VEÐURSTOFA ÍSLANDS

Report
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Hazard zoning for Eskifjörður

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Contents

1 Introduction

This report describes the results of a project carried out by the Icelandic Meteorological Office (IMO) with the aim to evaluate avalanche, debris flow and rockfall hazard in Eskifjörður. The result is a hazard zoning proposal for Eskifjörður based on the current Icelandic hazard zoning regulation.

Similar reports have been published for Neskaupstaður, Siglufjörður and Seyðisfjörður where new hazard maps have recently been issued (Thorsteinn Arnalds *et al.* 2001a,b,c, 2002).

1.1 Work process

The main participants in this project were Thorsteinn Arnalds, Tómas Jóhannesson, Esther H. Jensen and Kristján Ágústsson (Icelandic Meteorological Office), Siegfried Sauermoser (Austrian Foresttechnical Service in Avalanche and Torrent Control, WLV) and Thomas Sönser (Ingenieurbüro für Naturraum-analyse und Naturgefahren-management, INN).

Other employees of the IMO contributed to the work. Preparation of climatic data was done by Thóranna Pálsdóttir. Leah Tracy and Hörður Þór Sigurðsson drew maps for the report. The local snow observer in Eskifjörður, Hjalti Sigurðsson, participated in parts of the work.

Work on the project started formally in the winter 1999/2000 at the IMO with the collection of basis data. A chronicle of avalanches and other slides was compiled by Kristín Ágústsdóttir *et al.* (2002) based on previous work by Jón Gunnar Egilsson (1990).

Field work was carried out in the summer of 2000. On 29 June to 3 July Thorsteinn, Esther, Siegfried, Thomas and Kristján visited Eskifjörður. The fieldwork was split into three parts; i) analysis of avalanche conditions, ii) investigation of debris flow, torrent and rockfall hazard focusing on three paths and iii) a discussion within the group on how to integrate the landslide hazard into a final hazard map. Thorsteinn, Siegfried and Kristján worked on part i), Esther and Thomas on part ii) and the whole group on part iii).

The scope and extent of the inspection of avalanche conditions was defined to be an examination of relevant areas in the field, review of avalanche chronicles and climatic information and to describe the following:

a) *Topographic conditions, i.e.* the topography of the starting zone, track and runout area.

b) *Climatic conditions* would be dealt with mostly on a regional basis, but locally the effect of the regional climate on snow accumulation in starting areas would be discussed.

c) *Assessment*. The group would give its general opinion of the avalanche hazard in a particular path. This would be done by quantifying the size of the starting areas and their relative frequency with respect to other paths.

These descriptions formed the basis of the final report for the project.

The debris flow work group applied a process orientated Austrian method. Their work was concluded with a separate report (Esther H. Jensen and Thomas Sönser, 2002). This work was extended to other paths in Eskifjörður and integrated into the final hazard zoning by the staff of the IMO. Section 4 discusses this work. A part of that work was a field trip to Eskifjörður on 11 February 2002 by Esther, Hörður, Thorsteinn and Tómas.

Erik Hestnes (2002) investigated slushflow hazard in Eskifjörður. He made a field trip to Eskifjörður on 24 July 2001 accompanied by Esther and Thorsteinn.

A regulation on avalanche and debris flow hazard zoning was issued in July 2000 (The Ministry for the Environment, 2000). According to the regulation a hazard zoning committee was to be formed for communities where avalanche and debris flow hazard should be evaluated. The committee consists of two representatives from the local government and two for the Ministry for the Environment. The settlement in Eskifjörður is a part of the community of Fjarðabyggð. A hazard zoning committee for the community Fjarðabyggð was established in August 2000.

The hazard zoning committee of Fjarðabyggð held its first meeting to discuss hazard zoning in Eskifjörður on 4 January 2002. At that meeting the IMO presented its work and some preliminary findings. A rough plan was laid out for the completion of the hazard map.

To strengthen the basis of the hazard zoning, two-dimensional model calculations were carried out by Advanced Simulation Technologies (AVL) of Graz, Austria (Tómas Jóhannesson *et al.*, 2002).

Based on the background data described above the hazard zones were delineated. The delineation was done by Thorsteinn and Tómas with Esther and Kristján participating in parts of the task. A part of the finalisation of the hazard zoning was carried out by Esther, Thorsteinn and Tómas during the field trip to Eskifjörður in February 2002. They were accompanied by the local snow observer Hjalti Sigurðsson.

1.2 Organisation of the report

The investigated area reaches from west of the farm Eskifjörður and to the eastern boundary of the settlement. The area is shown on Map 1.

The report is split into four main sections. The first part contains an overview of topographic and climatic conditions, a summarised avalanche chronicle, and a review of previous hazard assessments. The next two sections deal with avalanches and landslide hazard. For the analysis of avalanche hazard the area is split into four smaller areas. For these areas the following is described:

Topographic conditions: Physical characteristics of the starting zone, track, and runout area.

Climatic conditions: Weather indicative of avalanche danger and past weather patterns that have led to avalanches.

Assessment: Discussion of avalanche conditions and qualitative hazard analysis.

Table 1. *Icelandic hazard zone definitions*

Zone	Lower level of local risk	Upper level of local risk	Construction allowed
C	$3 \cdot 10^{-4}$/yr	–	No new buildings, except for summer houses*, and buildings where people are seldom present.
B	$1 \cdot 10^{-4}$/yr	$3 \cdot 10^{-4}$/yr	Industrial buildings may be built without reinforcements. Domestic houses have to be reinforced. Existing hospitals, schools *etc*. can be enlarged and then have to be reinforced.
A	$0.3 \cdot 10^{-4}$/yr	$1 \cdot 10^{-4}$/yr	Houses where large gatherings are expected, such as schools, hospitals *etc*., have to be reinforced.

*If the risk is less than $5 \cdot 10^{-4}$ per year.

Model estimates: Model results that are the basis of the hazard zoning. For explanations of technical concepts and notation, refer to Appendix A.

Conclusion: Hazard evaluation and a proposed hazard zoning.

Finally a short conclusion is given on the overall results of the project.

1.3 Methodologies and regulations

The hazard zoning presented in this report is based on Icelandic hazard zoning regulations that were issued in July 2000 after having been under development for several years. A summary of these regulations is included below.

Hazard zoning in Iceland has since 1995 been based on individual risk which is the yearly probability that a person living at a given place will be killed by an avalanche. The definition of hazard zones is based on the *local risk* defined as the annual probability of being killed given that a person is staying all the time in an unreinforced house. The *actual risk* can be found by taking into account the probability of the person being present in a house when an avalanche hits and the increased safety obtained by reinforcing houses. Increased safety by evacuations and other non-permanent safety measures are not taken into account in the hazard zoning. The authorities in Iceland have adopted the value $0.2 \cdot 10^{-4}$ per year as an accepted actual risk for avalanche hazard zoning (The Ministry for the Environment, 1997). This value corresponds to different values of the local risk for different types of constructions depending on the fraction of time people may be expected to spend in the buildings (typical values are assumed to be 75% in domestic houses, and 40% in commercial buildings). The regulation on hazard zoning (The Ministry for the Environment, 2000) defines three types of hazard zones, see Table 1.

These guidelines for zoning are tailored to attain the acceptable risk level of $0.2 \cdot 10^{-4}$ per year in residences when presence probability and increased safety provided by reinforcements have been taken into account. The risk in industrial buildings is probably somewhat higher.

The methodology used here to estimate avalanche risk in parts of Eskifjörður was developed at the University of Iceland and the Icelandic Meteorological Office in the period 1995–1998. The methods are described by Kristján Jónasson *et al.* (1999).

This discussion is concluded by quoting §10 of the Icelandic regulations on how to proceed where formal risk calculation is impossible: "In areas, where it is not possible to estimate the risk formally due to insufficient information, a hazard map shall nevertheless be prepared according to §12 [§12 describes the risk zones of a hazard map]. In the preparation of the map an attempt should be made to estimate risk."

1.4 Uncertainty

The estimation of avalanche risk is difficult in many areas. This is especially the case when dealing with a slope that from the topographical point of view has the characteristics of an avalanche path, but where no avalanches have been recorded. Accurate records of avalanches have only been kept for a few years or decades in many areas and the settlement may be quite recent. In such a situation, it is almost impossible to rule out the possibility that an avalanche hitting the settlement might be released from the slope. An attempt must then be made to strike a compromise that balances the lack of recorded avalanches and the possibility of avalanche release.

Another problem that must be addressed is the estimation of avalanche hazard in non-typical or low avalanche tracks. The available data about Icelandic avalanches was mostly collected from hills between 500 and 800 m high with large starting areas. The runout potential of avalanches from smaller slopes, both with a lower fall height and smaller starting areas, is not as well investigated.

While delimiting the hazard zones, an attempt has been made to classify the uncertainty in each area by dividing the uncertainty into three classes according to the level of uncertainty in the area. An uncertainty of $\frac{1}{2}$ means that the estimation could be wrong by half a hazard zone, *i.e.* the hazard lines may misalign by approximately $\frac{1}{2}$ of a hazard zone. Since the risk varies by a factor of 3 between the risk lines of the hazard map, the risk may be over- or underestimated by factor of $\sqrt{3}$. Similarly, classes 1 and 2 certainty mean that the zoning could be wrong by 1 and 2 zones in either direction, respectively, meaning that the risk could be over- or underestimated by factor of 3 or 3^2 respectively. Considering the "nominal" nature of avalanche risk estimates, it is not possible to attach a given significance level in a statistical sense to these uncertainty indicators. They are intended to mean that the work group considers it "unlikely" that the risk is over- or underestimated by the indicated uncertainty, but the meaning of "unlikely" is not further quantified.

The three chosen classes of uncertainty and their characteristics are:

$\frac{1}{2}$ Records of avalanches are available and the avalanche path is large and typical.

1 Some records of avalanches are available and the avalanche path is small or atypical.

2 No records of avalanches are available, but the topography indicates avalanche hazard.

The uncertainty of hazard zoning in areas where protective measures have been built will probably be in class 1 or 2.

2 General

2.1 Topographic description

The settlement of Eskifjörður is part of the community of Fjarðabyggð. It is located on the northern coast of the fjord Eskifjörður which is directed towards northwest from a larger fjord, Reyðarfjörður, see Map 1 and Figure 1. Most of the settlement is located along the coast but the most recent part reaches into the valley at the head of the fjord. South of the fjord, facing the settlement, rises Hólmatindur which is about 1000 m high and quite steep. To the north of the fjord and above the settlement there are mountains which are also up to about 1000 m high, but not as steep. To the west of the head of the fjord is the mountain Harðskafi, and then to the east are Ófeigsfjall and Hólmgerðarfjall. Between Harðskafi and Ófeigsfjall is the valley Ófeigsdalur. Above the settlement and to the east of Ófeigsfjall there is a large shelf in the mountain at about 4–600 m a.s.l. which is called Lambeyrardalur. The mountainside above the settlement is marked by many rivers and brooks. Most of the torrents are small, but five of them have eroded large gullies above the settlement but they flow in shallow creeks through the settlement. The westernmost river is Bleiksá, to the east are Grjótá and Lambeyrará and Ljósá and Hlíðarendaá are in the easternmost part of the settlement.

