S-637

VEÐURSTOFA ÍSLANDS

Report
01020

Þorsteinn Arnalds
Siegfried Sauermoser
Tómas Jóhannesson
Harpa Grímsdóttir

Hazard zoning for Siglufjörður

Technical report

VÍ-ÚR11
Reykjavík
December 2001

Report - Greinargerð
01020

Þorsteinn Arnalds
Siegfried Sauermoser
Tómas Jóhannesson
Harpa Grímsdóttir

Hazard zoning for Siglufjörður

Technical report

VÍ-ÚR11
Reykjavík
December 2001

Contents

1 Introduction

This report is an assessment of avalanche hazard in Siglufjörður and part of the final report for the project *Pilot Hazard Zoning for Ísafjörður, Siglufjörður and Neskaupstaður* (Tilraunahættumat fyrir Ísafjörð, Siglufjörð og Neskaupstað). In 1999 it was decided to make the pilot hazard maps a basis for the final hazard maps of the three communities.

General information about the project and necessary background information for this report are included in a separate report (Thorsteinn Arnalds *et al.*, 2001a). Among other things, it contains a short description of Icelandic and Austrian hazard zoning regulations and a discussion of uncertainty in the hazard evaluation. A technical report for Neskaupstaður was published in May 2001 (Thorsteinn Arnalds *et al.*, 2001b).

The investigated area reaches from Jörundarskál in the south to an unnamed gully to the north of the settlement. The area is shown in Map 1.

The report is split into ten main sections. The first part is general and contains an overview of topographic and climatic conditions, a summarised avalanche chronicle, a review of previous hazard maps and discussion of debris flow hazard. The next eight sections deal with each of the main avalanche paths above the settlement. For each of these areas the following is described.

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

Assessment: Discussion of avalanche conditions and qualitative hazard analysis.

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.

2 General

2.1 Topographic description

The village Siglufjörður is located on the west side of the fjord Siglufjörður, see Map 1 and Figure 1. The oldest part of the settlement is on the promontory Þormóðseyri, but more recent parts of it extend towards the hillside above the promontory and to the north and south of it.

Siglufjörður opens towards the north and is surrounded by 600–900 m high mountains to the west, south and east. The northernmost mountain on the western side is called Strákar. To the south of Strákar is Hvanneyrarhnjúkur, more than 600 m high, and to the east of Hvanneyrarhnjúkur is the mountain Gróuskarðshnjúkur rising above the northernmost part of the settlement. The bowl Hvanneyrarskál separates Gróuskarðshnjúkur from Hafnarhyrna to the south. Hvanneyrarskál is a large bowl or a valley at about 200 m a.s.l. The top of Hafnarhyrna is at 687 m a.s.l. and rises above Þormóðseyri. To the south from Hafnarhyrna are the mountains Hafnarfjall and Snókur. The valley Skarðdalur extending from Siglufjörður towards southwest cuts the mountainous area between Snókur in the north and Leyningssúlur in the south. The current skiing area for Siglufjörður is located in Skarðdalur. To the south of Siglufjörður is the valley Hólsdalur between the mountains Leyningssúlur and Hólshyrna. East of the fjord is the valley Skútudalur. East of Siglufjörður and north of Skútudalur are the mountains Hestskarðshnjúkur and Staðarhólshnjúkur. Between these mountains is the bowl Skollaskál. A small valley, Kálfsdalur separates Staðarhólshnjúkur and Hinrikshnjúkur from the mountainous area to the east and north. To the north of Kálfsdalur area is steep scree, Nesskriður, down to the sea. The northernmost part of the mountain is called Nesnúpur. The ness Siglunes protrudes out into the opening of the fjord on the northeast.

Above the innermost part of the settlement is the bowl Jörundarskál and a little to the north are the gullies Syðra-Strengsgil and Ytra-Strengsgil. Two deflecting dams have been built recently to protect against avalanches starting in these gullies. To the north of Strengsgil, the potential starting areas are separated by the plateau Fífladalir. Above Fífladalir there is a gully that has been called "Grindagil" with reference to supporting structures that have been built there for experimental purposes. The gullies Skriðulækjargil are located below the southern boundary of Fífladalir and the gully Fífladalagil a little further to the north. Hafnarhyrna is marked by cliffs called Gimbraklettar at about 200 m a.s.l. just north of Hvanneyrarskál.

The town of Siglufjörður is on the land belonging to two farms from the early settlement of Iceland, Höfn and Hvanneyri. These were probably settled before the year 1000. Around 1790 two retailers started their businesses on Þormóðseyri. The houses of these retailers were for a long time the only houses in the area except for Höfn and Hvanneyri. Workers and fishermen built residential houses near the shore in the early part of the nineteenth century before herring fisheries started off the coast of north Iceland. Once the herring fisheries took off the settlement started to develop rapidly. After 1880 a small village started to form around the trading houses on Þormóðseyri.

The herring fisheries is commonly referred to as "Síldarævintýrið" (the herring adventure). In 1903 the Norwegians started to bring deep sea herring caught off the coast of north Iceland to Siglufjörður. In the first two decades of the twentieth century the population grew rapidly and

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

the progression of the town was fast. The increase in population continued until the middle of the century when the population was about 3000 people. Following the decline in the herring catchment the population of Siglufjörður has decreased gradually and inhabitants are presently about 1500.

The farms Höfn and Hvanneyri were on the opposite sides of Þormóðseyri. Neðri-Höfn, an annex, from Höfn was established by the sea south of Þormóðseyri in 1864. As stated previously the first retail facilities in Siglufjörður were built on Þormóðseyri and the village developed around these. The settlement developed towards the mountain above Þormóðseyri and towards south along the mountain. Factories and facilities for herring processing were established in numerous locations along the coastline. In the mid twentieth century the settlement started to develop more towards north and south and closer to the mountain. The first houses below Strengsgil were for instance built during that time. In the 1960's to 1980's the settlement developed further and many houses were built in the area below Strengsgil and most of the houses in Hólavegur and Fossvegur were built during that period.

Building years and names of houses in Siglufjörður have been documented in detail by Harpa Grímsdóttir (1998).

2.2 Chronicle

Map 2 shows recorded avalanches in Siglufjörður.

No lives have been lost due to avalanches in the present settlement of Siglufjörður. Several times accidents have been escaped narrowly and several times considerable damage has been caused to houses and other properties. The most active avalanche paths are Ytra-Strengsgil and Jörundarskál. The largest documented avalanches have been released from these paths above the southernmost part of the settlement. Three or four avalanches from these paths reached the shoreline in the beginning of the twentieth century. In other parts of the settlement smaller avalanches have struck, some of which have caused damage.

In 1938 several avalanches reached the settlement. One of these was released in Hafnarhyrna and caused damage to the house Seljaland. People staying there were rescued. Another avalanche hit hen houses at a similar location. The third avalanche fell below Fífladalir and piled snow against the uppermost houses in Skriðuhverfi.

In 1963 an avalanche started in Gróuskarðshnjúkur. It hit a hen house and damaged two domestic houses by Fossvegur.

In February 1968 an avalanche starting in Ytra-Strengsgil hit the house Suðurgata 76 causing extensive damage.

In 1971 an avalanche starting in the slope below Fífladalir flowed through the house Hlíðarvegur 1b. People staying there managed to free themselves from the deposit and escaped suffering only minor injuries. At the same time another avalanche (or part of the same avalanche) hit the cemetery and broke the uppermost rows of tombstones. The third avalanche (or part of the same) hit sheep sheds to the south of the cemetery. Several sheep sheds were destroyed and 75 sheep were killed. At the same time an avalanche started in the a gully immediately to the north of the settlement. That avalanche hit a summer house and a sheep shed, killing 12 sheep.

In December 1973 a large avalanche fell from Jörundarskál damaging the playschool Leikskálar and a hen house, killing 250 hens. The avalanche fell during the night so no persons were staying in Leikskálar.

In December 1974 an avalanche started in Ytra-Strengsgil. It caused damage to the houses Suðurgata 76 and 78. After this people did not stay there during the winter and they were referred to as the "avalanche houses" (snjóflóðahúsin).

In other locations within the fjord disasters have occured. In 1919 a large avalanche started in Skollaskál on the opposite side of the fjord. This avalanche destroyed a herring factory and four domestic houses. Sixteen people in total were staying in three of these houses. Nine died. The avalanche also started a floodwave that damaged boats and buildings at the harbour of Siglufjörður.

Before 1981 no systematic records were kept on avalanches in Siglufjörður. Existing records are therefore probably quite incomplete before this time, and mostly damage causing avalanches are recorded. The position of snow observer in Siglufjörður was established in 1981. Örlygur Kristfinnsson has held the position since then. Until 1995 he was employed jointly by the community of Siglufjörður and the Icelandic Meteorological Office (IMO) but after that he became a full time snow observer of the IMO. The snow observer is responsible to keep records on avalanches. This means that after 1981 most avalanches falling close to the settlement have been recorded and measured when possible.

An avalanche chronicle for Siglufjörður was compiled at the IMO by Harpa Grímsdóttir and Thorsteinn Sæmundsson (2001).

2.3 Previous hazard assessments

In 1975 the Icelandic Civil Defence hired M. R. de Quervain from the Swiss Avalanche Institute (SLF) to assess the avalanche hazard in Siglufjörður, Seyðisfjörður and Neskaupstaður (SLF, 1975) following the catastrophic avalanche accidents in Neskaupstaður in 1974. He analysed the hazard situation and discussed possible measures to increase the safety.

The first laws concerning avalanches and debris flows were issued in 1985. The §2 of the laws states: "Hazard assessment shall be performed in communities where avalanches and debris flows have fallen into the settlement or close to it. The hazard assessment shall both cover settled areas, as well as areas that are due to be planned. The hazard assessment shall be taken into consideration in the entire planning process and shall be attached to planning proposals." In §3 of the laws the Icelandic Civil Defence is responsible for specifying further guidelines and regulations on hazard zoning, classification of hazard zones and the construction of defence structures. It was also given the role of supervising the preparation of hazard maps.

In regulation 247/1988 on hazard zoning it was specified that a particular physical model should be used for hazard zoning and guidelines on how to apply it were given. The model was developed by Thorsteinn Jóhannesson at Verkfræðistofa Siglufjarðar sf. (VS, 1986). In the next few years hazard zoning was done in several villages by independent consultants, supervised by the Icelandic Civil Defense.

Árni Jónsson at Hnit hf. prepared a hazard map for Siglufjörður based on the regulation from 1988 (Hnit, 1989). The hazard map showed deliniation between a hazard area and a "safe" area as the regulation required, see Map 3. According to the map about a fifth of the domestic houses in Siglufjörður were within the hazard zone. In 1990 the Icelandic Civil Defense made a recommendation, to the local authorities in Siglufjörður and the Ministry of Social Affairs, that the approval of the assessment by the ministry should be postponed. This was done since the regulation on hazard zoning was under revision at that time. In 1992 the local authorities requested that the Minister of Social Affairs would not approve the assessment before it had been revised.

In 1996 the Icelandic Meteorological Office made plans for emergency evacuations of several communities in Iceland. The plans included a division of the communities into subareas and description of under which conditions each subarea should be evacuated. Such a plan was made for Siglufjörður (IMO, 1996) and revised in 1997. According to the plan a large proportion of the settled area in Siglufjörður is a part of evacuation zones that need to be evacuated under extreme conditions. The evacuation plans have not been revised after the deflecting dams below Jörundarskál and Strengsgil were built.

A pilot project for testing the feasibility of supporting structures for avalanche protection in Iceland and for obtaining data which will be used to define an optimal setup of such structures under Icelandic conditions has been implemented in the gully Grindagil above Fífladalir. About 200 m of supporting structures, both stiff steel constructions and snow nets, were installed in 1996 for experimental purposes. The project was financed by the Icelandic Avalanche Fund. The results of the experiment have been used to formulate guidelines for the design of supporting structures for Icelandic conditions (Tómas Jóhannesson and Stefan Margreth, 1999).

Deflecting dams in the south of Siglufjörður were designed by Verkfræðistofa Siglufjarðar (VS) in cooperation with the Norwegian Geotechnical Institute (NGI) (VS and NGI, 1997). Furthermore Stefan Margreth (1997) estimated velocities of avalanches hitting the dams to assist in the design.

In 2001 the SLF evaluated avalanche defence measures in the unprotected parts of Siglufjörður north of Strengsgil. Proposals were made for several areas and actions prioritised based on the situation in each area (SLF, 2001).

2.4 Climatic conditions

Climatic conditions in Siglufjörður are different from the climatic conditions in most other parts of Iceland. This is mainly caused by the local landscape, i.e. a fjord that is surrounded by high mountains to the east, south and west, but opens towards open sea in the north. Climatic data for Siglufjörður and neighbouring meteorological stations can be found in Appendix C.

The meteorological station in the neighbourhood of Siglufjörður with the longest rocord was located on the eastern coast of the fjord, at Siglunes and Reyðará, in the period 1968–1988. The distance between the two locations is only 2 km and therefore a distinction is not made between observations at these two stations. Since 1995 automatic weather stations have been operated at Siglunes, Siglufjörður and by Siglufjarðarvegur (the road between Siglufjörður and Skagafjörður). Since 1990 synoptic observations have been carried out at Sauðanesviti, which is the only station in the area where present weather is observed. In addition several stations close to Siglufjörður record precipitation and snow depth. These are Skeiðsfoss in Fljót, Kálfsárkot in Ólafsfjörður and Tjörn in Svarfaðardalur. The manual observations of precipitation in Siglufjörður were replaced by an automatic precipitation recorder in 1995. The location of these stations is shown in Figure 1.

Measured wind speed is lower in Siglufjörður than at other locations on the Tröllaskagi peninsula and there is more difference between winter and summer temperature. The average temperature in Siglufjörður is about 3.2°C (see App. C.1). The winter is colder in Siglufjörður than at other observation sites in the area, but it is comparatively warmer there during the summer. In 1995–2001 it was significantly colder during winter in Siglufjörður than at Siglunes and by Siglufjarðarvegur, but the temperature difference is smaller during the summer. There are often favourable conditions for Föhn winds during southerly wind directions in northern Tröllaskagi. A temperature up to 15°C has been recorded in December and January in Siglufjörður in southerly Föhn winds.

Wind roses from Siglufjörður, Sauðanesviti and Siglunes/Reyðará are shown in Appendix C.6. The average wind speed in Siglufjörður is 4.1 m/s which is considerably lower than at Siglunes (6.3 m/s), and by Siglufjarðarvegur (5.3 m/s). Gusts can be quite high and a gust of 46.8 m/s has been recorded. The wind roses show that the most common wind directions are south-westerly and north-north-easterly. The latter is more common during the winter. When it is cold the north-north-easterly winds are dominant and even more so when the winds are strong. When the temperature is lower than 1°C and the wind speed higher than 15 m/s the only wind direction recorded is north-north-easterly. This has been observed 236 times during 26 168 observations or 0.9% of the time.

The most common wind directions at Sauðanesviti are east-north-easterly and south-south-westerly. Conditions when temperature is lower than 1°C during precipitation at Sauðanesviti are almost only observed when the wind is from the north to the north-east. In 1971–1988 the wind direction during precipitation and temperature lower than 1°C at Siglunes is mostly north-easterly.

The recorded precipitation in Siglufjörður is far greater than at neighbouring stations (C.2). In 1991–2000 the average precipitation at Skeiðsfoss was 1009 mm and 919 mm at Kálfsárkot and Sauðanesviti. The nine year precipitation average for 1981–1990 in Siglufjörður was 1350 mm and observations from the automatic weather station give similar results. The maximum daily precipitation is also greatest in Siglufjörður (C.2). The daily precipitation on 10 August 1982 was 190.5 mm and it has four times been observed to be more than 100 mm, on 19 September 1983 (107 mm), 22 May 1986 (135 mm) 27 July 1988 (120.2 mm) and 9 September 1992 (115 mm). A daily precipitation of 146 mm was recorded by the automatic station on 1 October 2001 and 99 mm were recorded on 8 September 2000.

