic weather stations:

- precipitation
- wind speed and direction

- new snow
- air temperature
- snow height
- snow temperature

For practical reasons it is suggested that precipitation is measured at a lowland or valley site while the other measurement are measured at an elevation close to the avalanche starting zones.

Daily evaluation of:

- snow drift
- snow accumulation in the starting zones
- weather forecast

Periodic evaluation of

- snow stratigraphy
- snowpack stability
- avalanche activity

7.3 Forecasting Program

If the forecasting program has as its main objective to forecast relatively rare or extreme avalanches and not **every** avalanche, including the very small ones, it is possible to organise the forecasting program using a two step hazard evaluation scheme:

1. A daily, short survey of avalanche activity, weather, snow pack and weather forecast. The time necessary for this will be about 1-2 hours/day.
2. Full time monitoring procedure with detailed investigations and continuous evaluation of avalanche hazard. Updated reports are sent as often as required. A two way communication between the observer in charge and the official avalanche institute (in Iceland: the IMO, in Norway: the NGI) is established.

The indications for moving from step 1 to step 2 could be:

- Avalanche hazard degree developing from moderate (2: 'large natural avalanches not likely') to considerable (3: 'medium and occasionally large sized avalanche may occur')
- Indications from weather forecast of a potential avalanche situation developing
- Alert from the official avalanche institute (in Iceland: the IMO, in Norway: the NGI)

A procedure like the one outlined above will be advantageous not only because of economic considerations, but also for the motivation of the local observers/forecasters who may be working for years without seeing any direct use of their work.

7.4 Message Format

An avalanche forecast of hazard degree three or higher should be reviewed and approved by the official avalanche institute (in Iceland: the IMO, in Norway: the NGI) before it is sent. The following outline for the avalanche warning and forecasting message should be used:

- names of author and reviewer
- name of recipient
- number of pages in document
- location, data and time of writing
- location and time span which the message concerns
- main message (flash, one to two lines of text in bold types) and a reference to the European Avalanche Hazard Scale
- background weather and snow data
- avalanche probability now (snow stability evaluation)
- future avalanche probability (development of the snow stability)
- specification of the confidence level of the evaluation, if appropriate
- time of next evaluation
- request of acknowledgement
- signatures

The forecasts should be stored and reported after each winter as outlined in point 2.4.4.

7.5 Cost

The cost of establishing a local forecasting program is estimated to:

Item	Investment ISK (1000)	Annual cost (maintenance, upgrading) ISK (1000)
mountain automatic weather station*	400-550	300
lowland automatic weather station**	700	300
office tools	1 000	1 000
observation equipment	500	100
misc.	500	100
mapping, hist. research	500	
work hours		2 000
Total	3600 - 3750	3 800

* temperature sensors and anemometer
** temperature sensors, anemometer and precipitation gauge

The price of one microwave snow stratigraphy radar is estimated to about ISK 2,500 000.-. In addition there are field installation costs.

Costs connected with transportation, office rental, electricity, phones etc. are not included in the table above.

7.6 Military Operations (Norway)

It is recommended that avalanche forecasting programs during military operation are implemented in accordance to the guidelines set out in this report. Movable automatic weather and snow observation stations, that are placed in representative sites and transmitting in real time, should be used in addition to manual measurements.

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Appendix A - Avalanche Forecasting for Highway 15, Stryn, Norway

The operation is concerned with two kilometres of the Highway 15 in the Strynefjell mountain area. The operation is a contract project for the Public Road Administration and it is run by the Norwegian Geotechnical Institute.

Data available:

- Data from an automatic station at the same altitude as the road (930 m a.s.l.) with precipitation, air temperature, snow temperature, snow height, wind speed and direction. Data from an automatic station at a mountain crest near the starting zone (1420 m a.s.l.) with air temperature, wind speed and direction.
- Weekly snow profiles and stability tests near starting zones.
- Ten years of weather and avalanche data.
- Weather forecast based on a high resolution limited area atmospheric model (HIRLAM) which gives the forecast parameter values at three hour intervals up to 36 hours ahead. The forecast is updated four times daily and it is downloaded to the avalanche forecasters computer from the Norwegian Meteorological Institute.

Analysis tools available:

- Nearest neighbour program
- wind and precipitation index.