The first settler in Eskifjörður was Brynjólfur gamli (Brynjólfur the old). The farm Eskifjörður in the valley to the west of Eskifjörður is built on his land. The farm is known with certainty to have been habitated since the 1500's and has probably been habitated since it was settled around the year 1000. When a Danish trading monopoly in Iceland was lifted near the end of the eighteenth century Eskifjörður became an official community for trading ("kaupstaður"). The first shop was built at Lambeyri and after that the settlement in Eskifjörður started to develop gradually. The main sites were clusters of houses around the traders in Útkaupstaður and Framkaupstaður. When the Norwegians started their herring fisheries in Iceland at the end of the nineteenth century the population of Eskifjörður increased significantly. The settlement first developed in the area around the road Kirkjustígur, but later towards the east along the coast around Ljósá and Hlíðarendaá. The settlement to the west of Framkaupstaður also grew but was rather sparse in the beginning. During the Great depression the number of inhabitants in Eskifjörður decreased, but increased again in the second half of the twentieth century. The population was at a maximum in 1982 when 1135 people were living in Eskifjörður. At present the inhabitants are about 960.

The names of houses in Eskifjörður, and the year which they were built have been documented by Kristín Ágústsdóttir (2001).

2.2 Chronicle

Map 2 shows recorded avalanches, slushflows, torrents and landslides in Eskifjörður. Appendix B contains a list of the events.

In the early nineteenth century a water mill to the west of Grjótá was destroyed by a "very large torrent".

Figure 1. *An overview of the area around Eskifjörður with the locations of meteorological stations indicated. © The National Land Survey of Iceland.*

In November 1849 a slushflow from Grjótá destroyed the farm Klofi, killing three persons.

In 1904 a slushflow from Lambeyrará filled a domestic house and caused various damages.

On 16 March 1919 two slides within the settlement of Eskifjörður caused damages. These were probably slushflows. A slide a little to the west of Grjótá damaged stables, killed livestock and damaged fishing equipment, food and more. To the east of Hlíðarendaá a slide hit a domestic house which was under construction og caused considerable damages.

In the summer of 1930 a torrent from Grjótá damaged fish and fish drying racks.

On 16 June 1935 there were torrents and debris flows in many paths in Eskifjörður. Damages were mostly done to fields.

On 29 June 1940 most of the paths in Eskifjörður were flooded. Damage was caused to houses, infrastructure and to fields.

In the beginning of August 1946 many paths were flooded and floods in Grjótá and Lambeyrará caused damages to houses and furniture.

In 1950 several paths were flooded and Grjótá flooded into one house. Roads in the inner part of the settlement were damaged.

In the autumn of 1959 a torrent in Bleiksá damaged the bridge over the river.

At the end of October 1972 a debris flow from Ljósá damaged streets, a storage house and more.

In September 1981 a debris flow from Lambeyrará damaged many gardens.

In September 1999 and August 2000 there were large landslides in Hólmatindur on the southern side of the fjord.

In the last few years several dry slab avalanches are recorded in Harðskafi. All of them stopped a short distance below the starting area.

Debris flows are frequently released from the mountain Hólmatindur on the south side of Eskifjörður. Many of the debris flows have reached the road and disrupted traffic and some have damaged the road, telecommunication lines and farmland. A large debris flow in 1906 fell into the ocean and caused a flood wave that damaged boats and piers in the settlement on the other side of the fjord. As debris flows from Hólmatindur are not considered to threaten the lives of people within the village of Eskifjörður they are not further described here and they are not listed in the lists of landslide events in Eskifjörður in this report.

An avalanche and landslide chronicle for Eskifjörður was compiled by Kristín Ágústsdóttir *et al.* (2002).

2.3 Previous hazard assessments

In 1997 the Icelandic Meteorological Office made plans for emergency evacuations of several communities in Iceland. The plans included a division of the communities into evacuation zones and description of the conditions when the individual zones should be evacuated. Such a plan was made for Eskifjörður (IMO, 1997). According to the plan a considerable part of the settled area in Eskifjörður is a part of evacuation zones that need to be evacuated under extreme conditions.

After a final hazard map has been issued officially the evacuation plan will be revised to reflect the hazard zoning.

2.4 Climatic conditions

High mountains in the area and the cold ocean have a primary influence for the climatic conditions in Eskifjörður. The average temperature is about 4°C, the maximum recorded temperature is 25.5°C and the minimum 13°C. Temperatures as high as 28°C and as low as -17°C have been recorded at Kollaleira in Reyðarfjörður since measurements there started in 1977. Temperatures below zero have been observed during all months except August.

In the years 1992 and 1993 precipitation measurements were carried out in the eastern part of Eskifjörður, but at present the observations are located near the head of the fjord, where there is a local precipitation shadow. The yearly accumulated precipitation in Eskifjörður is lower than at Kollaleira and Neskaupsstaður, but the maximum accumulated daily precipitation of 103 mm, recorded on 8 September 1999, is as high as at the other stations.

The average wind speed in Eskifjörður is similar as in Seyðisfjörður, but higher than in Neskaupstaður and at Kollaleira. The most common wind directions are from northwest and southeast as excepted from the landscape. Winds from these directions are also the strongest. During the winter winds from northwest become more frequent, especially when the temparature is low (below 1°C). Wind direction during precipitation and temperature lower than 1°C are dominantly northwesterly, but occasionally northeasterly winds, *i.e.* in the direction of the aspect of the slope, are observed.

Snow cover and snow depth has not been recorded regularly in Eskifjörður.

Climatic data for Eskifjörður and neighbouring meteorological stations can be found in Appendix D. The climatic conditions in the eastern part of Iceland have also been described in previous hazard assessments for Neskaupstaður and Seyðisfjörður (Thorsteinn Arnalds *et al.*, 2001b, 2002).

Slushflows and wet avalanches are typically preceded by heavy rainfall on a thick snowcover during a thaw. The slushflows on 16 March 1919 are representative of this. Landslides and torrents are mostly associated to intense rainfall. The precipitation has been observed to be more than 100 mm in 1–2 days during landslide cycles in Eskifjörður and Reyðarfjörður. Conditions that lead to avalanche hazard below Harðskafi and Ófeigsfjall are probably similar to the most hazardous avalanche conditions in Neskaupstaður and Seyðisfjörður, *i.e.* strong northwesterly to northeasterly winds with heavy snowfall. Preceding the avalanches released in Harðskafi in April 1999 there were strong northerly winds with intense snowdrift, accumulating snow in the starting areas.

The weather preceeding avalanches and landslides in Eskifjörður is described in the reports by Kristín Ágústsdóttir *et al.* (2002), NGI (2002) and Esther H. Jensen and Thomas Sönser (2002b).

2.5 Snow depth measurements in starting areas

Three stakes for monitoring of snow depth in the hillside above Eskifjörður were installed in the winter 1997/1998 (Map 3). The stakes are 3.0 m high. Two of the stakes are located in Harðskafi at 450 to 550 m a.s.l. and one is located at 250 m a.s.l. near Bleiksá. Stakes have also temporarily been installed at other locations in the lower parts of the hillside. The stakes in Harðskafi have repeatedly been taken by avalanches or fallen due to rockfall or other causes. The lowest stake has also been lost several times and the lower part of the slope has, furthermore, been almost snow free in the winters since the start of the measurements. Few stake readings have been taken and the measurements are therefore of limited value.

The stakes in Harðskafi have several times been buried by snow, indicating great snow depths in the starting zones labelled 1–4 on Map 3. Snow profiles taken in the fracture line of slab avalanches released from Harðskafi in April 1999 confirm a very great snow depth in this part of the mountain. A total vertical snow depth exceeding 5 m was then observed at several locations in and to the west of starting area 1. These starting areas are adjacent to a large catchment area for snowdrift and may, therefore, be expected to collect large amounts of snow in a short time in strong NW–NE winds. Enough snow to form a 1.5–3 m thick slab avalanche (measured perpendicular to the slope) was observed to accumulate in less than 3 days between 13/14 and 16/17 April 1999. The starting areas in Harðskafi extend over a comparatively narrow altitude range ($\simeq$100 m vertically). They will, therefore, not collect as much volume of snow pr. unit width as the large bowl shaped starting areas with a similar aspect in Neskaupstaður and Seyðisfjörður that cover an altitude range of several hundred metres.

The catchment area near the starting areas 5–7 in Ófeigsfjall (Map 3) is not as large as the catchment area above Harðskafi. Nevertheless, large snow depths have been observed below the rockbands of this mountain (Hjalti Sigurðsson, personal communication). In spite of the limited observations, it may in general be assumed that snowdepth in bowls and areas favourable for accumulation of drift snow in the upper part of the mountains above Eskifjörður may become as large as in areas with the largest observed snow depth in Neskaupstaður and Seyðisfjörður (see Thorsteinn Arnalds *et al.*, 2001b, and Thorsteinn Arnalds *et al.*, 2002).

Snow depth at lowland stations in the area has been analysed by Kristján Jónasson and Trausti Jónsson (1997).

2.6 Debris flow hazard and rockfall

The current Icelandic regulation on hazard zoning requires the same criteria to be used for debris flow/rockfall hazard zoning as for avalanche hazard zoning, *i.e.* individual risk. Furthermore, the combined risk should be presented on one map. Therefore, landslide hazard zoning should be done in combination with snow avalanche hazard zoning.

A debris flow chronicle for Eskifjörður has been compiled (Kristín Ágústsdóttir, 2002) and a geological study has been conducted to evaluate the debris flow activity and potential (Esther H. Jensen and Thomas Sönser, 2002b).

2.7 Flood waves

Landslides and avalanches, released in Hólmatindur, can start a flood wave that would hit the coast below the settlement in Eskifjörður. The risk due to such events is considered to be negligible and taking it into account would not significantly alter the hazard zoning. In spite of this it may be feasible to take actions to prevent property damage due to such flood waves at some locations within the village.

Figure 2. *Eskifjörður and the names of main landmarks. (Photo: Esther H. Jensen).*

3 Avalanche hazard

3.1 Harðskafi

Harðskafi rises above the most recent part of settlement. The slope is not very steep and most of it inclines much less than 30°. Between about 500–600 m a.s.l. there is a rockband with inclination higher than 30°. The area can be seen on Figure 2, Maps 1 and 3, and longitudinal sections (`esin03aa` and `esin06aa`) are shown in Drawings 1–2.

3.1.1 Topographic description

Starting area

Map 3 shows four areas in Harðskafi, labelled 1–4 that are considered to be potential starting areas for dry slab avalanches. In addition area 8 in the lower part of the slope is considered a potential starting zone. The aspect of the starting areas is south.

Area 1 consists of a gully and a shallow depression interrupted by a cliff wall. It starts at 460 m a.s.l. and reaches up to 600 m a.s.l. in the gully and about 580 m a.s.l. in the depression. The area is on average about 150 m wide and 3.5 ha in total. The average inclination is 41°. The surface of the area is similar to area 2 described below.

Area 2 is located between 460 up to 560 m a.s.l. Above it there is about a 30 m high rockband.

The area is 300 m wide and about 5.6 ha. The average inclination is 41°. The lower part up to 520 m a.s.l. is scree and above that there are terraced cliffs. The lower part of the area is partly covered with vegetation.