About 63% of the precipitation in Siglufjörður is snow or sleet. August was the only month when no snow or sleet was recorded in the period 1981–1990 (C.4). The precipitation in the months October through April is almost exclusively snow or sleet. The proportion of snow is a little higher than at Skeiðsfoss. The ground is covered with snow 90% of the time in January through March and between 80–90% of the time in December through April. There is more snow in the area than at most other locations in Iceland. The estimated 50 year snow depth is more than 200 cm in Siglufjörður and at Kálfsárkot and about 150 cm at Tjörn and Siglunes (Kristján Jónasson and Trausti Jónsson, 1997). The average snow depth in December through March is shown in Appendix C.5.

Weather preceding avalanche cycles in Siglufjörður has been analysed by Halldór Björnsson (2001). Avalanches are most common during strong north-easterly winds with snowfall. There are relatively more days with wind speed higher than 15 m/s and accumulated five day precipitation of more than 30 mm preceding avalanches than on a normal winter day. Avalanches that fall during south-westerly winds are associated with lower wind speeds. There is not a simple relationship between runout of avalanches and wind speed or runout and accumulated precipitation. If the accumulated precipitation is less than about 55 mm the longer avalanches fall during strong winds or heavy precipitation. Avalanches that are preceded by high accumulated precipitation do not have the longest runout.

2.5 Snow depth measurements in starting areas

Regular monitoring of snow depth in the mountain above Siglufjörður was initiated in 1996/1997. The measurements were carried out on 10 stakes in the first winter and on 15 stakes after that. The stakes were 3.6 to 4.5 m high and placed in the elevation range from about 170 m a.s.l. to 570 m a.s.l. The locations of the stakes are shown on Map 4. Several stakes have been lost in avalanches and rock falls or due to other causes during the period of the measurements leading to some gaps in the snow depth time-series. The measurements are described by Sigurður Kiernan, Jón Gunnar Egilsson and Tómas Jóhannesson (1998), Sigurður Kiernan and Tómas Jóhannesson (1998), Sigurður Kiernan, Jón Gunnar Egilsson and Tómas Jóhannesson (1999) and Tómas Jóhannesson (2000a).

The maximum vertical snow depth measured in the starting zones is typically about 2 m for the lower parts of the slope and up to 3.5 m in the upper part of the slope above Fífladalir. The highest snow depths were reached in 1998/1999. The stakes are all located on relatively unconfined terrain and much higher snow depths may be expected to have occurred in the gullies that are located near the middle of several of the starting zones. Figure 2 shows the measured snow depth at stake `sigl04` at 531 m a.s.l. above Fífladalir since the start of the measurements in the winter 1996/1997.

Snow depth in the mountain above Siglufjörður has also been measured manually along lines in the Fífladalir area, below Hvanneyrarskál and below Strengsgil. These measurements are described in the reports referenced above. They show the distribution of snow depth at a specific point in time in more detail than the stake measurements and confirm that the snow depth recorded at the stakes is representative for the large unconfined parts of the starting areas.

Snow depth has been monitored regularly in the supporting structure test area in the gully Grindagil above Fífladalir since 1996. These measurements are summarised by Stefan Margreth (SLF, 2001) and tabulated in technical reports describing the results of the supporting structure experiment. They show that large amounts of snow accumulate in the gully, in some cases exceeding

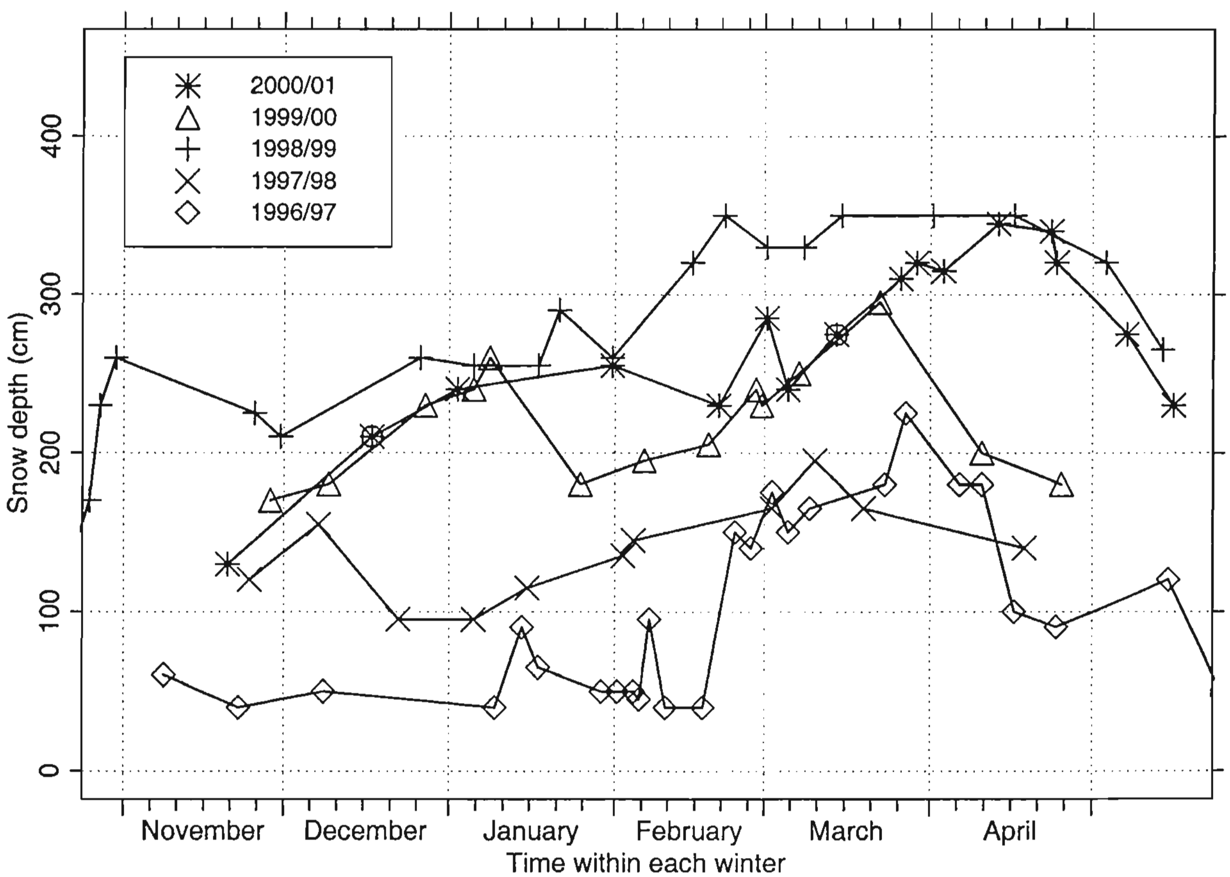


Figure 2. *Snow depth at stake* sigl04 *at 531 m a.s.l. above Fífladalir in Hafnarfjall.*

8 m vertical snow depth. This indicates that snow depth in the main gullies above Siglufjörður can exceed the snow depths in the unconfined parts of the slope by a factor of 2–3 or even more. Field observations in the spring of 2001 showed locally very high snow depths (> 4 m) in several large cornices that are formed above 520 m a.s.l. near the top of Hafnarhyrna.

Return period analysis of snow depth at lowland stations in the neighbourhood of Siglufjörður (Tómas Jóhannesson, 2000b) indicates that the winters 1989/1990 and 1994/1995 had relatively much snow fall on a decadal time scale. Since 1995 the highest snow depths were recorded in the winter 1998/1999. Available information on snow depth in the mountain above Siglufjörður, including photographs of the mountainside from the winter 1994/1995, was summarised and interpreted by Stefan Margreth (SLF, 2001). He concluded that the return period of the observed snow depth on the stakes in the mountain from 1998/1999 is about 5 years and that the 100 year snow depth could be higher than the observed snow depth from 1998/1999 that by a factor of about 1.75.

The snow depth measurements and winter photographs of the hill clearly show that drift snow is the main controlling factor for differences in the local snow depth in the mountainside. The measurements indicate that the snow depth does typically not exceed 2–3 m on unconfined or concave parts of the hill and the 100 year snow depth may be larger than this by a factor of 1.5–2. In gullies and depressions and near the top of Hafnarhyrna the snow depth can, however, become many times larger than this. There, the snow depth seems to be mostly controlled by the depth of the depression and other landscape features, rather than by the local amount of precipitation that falls as snow. Observations in the Grindagil gully show that vertical snow depths in depressions has exceeded 8 m and it is likely that local vertical snow depth in the gully Ytra-Strengsgil becomes even larger than that.

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, debris flow hazard zoning should be done in synchronization with avalanche hazard zoning.

A debris flow chronicle for Neskaupstaður has been compiled and a geological study has been conducted to evaluate the debris flow activity and potential (Halldór G. Pétursson and Þorsteinn Sæmundsson, 1999; Þorsteinn Sæmundsson and Halldór G. Pétursson, 1999).

Although debris flows have caused property damage in Siglufjörður and may impose some threat to the inhabitants the debris flow hazard must be considered to be insignificant compared with the avalanche hazard. It is therefore concluded that taking debris flows specifically into account will not significantly alter the risk and the hazard zoning presented here would be unaffected. In spite of this it may be feasible or even advisable to take actions to prevent property damage due to debris flows at some locations in the village.

3 Jörundarskál

3.1 Topographic description

Jörundarskál is a large bowl near the top of the mountain Hafnarfjall at the southern boundary of the settlement of Siglufjörður (Figure 3). It can be seen on Maps 1 and 4 and longitudinal sections (`sist06ba` and `sist07aa`) are shown in Drawings 1–2. Below the bowl there is a gully and a debris cone. At the southern side of the gully there used to be small hills named Nautskálahólar. In the year 1999 a large deflecting dam was finished below the gullies of Strengsgil and in connection to that another smaller one was constructed below Jörundarskál. It was partly made out of material from Nautskálahólar, so the whole landscape is now different from before. The following description applies to the original landscape.

Starting area

The large almost symmetric bowl shaped starting area extends down from 540 m to about 400 m a.s.l. The location of the bowl is indicated by the number 1 on Figure 3 and Map 4. The bowl averages 450 m wide with an inclination between 35° and 40°. The bowl faces east with an area of about 9 ha. The steep inner part of the bowl is interrupted by cliffs while the outer part of the bowl terminates in a low ridge that separates the starting area of the bowl from the starting area of the gullies Syðra- and Ytra-Strengsgil.

Track

The avalanche track begins below the starting area at 400 m a.s.l. and reaches down to the β-point around 30 m a.s.l. The track inclination averages 22° and inclines 26° from 400 to 300 m a.s.l., 37° from 300 to 100 m a.s.l., and 15° on the debris cone between 100 and 30 m a.s.l. Two gullies characterize the track. The inner gully is the main avalanche track. It is 20–40 m deep with an average width of about 60 m. The smaller outer gully is about 10 m deep and approximately 20 m wide. The 70 m wide area between the gullies and the 50 m wide area south of the inner gully are considered part of the track. The two gullies start in the bowl and terminate about 100 m a.s.l. on a slightly convex debris cone.

Runout area

The runout area has an inclination of 5–10° and terminates in the sea. The width of the potential runout area is about 300 m. The debris cone is covered with grass and the surface is rough due to old debris flows. Several houses, mainly built in the beginning of the 1980's, stand in the northern part of the runout area. The northernmost houses are older. The kindergarten Leikskálar, which was used during the summer only, was located in the middle of the runout area and was hit by an avalanche in 1973 as well as a hen house in the same area.

Figure 3. *View from north east of the avalanche paths above Siglufjörður. The red numbers indicate the approximate location of starting areas that were deliniated during field investigation (see Map 4) (Photo: Mats Wibe Lund).*

3.2 Climatic conditions

Because of the shape and aspect of the bowl, snow accumulation is possible in north to southwesterly winds although it is most likely in northwesterly winds. As described in the general description of climatic conditions, northwesterly winds are not common in Siglufjörður.

3.3 Chronicle

Some large avalanches are recorded from Jörundarskál. The longest one fell between 1936 and 1938. At the time the fjord was covered with ice and the avalanche is reported to have reached most of the way to the seashore on the other side. Accounts on injury are inaccurate but no damage was caused.

In 1973 an avalanche hit the playschool Leikskálar (not in use during the winter) and a henhouse and went almost all the way down to the sea. A storage shed standing in the same place as the previously destroyed henhouse was then damaged by an avalanche in 1994.

Recorded avalanches in the area are shown on Map 2 and listed in the following table:

Number Time *Runout index*	**Description**
2007 1936–1938 *>15.2*	A large avalanche fell from Jörundarskál and/or Syðra-Strengsgil. From the width of the avalanche it is likely that it came from both the starting areas. The south edge of the avalanche went by an old swimming pool below Suðurgata. The north edge of the avalanche is less clear, but it is likely that it went below Suðurgata 76 and 78 near the sea. The sources on the avalanche are somewhat unclear but it probably extended almost over the ice covered bottom of the fjord. The width of the deposit is unknown. One man may have been caught by the avalanche and injured.
2027 19.12.1973 *15.0*	A dry slab avalanche was released from Jörundarskál and fell all the way to the sea. The avalanche destroyed the playschool Leikskálar and severed a power line. A hen house was also destroyed and 250 hens were killed. The tongue was 50 m wide above Nautskálahólar, 200 m wide below Nautskálahólar, and 100 m wide below the road Suðurgata. The volume of the tongue is estimated between 10,000 and 15,000 m^3.
2037 4.4.1980	A small wet slab avalanche fell in Jörundarskál.
2040 11.4.1980	Two loose dry avalanches came from Jörundarskál. The tongue was around 100 m long.
2050 23.3.1981	A small avalanche was triggered by a cornice collapse into Jörundarskálargil.

Number Time *Runout index*	**Description**
2051 11.4.1981	A loose wet avalanche fell from Jörundarskál, and stopped on a steep rocky debris. The deposit was around 150 m long and about 10 m wide.
2064 8.1.1984 *13.3*	Dry slab avalanches seem to have been released simultaneously from Jörundarskál and Syðra-Strengsgil. The avalanche carried rocks and debris to the lowland and stopped on the road below Leiksskálar at 25 m a.s.l. The maximum width of the deposit was 800 m.
2067 17.12.1984	A small avalanche fell in Jörundarskál.
2068 27.1.1985	A small, dry and loose avalanche fell in Jörundarskálargil.
2986 2–4.4.1986	Two or three small avalanches were released in Jörundarskál.
2092 25.3.1989 *9.5*	A loose dry avalanche fell from Jörundarskálagil. The deposit was approximately 20 m wide.
2975 8.3.1990 *8.6*	A small avalanche was released in Jörundarskál.
2974 25.3.1990	A small loose wet avalanche fell in Jörundarskál.
2100 29.1.1991 *8.5*	An avalanche fell in Jörundarskál. It was 75 m long and 20 m wide. It stopped in the uppermost part of Jörundarskálargil.
2101 21.3.1991 *9.6*	A dry slab avalanche fell from Jörundarskál and stopped in the gully at about 130–140 m a.s.l.
2110 19.12.1994 *14.4*	A slab avalanche fell from Jörundarskál and stopped below the road Fjarðarvegur 150–200 m from the southernmost residential area of the town. The avalanche damaged the wall of a storage shed that stood where a henhouse was previously destroyed by an avalanche in 1973. The deposit was about 70 m wide.
2132 7.12.1997	A small avalanche fell in Jörundarskál and it only barely made it to the bottom of the bowl.
2147 12.3.1999 *9.4*	A small avalanche fell in Jörundarskál. It stopped at about 150 m a.s.l.
2151 1.4.1999	Two very small avalanches fell in Jörundarskál. Snow that was melting by the sun was released.

