# Preparedness of the Icelandic Meteorological Office in response to potential avalanche danger

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## ABSTRACT

In the wake of avalanche disasters in the last year that left 36 people dead, the law in Iceland concerning avalanche safety was changed. In addition to monitoring potential avalanche situations, the responsibility of defining evacuation areas and ordering evacuations was given to the Icelandic Meteorological Office (IMO).

In order to prepare for this, the IMO set up an internal avalanche situation watch. Reports were written describing potentially dangerous situations in terms of weather conditions and snow accumulation. In addition, maps were compiled showing distinct evacuation zones. Three stages where defined, depending on the severity of the situation and potential runout distances of avalanches.

An increase in the staff of the avalanche section at the IMO has taken place with additional resources given to the section. The mandate of the IMO has been set to prevent further disasters like the ones that occurred in 1995.

The system of local snow observers was strengthened both in terms of manpower and equipment. A system of senior observer and assistants has been set up and their function has been integrated into the workings of the IMO. They comprise an integral part of the decision making within the office.

Future plans for an improvement of the safety of the avalanche prone communities include, further instrumentation in the starting zones as well as in the villages, monitoring weather, precipitation and snow depth. Plans are to adapt nearest neighbour forecasting systems, based both on local and synoptic conditions.

## INTRODUCTION.

In 1995, a total of 36 avalanche fatalities occurred in Iceland. Of those, 20 fatalities occurred in the village of Flateyri on the 26th of October 1995 and 14 fatalities in the village of Sudavik on the 16th of January earlier the same year. One farmer was also killed tending to his livestock. Those three accidents all occurred in the northwest peninsula Vestfirdir or Western Fjords. In addition, a skier was killed in the neighborhood of Reykjavik.

As a result of these disasters, the Government of Iceland gave the Icelandic Meteorological Office (IMO), the agenda to reduce the chance of further disasters such as those that occurred in the year 1995. As a result, various programs have been initiated in order to improve the effectiveness and preparedness of the IMO.

Up until then, the threat of avalanches was always considered somewhat secondary to all the other natural hazards that are present in Iceland. These accidents caused people to realize that this is indeed a very serious threat in Iceland.

Eighteen months ago there were two people employed in the field of avalanches and a few snow observers stationed at the threatened villages but their work was mostly voluntary since no funding was available to employ them to the extent that was actually needed. Now there are seven people employed full time at IMO and snow observers have been employed at several communities in varying capacity, ranging from 30% to 100% on a yearly basis.

At present there are hardly any avalanche defense structures in Iceland to speak of. Thus, a project was initiated to evaluate the need for such structures.

## THE NEW LEGISLATION.

A new law about snow avalanche defenses and debris flow was passed before the Icelandic Parliament, Althingi, on the 28th of December 1995. It states that the responsibility of avalanche related matters falls under the Ministery of the Environment. Previously that responsibility had been divided under three ministeries. In particular all professional matters related to avalanches s.a. the responsibility of determining the extent and timing of evacuations during the time of impending avalanche danger, hazard zoning and avalanche research was put in the hands of the Icelandic Meteorological Office.

## THE CHANGE IN PEOPLES ATTITUDE.

The avalanche disasters have changed people's attitude and new information about past avalanches has surfaced. For example in the village of Flateyri we have new information on 9 avalanches that we were not aware of before and we received additional information on 4 already known avalanches. This does not mean that all this information was willfully held back from us, although we have an example of that. More importantly, the new information is the result of more intense data collection. People dig deeper into their memory and are more willing to discuss past avalanches.

Also, reporters have joined us in the search for past avalanches. It is considered news that an avalanche has been omitted in the hazard evaluation process. This has then been discussed in the media and more people have come forward with additional information. There is even a case were a police investigation was initiated to investigate a claim that an avalanche had fallen down to a specific location far within what is now a residential area.