Area 3 is a gully in the upper part. The gully is about 100 m wide and reaches from about 615 down to 560 m a.s.l. The starting area continues below the gully down to about 500 m a.s.l. The average inclination is 36° and the total area is about 2 ha. The surface is a combination of rocks and scree with hardly any vegetation. The roughness according to the Swiss guidelines is about 1–2.

One further starting area, no. 4, was delineated east of the gully. It is 240 m wide and reaches from 535 to 615 m a.s.l. The area is about 2.5 ha.

Lower down in the slope a small starting area was delineated at about 120–140 m a.s.l. This is mainly done for experimental purposes with the two-dimensional SAMOS avalanche model. This area is about 1.7 ha.

Track

Starting area no. 4 is not considered to threaten the houses below, since avalanches released in the are would stop on the plateau below. The track below starting area 4 is thus not described here.

The tracks of starting areas 2 and 3 start at about 460 m a.s.l. and reach down to the β-line at about 20–30 m a.s.l. The inclination of the track is mostly between 15 and 20°. The track is unconfined although it is slightly concave in the middle part. In the upper part the track is grassy and in the lower part there are low bushes. In the lower part there are some small channels.

The track of starting area 1 is similar to that of the outer two, except that it has a plateau with an inclination of about 9° between 385 and 410 m a.s.l.

Runout area

The runout area starts by the β-line at about 20–30 m a.s.l. and goes down to the bottom of the valley which is near sea level. In the highest part of the runout area there is a sedimentary terrace interrupted by small depressions. There are several houses in the outer part of the area built in the 1980's and 1990's.

3.1.2 Climatic conditions

Above the starting zones to the north there is a wide, relatively flat area. It will act as a catchment area for snow drift during northerly winds, which can accumulate snow below the mountainedge. As mentioned in a previous discussion very large snow depths have been observed in the starting zones in the past few years.

3.1.3 Chronicle

There are five dry avalanches recorded in the area. They all started in the upper part of the mountain and stopped a short distance below the starting zone. The avalanches fell in April 1999 and January 2002 and are listed in the table in Appendix B and shown on Map 2.

3.1.4 Assessment

Starting area 2 is considered to be the most hazardous for the settlement of the three investigated areas. The potential size of an avalanche released in the area is estimated to be in the size class of about 100 thousand m^3. Such an avalanche would be able to reach the settlement. The inner part of the investigated area is less hazardous, because the starting are is smaller and there is a plateau below the starting area, that will slow down and spread an avalanche. The fact that no avalanches are recorded down to where the settlement is located does not give much information since the area has only been settled for a short period.

3.1.5 Model estimates

Map 3 shows the results of model calculations and the profiles used for the calculations. The profiles `esin03aa` and `esin06aa` and the results of the calculations are shown in Drawings 1 and 2. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

An avalanche with runout of about $r = 14$ to $r = 15$ will reach the settlement.

The β-point is located close to the uppermost houses and avalanches with runout angle of about $\alpha + \sigma$ will reach the settlement.

The Austrian avalanche model SAMOS was applied to evaluate the direction of avalanches from the starting areas and the lateral extent of avalanches. The results are described by Tómas Jóhannesson *et al.* (2002). These results indicate that larger avalanches will not stop in the areas of the track with gentler inclination and will thus be able to reach the settlement.

3.2 Ófeigsfjall, inner part

3.2.1 Topographic description

Ófeigsfjall rises east of Ófeigsdalur up to about 680 m a.s.l. The area can be seen on Figure 2, Maps 1 and 3, and a longitudinal section (`esut02aa`) is shown in Drawing 3.

Starting area

The potential starting area is located in the rockband and the scree below, labelled 5 on Map 3. It is located between 680 and 520 m a.s.l. The average inclination is about 41°. The area is slightly concave. Its width is about 170 m and the area is about 4.4 ha.

The area faces SW. It is terraced by high rockbands in the upper part. In the lower part the area is a scree with some large rocks and hardly any vegetation. The roughness according to the Swiss guidelines is about 1 in the upper part and about 2.4 in the lower part.

Track

The track starts at about 520 m a.s.l. and reaches down to the β-point at about 10 m a.s.l. The inclination of the track is mostly between 15 and 20°. The track is unconfined and in the upper part it is generally convex with two small depressions. In the upper part the track is grassy and in the lower part there are low bushes. In the lowest part of the track there are some houses mostly built in the 1970's. In the lower part there are shallow channels.

Runout area

The runout area starts by the β-point at about 10 m a.s.l. and reaches down to the sea. It is settled and the oldest houses in the area are built early in the twentieth century.

3.2.2 Climatic conditions

Above the starting zone to the northeast there is a plateau. Snow accumulation in the starting zone may therefore be expected during north- and northeasterly winds. Snow could also be accumulated during easterly winds transporting snow over the ridge to the east of starting area no. 5.

3.2.3 Chronicle

There are no avalanches recorded in the area.

3.2.4 Assessment

According to the local snow observer Hjalti Sigurðsson most of the cliffs are covered by snow during the winter as in the area further to the west, see above. Therefore, it is thought to be possible that an avalanche will start in the whole area. Avalanches in the size class of 50–100 thousand m^3 are considered to be possible. The upper part of the track is convex and will therefore tend to spread avalanches that are released. Due to the spreading, a part of the avalanche will probably be deflected into the channel of Bleiksá so only a part of the avalanche will be able to reach the settlement below.

3.2.5 Model estimates

Map 3 shows the results of model calculations and the profiles used for the calculations. The profile `esut02aa` and the results of the calculations are shown in Drawing 3. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

An avalanche with runout of about $r = 13$ will reach the settlement.

The β-point is located below about three rows of houses. An avalanche with runout angle of $\alpha + \sigma$ will have a runout down to level ground below several rows of houses.

The Austrian avalanche model SAMOS was applied to evaluate the direction of avalanches from the starting areas and the lateral extent of avalanches. The results are described by Tómas Jóhannesson *et al.* (2002).

3.3 Ófeigsfjall - outer part

3.3.1 Topographic description

In the eastern slope of Ófeigsfjall two potential starting areas were investigated. The area can be seen on Figure 2, Maps 1 and 3, and longitudinal sections (`esut07aa`) is shown in Drawing 4.

Starting area

There are two potential starting areas located in the rockband and the loose debris below the rocks, labelled 6–7 on Map 3. They are located between 560 and 720 m a.s.l. The average inclination is about 38°. The inner area is a shallow bowl with two shallow depressions within it. Its width is about 250 m and the area is about 4.3 ha. The outer area is a gully about 120 m wide and 30 m deep with an area of about 3.8 ha.

The areas are facing S to SSE. The areas are terraced by high rockbands in the upper part. In the lower part there is a scree with some large rocks and hardly any vegetation. The roughness according to the Swiss guidelines is about 1 in the upper part and about 2.4 in the lower part.

Track

The track starts at about 560 m a.s.l. and reaches down to the β-point at about 10 m a.s.l. The inclination between 560 m a.s.l. and 440 m a.s.l. is 14–23°. From 440 m a.s.l. down to 420 a.s.l. there is about 150 m wide plateau with an average inclination of 8°. From the plateau down to about 340 m a.s.l. the average inclination is 13°. From there and down to the β-point at 10 m a.s.l. the inclination is 14–23°. The track is mostly unconfined and fairly straight although in the upper and eastern part there is a small gully. In the upper part the track is grassy and in the lower part there are low bushes. In the lowest part of the track there are some houses mostly built in the 1960's and 1970's. In the lower part there are some small channels.

Runout area

The runout area starts by the β-point at about 10 m a.s.l. and goes down to the sea. It is settled and the oldest houses in the area are built early in the twentieth century.

3.3.2 Climatic conditions

Above the starting areas to the north there is a plateau. It is favorable for snow accumulation during north and northwesterly winds. Preceding the avalanche in 1919 (see below) there had been periods with strong northerly wind which may have caused that avalanche. Snow could also be accumulated during westerly winds transporting snow over the ridge to the west of the inner starting area.

3.3.3 Chronicle

No dry avalanches are recorded in the area but in 1919 a wet avalanche or possibly a slushflow hit a stable killing livestock, see Appendix B.

3.3.4 Assessment

It is most probable that the avalanche in 1919 was a slushflow released lower down in the slope and the upper starting zones are not considered to be a likely release area of that avalanche. According to the local snow observer Hjalti Sigurðsson most of the cliffs are covered by snow during the winter. Therefore, avalanches extending over the whole of each of the two starting areas are considered to be possible. Avalanches in the size class of 50–100 thousand m^3 are considered to be possible. The upper part of the track is convex and will therefore tend to spread avalanches that are released. A part of the avalanche will probably be deflected into the small gully and the slight confinement caused by the gully may lead to a long runout of the avalanche below the gully.

3.3.5 Model estimates

Map 3 shows the results of model calculations and the profiles used for the calculations. The profile `esut07aa` and the results of the calculations are shown in Drawing 5. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

An avalanche with runout of about $r = 15$ will reach the sea.

The β-point is located close to main road below about two rows of houses. Avalanches with runout angle of about $\alpha + \sigma$ will reach the sea.

The Austrian avalanche model SAMOS was applied to evaluate the direction of avalanches from the starting areas and the lateral extent of avalanches. The results are described by Tómas Jóhannesson *et al.* (2002). These result indicate that even if a large avalanche starts in starting areas

6 and 7 almost all of it would be stopped by the plateau of Lambeyrardalur, although it cannot be ruled out that a part could reach the settlement.

3.4 Svartafjall/Svínaskálahlíð

3.4.1 Topographic description

Starting area

Two small bowls are considered to be potential starting areas. They are between 130 and 100 m a.s.l, labelled 20–21 on Map 3. The inclination is 30–32°. The outer gully is 70 m wide with an area of about 0.3 ha and the inner one 50 m wide with an area of about 0.3 ha. The aspect is S-SW. Both gullies are covered with low bushes and the surface is rather smooth with roughness of about 2 according to the Swiss guidelines.

Track and runout area

The track starts at 115 and 100 m a.s.l. for the outer and inner bowls, respectively. The two small gullies mark the track as shallow depressions down to about 40 m a.s.l. From about 100 down to 70 m a.s.l. the inclination is 15–20° and from 70 down to 30 m a.s.l. it is 10–15°. The inclination decreases gradually in the track which is unconfined.

The uppermost houses are around 30 m a.s.l. and the inclination from there and down to sea level is around 10°. The area is densely settled and a house at about 20 m a.s.l. was hit by an avalanche in 1919 while still under construction. Around that house there are quite a number of houses built before 1919.

3.4.2 Climatic conditions

To the north of the starting areas there is a plateau and to the northwest there is a ridge. The area is favourable for snow accumulation when wind is blowing along the fjord from NW to SE.

3.4.3 Chronicle

No dry avalanches are known in the area. In 1919 a slide caused damage to a house that was under construction. This was probably a slushflow.

3.4.4 Assessment

The potential size of an avalanche released in starting areas 20 and 21 is about 1–3,000 m^3. A bit higher in the mountain between 300 and 380 m a.s.l. there is another slope with inclination higher than 30° and a shape that could make it a potential starting area. Avalanches from this slope are not considered to threaten the settlement. The smaller bowl is a little bit steeper than the outer one and is considered to be more likely to be the starting area of an avalanche.