Contract terms:

- Working days. Potential avalanche hazard is checked every morning on workdays. This is done by checking the weather conditions from the automatic station and the latest weather forecast together with the latest snow profile/stability test.
- Before holidays: The snow and weather conditions along with the long term weather forecast are evaluated.
- In case of potential avalanche hazard: If the initial evaluation of the present weather and the forecast indicates that the avalanche hazard could rise above degree two, a forecast for the next 24 hours is worked out. The same day a new forecast is made at a time set in the previous forecast, usually in the afternoon by the end of the work day. The next evaluation is done the following morning.
- Outside working hours or more frequent forecasts: If hazard evaluation is required outside working hours or more frequently this is done by special agreement with the client and the client will be charged for extra time in addition to the agreed contract sum.

Forecasting procedure:

The weather data is checked against precipitation and wind indices and the nearest-neighbour program is run with prognosticated parameter-values. A template on a word processor, containing headings for present and past weather conditions, snow stratification and stability, synoptic situation and weather forecast, recent avalanche observations and the result from the nearest-neighbour program, is filled in by the forecaster. The forecaster then evaluates present and expected avalanche hazard (i.e. the snow stability and the probability for an avalanche to reach the road) on the basis of this. The contents and the wording of the warning to be sent out is discussed briefly with another forecaster and agreed upon.

Distribution:

An avalanche warning sheet consisting of a main heading with the avalanche hazard degree, with textual information below added as required, is then finished on a word processor. The name of the forecaster and the person who has reviewed it is written on the avalanche warning sheet. The avalanche warning sheet is then faxed according to the agreed recipient list from the word processor via a fax program and modem.

All sent avalanche warnings are stored on paper and computer file.

Verification:

The forecasts are verified against observed avalanche activity and an a posteriori subjective evaluation of the snow stability.

Decision making:

The decision of what measures to implement is taken by the regional supervisor on duty. The decision is based on the probability of avalanche reaching the road, amount of traffic, driving conditions and the need for maintenance.

Appendix B - Avalanche Forecasting for the Municipality of Odda, Norway

The operation is concerned with areas of habitations in the community of Odda by the Hardanger fjord. The operation financed over the municipal budget and the police budget. External services are purchased from the Norwegian Geotechnical Institute and the Norwegian Meteorological Institute as required.

Data available:

- Data from an automatic station in the valley with precipitation and air temperature sensors
- Wind data is obtained from an automatic station near the coast.
- Weather forecast based on a high resolution limited area atmospheric model (HIRLAM) which gives the forecast parameter values at three hour intervals up to 36 hours ahead.

Forecasting tools available:

- temperature and precipitation criteria for potential avalanche hazard prepared by Norwegian Geotechnical Institute
- consultation with the Norwegian Geotechnical Institute when the criteria are met

Forecasting procedure:

- The daily weather observation is the responsibility of the fire department officer on duty. This is done by checking the weather conditions from the automatic station and the latest weather forecast daily.
- In case the criteria for potential avalanche hazard are met, the avalanche committee, consisting of the mayor, the administrative head of the municipality, the head of the technical division and the chief of Police in Hardanger, is alerted.
- an avalanche expert at the Norwegian Geotechnical Institute, and possibly a meteorologist at the Norwegian Meteorological Institute, are consulted.

Decision making:

The decision of what measures to implement is taken by the avalanche committee. The decision is based on the probability of avalanches reaching inhabited areas.

Appendix C - Avalanche Forecasting for Local Communities in Iceland

The operation is concerned with areas of habitations in different communities in Iceland. The forecasting is done by the IMO and the operation is financed over the state budget.

Data available:

- Data from differently equipped automatic stations at locations near threatened areas.
- Data obtained from IMO's synoptic stations.
- Snow and avalanche data from local observers.
- Weather forecasts from IMO.

Forecasting tools available:

- knowledge from the local observers
- data base of historic synoptic situations leading to avalanches in the area

Decision making:

The decision of what measures to implement is taken by IMO in conjunction with the chief of police and the local civil defence committees. When the IMO issues a warning on localised avalanche hazard and declares an emergency, people shall be evacuated from all buildings in the zones that are named in the IMO's warning, in accordance with an existing emergency plan.