Number Time *Runout index*	Description
2919 26.5.1999	A very small wet and loose avalanche was released in Jörundarskál.
2164 4–5.1.2001	A small avalanche was released in Jörundarskál and reached down below the openings of the gullies.
2176 8–10.3.2001	A small avalanche started in Jörundarskál. It fell down the gully below the bowl and ran about 25 m along the deflecting dam Litli-Boli below. The deposit was about 0.4 m thick.
2266 3.4.2001 *14.7*	A dry slab avalanche started in Jörundarskál. The deposit was about 70 m wide and the volume about 20,000 m^3. The tip of the avalanche terminated at about 10 m a.s.l. The avalanche was deflected by the deflecting dam below Jörundarskál (Litli-Boli).

3.4 Assessment

Due to the size and inclination of the starting area, large avalanches are possible. The potential size of an avalanche is estimated around 250,000 m^3. The main avalanche track is the inner gully so most of the avalanche flows in a confined track. The runout area on the debris cone is quite wide. An avalanche could either spread on the debris cone or form a tongue down to the shoreline.

3.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profiles `sist06ba` and `sist07aa`, 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. The risk estimation methods of RiskEst (*Estimation of avalanche risk*, Kristján Jónasson *et al.*, 1999) were applied. For explanation see Appendix A.

The uppermost houses are located at about runout index 13–14 and the old shoreline has a runout index of 15. Thus avalanches with relatively short runout with respect to the potential starting area are needed to pose a threat to the settlement.

The α/β-model gives similar results, the α-point is located beyond the old coastline, and an avalanche with a runout of $\alpha - \sigma$ would go into the sea.

There are five recorded avalanches with a runout index greater than 13, in 1936–1938, 1973, 1984, 1994 and 2001. The avalanches in 1936–1938 is the longest. It is not possible to establish its runout, but since it went into the sea it is known that it had a runout greater than runout index 15. The avalanche in 1973 had a runout of a little less than 15. It is difficult to estimate an observation time to establish the frequency since there has not been much settlement in the area. One avalanche with runout $r \geq 15$ in 100 years would imply a frequency $F_{13} = 0.05$, four avalanches with $r \geq 14$

in the same time would imply a frequency F_{13} = 0.08. Two avalanches with a runout of $r \geq 14$ in 20 years implies a frequency of F_{13} = 0.2. The estimated frequency is therefore in the range 0.05–0.2.

By using the frequency 0.075 the risk was calculated for the area with the methods of RiskEst. In the uppermost houses at runout index 14 the risk was about $75 \cdot 10^{-4}$, about $25 \cdot 10^{-4}$ at the old shoreline, and about $2 \cdot 10^{-4}$ at the new shoreline. This frequency estimate indicates that avalanches from Jörundarskál will reach on the order of 100 m into the fjord on a time scale of several thousand years. It is possible that an avalanche reached significantly further than this in the early part of the century. Thus the potential for very large avalanches from Jörundarskál may be higher than this frequency indicates. Since all the lowland below Jörundarskál is in the category C hazard zone this was not considered further.

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.* (2001).

3.6 Conclusion

The avalanche chronicle provides ample evidence that the area was hazardous before defence structures were built.

Using the results of risk calculations the boundary between the catecory C and B hazard zones is close to the sea. It is considered appropriate to apply the base frequency $F_{13} = 0.075$. The SAMOS calculations indicate relatively shorter runout from the Strengsgil gullies, than from Jörundarskál. This is taken into account in the hazard zoning. The resulting hazard zones are shown with dashed lines on Map 5.

The path is a typical path and the uncertainty of the estimate is considered low (1/2).

3.7 Defence structures

Description

Two deflecting dams have been built in the area below Jörundarskál. One dam is on the northern edge of the gully below Jörundarskál. Its purpose is to prevent an avalanche from spreading or otherwise taking direction towards north. The height of the dam is 15 m with a deflecting angle of 10° and it is about 200 m long. Another larger dam deflects avalanches originating in Strengsgil as well as avalanches from Jörundarskál. The height of the second dam is 18 m high with a deflecting angle of 15–18° and it is about 700 m long.

The design of the protection measures aimed to reduce the risk to people below $0.2 \cdot 10^{-4}$.

Assessment

Uncertainties are unavoidable in avalanche hazard zoning. The uncertainty is even greater for areas protected by defence structures than for areas where no such measures have been taken. Therefore it is not advisable to increase the risk implied by this uncertainty by significantly increasing the number of buildings in a protected area or by increasing the total risk by other means.

Map 5 shows the proposed hazard zones after the completion of the defence structures for the Jörundarskál/Strengsgil area as solid lines. The hazard lines do not necessarily represent risk in a formal sense but are intended to reflect both the increased safety provided by the defence structures and the unavoidable uncertainty about their effectiveness. The boundary of the C hazard zones is located just above the uppermost houses in the area. This can be interpreted as a statement that in spite of the defence structures it is not advisable to build houses closer to the mountain than the current settlement. Below Jörundarskál no category B hazard zone is delineated but the category A hazard zone is delineated almost down to where the category C hazard zone ended before. Below the Strengsgil gullies the lower boundary of the category B hazard zone is above the uppermost houses, and connects to the boundary of the hazard zones below Skriðulækjargil.

The uncertainty of the hazard assessment after the buildup of defences is considered to be medium to high (1–2).

4 Syðra- and Ytra-Strengsgil

4.1 Topographic description

Syðra- and Ytra-Strengsgil are two 15–20 m deep gullies above the southern part of the settlement. The gullies are separated by a narrow ridge. Figure 3 shows the gullies. They can be seen on Maps 1 and 4 and longitudinal sections (`sist08ba`, `sist08aa` and `sist09aa`) are shown in Drawings 3–5.

Starting area

The starting area faces southeast and ranges from about 520 m to 350 m a.s.l. The inclination averages 35°, and the width of the entire starting area is 250 m. The area can be divided into three smaller starting areas (indicated with the numbers 2–4 on Figure 3 and Map 4). The southernmost area (2) is about 75 m wide. The Syðra-Strengsgil gully starting area (3) is 12 m deep and about 100 m wide while the northern Ytra-Strengsgil gully starting area (4) is 15 m deep and about 75 m wide. The whole starting area is around 6.5 ha. A large nearly flat possible catchment area is above the starting area. A low ridge on the southern boundary of the starting zone divides this starting area from Jörundarskál. The northern boundary of the starting zone is the outer edge of Ytra-Strengsgil.

Track

Below 350 m a.s.l., the avalanche track begins in two gullies. They are deeper than the corresponding depressions in the starting area. The average depths of both gullies are 15–20 m. The inner gully averages 60 m wide, and the outer one is 80 m wide. The inclination is 24° from 350 m to 200 m a.s.l., 20° from 200 to 100 m a.s.l., and 14° down to the β-point at 25–40 m a.s.l. At 150 m a.s.l., the gullies terminate in a debris cone.

Runout area

The inclination of the runout area is close to 10° down to the landfill at the original shoreline. The area is densely settled with houses built mostly in the 1980's.

4.2 Climatic conditions

Due to the shape and aspect of the gullies, snow accumulation is possible in north to southwesterly winds. In northwesterly wind, snow can be transported from the plateau above the area, but such a wind direction is not common in Siglufjörður. In northerly winds drift snow that is transported along the mountainside accumulates in the gullies leading to very large snow depths along their northern edges.

4.3 Chronicle

Only a handful of avalanches are known to have started in Syðra-Strengsgil. The recorded avalanches in the gully are shown on Map 2 and listed in the following table:

Number Time *Runout index*	**Description**
2046 20.2.1981 *11.8*	A loose wet avalanche started high in Syðra-Strengsgil and stopped above some fences at 70 m a.s.l. The tip of the deposit was 20–25 m wide.
2997 17.12.1984	A small avalanche was released by conices collapsing in Syðra-Strengsgil.
2995 27.1.1985	A small loose and dry avalanche fell in Syðra-Strengsgil.
2214 13.2.1988 *13.0*	An avalanche that fell in Syðra-Strengsgil reached down to about 45 m a.s.l.

Many more avalanches are recorded in Ytra-Strengsgil than Syðra-Strengsgil. Quite a few of these have caused damage. Recorded avalanches from Ytra-Strengsgil are shown on Map 2 and listed in the following table:

Number Time *Runout index*	**Description**
2002 1901 *13.7*	An avalanche fell down to around 20–30 m a.s.l. on a new road in front of Höfn. It probably came from Ytra-Strengsgil.
2005 12.4.1919 *14.5*	An avalanche fell south of Efri-Höfn and went almost to the sea. It took a small summercottage which belonged to Sören Goos. The avalanche probably came from Ytra-Strengsgil rather than Jörundarskál.
2012 1938/39 *14.5*	A large avalanche fell probably from Ytra-Strengsgil. The avalanche went between the houses Suðurgata 91 and Hávegur 65 and almost down to the sea. It hit a hut, that was located where Sören Goos's summerhouse had been located, and carried it down close to the sea. The width of the deposit was about 150 m.
2013 Around 1958–1960 *13.8*	An avalanche fell in Ytra-Strengsgil and stopped at about 25 m a.s.l.

Number Time *Runout index*	**Description**
2017 4.2.1968 *13.8*	A cornice collapse triggered a wet avalanche in Ytra-Strengsgil. It hit a house at Suðurgata 76. The snow went into the house and caused considerable damage. The avalanche piled up above the house but a part of it fell further down north of the house. The tongue stopped around 25 m a.s.l., and it was approximately 40 m wide above Suðurgata.
2019 1969 *13.2*	An avalanche from Ytra-Strengsgil stopped 20–30 m above the houses at Suðurgata 76 and 78.
2028 1973 *10.6*	A cornice collapsed on the north wall of Ytra-Strengsgil, below snowdrift fences. The avalanche stopped slightly below the gully at about 125 m a.s.l.
2029 19.12.1974 *13.9*	A dry slab avalanche fell from Ytra-Strengsgil inflicting significant damage on the houses at Suðurgata 76 and 78. It also toppled an electricity pole and damaged a car. The deposit was about 170 m wide 70 m a.s.l. and 80 m wide by the road Suðurgata. It stopped around 25 m a.s.l.
2036 4.4.1980 *11.6*	A wet slab avalanche fell from Ytra-Strengsgil and stopped around 80 m a.s.l., 200–250 m above the houses at Suðurgata 76 and 78. The deposit was 30–40 m wide at the tip.
2049 23.3.1981 *10.2*	A cornice collapsed above the north wall of Ytra-Strengsgil and triggered an avalanche that reached down to the opening of the gully. The deposit was 5–10 m wide.
2055 16–18.12.1982 *9.7*	A long cornice fell from the north wall of Ytra-Strengsgil causing a loose dry avalanche that stopped in the lower part of the gully. The tongue was around 5 m wide.
2060 30/31.3.1983 *9.9*	A small avalanche fell in Ytra-Strengsgil and stopped in the opening of the gully.
2063 14.–16.12.1983 *11.5*	A cornice collapsed onto the north wall of Ytra-Strengsgil and started a loose dry avalanche. The 20 m wide avalanche stopped by the town fences at about 80 m a.s.l. The width of the deposit was about 20 m.
2998 17.12.1984	A small dry slab avalanche fell in Ytra-Strengsgil.
2994 27.1.1985	A small loose and dry avalanche fell in Ytra-Strengsgil.
2070 28.3.1985	A loose dry avalanche fell in Strengsgil and stopped at the base of the hill. It is likely that the avalanche was triggered by a cornice collapse.
2213 18/19.4.1986	A small loose and dry avalanche was released from Ytra-Strengsgil.

Number Time *Runout index*	**Description**
2080 3.12.1986 *12.7*	An avalanche from Ytra-Strengsil stopped about 100 m from the houses Suðurgata 76 and 78. The width of the deposit was about 40 m. The avalanche caused slight damage to the town fence.
2980 13.2.1988 *11.1*	A dry slab avalanche that was released in Ytra-Strengsgil stopped at about 100 m a.s.l.
2093 25.3.1989 *11.9*	A loose dry avalanche fell from Ytra-Strengsgil. The deposit was approximately 60 m wide terminating at about 75 m a.s.l.
2095 4.2.1990 *10.3*	A loose wet avalanche started in Ytra-Strengsgil and stopped just below the opening of the gully. The width of the deposit was 20–30 m.
2106 21–23.1.1994 *13.5*	An avalanche from Ytra-Strengsgil stopped on the house at Suðurgata 76. The avalanche was probably loose and dry.
2111 18.1.1995 *13.4*	A dry avalanche fell from Ytra-Strengsgil. The maximum width of the deposit was 135 m, and it stopped 30 m above the road Suðurgata.
2117 7.3.1995 *9.6*	An avalanche started in Ytra-Strengsgil and stopped in the lower part of the gully. The deposit was 5–8 m wide.
2120 3.1.1996 *12.9*	A dry slab avalanche fell from Ytra-Strengsgil and stopped about 75 m above the house at Suðurgata 76.
2962 11.2.1996	A small avalanche fell in Ytra-Strengsgil.
2124 2/3.12.1996	A slab avalanche was released in Strengsgil and stopped in the lower parts of the gullies. The deposit was about 6–7 m wide and 0.5–0.6 m deep.
2125 15.1.1997 *12.1*	A slab avalanche fell in Ytra-Strengsgil and stopped around 140 m above Suðurgata 76. The width of the deposit was around 70 m and its thickness about 1.5 m.
2131 14/15.11.1997	A small avalanche was released from the upper part of Ytra-Strengsgil but it did not reach down to below the gully.
2936 26.12.1998	A narrow and very small avalanche started in Ytra-Strengsgil.
2148 12.3.1999	A wet avalanche fell from Ytra-Strengsgil and hit the deflecting dam which was under construction. It was deflected by the dam and stopped by the lowest part of it. The avalanche was estimated to have been about 15,000 m^3.

Number Time *Runout index*	Description
2163 3–5.1.2001	A small avalanche was released in Ytra-Strengsgil and reached down to below the opening of the gully.
2175 8–10.3.2001	A small avalanche was released in Ytra-Strengsgil.
2190 1.4.2001	A small dry slab avalanche fell in Ytra-Strengsgil.

4.4 Assessment

As stated in the description of the starting area, it can be divided into three parts. It is possible to have isolated avalanches from each of these smaller areas or a big avalanche from all the areas at same time. Furthermore, it is impossible to rule out the possibility that an avalanche could simultaneously start in the Jörundarskál bowl. The potential size of an avalanche from the Strengsgil gullies is estimated around 100,000 m^3. According to the avalanche chronicle, the frequency of avalanches is high.

4.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profiles (`sist08ba`, `sist08aa` and `sist09aa`), and the results of the calculations are shown in Drawings 3–5. The runout was calculated using runout indices and an α/β-model. The risk estimation methods of RiskEst (*Estimation of avalanche risk*, Kristján Jónasson *et al.*, 1999) were applied. For explanation see Appendix A.

Runout calculations for Strengsgil yield similar results as for Jörundarskál. The uppermost houses are however a little closer to the mountain with a runout index about 13.5. The old shoreline is located at runout index 15 and the new one between 15.5 and 16.5.

According to the α/β-model an avalanche with runout α will run most of or all the way into the sea.

Judging from the avalanche chronicle avalanches are much more frequent in Ytra-Strengsgil than Syðra-Strengsgil. Before 1980 there are no avalanches recorded from Syðra-Strengsil. In 1988 an avalanche with runout index 13.0 fell from the gully. In Ytra-Strengsgil there are seven avalanches with $r \geq 13$ recorded before 1980. After 1980 there are further two dry avalanches with $r \geq 13$ recorded in Ytra-Strengsgil. When the construction of the deflecting dam was well under way in 1999 a wet avalanche was released from Ytra-Strengsgil and had quite a long runout although its interpretation is not straightforward due to the channelisation caused by the impact with the dam.

Assuming an observation period of 100 years and the nine recorded avalanches with $r \geq 13$ the frequency of avalanches from Ytra-Strengsgil would be estimated as $F_{13} = 0.09$. A lower estimate would be obtained by looking at the number of $r \geq 14$ avalanches. It has to be borne in mind that the records are somewhat inaccurate and the exact runout may not be known. Also the records may not be complete, and the frequency thus higher. The frequency F_{13} is therefore estimated to be 0.05–0.1 which is similar as in Jörundarskál.