3.4.5 Model estimates

Map 3 shows the results of model calculations and the profiles used for the calculations. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

3.5 Other starting areas

In addition to starting areas delineated during field investigation several other areas were delineated based on inclination maps. This was mainly done for experimental purposes with the two-dimensional SAMOS model. Most of the areas are small and with an inclination that is barely high enough to allow for the release of dry snow avalanches. Others are located in such a way that they do not threaten the settlement. These areas are labelled 9–19 on Map 3.

3.6 Conclusion

The potential for snow accumulation in the starting areas in Harðskafi and the inner part of Ófeigsfjall are considered to be similar to the main starting areas in Neskaupstaður. The starting areas in Harðskafi are probably a little more favourable for snow accumulation than the areas in Ófeigsfjall.

The small size of the starting areas and the shape of the avalanche tracks will shorten the runout of avalanches compared to avalanches from the main starting areas in Neskaupstaður. Two-dimensional model calculations using the SAMOS model indicate that the runout of avalanches from Harðskafi and Ófeigsfjall may be about 2 runout indices shorter than avalanches from the main starting areas in Neskaupstaður with the same fracture depth.

The boundary of the category A hazard zone is set at about $r = 15$ below Harðskafi and at about $r = 14$ below the inner part of Ófeigsfjall. The risk due to avalanches below the outer part of Ófeigsfjall is considered to be insignificant. The same applies to the areas east of Ófeigsfjall.

The avalanche hazard due to avalanches released from Hólmatindur in the south side of the valley was briefly considered. It was decided that locating the boundary of the investigated area at about $r = 17$ would place it outside of hazard zones due to avalanches from Hólmatindur.

The uncertainty of the hazard zoning with regard to avalanches in Eskifjörður is considered to be medium to high (1–2).

4 Debris flows, rockfall, slushflows and torrents

Snow- and landslide hazard in Eskifjörður is to a large degree caused by debris flows, slushflows and torrents. Hazard zones with respect to slides other than dry and wet snow avalanches were delineated based on a landslide chronicle, geomorphological mapping of loose materials, an estimate of the volume of loose materials in potential source areas for debris flows, modelling of the volume of debris flows, and an estimate of extreme torrents in the watersheds of the mountainside.

4.1 General guidelines for the hazard zoning

Hazard zones in Iceland shall according to the hazard zoning regulation of July 2000 (Ministry for the Environment, 2000) take into account hazard due to debris flows and other landslides, rockfall and torrents in addition to snow avalanches and slushflows. Guidelines for hazard zoning with regard to such processes have been formulated by IMO (Tómas Jóhannesson and Kristján Ágústsson, 2002). The guidelines attempt to formulate a zoning procedure where the delineation of hazard zones reflects the risk that people are exposed to due to the respective events.

The principle problem encountered in this type of hazard zoning is how to treat the risk in areas where neither the landslide chronicle nor geological investigations directly indicate an impeding danger to the settlement. Another problem is the widely different probability of death for people that encounter the different types of events. It is, for example, clear that the torrents pose a much smaller risk to the lives of people than snow avalanches. Thus, the probability or return period corresponding to a set value of acceptable risk is widely different for the different events.

According to the guidelines, the landslide chronicle and geological investigations are first used to identify potential areas of high risk where the danger of catastrophic landslide events may be directly inferred from such investigations. The delineation of hazard zones with regard to the results of these investigations cannot be formulated beforehand and must be subjectively determined by the experts performing the zoning.

It is assumed that hazard zones with regard to *rockfall* will typically be of type A (the lowest risk zones), except in special circumstances where the danger of rockfall is judged very high. It is recommended that the hazard line with regard to rockfall is drawn where the return period of rockfalls is on the order of 50–100 years. This return period should reflect an area of the size of a building or a typical lot on which a building stands. This location may be estimated by a statistical or a dynamical rockfall model. The model should be calibrated to reproduce the runout distance corresponding to observed loose rocks below source areas of rockfall that have fallen during the last decades or century.

The avalanche chronicles of Eskifjörður and the nearby village Fáskrúðsfjörður indicate some danger of *slushflows and wet snow avalanches* from unconfined, relatively featureless mountainsides with slopes down to 20°. Under such circumstances, the guidelines generally recommend the delineation of hazard zone A down to level terrain below the slope.

The avalanche chronicles of Seyðisfjörður, Eskifjörður and Fáskrúðsfjörður also indicate that *slushflows and debris flows* pose a threat to human lives in essentially all paths of rivers and brooks in mountainsides with slopes higher than 10–20°. The guidelines propose the following classification of such paths.

1. **A well confined path of a river or a brook** such that a landslide may be expected to be largely limited to the course of the river. A less powerful part of it may overflow the banks and spread into nearby areas. The area of the watershed of paths in this class is on the order of 10–30 hectares up to and over 100 hectares and extreme floods may range from a few m^3/s up to tens of m^3/s.

2. **A partly confined path of a river or a brook** where landslides do not follow a predetermined direction and may take different directions when they enter the endangered area. The area of the watershed and the size of extreme floods is similar as in class 1.

3. **A gully or the path of a small brook** which may be dry for a part or most of the year. The watersheds of these paths are smaller than in the first two classes, *i.e.* on the order of a hectare or a few hectares, and extreme floods are on the order of a m^3/s or less.

The guidelines propose that type C hazard zones will in general be delineated for the centre parts of paths of class 1, type B hazard zones will be defined for the wide paths of type 2 and type A hazard zones in areas affected by paths of type 3. A delineation of watersheds and an estimation of extreme floods in the main rivers and brooks of the mountainside is recommended as a part of the preparation of a hazard zoning for paths of this kind.

In some areas there is a danger of *debris flows* outside of the courses of rivers or brooks that are classified above. Unless there are special indications of high danger, such debris flows are considered to be much less dangerous than snow avalanches. The guidelines propose that the hazard line with regard to debris flows in such areas corresponds to a return period of several hundred years, *i.e.* a much shorter return period than for snow avalanches but longer than for rockfall.

According to the guidelines, river floods should only be considered in steep paths where there is a danger of debris flows or slushflows. General river flooding problems are not to be considered as a part of the snow- and landslide hazard zoning according to the Icelandic hazard zoning regulation of July 2000.

Hazard zones in Eskifjörður were delineated on the basis of the ideas described above. In spite of these rough guidelines, much is left to the subjective judgement of the experts responsible for the hazard zoning. The final result is intended to reflect the risk that landslides pose to the local population in a nominal sense, but it can clearly not be considered to be the result of an exact statistical computation.

4.2 Geological investigations and investigations of slushflow hazard

A geomorphological mapping of loose materials and an investigation of landslide hazard in Eskifjörður was carried out by Esther H. Jensen and Thomas Sönser (2002b). Their report gives an

Table 2. *Accumulated precipitation over 1, 2, 3, and 5 day periods (P_{1d}, P_{2d}, P_{3d} og P_{5d}) with a return period T (1, 2, 5, 10, 20 og 50 years) at the meteorological station Kollaleira in Reyðarfjörður (station 635) for the time period 1976–1996.*

$\mathbf{T}$	$\mathbf{P_{1d}}$	$\mathbf{P_{2d}}$	$\mathbf{P_{3d}}$	$\mathbf{P_{5d}}$
1	60	87	102	124
2	72	105	123	146
5	87	129	151	176
10	98	146	172	198
20	110	164	192	220
50	124	187	220	249

overall description of the geology of the area, including a description of the main debris flow paths and an evaluation of the debris flow activity in each of them. The report also summarises the landslide chronicle of the village and nearby areas by Kristín Ágústsdóttir *et al.* (2002) and debris flow chronicles by Halldór G. Pétursson *et al.* at the Institute of Natural History at Akureyri (see the list of references in the report by Kristín Ágústsdóttir *et al.*). In addition to an overview investigation and mapping of the whole area, they investigated the paths Bleiksá, Grjótá and Lambeyrará in detail. They estimated the volume of loose materials in potential source areas for debris flows in these paths and modelled the volume of loose materials that might be released as debris flows under different conditions. The investigated conditions included short intensive precipitation events and prolonged precipitation periods that extend for several days.

Slushflow hazard in Eskifjörður was analysed by NGI (2002) and a map of the relative slushflow potential was drawn for the whole village. It was concluded that potential source areas for slushflows are located in both the lower and upper part of the hillside. The most destructive slushflows are expected to be released from the highest located basins when the whole length of the path has a well developed and water-soaked snow cover. The highest slushflow hazard is associated with the rivers Bleiksá, Grjótá and Lambeyrará and to a somewhat smaller degree with Ljósá and Hlíðarendaá. Some, but much lower, slushflow hazard is delineated along the small brooks flowing down the hillside west of Bleikslá, in Bleiksárhlíð and the hillside east of Hlíðarendaá. Weather conditions favourable for slushflow release are judged to be fairly common in Eskifjörður based on meteorological observations, occurring at least once each winter.

4.3 Extreme precipitation intensity

Extreme accumulated precipitation at Kollaleira in Reyðarfjörður and at Neskaupstaður in Norðfjörður over 1, 2, 3, and 5 day periods has been analysed by Tómas Jóhannesson (2000) and the results are given in Tables 2 and 3. These results and similar results from other meteorological stations in eastern Iceland were used by Esther H. Jensen and Thomas Sönser (2002b) in their analysis of debris flows and torrents from Bleiksá, Grjótá and Lambeyrará.

Table 3. *Accumulated precipitation over 1, 2, 3, and 5 day periods (P_{1d}, P_{2d}, P_{3d} og P_{5d}) with a return period T (1, 2, 5, 10, 20 og 50 years) at the meteorological station Neskaupstaður (station 625) for the time period 1975–1996.*

T	$\mathbf{P_{1d}}$	$\mathbf{P_{2d}}$	$\mathbf{P_{3d}}$	$\mathbf{P_{5d}}$
1	72	103	122	150
2	87	124	146	177
5	106	151	177	213
10	120	171	201	240
20	134	191	224	267
50	153	218	255	302

In an analysis of debris flows and torrents from small watersheds it is necessary to obtain an estimate of precipitation intensity on much shorter time-scales than one day, which is the shortest time window given in Tables 2 and 3. Maximum intensity over a time period T_c (in minutes) shorter than a day may according to Páll Bergþórsson (1968, 1977) be estimated by Wussov's formula as

$$I_{T_c} = I_{24h} \cdot (1/1440) \cdot \sqrt{T_c \cdot (2880 - T_c)}$$

where I_{24h} is the 24 hour intensity (in mm) with an appropriate recurrence interval, *e.g.* 50 or 100 years. The highest return period given in Table 2 is 50 years. The P_{1d} value corresponding to a return period of 100 years was estimated by Esther H. Jensen and Sönser (2002a) to be 172 mm for the meteorological station in Seyðisfjörður. The estimated extreme precipitation at Kollaleira is lower than at Seyðisfjörður, but the values for the station at Neskaupstaður are similar as in Seyðisfjörður. The lower value for Kollaleira does not need to be more representative for Eskifjörður than the values for Seyðisfjörður and Neskaupstaður. Therefore, it was decided to use the same value for the 100 year precipitation for Eskifjörður as was previously adopted for Seyðisfjörður, *i.e.* 172 mm.