## AVALANCHE WARNING PROCEDURES.

The Icelandic Meteorological Office has put down operational procedures for the monitoring of potential avalanche danger. It specifies what shall be done and in what order. It places the IMO in one of three stages of alertness. See figures 1 to 3.

- **Code Gray:** This means an ordinary winter day with nothing in particular going on but ensures that all the vital signs are looked at. Snowpits are dug on a regular basis and stability is evaluated. Snow accumulation is monitored. If something looks as if it might develop into a potential avalanche situation the IMO enters into what is called Code Green.
- **Code Green:** This is when a situation might develop within a few days and the office is put into a state of more preparedness, more personnel is called to the office and all the relevant authorities are notified. Additional data is gathered s.a. fresh snowpits are dug and the snow observer makes a round of his domain to get a fresh overview of what the situation is like. If it looks like the forecast is going to be realized the IMO enters into what is called Code Yellow.
- **Code Yellow:** During this stage the evacuation areas are determined in collaboration with the local authorities and a formal notification is sent to the local Chief of Police who is responsible for the execution of the evacuation.

All these codes are determined so as to correlate with the plans of the National Civil Protection organization. The timing would maybe be slightly different e.g. the IMO would enter into its Code Green slightly earlier than local Civil Protection Committees as well as the Code Yellow. This is because the IMO is supposed to initiate the procedure. Code Yellow can only be lifted when the local Civil Protection Committee and the IMO agree. The Civil defense has an additional code, Code Red which is when disaster has struck. During that phase the local Chief of Police is in total charge and the IMO is purely an advisory body.

## EVACUATION PLANS.

The initial effort went into laying out and defining evacuation plans. Three levels of evacuation are defined.

- **Evacuation level 1:** An area which relates to known avalanches and moderate snow accumulation. The extension of the evacuation area may be smaller than indicated by the avalanche history i.e. excluding extreme conditions.
- **Evacuation level 2:** An area which is predominately determined by known avalanches and other paths with similar topological conditions. Possible hazard situation might arise during heavy snow accumulation. The area will be evacuated during impending weather conditions which are known to impose a serious threat of avalanches.
- **Evacuation level 3:** An area which is considered threatened by catastrophic avalanches that need not be included in the known avalanche history; meteorological conditions with extreme snow accumulation and extreme storm conditions. Also included are areas which are threatened during extremely rare meteorological conditions.

The lateral influence zone of each avalanche path was determined and vertical lines were drawn to show the extent. Then horizontal lines were drawn to show how far downhill each level extends. Each area was then given a letter that will be used when an order for evacuation is issued. See figure 4.

To date evacuation plans have been made for 9 communities with a total population of 10,000 and an additional 3 communities with 2,500 people will be added shortly.

The work included, a description of the conditions that are threatening to the various zones within the individual communities, e.g. what wind direction is most dangerous for the various avalanche paths and how common it is and what synoptic situation can create such a wind direction.

The evacuation plan was made by a workgroup which included avalanche personnel that had collected data on past avalanche cycles, meteorologists that had investigated past meteorological conditions that lead those avalanche cycles and people that had done a statistical evaluation on the extreme runout of Icelandic avalanches.

The work group also included a local committee which consisted of the local snow observer and various people selected because of their knowledge of local avalanche conditions. Things were discussed and modified until an agreement was reached. Then a formal map was drawn up and a short report written which described the evacuation zones and levels and the weather conditions that were needed for the various stages and levels to be initiated.

A small booklet was then prepared which included an extract of the report and listed which buildings were in the various evacuation areas and other practical information that might come in handy in case of an evacuation. This booklet was distributed to every house in the respective communities.