For Syðra-Strengsgil the frequency estimation is more tricky. The observation that avalanches are less frequent than in Ytra-Strengsgil may in part be due to different observation conditions. There has been less settlement in the area and avalanches thus less likely to be recorded. However it can be taken as a fact that in the last 20 years the frequency is lower. Therefore the frequency of avalanches from Syðra-Strengsgil is estimated to be $F_{13} = 0.025$–0.05.

Using the methods of RiskEst the frequency estimate $F_{13} = 0.075$ will result in a risk of about $100 \cdot 10^{-4}$ for the uppermost houses below Ytra-Strengsgil and about $10 \cdot 10^{-4}$ by the shoreline. Somewhat lower risk is obtained below Syðra-Strengsgil. It should however be noted that avalanches from Jörundarskál also threaten the area below Syðra-Strengsgil.

If the only potential hazard was avalanches from each of the three starting areas these risk estimates would probably be too high due to properties of the utilized runout distribution. Although an avalanche from all the starting areas at the same time has not been observed, it cannot be ruled out. This reduces the probability that the risk is overestimated.

The Austrian avalanche model SAMOS was applied to evaluate the direction of avalanches from the starting areas and the lateral extent of avalanches. The similations indicated that avalanches with the same fracture height would have a shorter runout from Strengsgil than Jörundarskál. The results are described by Tómas Jóhannesson *et al.* (2001).

4.6 Conclusion

As for Jörundarskál there is no doubt that the area was very hazardous before the deflecting dams were built. The category C hazard zone would have reached into the sea in most of the area.

The frequency estimate $F_{13} = 0.075$ is considered appropriate. The boundary of the category C hazard zone is set a little closer to the mountain than for Jörundarskál based on the results from the SAMOS simulations. The resulting hazard zones are shown with dashed lines on Map 5.

4.7 Deflecting dams below Jörundarskál/Strengsgil

See Section 3.7.

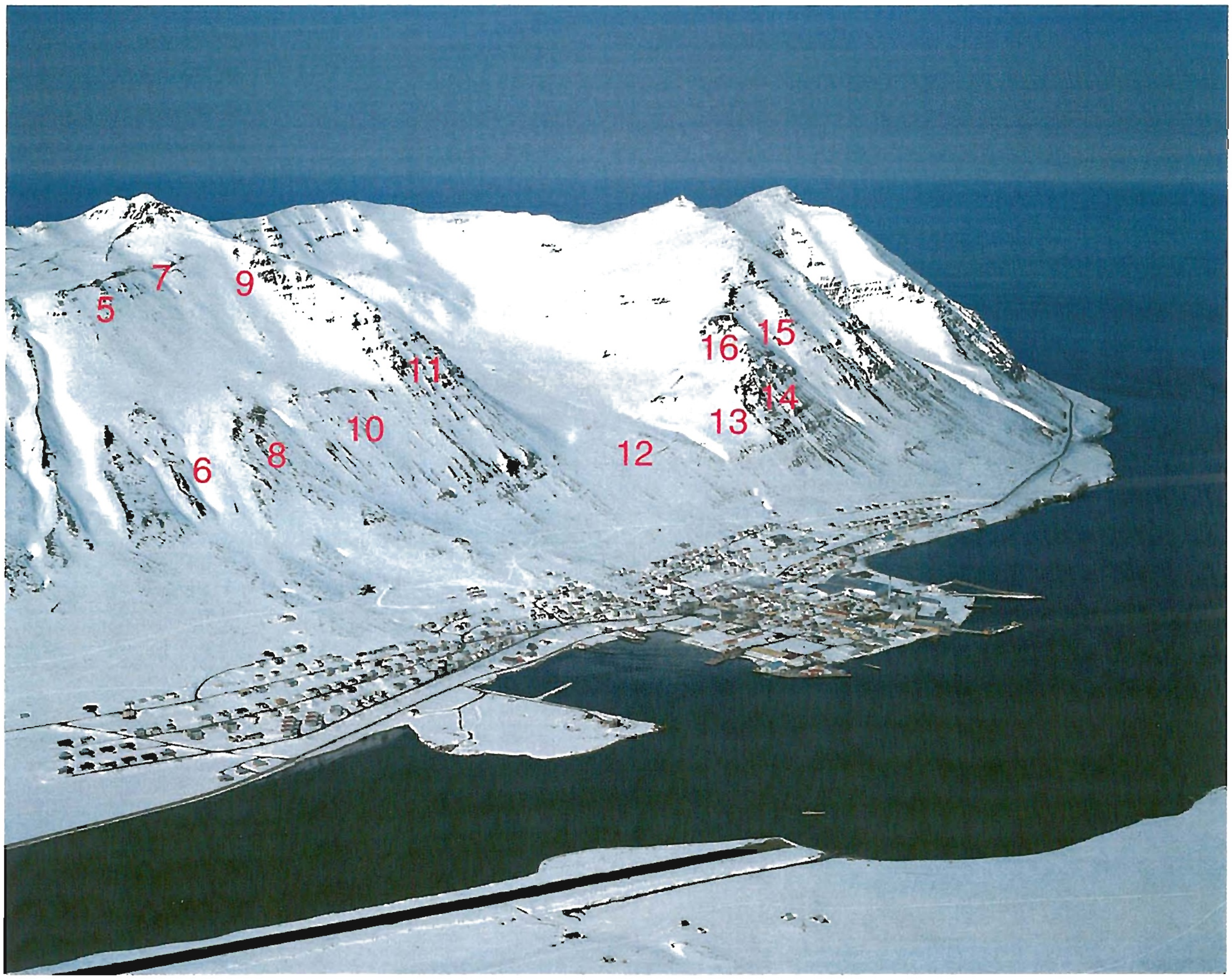


Figure 4. *View from south east of the avalanche paths above Siglufjörður. The red numbers indicate the approximate location of starting areas that were deliniated during field investigation (see Map 4) (Photo: Mats Wibe Lund).*

5 Fífladalir/Skriðulækjargil

5.1 Topographic description

North of Strengsgil there is a shallow plateau called Fífladalir, with a lower edge at about 320 m a.s.l. In the southern part the plateau is over 25° steep, and below it there are three shallow gullies called Innra-Skriðulækjargil, Mið-Skriðulækjargil and Ytra-Skriðulækjargil. Figures 3 and 4 show the area. It can be seen on Maps 1 and 4 and longitudinal sections (`sifi08aa` and `sifi04aa`) are shown in Drawings 6–7.

Starting area

There are three starting areas located in this part of the mountain (indicated with the numbers 5, 6 and 8 on Figures 3 and 4 and Map 4). An upper starting area is located above the Fífladalir plateau, and two lower ones below Fífladalir. The upper starting (5) area extends from 530 m to 400 m a.s.l. It is about 200 m wide and fairly even with an average inclination of 35°. The area is 4.2 ha. Small cliffs can be seen in the upper part of the area while the rest of the area is covered with weathered debris. The aspect of the area is ESE.

The southern lower starting area (6) is located between 325 and 200 m a.s.l. It is approximately 150 m wide with an average inclination between 30° and 35°. The area is around 3.5 ha. In the outer part of the starting area, the gully Ytra-Skriðulækjargil is about 50 m wide and around 15 m deep. In the inner part, the Mið-Skriðulækjargil gully is about 60 m wide and 15 m deep. South of the inner gully is the Auðimelur ridge and another gully that is sometimes called Innsta-Skriðulækjargil. These areas are not considered to be starting zones due to their shape and inclination. Between the gullies, the landscape is covered with talus.

The northern lower starting area (8) is located between 300 and 200 m a.s.l with an average inclination of about 33°. The area is convex and about 1.8 ha. The average width is about 100 m.

Track

The slightly confined avalanche track starts at 400 m a.s.l. and includes both the lower starting areas described above. The maximum width of the track is about 300 m. The inclination between 400 and 325 m a.s.l. is 20–30°. Between 325 and 200 m a.s.l., the inclination increases to 30–35°. From 200 m a.s.l. to 100 m a.s.l., the inclination remains between 25° and 30°. The 120 m wide track from the lower starting area is somewhat narrower and begins at 200 m a.s.l. This track is in the lower part of the Mið- and Ytra-Skriðulækjargil gullies and on the debris cone below. From 100 m a.s.l. to the β-line at about 5 m a.s.l., the inclination decreases gradually. Some houses, mostly built after 1940, are located in the lower part of the track.

Runout area

The runout area for larger avalanches is a narrow strip along the sea.

5.2 Climatic conditions

Snow accumulation in the upper starting area is not as likely as in the gullies on either side. During northerly winds the east facing and rather convex area is unlikely to accumulate snow. North westerly winds that are more favourable for snow accumulation in the area are uncommon in Siglufjörður. Snow accumulation in the gullies in the lower starting area is more likely during northerly winds than in the upper area.

5.3 Chronicle

Only a few avalanches are recorded from Skriðulækjargil and all of them are small. One avalanche that stopped on the Fífladalir plateau is recorded from the upper starting area. One avalanche is supposed to have fallen sometime before the year 1907, but the description of the location is inaccurate. It is most likely that it came from Skriðulækjargil but this is uncertain.

Recorded avalanches in the area are shown on Map 2 and listed in the following table:

Number Time *Runout index*	**Description**
2003 Before 1907	An avalanche is supposed to have fallen north of Hafnarhæð. An exact location is not known. The avalanche might have started in Syðra- or Ytra-Skriðulækjargil or even in Fífladalagil.
2061 30/31.3.1983 *11.0*	An avalanche fell below the southernmost part of Fífladalir, probably from Ytra-Skriðulækjargil. A narrow tongue went down to a power station for the district heating utility at about 70 m a.s.l.
2215 13.2.1988 *8.9*	Small dry slab avalanches were released in both Mið-Skriðulækjargil and Ytra-Skriðulækjargil.
2979 13.2.1988 *8.9*	Small avalanches were released in Mið- and Ytra-Skriðulækjargil.
2109 18/19.4.1994	A small dry slab avalanche fell in Ytra-Skriðulækjargil.
2955 2/3.12.1996	A small avalanche was released in Mið-Skriðulækjargil and stopped in the lower part of the gully. The width of the deposit was about 6–7 m.
2181 26.3.2001	A thin avalanche started at about 500 m a.s.l. above the northern part of Fífladalir. The avalanche terminated in Fífladalir at about 350 m a.s.l.
2193 1.4.2001	A small avalanche fell in Breiðimelur below Fífladalir.

5.4 Assessment

Avalanches with a volume of tens of thousands of cubic meters are considered possible from the upper starting area. It is difficult to estimate the probability of such an event because no avalanches have been recorded from this area, and the houses below are relatively old. Topographical conditions, however, make it impossible to rule out such an event. Avalanches from the lower starting area are probably more frequent judging from both the chronicle and the climatic conditions. The potential size of avalanches from the lower starting area is 10,000 m^3 or higher. Smaller avalanches can also be expected from the upper starting area. Avalanches from the upper starting area might divide on the ridge between Ytra-Skriðulækjargil and Fífladalagil. While the main part of the avalanche is expected to flow through the Ytra- and Mið-Skriðulækjargil gullies, a smaller part could flow through Fífladalagil. It is also possible that some small part could fall along the ridge. The protection that the ridge provides should not be overestimated because an avalanche that falls down Skriðulækjargil might be directed along the gully towards the houses below the ridge.

5.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profiles `sifi08aa` and `sifi04aa`, and the results of the calculations are shown in Drawings 6–7. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

An avalanche with runout index about 12–12.5 is needed to reach the uppermost houses, and about $r = 14$ to reach the shoreline.

The β-point is located close to the shore and an avalanche with runout of $\alpha - \sigma$ according to the α/β-model would 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.* (2001).

5.6 Conclusion

Formal risk calculations are not possible in the area. Therefore it is necessary to apply subjective judgement to the existing data as well as comparing the area to other "similar" areas.

The upper starting area has a rather low snow accumulation potential. It is therefore considered unlikely that very large avalanches would start there. In spite of that it has to be borne in mind that the starting area is rather large and near the top of the mountain.

The border of the category C hazard zone was set at about runout index 12.5. This causes a few houses to be situated in this zone.

The hazard zoning proposal is shown on Map 5.

The uncertainty of the hazard assessment is considered to be high (2).

6 Northern Fífladalir

6.1 Topographic description

The plateau Fífladalir is wider in the northern part than in the southern part. Above the plateau is the gully "Grindagil" (fence gully) which derives its name from supporting structures that have been built in the gully for experimental purposes. A large bowl shaped starting area is located to the north of Grindagil. Below Fífladalir is the gully Fífladalagil which is a part of a large starting area. Figures 3 and 4 show the area. It can be seen on Maps 1 and 4 and longitudinal sections (`sifi09aa`, `sifi10ba` and `sifi07aa`) are shown in Drawings 8–10.

Starting area

Three starting areas are in the area of northern Fífladalir. The areas are indicated with the numbers 7, 9 and 10 on Figures 3 and 4 and Map 4. Two starting areas are above the Fífladalir plateau and a lower one is below Fífladalir. The smaller of the upper starting areas is the gully Grindagil with an area of about 0.7 ha. The main upper starting area extends from 650 m to 350 m a.s.l. This bowl shaped area is widest in the lower part where the width is about 300 m. Most of the area is fairly even though the upper northern part is cliffy and the rest of the area is covered with talus. The inclination is between 30° and 39°. The area is about 10.4 ha. The aspect of the area is from SSE to ESE.

The lower starting area is located between 320 and 140 m a.s.l. with an average width of 320 m. The average inclination is between 30° and 35°. The area is around 11 ha. The Fífladalagil gully is in the inner part of the starting area. It is about 30 m wide and between 5 and 10 m deep. The area is fairly even with no distinctive depressions. The landscape is covered with talus.

Track

The unconfined avalanche track starts at 400 m a.s.l. and includes the lower starting area described previously, the area between the starting areas, and the area below the lower starting area down to the β-line at about 5 m a.s.l. The maximum width of the track is about 320 m. The inclination between 400 m and 325 m is between 20° and 26°, and between 325 m and 120 m, the inclination is between 30° and 35°. From 120 m to 20 m a.s.l., the inclination is between 30° and 10°. The track from the lower starting area is the same as the lowest part of the track from the higher starting area. That part of the track is covered with talus and some vegetation. The Fífladalagil gully will probably direct avalanches more to the northeast. In the lowest part of the track, houses were mostly built in this century, but the oldest house that is known to have been located there was built in 1866.

Runout area

The runout area is considered to be below the β-line at about 5 m a.s.l. The church is on the northern boundary of the runout area and the southern boundary is a little to the south of the fire department. The area has been densely settled during most of this century.

6.2 Climatic conditions

Due to the shape and aspect of the upper starting area, snow accumulation should be expected in winds from north to west. North and northwesterly winds are probably more dangerous because in westerly winds snow might tend to accumulate on the plateau above the starting area on the lee side of the mountain ridge. Snow accumulation in the lower starting area is not as likely since northerly winds will probably clear snow from the area, and in northwesterly and westerly winds, snow will tend to accumulate higher in the mountain.

6.3 Chronicle

Only one avalanche is recorded for sure to have started in the upper starting area and gone over the plateau of Fífladalir (20.11.2000). However some of the older avalanches in the area do not have a known starting area. In 1938, 1971 and 1988 avalanches caused damages in the area. Some of them killed some sheep or hens. Only one avalanche, in 1971, hit a house but the people survived.

Number Time *Runout index*	**Description**
2003 Before 1907	An avalanche is supposed to have fallen north of Hafnarhæð. An exact location is not known. The avalanche might have started in Syðra- or Ytra-Skriðulækjargil or even in Fífladalagil.
2010 23.11.1938 *10.4*	An avalanche fell from the southern part of Fífladalabrún, perhaps from Fífladalagil. Snow piled up at the uppermost houses in Skriðuhverfi. The avalanche damaged a domestic house. A sheep shed was destroyed and five sheep were killed. A henhouse was also destroyed and some hens were killed.
2023 14.2.1971 *10.1*	An avalanche hit the house Hlíðarvegur 1c, and stopped in the next garden below. The house was badly damaged but the people staying in it escaped. A woman suffered minor injury.