4.4 Extreme torrents from the main watersheds

Extreme flood discharges were estimated for all the main watersheds of rivers and brooks in Eskifjörður in order to provide a comparison with the results of Esther H. Jensen and Sönser (2002b) for Bleiksá, Grjótá and Lambeyrará. This estimate was based on a methodology that is used by the Icelandic Public Roads Administration for the calculation of design floods for culverts and bridges for small watersheds (Helgi Jóhannesson, personal communication). According to this methodology, an extreme flood from a small catchment may be estimated as

$$Q_x = C \cdot I_{T_c} \cdot A$$

where Q_x (m^3/s) is the flood discharge, C is a runoff coefficient, I is the precipitation intensity over the time of concentration T_c for the catchment and A is the catchment area. The time of concentration T_c is estimated with the Kirpich equation

$$T_c = 0.0078 \cdot (3.28 \cdot \sqrt{l^3/h})^{0.770}$$

Table 4. *Runoff coefficients C for different types of catchments.*

Type of surface	C
Concrete and asphalt	0.75–0.95
Brick covered surfaces	0.70–0.80
Bare bedrock	0.60–0.80
Gravel roads	0.30–0.70
Cultivated fields	0.05–0.25
Meadows, parks	0.10–0.20
Forested areas	0.05–0.15

where l and h are the length and altitude range of the watershed, respectively. The value of the precipitation intensity over the time of concentration T_c was computed from Wussov's formula based on an estimate of the extreme precipitation with a return period of 100 years as described above.

The runoff coefficients C are roughly estimated from the guidelines given in Table 4. At the Icelandic Public Roads Administration, the value $C = 0.4$ is used for steep hillsides of the type encountered in Eskifjörður.

The runoff per unit area $q_x = Q_x/A$ in units of $\mathrm{m^3/s/km^2}$ is computed as a part of the flood discharge computations. This is often on the order of 10 $\mathrm{m^3/s/km^2}$ in computations of this kind in Iceland. Values much above 10 are sometimes considered "unrealistically high" based on subjective judgement and the limited available flood discharge measurements in small watersheds in Iceland.

Increase of precipitation with altitude in mountainous terrain is usually not explicitly taken into account in flood discharge computations of this kind. Snowmelt is also not considered although this may be expected to add some water to the floods if an extreme precipitation event occurs over snow covered terrain. The runoff coefficient may to some extent be considered an effective value taking such effects into account in a very rough way.

The above formulae were applied to five catchments in Eskifjörður, using a 100 year one day precipitation of 172 mm. The results are given in the Table 5.

The values of the runoff per unit area q_x are all approximately 10 $\mathrm{m^3/s/km^2}$. The resulting Q_x may, thus, be considered to be quite high values. They should nevertheless be, within a factor of 2, say, similar to flood discharge values that are used in engineering applications in similar watersheds in Iceland.

4.5 Conclusion

Based on the guidelines described above and the compilation of geological and hydrological information about the area, hazard zones of type C are delineated to the bottom of the valley or into the

Table 5. *Watersheds and extreme floods from the main watersheds in Eskifjörður. For each watershed the table specifies the length l (km), the surface area A (km^2), the altitude range h (m), the estimated extreme flood Q_x (m^3/s) and the runoff per unit area q_x (m^3/s/km^2).*

Gully/watershed	$\mathbf{l}$	$\mathbf{A}$	$\mathbf{h}$	$\mathbf{Q_x}$	$\mathbf{q_x}$
Bleiksá	3.7	4.3	907	42	10
Grjótá	3.4	2.3	884	24	10
Lambeyrará	3.3	1.8	800	19	10
Ljósá	3.4	1.7	748	17	10
Hlíðarendaá	2.9	1.0	690	11	11

ocean along the paths of the main rivers Bleiksá, Grjótá, Lambeyrará, Ljósá and Hlíðarendaá that all have watersheds around or considerably over 1 km^2.

A type B hazard zone is delineated at several locations to the sides of the category C hazard zones and along the small brooks flowing down the hillside west of Bleiksá, in Bleiksárhlíð and the hillside east of Hlíðarendaá. These brooks have much smaller watersheds than the abovementioned main rivers.

A type A hazard zone is delineated around the main rivers and down to the bottom of the slope west of Grjótá and east of Hlíðarendaá due to slushflow and debris flow hazard.

The uncertainty of the hazard zoning with regard to debris flows, slushflows, torrents and landslides in Eskifjörður is considered to be medium to high (1–2).

5 Conclusion

The risk due to large dry avalanches is relatively low in Eskifjörður. Houses have been built in areas where there is some avalanche hazard, but there is available space to develop new areas outside the boundaries of the hazard zones.

In addition to the avalanche hazard there is a significant risk due to debris flows, slushflows and torrents. Simple improvements, such as making the paths deeper and more confined and better design of infrastructure such as bridges, can improve the situation greatly.

References

Ágústsdóttir, Kristín. 2001. *Byggingarár húsa á Eskifirði. [Building years of houses in Eskifjörður.]* Náttúrustofa Austurlands, Rep. NA-37.

Ágústsdóttir, Kristín og starfsmenn snjóflóðavarna Veðurstofu Íslands. 2002. *Ofanflóð á Eskifirði. [Avalanches, debris flows, slushflows and torrents in Eskifjörður.]* IMO, Rep. 02012.

Arnalds, Thorsteinn, S. Sauermoser and Harpa Grímsdóttir. 2001a. *Hazard Zoning for Ísafjörður, Siglufjörður and Neskaupstaður — General Report.* IMO, Rep. 01009.

Arnalds, Thorsteinn, S. Sauermoser and Harpa Grímsdóttir. 2001b. *Hazard zoning for Neskaupstaður — Technical report.* IMO, Rep. 01010.

Arnalds, Thorsteinn, S. Sauermoser, Tómas Jóhannesson and Harpa Grímsdóttir. 2001c. *Hazard zoning for Siglufjörður — Technical report.* IMO, Rep. 01020.

Arnalds, Thorsteinn, S. Sauermoser, Tómas Jóhannesson and Esther H. Jensen. 2002. *Hazard zoning for Seyðisfjörður.* IMO, Rep. 02010.

Bergþórsson, Páll. 1968. Hvað getur úrfelli orðið mikið á Íslandi? [How intense can rainfall be in Iceland?] *Veðrið*, **13**(2), 52–58.

Bergþórsson, Páll. 1977. Aftakaúrkoma á Íslandi. [Extreme precipitation in Iceland.] *Veðrið*, **20**(2), 43–51.

Egilsson, Jón Gunnar. 1990. *Snjóflóð á Eskifirði. [Avalanches in Eskifjörður.]* IMO Rep. 1990.

IMO. 1997. *Greinargerð um snjóflóðaaðstæður vegna rýmingarkorts fyrir Eskifjörð. [Description of the avalanche situation in Eskifjörður in connection with an evacuation map for the town.]* IMO, Rep. VÍ-G97011-ÚR07.

Jensen, Esther H. and Thomas Sönser. 2002a. *Process orientated landslide hazard assessment for the south side of Seyðisfjörður.* IMO, Rep. 02003.

Jensen, Esther H. and Thomas Sönser. 2002b. *Process orientated landslide hazard assessment for Eskifjörður.* IMO, Rep. 02014.

Jóhannesson, Tómas. 1998a. *A topographical model for Icelandic avalanches.* IMO, Rep. VÍ-G98003-ÚR03.

Jóhannesson, Tómas. 1998b. Icelandic avalanche runout models compared with topographic models used in other countries. *In: 25 years of snow avalanche research.* Publikation nr. 203, Erik Hestnes, ed., p. 43–52, NGI, Oslo.

Jóhannesson, Tómas. 2000. *Return period of cumulative 1, 2, 3, and 5 day precipitation for several weather stations in Iceland.* IMO, Memo TóJ-2000/03.

Jóhannesson, Tómas and Kristján Ágústsson. 2002. *Hættumat vegna aurskriðna, grjóthruns, krapaflóða og aurblandaðra vatns- og krapaflóða í bröttum farvegum. [Hazard zoning for debris flows, rockfall, slushflows and torrents and slushflows mixed with soil in steep slopes.]* IMO, Memo TóJ/Kri-2002/01.

Jóhannesson, Tómas, Thorsteinn Arnalds and Leah Tracy. 2002. *Results of the 2D avalanche model SAMOS for Eskifjörður.* IMO, Rep. 02013.

Jónasson, Kristján and Trausti Jónsson. 1997. *Fimmtíu ára snjódýpt á Íslandi. [Estimated 50 year snow depth in Iceland.]* IMO, Rep. VÍ-G97025-ÚR20.

Jónasson, Kristján, Sven Þ. Sigurðsson and Thorsteinn Arnalds. 1999. *Estimation of Avalanche Risk.* IMO, Rep. VÍ-R99001-ÚR01.

Lied, K. and S. Bakkehøi. 1980. Empirical calculations of snow-avalanche run-out distance based on topographical parameters. *J. Glaciol.*, **26**(94), 165–177.

The Ministry for the Environment. 1997. *A letter concerning regulation on avalanche hazard zoning.*

The Ministry for the Environment. 2000. *Reglugerð nr. 505/2000 um hættumat vegna ofanflóða, flokkun og nýtingu hættusvæða og gerð bráðabirgðahættumats. [Regulation on hazard zoning due to snow- and landslides classification and utilisation of hazard zones and preparation of provisional hazard zoning.]* July 2000. *Available in an English translation.*

NGI. 2002. *Eskifjörður, Iceland. Interpretation of slushflow hazard.* NGI, Rep. 20011264-1. (Erik Hestnes author).

Perla, R., T. T. Cheng and D. M. McClung. 1980. A two-parameter model of snow-avalanche motion. *J. Glaciol.*, **26**(94), 197–207.

Sigurðsson, Sven, Kristján Jónasson and Thorsteinn Arnalds. 1997. Transferring Avalanches Between Paths. *In: 25 years of snow avalanche research.* Publikation nr. 203, Erik Hestnes, ed., p. 259–263, NGI, Oslo.

A Technical concepts and notation

α-angle: The slope of the line of sight from the stopping position of an avalanche to the top of the starting zone (see Figure 3).

β-angle: The slope of the line of sight, from the location in the avalanche path where the inclination of the slope is 10°, to the top of the starting zone (see Figure 3).

α/β-model: A topographical model used to predict avalanche runout or to transfer avalanches between paths. The model uses the β-angle to predict the α-angle of the longest recorded avalanche in a given path. The model was first derived by Lied and Bakkehøi (1980). The version of the model used in this project was derived by Tómas Jóhannesson (1998a, 1998b) using data on 45 Icelandic avalanches. The formula of the model is

$$\alpha = 0.85 \cdot \beta, \qquad \sigma = 2.2^\circ$$

where σ is standard deviation of the residuals from the model. It is customary to denote an avalanche with an α-angle $n\sigma$ lower than the predicted α- value as an avalanche with runout of $\alpha - n\sigma$ and conversely $\alpha + n\sigma$ if the α-angle is higher than given by the above equation. Note that as the α-angle is lower the runout is longer, and therefore $\alpha - \sigma$ corresponds to an avalanche with a longer runout distance than α.