## SNOW STAKES IN THE STARTING ZONES.

In order to be able to better evaluate the snow accumulation in the various starting zones, a system of snow stakes is being installed in the most threatened communities. The stakes are wooden with a multicolored plastic sleeve, al-

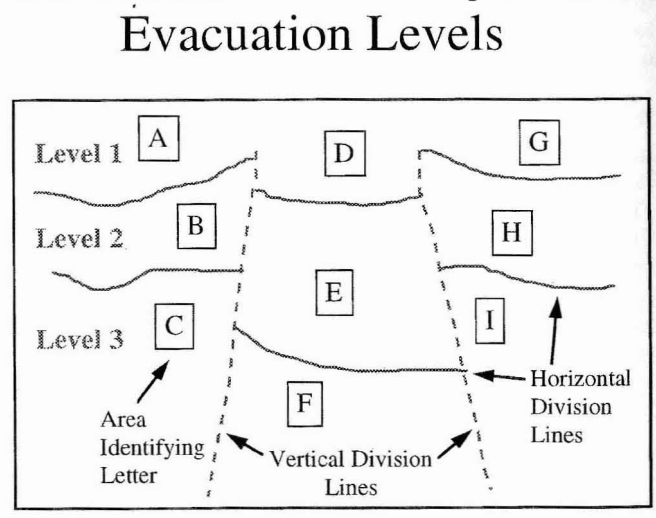


Figure 4. The figure shows how the individual evacuation zones are determined. The vertical division lines show the lateral influence zone of the avalanche path or paths and the horizontal division lines show the possible runout of the avalanches as determined by the three evacuation levels.

# Icelandic Meteorological Office
## Avalanche Warning Procedures

"Code Gray"

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 forcaster fills in form 2

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) and the local snow observers.
AF chairs the meeting and keeps a minute book.

*New information*

Evaluation of operations

No ALERT stage. End of meeting.

ALERT stage

"Code green"