Number Time *Runout index*	**Description**
2024 14.2.1971 *10.8*	An avalanche fell from the hill south of Syðsti-Gimbraklettur or from Fífladalagil. The starting zone is not known with certainty. It dislocated the uppermost rows of gravestones in the cementery. It damaged a storage shed on the SW corner of the cementery. A 2.8 ton transformer above the substation was moved 0.3 m. The width of the deposit was about 100 m above the substation. The longest runout of the avalanche was below the road south of the cementery where it stopped at about 30 m a.s.l.
2025 14.2.1971 *10.0*	An avalanche fell from the hill south of Syðsti-Gimbraklettur or from Fífladalagil. The starting area is not known with certainty. A tongue went over the south wall of Fífladalagil around 200 m a.s.l. and hit a group of sheep sheds. The three uppermost of four sheep shed rows were destroyed and about 75 sheep were killed. The width of the deposit by the sheep sheds was a little over 100 m, but north of the sheds snow went almost all the way to Hverfisgata.
2039 11.4.1980	A dry and loose avalanche was released above Fífladalir.
2996 17.12.1984	A small loose and dry avalanche was released above Fífladalir.
2915 17/18.4.1985	A small and wet loose avalanche was released above Leirdalabrún. Its width was about 70 m.
2077 2–4.4.1986	A small loose and wet avalanche fell in Fífladalir.
2083 13.2.1988 *10.6*	Loose dry avalanches caused damage to the town fence in several locations below Fífladalir. A small hut by the cementery was also destroyed. The total width of the avalanches was about 500–600 m.
2090 25.2.1989 *10.0*	A dry slab avalanche fell on the area below Fífladalir and damaged an old sheep shed. The deposit was 5–10 m wide and stopped at approximately 45 m a.s.l.
2094 25.3.1989 *10.4*	An avalanche was released in Fífladalagil. It stopped at about 45 m a.s.l. and the deposit was about 30 m wide.
2099 25/26.4.1990 *9.9*	A dry slab avalanche was released above Fífladalir. It stopped by the edge of the plateau at about 330 m a.s.l.
2119 26.10.1995 *6.6*	A wet loose avalanche fell in Fífladalir and down to about 350 m a.s.l.

Number Time *Runout index*	Description
2121 3.1.1996 *8.9*	A dry slab avalanche was released in Grindagil. It stopped in the plateau below at about 360–380 m a.s.l.
2232 10.11.1996	A small slab was released above Fífladalir. The release was initiated by a person.
2954 2/3.12.1996	A small avalanche was released in Fífladalagil. It terminated in the lower part of the gully.
2135 19.2.1998 *10.3*	A dry avalanche fell in Fífladalagil. The avalanche stopped in the lower part of the gully at around 100 m a.s.l. The 0.5 m thick deposit was about 50 m wide.
2154 26.5.1999	A semi wet avalanche was released above Fífladalir.
2156 5.6.1999	A small avalanche was started by the snow observer in "Grindagil" reaching about 15 m below the lowest row of supporting structures.
2159 31.2–5.3.2000	An avalanche started in "Grindagil" and stopped in the lowest part of the gully.
2238 18–20.11.2000 *9.3*	A dry slab avalanche started in the northernmost area above Fífladalir. The starting area was in cliffs. Most of the deposit stopped in the plateau below although a small part of it passed the plateau and went down a narrow and shallow gully above the southernmost cliff Gimbraklettur.
2162 28–30.12.2000	A small avalanche started in the upper part of Fífladalagil. It stopped half way down the gully at Lágseti at about 150–200 m a.s.l.

6.4 Assessment

Due to the size, shape, aspect, and inclination of the starting area especially the upper part between 350 and 650 m a.s.l., a large amount of snow could accumulate in this area. Therefore, avalanches of at least 100,000 m^3 are considered to be possible. Because no large avalanches are recorded from the upper starting area and houses have been standing below the slope for over a century, the frequency of large avalanches in the area is considered to be low. In the winter of 1998/1999, a vertical snow depth of over 3.5 m was measured in the area. This starting area is favorable for large avalanches and it is possible that during some unexpected weather situation, a large avalanche might fall. After the construction of deflecting dams below Jörundarskál and Strengsgil, this area must be considered the most dangerous avalanche path in Siglufjörður.

6.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profiles `sifi09aa`, `sifi10ba` and `sifi07aa`, and the results of the calculations are shown in Drawings 8–10. The runout was calculated using runout indices and an α/β-model. The risk estimation methods of RiskEst (*Estimation of avalanche risk*, Kristján Jónasson *et al.*, 1999) were applied. For explanation see Appendix A.

An avalanche with runout index less than 11 will reach the uppermost houses. This is a short runout in relation to the large avalanches that are expected in the area. A medium sized avalanche with runout of about $r = 14$ will run over many rows of houses and reach down to Þormóðseyri. An avalanche with runout a little more then $r = 18$ will completely pass Þormóðseyri.

The α/β-model shows similarily to the runout indices that even relatively small avalanches impose a great risk in the settlement. The β-line is located below the uppermost houses and an avalanche with a runout of α will run far into Þormóðseyri. An avalanche with a runout about $\alpha - \sigma$ will pass Þormóðseyri.

Direct frequency estimation cannot be done. The avalanche chronicle and the history of the settlement indicate that the frequency of avalanches down to the settlement could be about 1/100–1/30 per year. The runout below the uppermost row of houses is about $r = 11$. This can thus imply a frequency of about F_{13} = 1/1000–1/300. Risk calculations were carried out using the frequency $F_{13} = 1/300$.

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.* (2001).

6.6 Conclusion

The potential of the starting area and the observed snow depths give contradictory indications to the avalanche chronicle and the history of the settlement. The frequency estimate $F_{13} = 1/300$, which is suggested above, is about 20 times smaller than the estimated frequency below Jörundarskál and Strengsgil. It is very difficult to argue that the frequency could be less, both judging from the potential and the observed small avalanches down to the uppermost houses. Only one medium sized avalanche could alter the frequency estimate greatly. The slope has been observed for a period which length is on the order of a few hundred years. One avalanche with $r \geq 14$ would thus imply a frequency of $F_{13} = 0.01$–0.03. The suggested frequency estimate is clearly highly uncertain.

Although the protecting effect of houses for other houses lower down should not be taken into account in hazard zoning in Iceland it should be noted that the actual risk in the lower houses will probably be quite a lot less than the calculated risk due to this protecting effect. Therefore a high risk is probably not taken by choosing a frequency estimate that takes more account of the small recorded avalanches than the potential of large avalanches.

It was decided to base the deliniation of hazard zones on risk calculations using $F_{13} = 0.003$ and taking the results of the SAMOS calculations into account when finding the boundary of the runout area.

The uncertainty of the estimate is considered to be medium to high (1–2). The hazard zoning proposal is shown on Map 5.

7 Hafnarhyrna/Gimbraklettar

7.1 Topographic description

Hafnarhyrna separates Fífladalir and Hvanneyrarskál. Figures 3 and 4 show the area. It can be seen on Maps 1 and 4 and longitudinal sections (`siha07aa` and `siha08aa`) are shown in Drawings 11–12.

Starting area

The starting area (indicated by the number 11 on Figures 3 and 4 and the labels 11a and 11b on Map 4) is about 100 m wide in the upper part and 250 m wide in the lower part. It reaches from 460 m a.s.l. to 110 m a.s.l. The area faces east and the inclination ranges from 32° in the lower part to 40° in the upper part. The area is divided by two shallow gullies that carve through the starting area. To the south and north of the gullies the surface is composed of cliffs and weathered rocks. The largest cliffs at 175 and 200 m a.s.l. are called Gimbraklettar. The general shape of the area is convex, but along the gullies, the landscape is slightly concave. A 100 m wide shallow depression is in the northern part of the starting area from 300 m a.s.l. to 110 m a.s.l. Altogether, the starting area is about 10.9 ha.

Track

The unconfined track starts at 110 m a.s.l. and goes down to the β-line around 20 m a.s.l. The inclination is 30° at the top and decreases gradually down to the β-line. The avalanche track is even and the surface of the upper part consists of grass covered weathered debris.

Runout area

The runout area starts about 20 m a.s.l. around the β-line. The inclination decreases to 2° within the settled area at 5–10 m a.s.l. The runout area has been densely settled since the 1920's, but the uppermost houses are from the 1930's.

7.2 Climatic conditions

A large snow accumulation is only expected in the two gullies from northerly winds. Snow accumulation in the main part of the starting area is most likely in northwesterly to westerly winds.

7.3 Chronicle

There are many recorded avalanches in the area. Some of them have hit the houses and caused damage. The recorded avalanches are shown on Map 2 and listed in the following table:

Number Time *Runout index*	**Description**
2008 23.11.1938 *9.5*	A wet slab avalanche fell from Hafnarhyrna and hit the house Seljaland. Seljaland was a two story concrete house with a basement. Most of the snow stopped above the house. One window was shattered and allowed snow to fill half of the ground floor.
2009 23.11.1938 *10.1*	A wet slab avalanche damaged a henhouse above Hólavegur, but the hens escaped. The avalanche started in Hafnarhyrna, most likely between Mið- and Ysti-Gimbraklettur.
2022 14.2.1971 *10.6*	An avalanche fell south of Mið-Gimbraklettur. A narrow tongue hit potato storage sheds and stopped at Hólavegur.
2041 3.2.1981 *≪11*	A loose dry avalanche fell between Mið-Gimbraklettur and Ysti-Gimbraklettur. The avalanche stopped around 80 m a.s.l. and the deposit was 5–10 m wide.
2042 5.2.1981 *≪11*	A loose wet avalanche started in Hafnarhyrna and stopped just below Mið-Gimbraklettur around 125 m a.s.l. The deposit was about 5 m wide.
2917 30/31.1.1982	Snowballs rolled down Hafnarhyrna.
2057 19.1.1983 *≪11*	A loose wet avalanche fell south of Mið-Gimbraklettur and stopped around 100 m a.s.l. by the road to Hvanneyrarskál. The deposit was about 10 m wide.
2058 22.1.1983	Many small avalanches started in the lowest part of Hafnarhyrna below Hvanneyrarskál to the south of Mið-Gimbraklettur. The loose wet avalanches were 5–10 m wide.
2988 17/18.4.1985 *6.0*	A loose dry avalanche started south of Syðsti-Gimbraklettur. It passed the road and stopped a little above the town fence.
2102 23.3.1991 *9.7*	Two avalanches started below rockfaces in Hafnarhyrna. One of the avalanches reached down to about 65–70 m a.s.l. and the other down to about 30 m a.s.l. No damage is recorded except possible minor damage to the town fence.
2103 Prob. 25–26.10.1992	A loose wet avalanche fell south of Gimbraklettar.
2968 4/5.4.1993	An avalanche fell north of Gimbraklettar.
2113 30.1.1995	Several narrow avalanches started in Hafnarhyrna south of Gimbraklettar. The avalanches reached down to about 85–95 m a.s.l.
2122 11.2.1996	Small avalanches fell in many locations in the vicinity of Siglufjörður, including the Gimbraklettar area.

Number Time *Runout index*	Description
2127 21/22.2.1997	At least 12 small avalanches were released from Gimbraklettar and north to Gróuskarðshnjúkur.
2130 29.3.1997 *7.0*	Five small avalanches started in Hafnarhyrna. The avalanche with the longest runout stopped about 120 m from the uppermost houses in Hólavegur. The width was about 25 m.
2937 30/31.11.1998	Several small loose and wet avalanches started in the Gimbraklettar area.
2143 26.12.1998 *10.3*	Several small avalanches started in the Gimbraklettar area.
2931 29.3.1999	A small and dry slab avalanche started south of Gimbraklettar.

7.4 Assessment

Due to shape, aspect, and inclination, expected avalanches should be considerably less than 100,000 m^3. The recorded avalanches are small indicating early snow release in accordance with the high inclination. This reduces the probability of large avalanches.

7.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profiles `siha07aa` and `siha08aa`, and the results of the calculations are shown in Drawings 11–12. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

The uppermost houses are very close to the mountain at about $r = 10$. Small and medium sized avalanches will thus pose considerable risk to the settlement.

Similar indications are given by the α/β-model. There are about two rows of houses located above the β-line and an avalanche with runout of only $\alpha + \sigma$ will run about 150 m into the settlement.

The data are not suitable for risk estimations using the methods of RiskEst.

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 should be interpreted with care since an avalanche starting in the whole starting area is simulated while this is not considered realistic as described in the assessment section. The results are described by Tómas Jóhannesson *et al.* (2001).

7.6 Conclusion

A balance has to be found between the somewhat misleading indications regarding the hazard in the area. On one hand the area has been settled for quite a while, there is not considered to be a potential for very large avalanches and snow accumulation is not very likely. On the other hand quite a few avalanches are recorded in the area and the houses are located close to or even in the slope.

The boundary of the category C hazard zone was set at about runout index 12. The uncertainty of the estimate is considered to be medium (1).

The hazard zoning proposal can be seen on Map 5.

8 The hillside below Hvanneyrarskál, south of the river Hvanneyrará

8.1 Topographic description

Below Hvanneyrarskál there is about a 200 m high slope above the settlement. Figures 3 and 4 show the area. It can be seen on Maps 1 and 4 and longitudinal sections (`siha09aa` and `seha10aa`) are shown in Drawings 13–14.

Starting area

The potential starting area (indicated with the number 12 on Figures 3 and 4 and Map 4) is between 185 and 100 m a.s.l. with a width of 350 m. The average inclination is about 30°. The area faces ESE and the even form is interrupted by several shallow gullies. Above the potential starting area, the inclination decreases gradually to less than 10° at the bottom of the large bowl Hvanneyrarskál. The northern boundary of the starting area is marked by a deep gully, but the southern boundary is not as well defined and merges with the Hafnarhyrna starting area. The area is about 4.7 ha. The surface is weathered debris covered with grass.

Track

From 125 m a.s.l. to the β-line at around 20 m a.s.l., the inclination decreases gradually from 30° to 10°. The track is unconfined and several houses are in the northern part of the track. The oldest building is a hydroelectric power station built in 1936.

Runout area

The runout area starts about 20 m a.s.l. and the inclination is 6–10° down to the main road by the sea. It is densely settled with houses that were mostly built in the second half of this century.

8.2 Climatic conditions

The area is perhaps slightly on the lee side of the mountain ridge below Gróuskarðshnjúkur so snow accumulation is possible in northerly winds. Snow might also drift from Hvanneyrarskál. Snow accumulation conditions in this area are not considered to be favorable for the release of avalanches.

8.3 Chronicle

Avalanches have only once been recorded in the area:

Number Time *Runout index*	Description
2127 21/22.2.1997	At least 12 small avalanches were released from Gimbraklettar and north to Gróuskarðshnjúkur.

8.4 Assessment

Snow accumulation in the starting area is not likely. Furthermore parts of the area have inclination that is less than 30°. Only small avalanches are expected to be released in the area and they are considered to be infrequent.

8.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profiles `siha09aa` and `siha10aa`, and the results of the calculations are shown in Drawings 13–14. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

Similar results are obtained as for Gimbraklettar, see section 7.5. The β-line is below the uppermost houses and even small and medium sized avalanches reach far into 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.* (2001).

8.6 Conclusion

The starting area is not favourable for the release of avalanches and only small avalanches are expected. The settlement is located too close to the slope, although the threat is not considered immediate. It is therefore suggested to draw the boundary of the category C hazard zone right above the uppermost houses and let the category B and A hazard zones extend considerably into the settlement.

The uncertainty of the estimate is considered to be low to medium ($\frac{1}{2}$–1). The hazard zoning proposal is shown on Map 5.