Forecasting procedure: see the flowchart below

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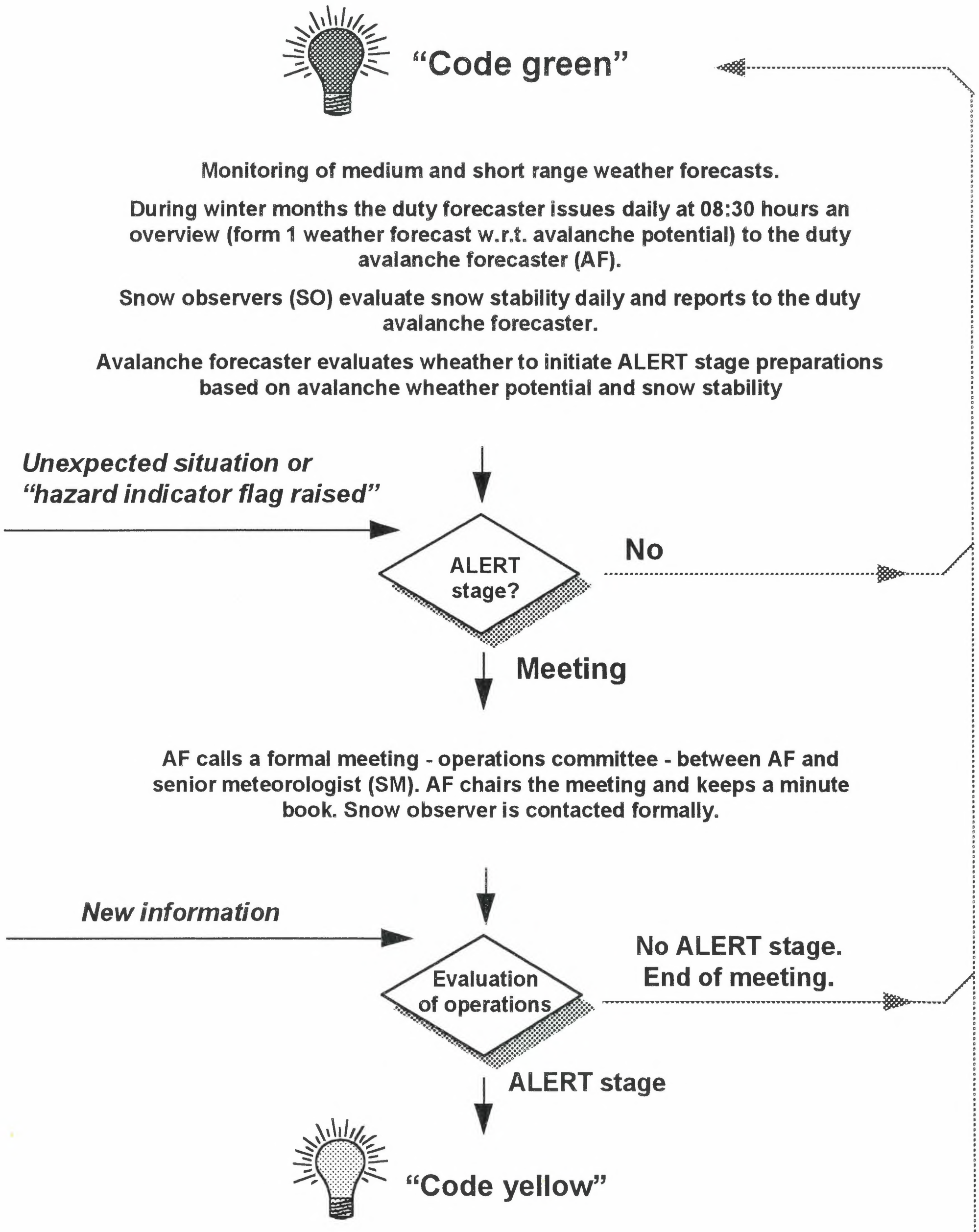
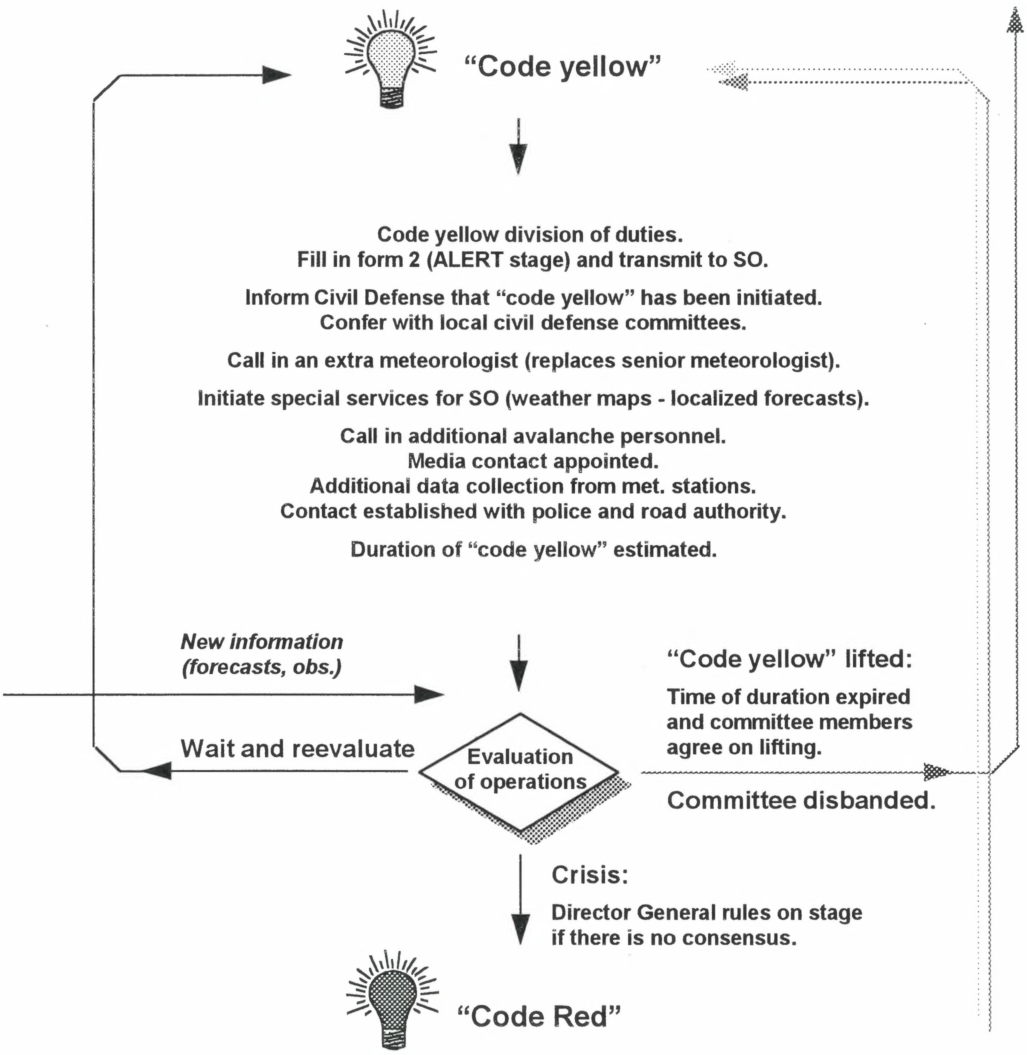
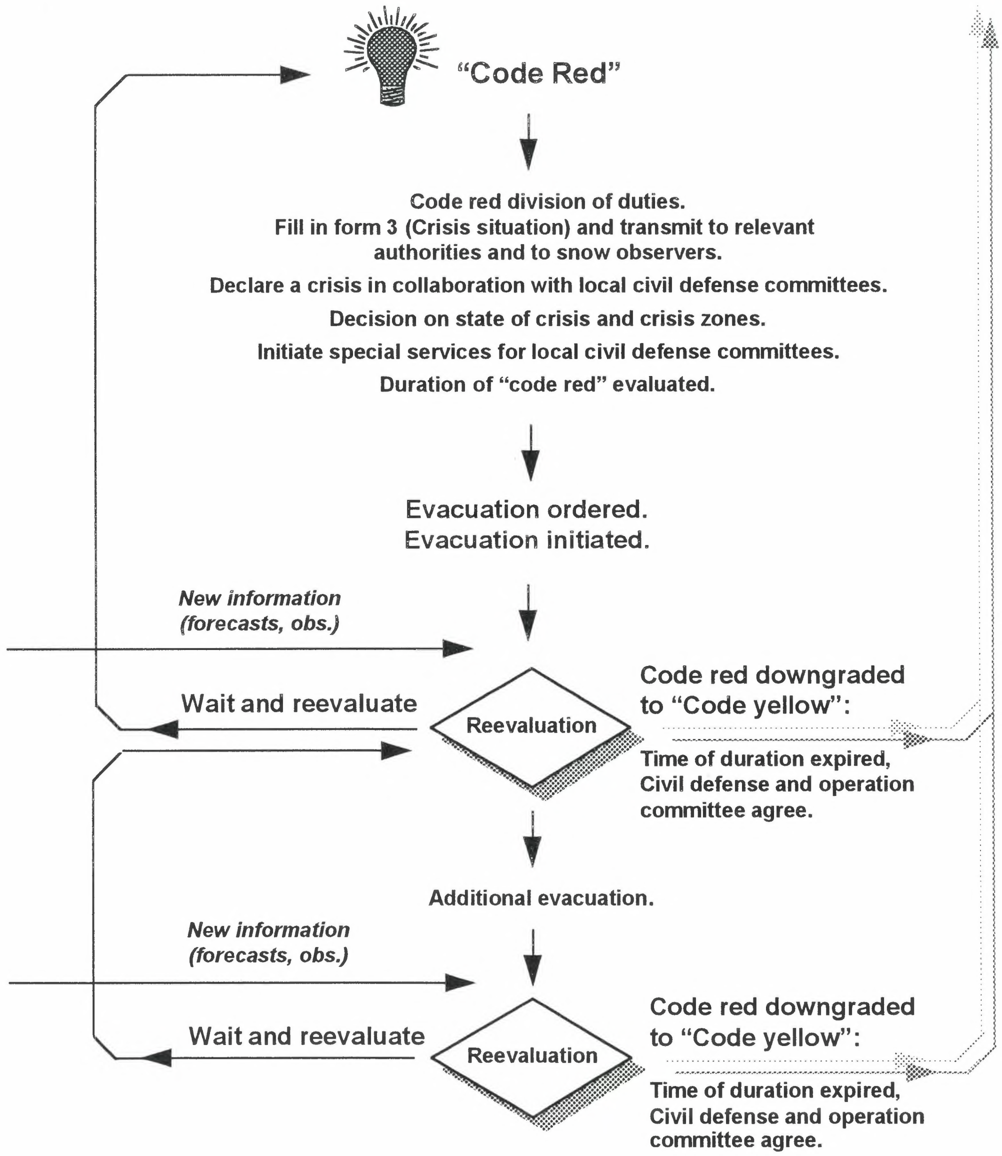