Figure 1

# Icelandic Meteorological Office
## Avalanche Warning Procedures

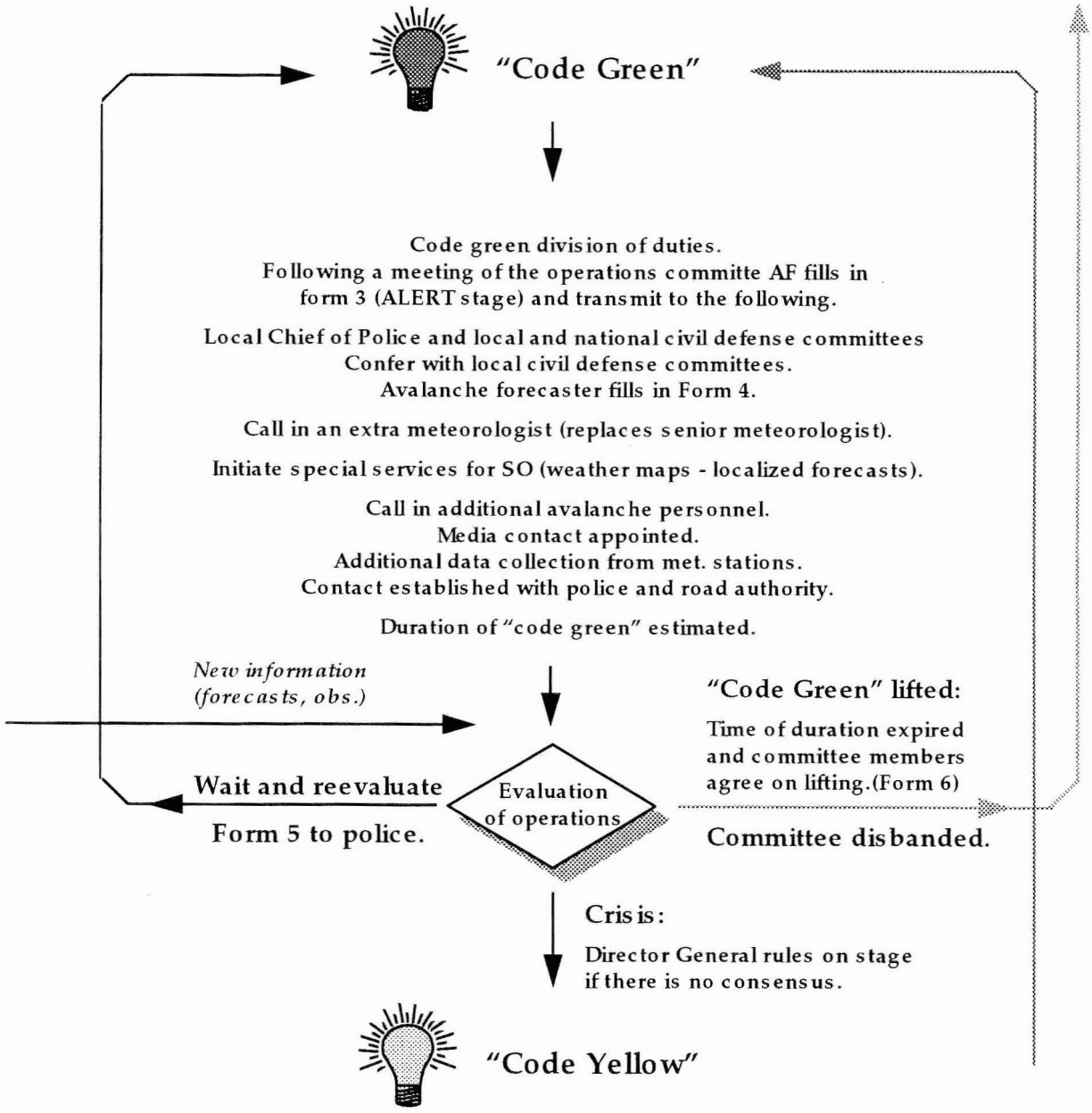


Figure 2

# Icelandic Meteorological Office
## Avalanche Warning Procedures

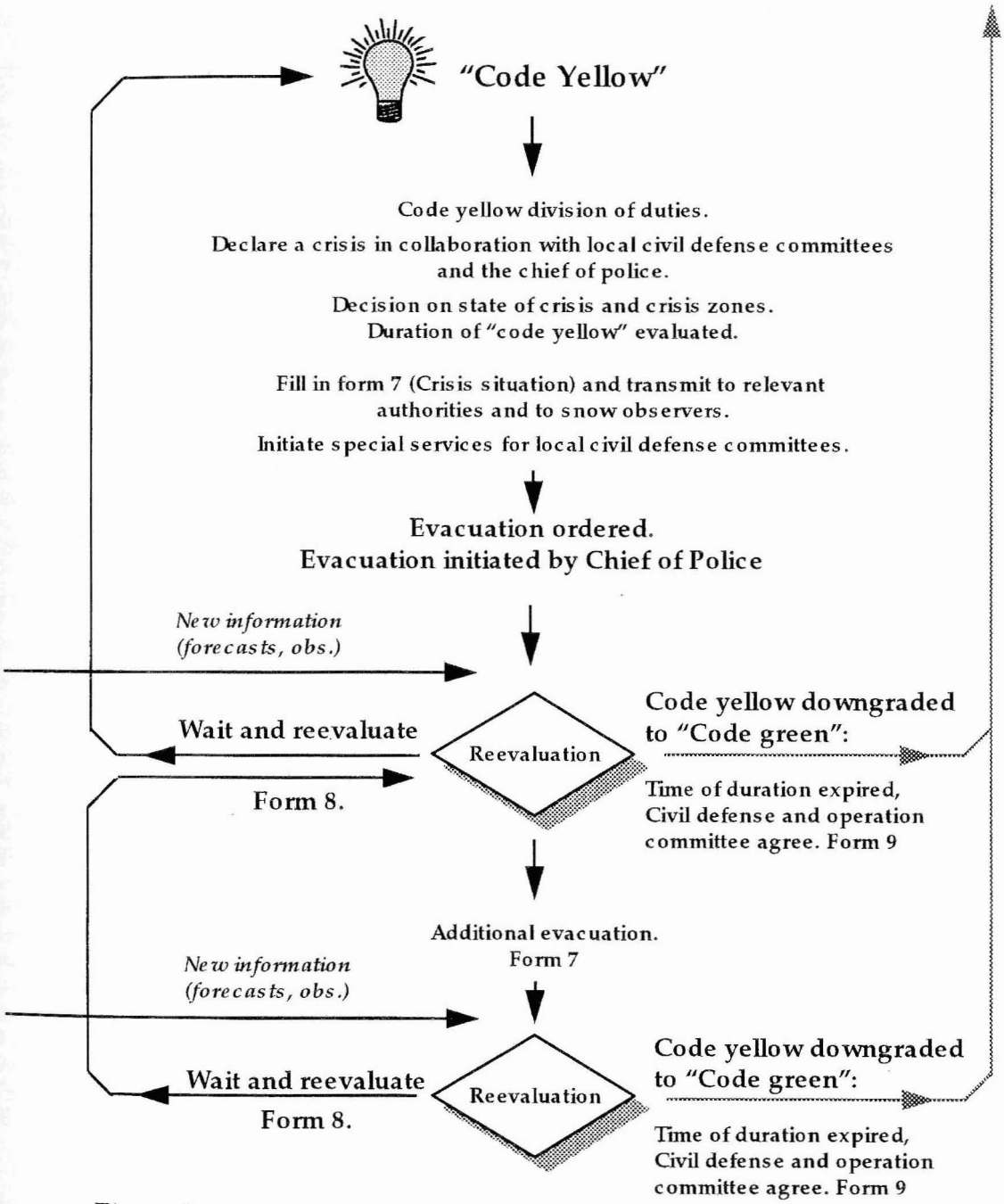


Figure 3

ternating bands of blue and yellow, each band 30 cm wide. A total of around 120 stakes will be in place this winter ranging from about 12 per community to 33.

In addition, the data collected about snow depth in the starting zones will serve as valuable information in future when defense structures will be designed for the respective avalanche paths.

The monitoring of the snow depth will be done by a theodolite from a fixed location e.g. a room in a building with a good overview of the paths. A fixed reference mark is laid out so it is possible to sight onto a stake even when visibility is bad and it would be virtually impossible to locate the stake by searching for it. This is a well known method used in the artificial release of avalanches using artillery.

## AUTOMATIC WEATHER STATIONS.

Three years ago the IMO was operating 4 automatic weather stations of which 2 were specifically set to be used to assist in avalanche forecasting. We had access to additional 8 stations. Now the office has access to data from 38 station of which 8 are designated as snow avalanche stations. Plans are to install automatic weather stations near the starting zones above all avalanche prone communities. All automatic lowland stations within those communities will have automatic precipitation gauges and mountain stations will have sonic snow depth sensors.

The station network is linked to the IMO headquarters and data is collected every hour and more frequently during avalanche cycles.

## SNOW OBSERVERS.

Previously, snow observers were in effect employed on a voluntary basis, i.e. their salary was so pitiful that only the most keen people remained in the post.

With the change in the government regulations it is now possible to employ people so they can maintain a living by becoming a snow observer, at least over the winter months. This will hopefully attract well qualified people and encourage them to remain in the position for several years.

Their job description includes regular weather observations, evaluation of snow accumulation, digging snow pits at regular intervals and more often during times of impending avalanche danger. They will evaluate each avalanche path with possible avalanches in mind. They will record in detail the avalanches that occur and try and gather as much data as possible on the various aspects, such as the extent, size, snow stratigraphy in the starting zone, characteristics of the debris etc. They will keep a record of all their observations in the various log books and computer software, e.g. Snowpro and the IMO snow avalanche database.

They will also be responsible for gathering historical data on past avalanches and take part in writing a detailed report on the local avalanche history.

Also they will be responsible for the maintainance of all their equipment and other equipment of the IMO in the area. They will monitor the various experiments that the IMO will conduct now and in the future such as glide and snow depth experiments.