9 Gróuskarðshnjúkur, southern part

9.1 Topographic description

The mountain Gróuskarðshnjúkur is north of Hvanneyrarskál. The area described below is in its south-eastern slope. Figures 3 and 4 show the area. It can be seen on Maps 1 and 4 and a longitudinal section (`sigr11aa`) is shown in Drawing 15.

Starting area

The starting area (indicated by the number 13 on Figures 3 and 4 and Map 4) is between 340 and 100 m a.s.l. with an average inclination of 31°. The width averages about 100 m with an area of about 4.7 ha. The area faces southeast and is a shallow depression covered with talus within a mountain ridge.

Another small starting area (indicated by the number 16 in Figure 4) to the west of the starting area described above was considered. After field investigation and model estimates the possibility of avalanches from the area reaching the settlement was ruled out.

Track

The avalanche track ranges from 80 m a.s.l. to the β-line at about 25 m a.s.l. It is covered with talus in the upper part and some vegetation in the lower part. The track is unconfined and even. A part of the snow from the upper part of the starting area will go down into the bowl Hvanneyarskál and thus has a separate track.

Runout area

The runout area is densely settled with houses. The houses closest to the mountain were built in the 1970's and the houses furthest away from the mountain were built just before 1950. The inclination is between 5° and 10°.

9.2 Climatic conditions

Snow accumulation is most likely in northerly winds. Snow can drift along the mountainside north of the starting area, over the mountain ridge and accumulate in this shallow depression.

9.3 Chronicle

There are three avalanches recorded in the area. One of them damaged a house. The recorded avalanches are shown on Map 2 and listed in the following table:

Number Time *Runout index*	**Description**
2014 26.12.1963 *12.1*	A wet avalanche started in Gróuskarðshnjúkur. It reached past the northern bank of Hvanneyrará. It hit and destroyed the henhouse Hvanneyrarhlíð. The avalanche also hit the domestic houses Fossvegur 8 and 10 and caused some damage. The longest runout of the avalanche was by the west wall of the house at Hvanneyrarbraut 51 at about 15 m a.s.l. The width of the deposit was about 100 m by Hvanneyrarhlíð.
2020 29.1.1971	A cornice in Hvanneyrarbrún collapsed when boys were playing on it, but it didn´t start an avalanche. The boys were saved from the snow mass.
2216 13.2.1988	A small wet and loose avalanche started in southern Gróuskarðshnjúkur. It stopped at about 220 m a.s.l. in Hvanneyrarskál.

9.4 Assessment

Due to the size and shape of the starting area, only medium sized avalanches with volumes of several tens of thousands of m^3 are expected to start in this area. This starting area is not a typical starting area for dry avalanches and the probability of release of a dry avalanche is uncertain.

9.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profile `sigr11aa`, and the results of the calculations are shown in Drawing 15. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

Most of the houses in the area are located below runout index 11. The β-line is located above all the 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.* (2001).

9.6 Conclusion

The hazard zones are deliniated so that the category C hazard zone extends a little longer than the longest recorded avalanche.

The uncertainty of the estimate is considered to be low to medium ($\frac{1}{2}$–1). The hazard zoning proposal is shown on Map 5.

10 Gróuskarðshnjúkur, northern part

10.1 Topographic description

The area described below is in the eastern slope of Gróuskarðshnjúkur. Figure 4 shows the area. It can be seen on Maps 1 and 4 and a longitudinal section (`sigr12aa`) is shown in Drawing 16. There is a rather large gully to the north of the area. It can be seen on the same Figure and Maps and a longitudinal section (`sigr13aa`) is shown in Drawing 17.

Starting area

The starting area (indicated by the number 14 on Figure 4 and Map 4) is located on an ESE facing slope between 340 and 100 m a.s.l. This triangular area is 250 m at its widest in the lowest part. The average inclination is between 35° and 40°. In the upper part of the area, large cliff formations protrude from the hillside with small gullies in between. Cliffs with the height of several meters divide the starting area into smaller areas. The lower part of the starting area is covered with talus and interrupted by some cliff belts. The area is about 6.5 ha.

To the north there is a large starting area in a gully (indicated by the number 15 on Figure 4 and Map 4). Avalanches from the area are not considered to threaten the current settlement and the area is thus not described in detail.

Track

The unconfined track begins at 110 m a.s.l. and stretches to the β-line around 40 m a.s.l. The inclination decreases gradually from 30° to 10°. The upper part of the starting area is covered with talus and the lower part consists of small debris cones covered with grass and isolated rocks that indicate high rock fall activity. In the southern part of the lower track, some houses were built around 1970–80, and one house was built in 1947.

Runout area

The runout area is between the β-line and the main street Hvanneyrarbraut. The inclination of the area is between 7° and 13°. The area is even and covered with grass and the southern part of it is settled. Most of the houses were built in the 1970's, but some houses are from around 1950.

10.2 Climatic conditions

Great snow accumulation by northerly and northwesterly winds is unlikely because of the shape and aspect of the starting area. Snow accumulation is restricted to the gullies and bowls between the cliffs. It is difficult to estimate the probability of snow accumulation by westerly and southwesterly winds from the large Hvanneyrarskál bowl.

10.3 Chronicle

Some avalanches are recorded in this area. Most of them came from the gully which is just north of the settlement. The recorded avalanches are shown on Map 2 and listed in the following table:

Number Time *Runout index*	**Description**
2015 26.12.1963 *12.4*	A wet slab avalanche probably started in the first gully north of Hvanneyrarskál on Hvanneyrarströnd. The avalanche went between sheep sheds most of the way down to the sea. The width of the deposit was probably a little below 50 m.
2026 14/15.2.1971 *>12.9*	An avalanche probably started in the hill between the first two gullies north of Hvanneyrarskál, above Hvanneyrarströnd. The avalanche damaged a sheep shed and killed 12 sheep. It also hit a summer cottage and moved parts of it to the seashore. The tongue was around 100 m wide.
2031 22.4.1979	A small loose wet avalanche started in Gróuskarðshnjúkur. The avalanche had a short runout.
2056 19.1.1983	A loose wet avalanche was released in the southernmost part of Strákafjall north of Hvanneyrará. The avalanche reached about two thirds of the distance down to the domestic houses in Hólavegur.
2217 13.2.1988 *7.7*	A small avalanche started in Gróuskarðshnjúkur in the first gully to the north of the settlement. The width of the deposit was about 25 m and its tip at about 80 m a.s.l.
2114 19.2.1995 *9.8*	In the gully north of Gróuskarðshnjúkur, a loose dry avalanche fell and stopped above potato fields to the north of the settlement. Formerly sheep sheds were located there. The width of the tip of the deposit was about 20 m.
2947 26.3.1997	Three small avalanches fell south of "Gróuskarðsgil".
2141 30.10.1998 *7.7*	Two small avalanches fell to the east below Gróuskarðshnjúkur above the northernmost houses in Hólavegur. The avalanches stopped at about 50–60 m a.s.l.
2144 20.1.1999	Avalanches started in all the gullies north of Selgil. One wide but thin avalanche started in a gully north of Gróuskarð, a little to the north of the settlement. In addition, two small avalanches started in Gróuskarðshnjúkur above Hólavegur.

10.4 Assessment

No large avalanches are recorded in this area, and a large avalanche starting in the whole starting area is not expected. Smaller avalanches in the range of several thousand cubic meters are more likely, and can start in the gullies between the cliffs.

10.5 Model estimates

Map 4 shows the results of model calculations and the profiles used for the calculations. The profiles `sigr12aa` and `sigr13aa`, and the results of the calculations are also shown in Drawings 16–17. The runout was calculated using runout indices and an α/β-model. For explanation see Appendix A.

The uppermost houses are located at about $r = 10$ and an avalanche with runout of about $r = 13$ will reach the shoreline.

The β-line is in and above the uppermost row of houses. An avalanche with a runout a little bit more than α will reach the shoreline.

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.* (2001).

10.6 Conclusion

The hazard zones are deliniated so that the boundary of the category C hazard zone is located at about $r = 11$.

The uncertainty of the estimate is considered to be high (2). The hazard zoning proposal is shown on Map 5.

11 Conclusion

The results presented in this report indicate that a large proportion of the residences in Siglufjörður are in a hazard zone according to the Icelandic regulation on hazard zoning.

The area in the southern part of the settlement below Jörundarskál and Strengsgil has for the past decades propably been one of the most hazardous in Iceland. The area has been protected by deflecting dams that should protect the area, even from catastrophic avalanches.

There is great uncertainty about the actual risk in the area below northern Fífladalir. It is however clear that there is a potential for large avalanches in the area and the houses are located close to and in the slope. Considering the density of the settlement, the area has to be considered very hazardous. It should therefore have a priority to improve the safety in the area by for example building defence structures.

In the area below southern Gróuskarðshnjúkur houses are currently standing in an area that has been overrun by an avalanche. The area should be monitored closely and permanent measures should be taken in due course.

The uppermost houses below Gimbraklettar have been hit by avalanches and relatively small avalanches endanger the houses below. There are quite a few houses located in the category C hazard zone. The potential for larger avalanches is uncertain and the area should be monitored closely to strengthen the basis for a future revision of the hazard zoning.

Below Skriðulækjargil the settlement is not located as close to the slope as further to the north. There are only a few houses in the category C hazard zone.

References

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

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

Björnsson, Halldór. 2001. *Veður í aðdraganda snjóflóðahrina á Siglufirði. [Weather preceding avalanche cycles in Siglufjörður].* IMO, Rep. 01018.

Grímsdóttir, Harpa 1998. *Byggingarár húsa á Siglufirði. [Building years of houses in Siglufjörður.]* IMO, Rep. VÍ-G98049-ÚR36.

Grímsdóttir, Harpa and Thorsteinn Sæmundsson. 2001. *Siglufjörður. Annáll snjóflóða til vorsins 2001. [The avalanche chronicle of Siglufjörður].* IMO, Rep. 01016.

Hnit. 1989. *Snjóflóðahættumat fyrir Siglufjörð. [Hazard Zoning for Siglufjörður.]* Proj. 69-3. (Author Árni Jónsson).

IMO. 1996. *Greinargerð um snjóflóðaaðstæður vegna rýmingarkorts fyrir Siglufjörð. [Description of the avalanche situation in Siglufjörður in connection with an evacuation map for the town].* IMO, Rep. VÍ-G96009-ÚR09.

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. 2000a. *Snow depth measurements in the mountain above Siglufjörður 1996–2000.* IMO, Memo TóJ-2000/02.

Jóhannesson, Tómas. 2000b. *Snow depth at meteorological stations in the neighbourhood of Siglufjörður.* IMO, Memo TóJ-2000/08.

Jóhannesson, Tómas, Thorsteinn Arnalds and Leah Tracy. 2001. *Results of the 2D avalanche model SAMOS for Siglufjörður.* IMO, Rep. 01019.

Jóhannesson, Tómas and Stefan Margreth. 1999. *Adaptation of the Swiss Guidelines for supporting structures for Icelandic conditions.* IMO, Rep. VÍ-G99013-ÚR07.

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.

Kiernan, Sigurður , Jón Gunnar Egilsson and Tómas Jóhannesson. 1998. *Snjódýptarmælingar á stikum veturinn 1996/97. [Snow stake measurements in the winter of 1996/97.]* IMO, Rep. VÍ-G98018-ÚR14.

Kiernan, Sigurður and Tómas Jóhannesson. 1998. *Snjódýptarmælingar á stikum veturinn 1997/98. [Snow stake measurements in the winter of 1997/98.]* IMO, Rep. VÍ-G98045-ÚR34.

Kiernan, Sigurður, Jón Gunnar Egilsson and Tómas Jóhannesson, 1999. *Snjódýptarmælingar á stikum, við leiðigarða og á snjódýptarsniðum í fjallshlíðum veturinn 1998/1999. [Measurements of snowdepth by now stake, in the vicinity of deflecting dams and in longitudinal sections of avalanche paths in the winter of 1998/1999.]* IMO, Rep. VÍ-G99021-ÚR11.

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

Margreth, S. 1997. *Velocity profiles, Siglufjörður, Iceland.* SLF Tech. Rep., Davos, 12. June 1997.

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

Pétursson, Halldór G. and Þorsteinn Sæmundsson. 1999. *Skriðuföll á Siglufirði. [Debris flows in Siglufjörður.]* Icelandic Institute of Natural History, Rep. NÍ-99011.

Sigurðsson, Sven, Kristján Jónasson and Thorsteinn Arnalds. 1998. Transferring Avalanches Between Paths. *In: 25 years of snow avalanche research.* Publikation nr. 203, Erik Hestnes, ed., p. 259–263, NGI, Oslo.

SLF. 1975. *Avalanche problems of Iceland. Analysis and recommendation for further action.* Eidgenössisches Institut für Schnee- und Lawinenforschung. SLF, Rep. G75.51 (author M. R. de Quervain).

SLF. 2001. *Siglufjörður, Iceland. Avalanche defences. Protection plan for the residential area.* SLF, Rep. G2001.01 (author S. Margreth).

Sæmundsson, Þorsteinn and Halldór G. Pétursson. 1999. *Skriðuhætta á Siglufirði. [Debris flow hazard in Siglufjörður.]* IMO, Rep. VÍ-G99025-ÚR15.

VS. 1986. *Útreikningur á hraða og skriðlengd snjóflóða. Þróun reiknilíkans fyrir tölvu. Samanburður við þekkt snjóflóð. Tillögur um reikniaðferðir. [Speed and runout calculations for avalanches. Development of a computerised computational model. Comparison with known avalanches. Suggestions for calculation methods.]* Verkfræðistofa Siglufjarðar sf. (Þorsteinn Jóhannesson author).

VS and NGI. 1997. *Frumathugun á snjóflóðavörnum. [Avalanche defence appraisal].*

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 5).

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 5).

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. 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 referred to as the runout index 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 $r_0 = 13$.