PCM-model: A one-dimensional physical model used to simulate the flow of avalanches. The model has two parameters, μ, a Coulomb friction coefficient, and, M/D, an inverse drag coefficient. It was developed by Perla *et al*. (1980).

Runout index: The runout measured in hectometers of an avalanche that has been *transferred* (Sven Sigurðsson *et al*., 1997) to the *standard path* making use of some transfer method. The runout index is in this report is obtained by using the PCM-model with parameters lying on a predefined parameter axis. An avalanche that has a runout index of r_0 is referred to as an avalanche with $r = r_0$. The method was developed by Kristján Jónasson *et al*. (1999).

$F_{r_0}(F_{13})$: The expected frequency of avalanches with a runout index greater or equal than r_0. The value F_{13} is most often used, *i.e.* the frequency at the runout index $r_0 = 13$.

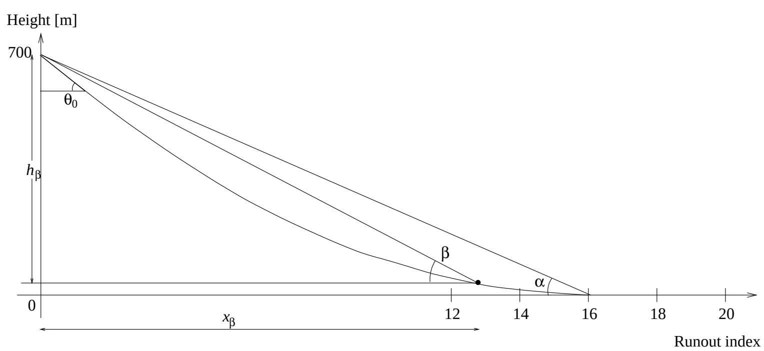


Figure 3. *The standard path. The α-angle is the expected runout angle of an avalanche according to the α/β-model.*

B Chronicle

The following table lists all recorded avalanches, torrents, slushflows and landslides in Eskifjörður. These are also shown on Map 2.

Number Time *Runout index*	**Description**
8502 early 19th century	A watermill a little to the west of Grjótá was destroyed by a large torrent shortly after 1805.
8503 21.11.1849	The river Grjótá was blocked at about 100 m a.s.l. A slushflow was released and hit the domestic house Klofi. It killed three persons. The slush and debris stopped at about 25 m a.s.l.
8504 23.2.1904	A slushflow hit the domestic house Lambeyri which was the residence of the sherrif Túlinius. It destroyed food and hay. The deposit ended at about 10 m a.s.l.
8505 1904–1906	A torrent in a brook by the farm Eskifjörður west of the current village.
8509 16.3.1919	A slushflow demolished a barn, fish drying rack and a cow shed in Framkaupstaður. These were the property of the tradesman Friðgeir Hallgrímsson. Two cows, a calf and two sheep were killed but one cow was rescued. The slushflow caused considerable other damage. The houses that were destroyed were located about where Strandgata 33 is presently.
8510 16.3.1919	A slushflow hit a domestic house owned by the tradesman Wilhelm Jensen. It caused considerable damage. The house that the slush flow hit is probably Hlíðarendavegur 1b or possibly Strandgata 92.
8512 summer of 1930	A torrent in Grjótá damaged fish drying racks and perhaps some fish in Útkaupstaður.
8514 16.9.1935	A torrent came from Grjótá. The river was diverted back to the river course and little damage was caused.
8515 16.9.1935	Debris flows caused severe damage. A 40–60 m wide debris flow in the easternmost part of the settlement in the vicinity of Hlíðarendi destroyed two valuable fields. The fields are believed to have stood where there now is Standgata 87A.

Number Time *Runout index*	**Description**
8517 29.6.1940	Torrents flowed from all the streams above the settlement. Water filled the basement of Landsbanki. The bridge over Eskifjarðará was taken by a flood and damage was caused to the dam for the Ljósá power station. The torrent caused damage to fields (including Bleiksártún and Lambeyrartún) and some vegetable gardens. Some fish drying racks were damaged. Extensive damage was caused to streets and other infrastructure. Some domestic houses were damaged. The maximum depth of the debris deposit was about 2 m.
8570 29.6.1940	A flashflood in Bleiksá damaged fields and the bridge over Eskifjarðará.
8571 29.6.1940	A flashflood in Grjótá damaged fish drying fields and flooded some buildings.
8572 29.6.1940	A flashflood in Lambeyrará damaged fields and flooded some buildings.
8573 29.6.1940	A flashflood in Ljósá damaged a dam at the power station.
8518 1941	A debris flow fell in the valley west of Eskifjörður.
8519 19/20.1.1942	Two British soldiers were killed in Háamelur between Stekklækur and Innrilækur in the valley west of Eskifjörður. It is assumed that they were caught by a debris flow.
8520 6/7.8.1946	A machine workshop was damage by flooding in Grjótá. The carpenters workshop of Guðni Jónsson at Strandgata 77 was also flooded. Damage was caused to the house as well as to tools and products in the house. Potato and tree plots were covered with mud and rocks. The rivers causing most trouble were Grjótá, Lambeyrará and Ljósá. About sixty people that were living closest to Grjótá fled from their homes.
8574 6/7.8.1946	A flashflood in Bleiksá overflowed the road.
8575 6/7.8.1946	A flashflood in Grjótá caused damage.
8576 6/7.8.1946	A flashflood in Lambeyrará damaged roads and buildings.
8577 6/7.8.1946	A flashflood in Ljósá damaged roads and buildings.
8551 20th century	Torrents in the small brooks in Bleiksárhlíð often cause damage to the roads in this part of the village.

Number Time *Runout index*	**Description**
8522 19.8.1950	Many rivers were flooded. People living closest to Grjótá fled from their homes but only one house was flooded. Some damage was caused to roads in the western part of the settlement.
8524 25/26.9.1959	A flashflood in Bleiksá damaged a bridge.
8526 27/28.10.1972	Debris flows are recorded in several rivers. A recently built road above the inner part of the settlement was torn apart in several places. Culverts were blocked and as a consequence roads were flooded. A debris flow hit an old warehouse and caused some damage. A lot of mud accumulated at the carpentry shop at Strandgata 77. The torrents also swept the earth away from a recently built house in Bleiksárhlíð.
8552 1974	A brook in Bleiksárhlíð damaged a road.
8528 25.9.1981	A debris flow fell in Lambeyrará. It started at about 400 m a.s.l. and blocked the river at about 75 m a.s.l. Considerable damage was caused to gardens and houses. Water and mud flooded the basement of Lambeyrarbraut 12 and the basement of the elementary school was flooded by water. The total bolume of the deposit in the settlement was estimated at 700–1200 m^3.
8529 apr 1988	A slushflow fell near the farm Eskifjörður. No damage.
8530 8.8.1988	A debris flow started in a newly built road up to Oddsskarð. It ran about 100 m down the slope and stopped 200–300 m above the houses in Svínaskálahlíð. Mud and water flowed into the house at Hlíðarendavegur 4b.
8531 18.10.1996	A small debris flow fell to the west of Grjótá and stopped several hundreds of meters above the middle of the settlement. It caused no damage.
8532 7.1.1998	A debris flow fell between Lambeyrará and Ljósá above the road up to Oddsskarð.
8533 13/14.4.1999 *12.6*	A dry slab avalanche was released in Harðskafi.
8535 16/17.4.1999 *14.0*	A dry slab avalanche was released in Harðskafi (westernmost tongue).
8536 16/17.4.1999 *12.6*	A dry slab avalanche was released in Harðskafi (center tongue).

Number Time *Runout index*	**Description**
8537 16/17.4.1999 *11.2*	A dry slab avalanche was released in Harðskafi (easternmost tongue).
8568 2–3.2.2002 *7.6*	A dry slab avalanche was released from Harðskafi.

C Maps

Map 1. An overview of Eskifjörður and the boundary of the investigated area (A4, 1:25 000).

Map 2. Recorded avalanches, slushflows, torrents and debris flows (A3, 1:10 000).

Map 3. Results of model estimates (A3, 1:15 000).

Map 4. Proposed hazard zoning for the investigated area (A3, 1:10 000).

D Climatic data

Summary statistics: Temperature and wind

The following abbreviations are used:

t: temperature (°C), **tx:** maximum temperature (°C), **tn:** minimum temperature (°C),
f: wind speed (m/s), **fx:** maximum wind speed, **fg:** gust speed (m/s), **r:** precipitation, **rx:** maximum 24 hour precipitation, **avg:** average, **AWS:** Automatic weather station.

Eskifjörður (AWS), no. 5981, 2 m a.s.l., 65°04'N 14°02'W (1999–2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	1.4	−0.4	−1.1	0.7	5.6	7.1	9.8	9.7	8.0	5.6	1.8	0.6	**4.1**
max(tx)	18.4	13.8	18.8	12.5	16.7	18.2	26.4	22.2	16.7	14.3	21.4	13.3	**26.4**
min(tn)	−11.9	−12.0	−11.5	−9.9	−3.2	−1.7	1.5	0.8	−1.7	−5.3	−10.1	−12.1	**−12.1**
avg(f)	5.5	6.9	5.6	4.8	4.2	4.3	3.4	3.1	4.2	4.4	5.3	5.6	**4.8**
max(fx)	26.6	23.7	32.3	23.5	23.7	22.3	16.1	14.8	18.7	17.4	22.2	22.2	**32.3**
max(fg)	39.5	33.4	38.9	31.3	35.5	29.0	23.5	22.7	35.8	25.1	41.9	30.5	**41.9**

Neskaupstaður (AWS), no. 5990, 50 m a.s.l., 65°10´N 13°40'W (1999–2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	1.6	−0.2	−1.0	0.7	6.1	7.4	10.3	10.0	8.2	5.7	2.4	0.7	**4.3**
max(tx)	17.0	12.4	15.6	13.9	20.4	23.5	25.5	21.9	19.3	15.2	20.8	15.1	**25.5**
min(tn)	−11.1	−12.2	−11.3	−10.1	−2.8	−0.3	0.0	2.0	−0.7	−5.0	−10.5	−13.1	**−13.1**
avg(f)	4.6	5.1	4.1	3.1	2.8	2.9	2.6	2.7	3.2	3.6	4.0	4.2	**3.6**
max(fx)	26.8	25.1	21.9	15.4	13.3	15.5	10.1	14.6	18.1	16.4	23.2	18.7	**26.8**
max(fg)	47.8	41.4	43.8	32.2	31.1	29.6	18.5	22.0	28.2	32.9	41.0	43.1	**47.8**

Seyðisfjörður (AWS), no. 4180, 92 m a.s.l., 65°16'N 14°00'W (1999–2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	1.0	−0.8	−1.9	−0.1	5.7	7.2	10.2	9.8	7.9	5.1	1.9	0.2	**3.9**
max(tx)	14.6	12.5	15.8	13.8	19.6	20.9	24.8	21.7	20.3	16.6	21.4	15.8	**24.8**
min(tn)	−11.4	−12.9	−13.0	−11.7	−3.8	−1.2	2.9	4.1	−0.1	−6.5	−10.0	−14.9	**−14.9**
avg(f)	5.7	6.7	5.2	3.7	3.7	3.8	3.1	2.8	3.8	3.7	5.0	5.4	**4.4**
max(fx)	23.3	22.6	28.5	21.3	22.0	20.7	15.8	19.8	20.0	18.1	24.1	20.5	**28.5**
max(fg)	40.4	39.6	43.7	49.7	46.8	37.4	25.9	27.8	30.1	34.3	42.1	44.7	**49.7**