"Code green"
Monitoring of medium and short range weather forecasts.
During winter months the duty forecaster issues daily at 08:30 hours an overview (form 1 weather forecast w.r.t. avalanche potential) to the duty avalanche forecaster (AF).
Snow observers (SO) evaluate snow stability daily and reports to the duty avalanche forecaster.
Avalanche forecaster evaluates wheather to initiate ALERT stage preparations based on avalanche wheather potential and snow stability
Unexpected situation or "hazard indicator flag raised"
ALERT stage?
No
Meeting
AF calls a formal meeting - operations committee - between AF and senior meteorologist (SM). AF chairs the meeting and keeps a minute book. Snow observer is contacted formally.
New information
Evaluation of operations
No ALERT stage. End of meeting.
ALERT stage
"Code yellow"


"Code yellow"
Code yellow division of duties.
Fill in form 2 (ALERT stage) and transmit to SO.
Inform Civil Defense that "code yellow" has been initiated.
Confer with local civil defense committees.
Call in an extra meteorologist (replaces senior meteorologist).
Initiate special services for SO (weather maps - localized forecasts).
Call in additional avalanche personnel.
Media contact appointed.
Additional data collection from met. stations.
Contact established with police and road authority.
Duration of "code yellow" estimated.
New information
(forecasts, obs.)
"Code yellow" lifted:
Time of duration expired
and committee members
agree on lifting.
Wait and reevaluate
Evaluation
of operations
Committee disbanded.
Crisis:
Director General rules on stage
if there is no consensus.
"Code Red"


"Code Red"
Code red division of duties.
Fill in form 3 (Crisis situation) and transmit to relevant authorities and to snow observers.
Declare a crisis in collaboration with local civil defense committees.
Decision on state of crisis and crisis zones.
Initiate special services for local civil defense committees.
Duration of "code red" evaluated.
Evacuation ordered.
Evacuation initiated.
New information (forecasts, obs.)
Wait and reevaluate
Reevaluation
Code red downgraded to "Code yellow":
Time of duration expired, Civil defense and operation committee agree.
Additional evacuation.
New information (forecasts, obs.)
Wait and reevaluate
Reevaluation
Code red downgraded to "Code yellow":
Time of duration expired, Civil defense and operation committee agree.

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