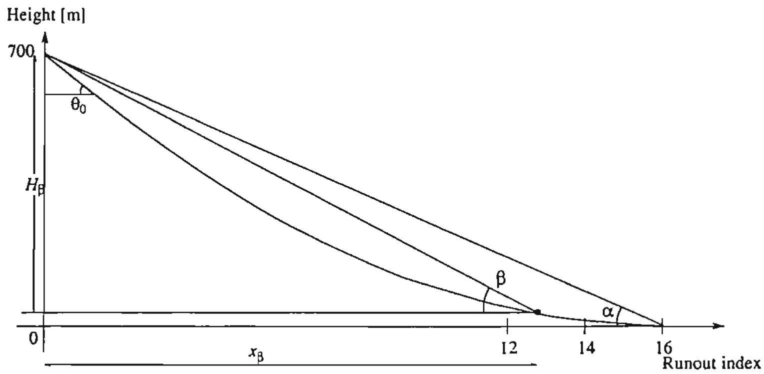


Figure 5. *The standard path. The α-angle is the expected α-angle of an avalanche according to the α/β-model.*

B Maps

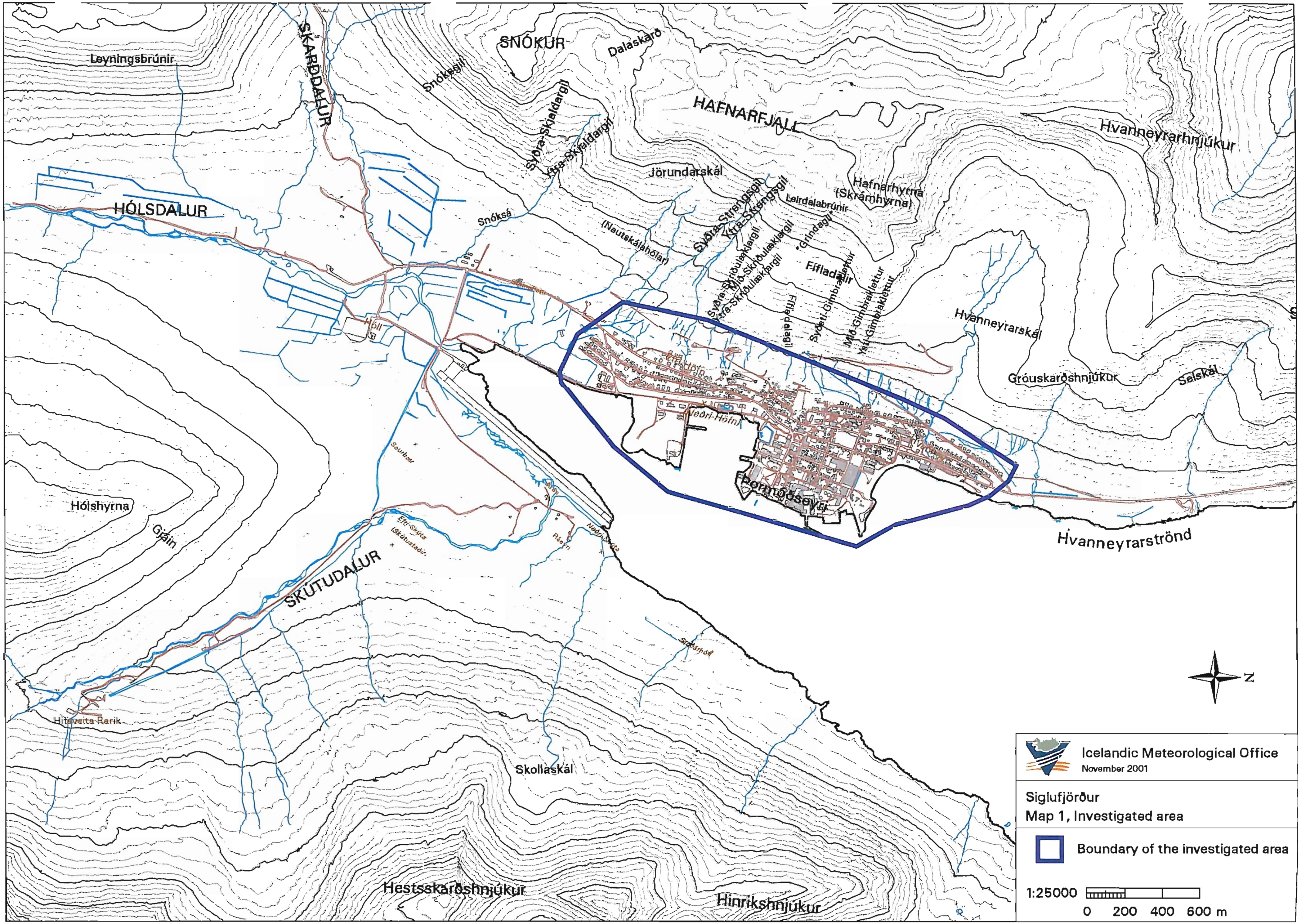
Map 1. An overview of Siglufjörður and the boundary of the investigated area (A4, 1:25 000).

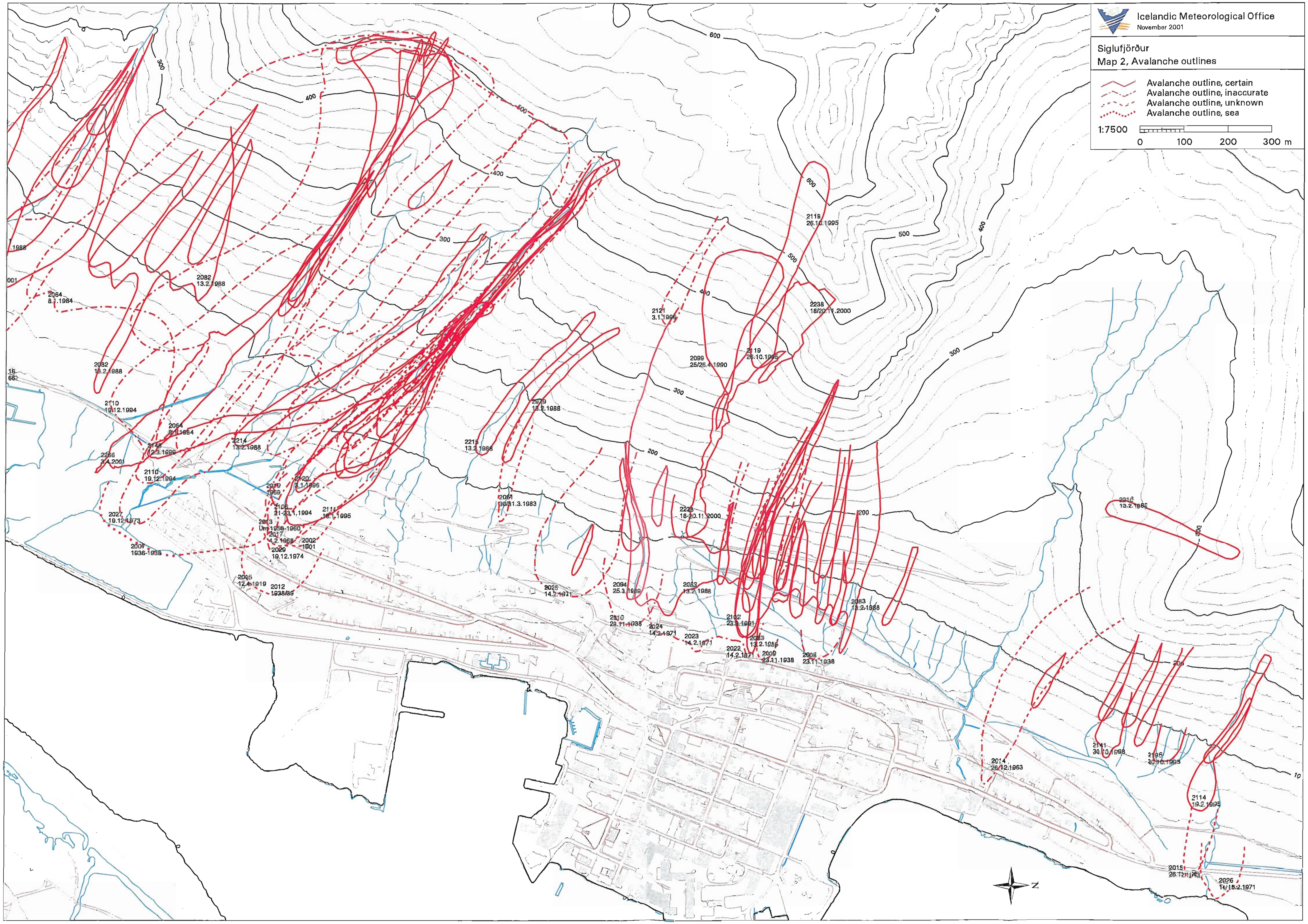
Map 2. Recorded avalanches (A3, 1:10 000).

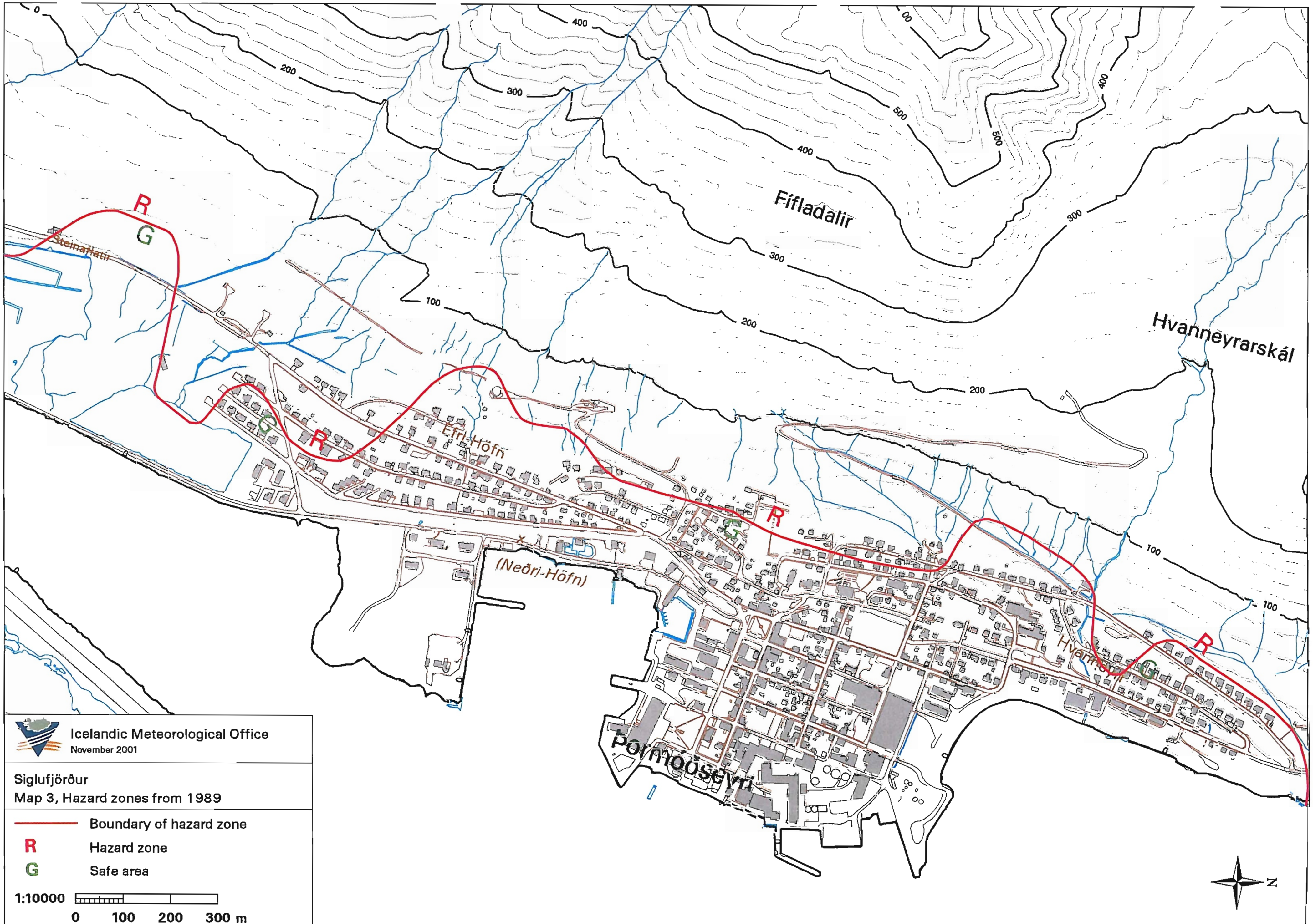
Map 3. A hazard map for Siglufjörður proposed in 1989 (A4, 1:10 000).

Map 4. Results of model estimates (A3, 1:10 000).

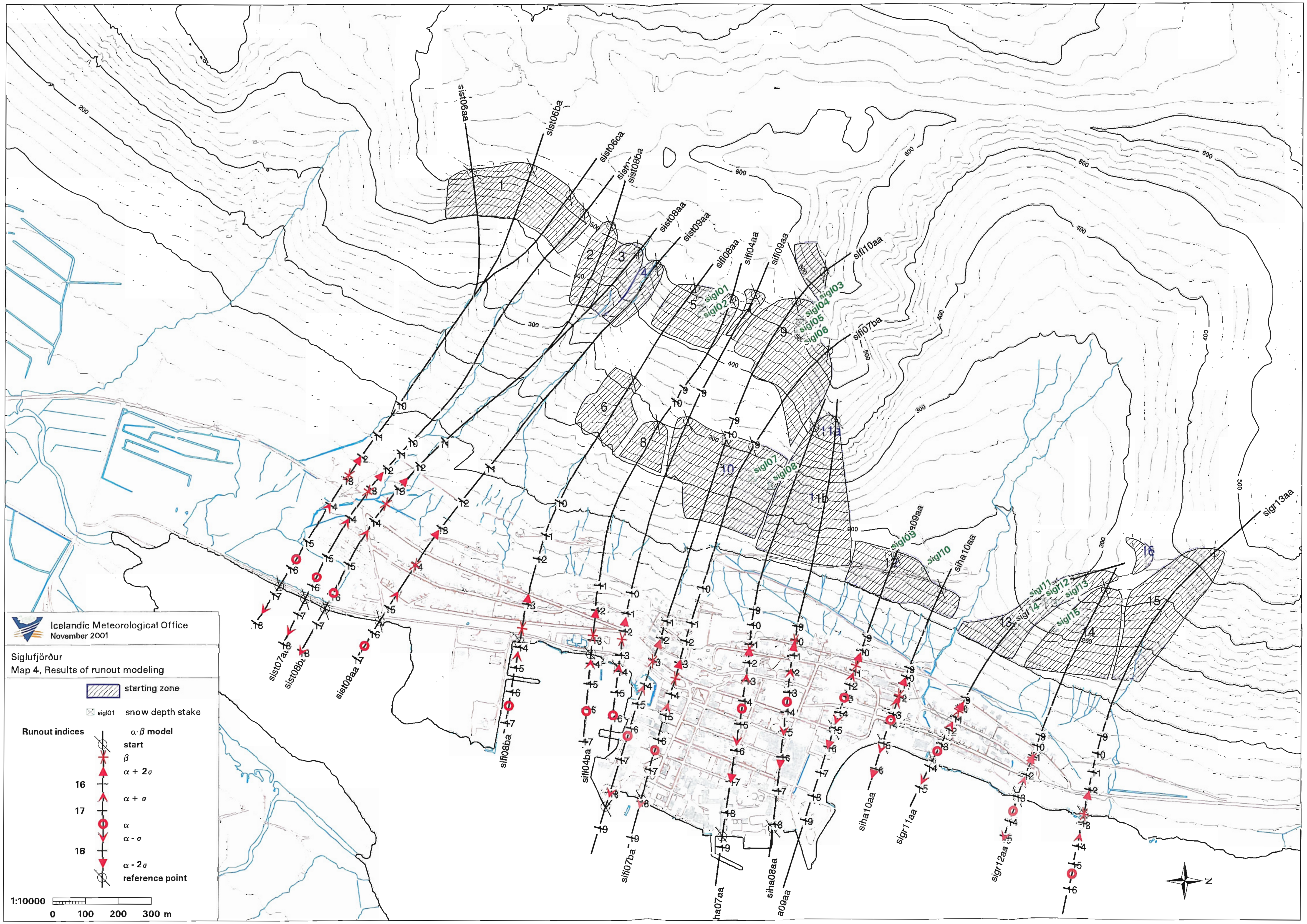
Map 5. Proposed hazard zoning for the investigated area (A3, 1:7 500).