Kollaleira (synoptic station), no. 635, 42 m a.s.l., 65°02'N 14°14'W (1977–2002)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	−0.6	−0.5	−0.5	1.4	5.1	8.1	9.9	9.6	6.9	3.7	1.1	−0.1	**3.8**
max(tx)	16.8	12.8	14.6	17.6	23.0	27.1	28.9	26.0	23.5	20.9	18.7	15.6	**28.9**
min(tn)	−17.1	−14.9	−17.1	−11.7	−7.6	−2.9	−0.2	0.6	−4.5	−8.7	−11.6	−15.1	**−17.1**
avg(f)	3.4	3.4	3.3	2.8	2.4	2.3	2.1	2.0	2.5	2.5	2.7	3.2	**2.8**

Precipitation

Eskifjörður, accumulated monthly precipitation (mm)

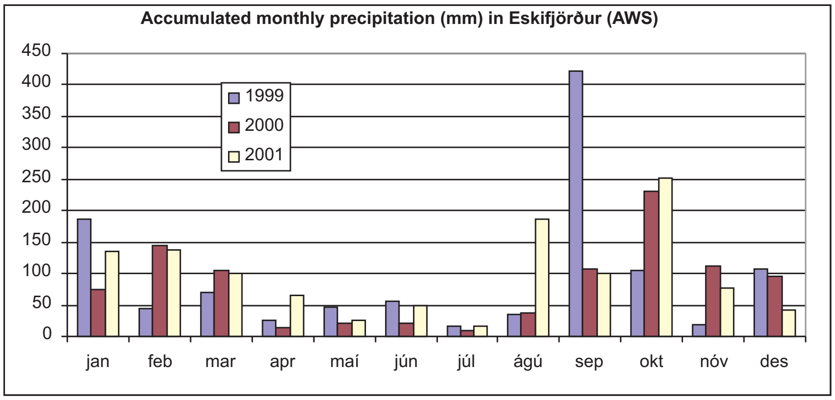
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1989											59.4	1.8	
1990	330.5	243.6	120.7	46.3	5.8		65.8	121.9	59.1	262.6	134.1	109.2	
1991	342.4	238.5	317.8	45.2	46.7	6.2	37.1	23.1	95.5	411.5	298.1	92.2	**1954.3**
1992	50.3	250.3	204.7	132.8	75.1	29.8	53.4	254.8	181.6	114.6	299.7	143.6	**1790.7**
1993	213.2	28.6	81.1	136.8	36.2								
Automatic weather station													
1998											279.6	225.4	
1999	186.7	43.4	69.7	26.5	45.9	55.8	16.7	34.2	422.2	105.7	19.8	106.3	**1132.9**
2000	74.6	144.2	103.9	14.7	21.7	19.9	8.3	36.3	106.7	230.3	111.6	95.6	**967.8**
2001	135.3	137.8	101.0	66.1	26.6	49.5	16.2	186.4	99.4	251.1	75.9	41.8	**1187.1**

Kollaleira, accumulated monthly precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1977	227.6	48.1	118.6	99.7	26.6	13.8	125.3	67.2	48.7	207.3	64.3	121.6	**1168.8**
1978	202.0	147.9	185.9	14.3	52.0	30.8	100.6	69.6	63.8	66.6	95.5	312.3	**1341.3**
1979	44.8	111.8	18.2	21.3	44.7	19.1	18.2	27.4	87.0	249.1	120.0	246.7	**1008.3**
1980	82.7	127.2	126.8	51.9	33.4	60.3	27.6	34.7	75.4	147.7	103.9	34.0	**905.6**
1981	55.1	188.5	138.3	56.2	40.5	30.5	17.7	77.5	248.6	124.6	139.3	88.7	**1205.5**
1982	158.2	213.3	142.4	19.5	51.8	15.4	58.8	80.2	83.0	262.8	119.2	171.9	**1376.5**
1983	91.8	35.8	106.7	32.3	33.1	61.0	30.8	44.6	47.2	205.7	60.0	127.9	**876.9**
1984	164.2	111.2	54.6	57.0	16.8	55.4	18.9	25.6	188.1	127.4	217.1	243.6	**1279.9**
1985	36.9	56.8	93.1	109.0	41.7	13.7	51.8	142.8	59.1	91.1	84.8	74.7	**855.5**
1986	140.8	51.2	263.3	187.8	97.0	29.3	32.5	26.7	38.5	112.4	163.1	216.4	**1359.0**
1987	91.2	106.5	135.2	61.9	17.2	23.4	105.6	18.5	234.9	117.6	111.8	96.3	**1120.1**
1988	157.7	93.9	35.0	34.0	99.0	14.7	74.3	190.4	140.8	97.8	93.0	51.4	**1082.0**
1989	185.4	137.6	155.0	158.2	100.8	47.6	57.0	147.2	152.4	139.9	84.9	114.9	**1480.9**
1990	235.4	127.4	98.5	52.4	7.6	44.1	67.2	85.5	122.3	245.9	131.6	120.8	**1338.7**
1991	288.6	197.8	196.0	113.1	53.7	7.6	26.1	31.3	108.1	266.6	240.9	99.8	**1629.6**
1992	32.9	260.4	160.6	115.2	55.5	37.0	50.0	196.5	237.8	137.5	240.1	103.7	**1627.2**
1993	233.2	70.8	146.0	179.3	87.9	185.9	48.1	48.0	40.6	28.2	548.2	188.3	**1804.5**
1994	216.2	289.5	98.0	40.2	65.7	59.9	85.5	134.6	59.1	79.8	197.1	274.5	**1600.1**
1995	255.6	82.9	78.4	20.2	48.8	170.5	36.4	49.8	35.0	197.4	35.3	180.4	**1190.7**
1996	184.6	187.9	120.5	185.8	27.0	67.8	49.4	82.2	120.9	332.9	59.1	115.8	**1533.9**
1997	93.5	135.0	120.4	61.0	4.5	95.2	95.9	156.3	122.0	111.8	245.1	202.1	**1442.8**
1998	280.2	76.9	76.0	48.7	12.7	50.3	39.7	47.0	181.2	89.1	384.5	224.3	**1510.6**
1999	242.8	55.3	107.3	41.0	51.8	50.9	17.9	26.0	405.0	158.4	29.5	164.8	**1350.7**
2000	56.3	211.8	224.7	22.1	37.1	17.3	10.3	43.8	159.0	322.6	133.3	108.9	**1347.2**
2001	231.6	143.8	149.5	106.0	42.2	67.0	22.9	223.3	100.0	238.6	88.4	88.2	**1501.5**
average	159.6	130.8	126.0	75.5	46.0	50.7	50.7	83.1	126.3	166.4	151.6	150.9	**1317.5**

Kollaleira, maximum daily accumulated precipitation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1977	87.3	13.5	29.1	42.4	17.2	9.2	95.6	20.5	21.0	28.9	21.9	29.1	**95.6**
1978	86.2	51.5	34.8	5.6	12.6	12.0	28.5	25.5	20.5	19.4	25.6	114.8	**114.8**
1979	21.0	36.6	7.2	5.1	14.6	3.4	4.5	13.0	32.1	45.5	34.5	43.3	**45.5**
1980	20.2	30.0	35.1	12.4	9.9	19.0	9.6	12.5	15.4	37.0	91.5	6.0	**91.5**
1981	26.3	52.7	29.6	37.5	12.0	16.6	3.9	21.0	37.5	32.2	29.8	31.1	**52.7**
1982	26.0	29.7	41.1	7.1	13.3	5.5	35.4	32.2	23.4	55.2	40.0	51.8	**55.2**
1983	33.5	12.7	41.1	8.5	15.0	33.5	7.8	14.1	11.2	32.0	17.5	38.1	**41.1**
1984	45.9	36.0	18.5	17.5	6.1	28.2	6.0	12.3	68.8	22.5	35.3	62.8	**68.8**
1985	8.6	10.1	25.7	40.3	9.8	3.0	10.4	42.7	13.6	43.1	19.4	12.6	**43.1**
1986	28.0	28.7	69.2	55.2	33.2	6.3	9.4	18.5	19.9	31.4	33.1	54.0	**69.2**
1987	32.0	44.7	29.9	29.9	6.8	7.3	27.1	6.1	61.2	23.3	35.1	43.2	**61.2**
1988	41.0	23.2	11.4	16.2	19.5	7.0	19.6	35.1	43.3	45.0	38.8	13.0	**45.0**
1989	43.7	32.2	31.9	48.9	36.1	27.9	22.9	31.0	38.7	39.6	22.1	31.5	**48.9**
1990	36.3	15.8	26.0	13.5	3.2	9.3	12.9	17.2	45.8	48.4	48.9	36.0	**48.9**
1991	70.9	51.4	38.4	59.4	18.4	5.0	6.5	6.6	29.1	94.9	52.9	35.0	**94.9**
1992	11.0	58.2	24.5	46.7	29.9	6.6	14.8	71.2	61.1	30.8	43.4	15.6	**71.2**
1993	51.3	31.7	50.3	46.6	22.3	69.7	10.5	15.3	22.9	8.2	71.0	64.1	**71.0**
1994	68.8	85.8	26.1	14.7	25.7	11.5	17.3	69.1	16.5	18.7	44.4	56.0	**85.8**
1995	39.9	25.8	46.0	6.0	19.5	75.9	10.7	15.5	20.6	30.5	10.3	53.6	**75.9**
1996	27.6	56.7	33.5	48.1	5.9	19.2	21.1	42.7	38.6	64.7	29.0	48.7	**64.7**
1997	41.4	37.5	24.0	28.6	1.5	29.5	25.0	37.0	71.4	40.4	29.8	112.1	**112.1**
1998	55.0	20.0	24.8	19.0	3.6	13.6	11.4	8.4	76.5	25.5	146.3	33.5	**146.3**
1999	38.9	11.5	55.3	16.4	16.2	23.8	5.1	9.1	88.2	34.5	7.0	29.1	**88.2**
2000	14.9	56.2	78.1	6.4	8.3	4.3	6.3	17.3	31.3	39.4	34.7	25.5	**78.1**
2001	66.4	35.6	45.7	41.2	15.4	34.9	6.8	80.1	74.8	52.5	25.1	30.3	**80.1**
maximum	87.3	85.8	78.1	59.4	36.1	75.9	95.6	80.1	88.2	94.9	146.3	114.8	**146.3**