A major improvement has taken place in their equipment and instrumentation. All are now supplied with snow skidoos, mobile telephones and/or VHF radios. All stations will be equipped with computers and will soon be linked with the IMO via the Internet.

They are supplied with the necessary clothing and other mountain equipment. Previously all this had to be supplied by the observer himself.

## OVERVIEW OF THE NEED FOR AVALANCHE DEFENSES IN ICELAND.

During this past summer a report was compiled that outlined the need for snow avalanche protection for the main avalanche communities. This was done in collaboration with the Swiss Federal Institute of Snow Avalanche Research in Davos SFISAR, and the Norwegian Geotechnical Institute, NGI.

This report gives an overview of the need for avalanche defense structures in Iceland and suggests a possible solution for the individual communities. An attempt is made to make a preliminary prioritization for the country as a whole and an estimate of the cost is also compiled. It is estimated that it will cost on the order of 8 to 10 billion Icelandic kronars or, 120 to 150 million US$, to build defense structures for. It is expected that it will take tens of years to complete an avalanche defense structure program.

It must be emphasized that this overview only included towns and villages that are considered at risk due to snow avalanches. No attempt was made to include roads that are threatened by avalanches. We have several road closures each winter due to avalanches and there are several avalanche accidents recorded on those roads. Neither were individual farms around the country evaluated and we have many at risk throughout the country. Ski areas were not included either, although obviously they are at risk.

## OTHER RESEARCH PROJECTS

Other programs have been initiated to improve the avalanche situation in Iceland. One such project is a pilot project to test retaining structures and obtain the relevant design parameters for the installation of such structures. The snow conditions in Iceland are quite different from those in the Alps and most other areas where these structures are predominantly used. This is due in part by the fact that our climate is maritime and the starting zones are on the order of 400 to 1000 m a.s.l. Thus our snow is quite dense, ranging from maybe 400 to 650 kg per $m^3$ giving rise to considerable forces on the structures. On the other side, because of the lack of vegetation and the rough terrain, we expect snow glide to be very small. Thus a close monitoring will be maintained on the structure, snow pressure forces measured and the strain on the structures monitored. Snow glide and snow creep will be measured, regular snow pits dug and snow depth monitored. It is the hope of the IMO that this will provide design parameters for future installations here in Iceland.

A snow stratigraphy radar will be installed at one site this winter to monitor the snow accumulation and stratigraphy. If this experiment is successful we might install more radar in some of the most dangerous avalanche

paths. It will provide us with a continuous record of the snow accumulation and stratigraphy irrespective of weather. Several sonic snow depth sensors will be installed to complement the radar.

This fall, construction on a pair of diverting walls, above the village of Flateyri, will be started. It is expected that it will take two years to complete it. They range from 15 to 20 meters in height and have a total length of 1.6 km or about one mile. When completed, an avalanche radar will be installed on top of the diverting wall to measure avalanche velocities. The aim is to investigate the effectiveness of a diverting wall and obtain data to verify model calculations used to obtain the height of the diverting wall. The actual run-up will be measured and mapped by the local avalanche observer. It is our hope that this will provide valuable data that will be of use in future avalanche defense structures in Iceland and the rest of the world.

In Iceland, the lack of vegetation precludes the use of vegetation data to determine historical runout of avalanches. We are hence looking for other ways to determine the maximum runout of avalanches. Thus, during the construction of the above mentioned diverting dams, on site inspection will be conducted so as to gather data for the possible identification of avalanche debris. The avalanche frequency is very high in this path and we hope that during the excavation of the fluvial fan, to collect information that will aid us in identifying past runout of avalanches. In addition, every effort will be made to collect similar data from other sites.

An investigation into what is an acceptable risk level when hazard zoning is considered is underway. This is being done in the preparation for new regulations and will provide the governing bodies with a foundation for determining what should be adopted as the acceptable level of risk in Iceland.

Furthermore, an effort is being made to develop a methodology to evaluate the return period of avalanches in Iceland based on existing data.

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