Accumulated monthly precipitation (mm) in Eskifjörður (AWS)
450
400
350
300
250
200
150
100
50
0
1999
2000
2001
jan
feb
mar
apr
maí
jún
júl
ágú
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okt
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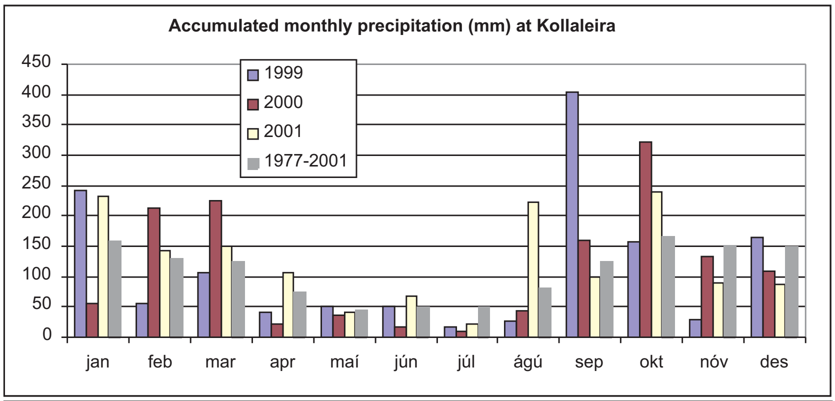
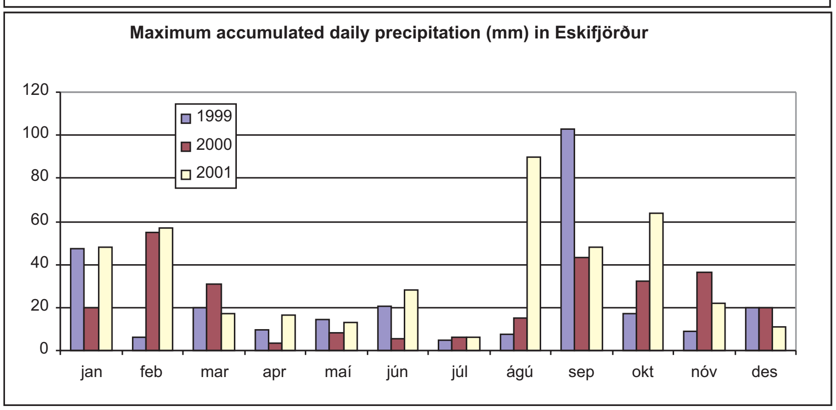
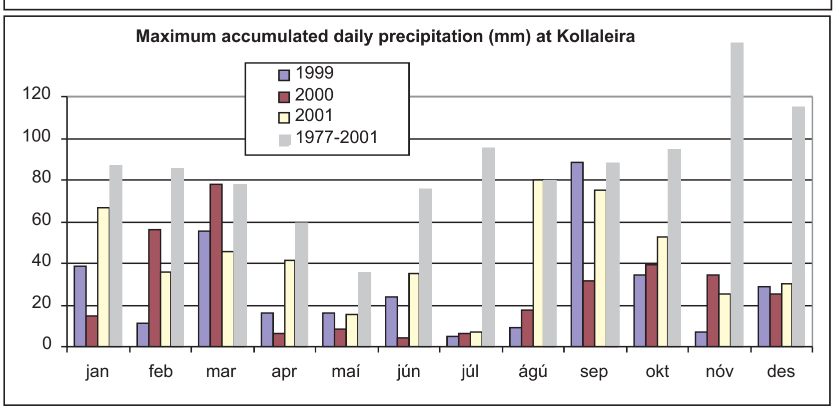
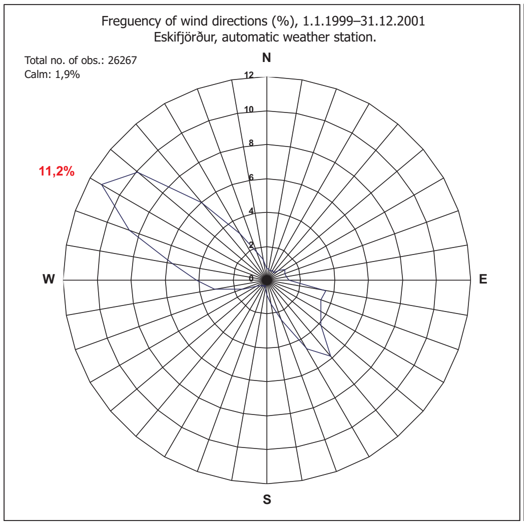
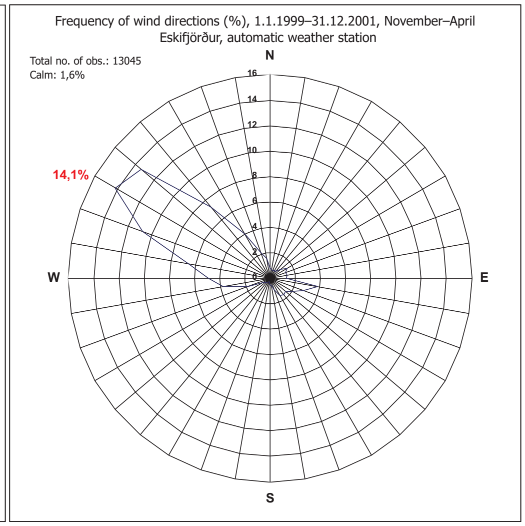

Accumulated monthly precipitation (mm) at Kollaleira
450
400
350
300
250
200
150
100
50
0
1999
2000
2001
1977-2001
jan
feb
mar
apr
maí
jún
júl
ágú
sep
okt
nóv
des

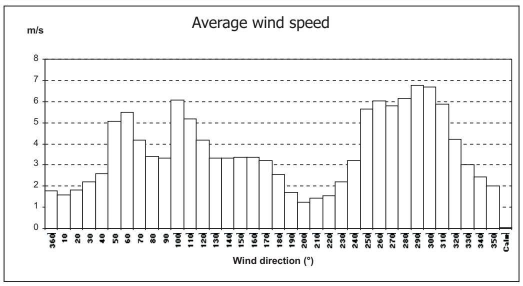

Maximum accumulated daily precipitation (mm) in Eskifjörður
120
100
80
60
40
20
0
1999
2000
2001
jan
feb
mar
apr
maí
jún
júl
ágú
sep
okt
nóv
des

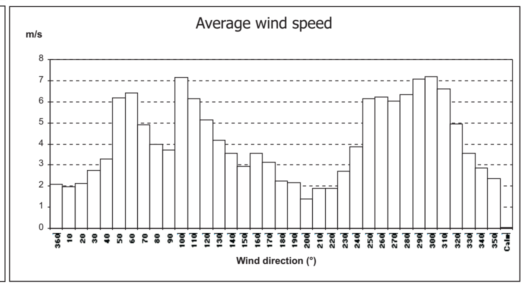

Maximum accumulated daily precipitation (mm) at Kollaleira
120
100
80
60
40
20
0
1999
2000
2001
1977-2001
jan
feb
mar
apr
maí
jún
júl
ágú
sep
okt
nóv
des

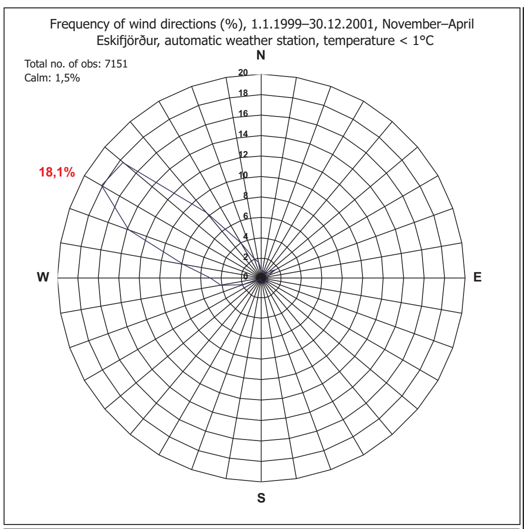
Wind roses

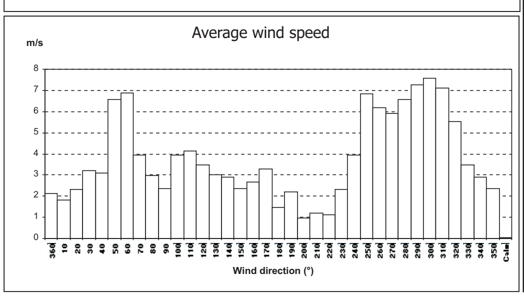

Frequency of wind directions (%), 1.1.1999–31.12.2001
Eskifjörður, automatic weather station.
Total no. of obs.: 26267
Calm: 1,9%
11,2%
N
W
E
S

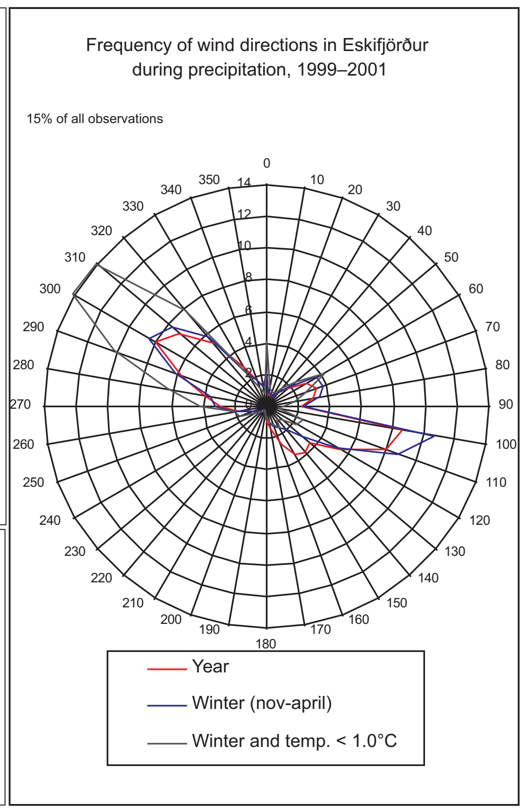

Frequency of wind directions (%), 1.1.1999–31.12.2001, November–April
Eskifjörður, automatic weather station
Total no. of obs.: 13045
Calm: 1,6%
14,1%
N
W
E
S


Average wind speed
m/s
Wind direction (°)


Average wind speed
m/s
Wind direction (°)


Frequency of wind directions (%), 1.1.1999–30.12.2001, November–April
Eskifjörður, automatic weather station, temperature < 1°C
Total no. of obs: 7151
Calm: 1,5%
18,1%
N
W
E
S


Average wind speed
m/s
Wind direction (°)


Frequency of wind directions in Eskifjörður
during precipitation, 1999–2001
15% of all observations
Year
Winter (nov-april)
Winter and temp. < 1.0°C

E Profile drawings

Drawing no.	Profile ID	Avalanche path
1	esin03aa	Harðskafi, upper starting area, east of settlement
2	esin06aa	Harðskafi, upper starting area, above Dalbarð
3	esut02aa	Ófeigsfjall, between Bleiksá and Grjótá, above Fagrahlíð
4	esut04aa	Bleiksárhlíð, between Bleiksá and Grjótá
5	esut07aa	Ófeigsfjall, between Bleiksá and Grjótá, above Bleiksárhlíð
6	esut08ba	West of Grjótá, lower starting area, above Tungustígur
7	esut10aa	East of Lambeyrará
8	esut12aa	Hlíðarendaá
9	esut13aa	East of Hlíðarendaá, above Svínaskálahlíð
10	esht03aa	Hólmatindur