SNÓKUR
Dalaskarð
Leyningsbrúnir
SKARÐDALUR
HAFNARFJALL
Hvanneyrarhnjúkur
Jörundarskál
HÓLSDALUR
Snóksá
Hafnarhyrna
(Skrámhyrna)
Fífladalir
Hvanneyrarskál
Gróuskarðshnjúkur
Selskál
Hólshyrna
Gjáin
SKÚTUDALUR
Hvanneyrarströnd
Skollaskál
Hestsskarðshnjúkur
Hinrikshnjúkur
Hitaveita Rarik
Neðri-Höfn
Þormóðseyri
Icelandic Meteorological Office
November 2001
Siglufjörður
Map 1, Investigated area
Boundary of the investigated area
1:25000
0 200 400 600 m

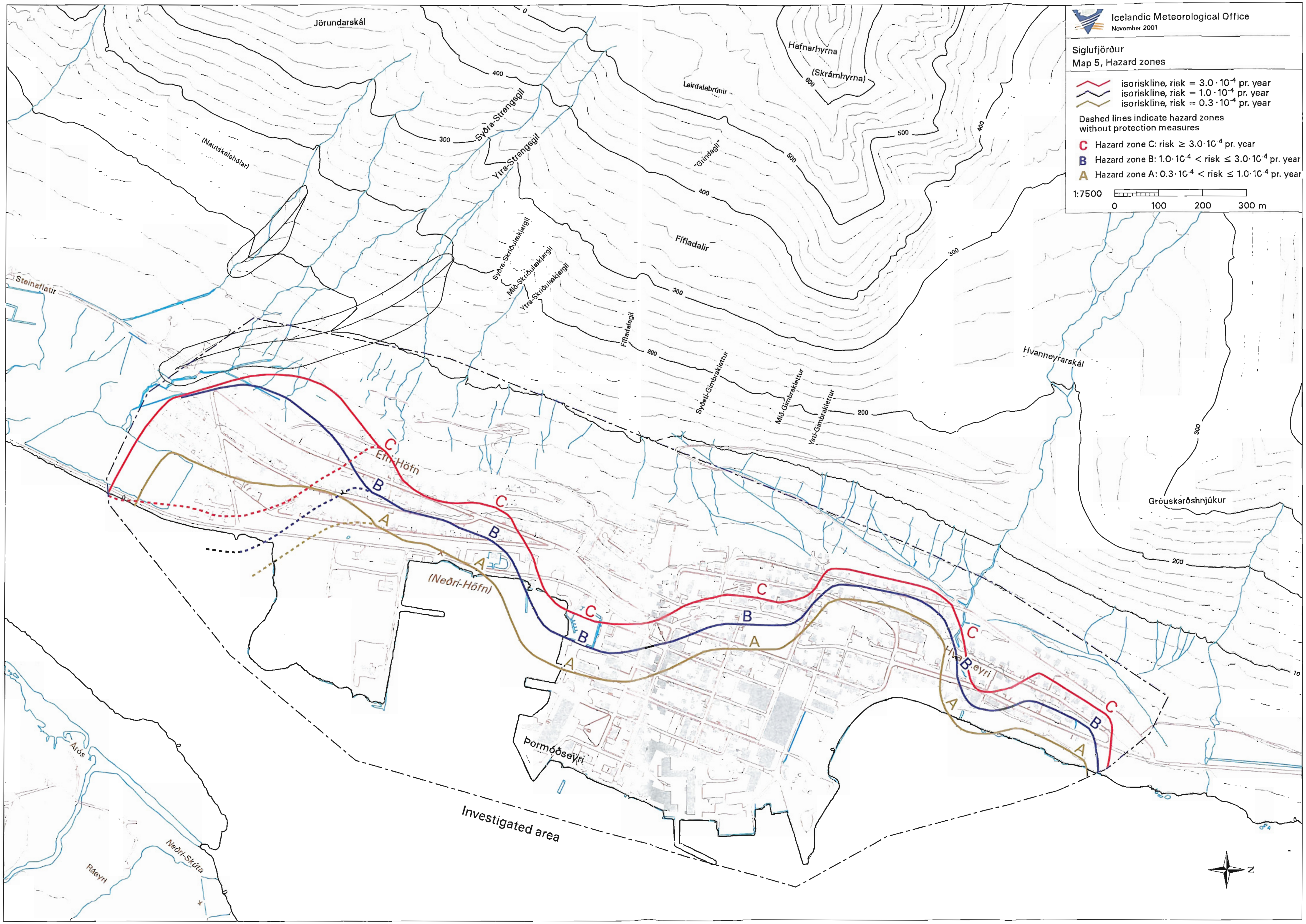

Icelandic Meteorological Office
November 2001
Siglufjörður
Map 2, Avalanche outlines
Avalanche outline, certain
Avalanche outline, inaccurate
Avalanche outline, unknown
Avalanche outline, sea
1:7500
0
100
200
300 m
2082
13.2.1988
2064
8.1.1984
2110
19.12.1994
2266
3.4.2001
2027
19.12.1973
2007
1936-1938
2214
13.2.1988
2005
12.4.1919
2012
1938/39
2029
19.12.1974
2111
18.1.1995
2079
13.2.1988
2215
13.2.1988
2025
14.2.1971
2094
25.3.1989
2099
25/26.4.1990
2121
3.1.1996
2119
26.10.1995
2238
18/20.11.2000
2063
13.2.1988
2102
23.3.1991
2024
14.2.1971
2023
14.2.1971
2022
14.2.1971
2009
23.11.1938
2006
23.11.1938
2216
13.2.1988
2141
30.10.1995
2196
30.10.1995
2014
26.12.1963
2114
19.2.1995
2026
14/15.2.1971
400
300
500
600
200
100



Fífladalir
Hvanneyrarskál
Steinaflatir
Efri-Höfn
(Neðri-Höfn)
Þormóðseyri
R
G
400
300
200
100
500
Icelandic Meteorological Office
November 2001
Siglufjörður
Map 3, Hazard zones from 1989
Boundary of hazard zone
R Hazard zone
G Safe area
1:10000
0 100 200 300 m



Icelandic Meteorological Office
November 2001
Siglufjörður
Map 4, Results of runout modeling
starting zone
sigl01 snow depth stake
Runout indices
α-β model
start
β
α + 2σ
α + σ
α
α - σ
α - 2σ
reference point
1:10000
0 100 200 300 m



Icelandic Meteorological Office
November 2001
Siglufjörður
Map 5, Hazard zones
isoriskline, risk = 3.0 · 10⁻⁴ pr. year
isoriskline, risk = 1.0 · 10⁻⁴ pr. year
isoriskline, risk = 0.3 · 10⁻⁴ pr. year
Dashed lines indicate hazard zones without protection measures
C Hazard zone C: risk ≥ 3.0·10⁻⁴ pr. year
B Hazard zone B: 1.0·10⁻⁴ < risk ≤ 3.0·10⁻⁴ pr. year
A Hazard zone A: 0.3·10⁻⁴ < risk ≤ 1.0·10⁻⁴ pr. year
1:7500
0 100 200 300 m
Jörundarskál
Hafnarhyrna
(Skrámhyrna)
Leirdalabrúnir
Syðra-Strengsgil
Ytra-Strengsgil
(Nautskálahólar)
"Grindagil"
Fífladalir
Syðra-Skriðulækjargil
Mið-Skriðulækjargil
Ytra-Skriðulækjargil
Fífladalagil
Syðsti-Gimbraklettur
Mið-Gimbraklettur
Ysti-Gimbraklettur
Hvanneyrarskál
Gróuskarðshnjúkur
Steinaflatir
Efri-Höfn
(Neðri-Höfn)
Hvanneyri
Þormóðseyri
Investigated area
Árós
Neðri-Skúta
Ráeyri

C Climatic data

C.1 Summary statistics: Temperature and wind

Siglufjörður, no. 3752, 6 m a.s.l. 66°08' N, 18°54' W (November 1995–October 2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	0.3	−1.6	−1.3	0.7	4.8	6.8	9.5	9.3	7.5	3.1	0.5	−0.6	**3.2**
max(tx)	15.2	12.0	14.4	15.3	21.4	23.4	21.2	20.8	21.1	18.0	19.4	15.1	**23.4**
min(tn)	−14.1	−16.0	−17.5	−15.2	−6.5	−3.5	0.4	−0.6	−4.8	−11.1	−15.1	−17.7	**−17.7**
avg(f)	6.0	5.2	5.2	3.7	3.4	3.2	2.9	2.8	3.9	4.3	4.5	4.3	**4.1**
max(fx)	23.8	21.5	25.6	18.2	15.9	15.1	14.6	14.7	24.8	23.0	19.1	19.4	**25.6**
max(fg)	46.8	38.9	45.5	33.3	32.9	25.9	26.1	28.3	42.8	46.5	36.7	36.9	**46.8**

Siglunes, no. 3754, 8 m a.s.l. 66°11' N, 18°49' W (November 1995–October 2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	1.0	−0.9	−0.5	1.0	5.1	6.9	9.4	9.7	7.3	3.7	1.4	0.3	**3.7**
max(tx)	14.4	12.9	14.3	16.6	21.9	25.6	23.9	21.0	19.5	18.2	17.3	15.9	**25.6**
min(tn)	−9.8	−15.6	−14.0	−8.3	−6.0	−1.5	2.3	1.0	−2.0	−7.4	−11.1	−13.2	**−15.6**
avg(f)	8.4	7.8	7.6	6.2	5.3	5.2	4.8	4.6	5.9	6.4	6.7	6.8	**6.3**
max(fx)	28.9	28.5	28.6	23.3	21.1	18.4	18.0	18.4	21.0	21.9	26.4	24.0	**28.9**
max(fg)	48.4	50.0	43.1	40.2	34.6	27.2	32.3	29.0	36.5	31.7	50.0	36.5	**50.0**

Siglufjarðarvegur, no. 33750, 20 m a.s.l. 66°10' N, 19°00' W (November 1995–October 2001)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	1.3	−0.8	−0.9	1.5	5.4	7.4	10.0	10.1	8.4	4.0	1.8	0.9	**4.1**
max(tx)	13.6	13.0	14.1	12.3	19.3	22.9	21.3	21.8	21.3	17.5	18.0	16.2	**22.9**
min(tn)	−10.6	−15.1	−14.7	−8.0	−6.0	−2.3	1.7	2.2	−2.0	−8.3	−8.1	−11.6	**−15.1**
avg(f)	7.7	7.4	7.0	4.6	4.5	3.7	3.5	3.0	4.8	5.6	5.9	6.0	**5.3**
max(fx)	31.4	29.1	29.5	23.1	21.4	16.8	19.5	18.4	23.9	27.5	26.3	30.3	**31.4**
max(fg)	45.8	41.8	42.5	32.3	34.2	25.3	26.0	26.5	37.6	41.4	45.9	43.8	**45.9**

Siglunes/Reyðará, no. 402/403, 8 m a.s.l. 66°11' N, 18°50' W (1961–1989)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(t)	−1.2	−0.6	−0.4	1.2	3.7	6.6	8.5	8.6	5.8	3.5	0.8	−0.8	**3.0**
avg(tx)	1.3	2.2	2.1	3.9	6.3	9.4	11.2	11.2	8.1	5.7	3.1	2.0	**5.6**
max(tx)	13.0	13.6	14.5	15.3	17.6	20.1	22.5	24.0	19.6	20.2	17.7	15.5	**24.0**
avg(tn)	−4.0	−3.4	−3.2	−1.5	1.4	4.6	6.6	6.4	3.4	1.0	−1.9	−3.5	**0.5**
min(tn)	−16.9	−17.1	−16.7	−15.5	−12.5	−4.0	0.0	−2.0	−5.3	−8.8	−16.5	−15.5	**−17.1**

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), **avg:** average.

C.2 Summary statistics: Precipitation

Average precipitation, avg(r) (1991–2000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Skeiðsfoss, 396	123	87	108	51	48	47	48	69	103	134	100	92	**1009**
Sauðanesviti, 400	61	60	64	40	49	67	75	72	101	128	84	71	**873**
Kálfsárkot, 406	92	73	77	45	42	43	36	73	100	138	109	90	**919**
Tjörn, 409	62	53	56	30	21	24	24	39	51	74	56	54	**546**

Maximum recorded monthly and yearly accumulated precipitation, max(r) (1991–2000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Skeiðsfoss, 396	241	122	184	132	121	196	103	116	237	263	212	193	**1379**
Sauðanesviti, 400	127	87	127	72	122	153	194	126	209	272	186	134	**1098**
Kálfsárkot, 406	209	130	141	147	96	161	68	243	223	296	231	247	**1383**
Tjörn, 409	105	81	125	62	52	63	42	70	87	161	93	117	**678**

Maximum recorded daily accumulated precipitation, max(rx) (1991–2000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Skeiðsfoss, 396	34	35	38	26	45	57	47	43	54	73	74	25	**74**
Sauðanesviti, 400	25	31	42	27	34	43	39	32	45	86	31	24	**86**
Kálfsárkot, 406	38	22	46	32	48	55	22	87	52	48	51	50	**87**
Tjörn, 409	27	21	34	14	21	19	18	27	29	39	31	39	**39**

Period 1971–2000

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(r)													
Skeiðsfoss, 396	106	85	88	58	43	44	57	71	90	115	104	96	**956**
Tjörn, 409	57	43	43	33	18	24	32	38	48	64	56	54	**509**
max(r)													
Skeiðsfoss, 396	241	218	184	132	121	196	199	163	237	263	212	232	**1379**
Tjörn, 409	140	95	125	65	52	63	79	82	88	161	106	170	**696**
max(rx)													
Skeiðsfoss, 396	59	44	51	26	45	57	82	91	54	73	74	40	**91**
Tjörn, 409	55	21	34	23	21	19	27	44	29	39	33	39	**55**

Siglunes/Reyðará (402/403) (1961–1989)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
avg(r)	50	37	43	38	37	51	64	73	89	92	60	53	**695**
max(r)	115	95	102	85	110	152	137	151	211	175	112	171	**939**
max(rx)	45	22	36	31	51	49	64	38	59	49	26	35	**64**

Note: September 1988, March, August and September 1989 are missing from the data series.

Precipitation in Siglufjörður AWS (3752) (1996–2000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max accum.	177	113	149	127	136	78	142	143	279	355	447	190	**1577**
Min accum.	40	59	19	29	14	21	30	24	130	168	127	47	**1458**
Max 24 hr. accum.	47	53	47	51	38	35	57	64	99	147	81	58	**147**
Max 1 hr accum	7	7	14	6	5	10	6	8	10	15	13	6	**15**

Precipitation in Siglufjörður (401) (1981–1995)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max accum.	207	226	170	144	234	219	290	357	445	316	272	173	**1704**
Min accum	17	3	40	24	12	13	16	12	36	48	12	47	**880**
Max 24 hr accum.	74	73	36	40	135	60	120	191	115	79	71	56	**191**

C.3 Precipitation in Siglufjörður

Monthly precipitation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1981	81	75	68	38	19	82	120	61	445	256	131	106	**1482**
1982	86	63	40	49	49	13	60	357		316	94	60	
1983	185	32	114	51	87	212	120	219	233	225	141	86	**1704**
1984	91	47	62	62	139	26	56	51	124	242	129	115	**1143**
1985	48	32	47	118	123	42	290	143	135	219	55	89	**1339**
1986	77	3	155	59	234	24	89	12	120	97	210	79	**1159**
1987	17	47	55	24	25	23	41	47	347	153	147	157	**1081**
1988	67	143	65	42	42	34	246	267	241	159	164	98	**1567**
1989	89	88	109	54	97	25	37	178	280	122	97	48	**1224**
1990	194	226	93	108	12	72	22	94	188	239	63	145	**1455**
1991		34	170	46	127	42	16	58	166	219	272	47	
1992					28	219	95	321	429	72	195	141	
1993	35	67	56	38	61	28	214	114	36	48	12	173	880
1994	207	24	78	144	25	107	30						
1995		141	77	40	27	60	107						
1995*												47	
1996*	40	98	19	127	14	65	42	83	95	100			
1997*			137	37	18	78	61	143	137			137	
1998*	177	104	79	33	43	23	142	96	130	313	127	190	**1281**
1999*	161	110	128	52	136	77	102	24	279	200	168	125	**1402**
2000*	97	113	149	29	77	21	30	98	176	168	447	173	**1577**
2001*	82	59	110	81	46	50	67	129	144	355			

Maximum precipitation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1981	16	14	18	8	6	19	58	7	96	57	26	52	96
1982	15	12	6	11	13	8	20	191		65	19	9	
1983	42	9	24	11	41	58	36	71	108	46	25	26	108
1984	23	7	22	17	69	6	14	18	48	48	26	33	69
1985	16	10	10	40	53	12	52	53	30	64	16	23	64
1986	25	2	32	20	135	10	20	6	32	13	39	10	135
1987	11	7	12	7	6	6	10	12	54	22	56	30	56
1988	16	38	11	8	25	28	120	98	54	79	36	38	120
1989	18	19	14	17	26	12	20	37	46	41	18	13	46
1990	31	73	15	19	6	29	5	22	30	41	21	56	73
1991		14	36	7	55	23	5	13	40	50	71	9	
1992					10	60	21	75	115	12	44	20	
1993	9	14	10	9	21	14	57	58	16	23	3	50	58
1994	74	6	18	24	16	27	9						
1995		33	14	5	8	18	54						
1995*												10	
1996*	9	16	6	51	6	16	14	16	17	14			
1997*			32	10	5	32	14	39	28			58	
1998*	47	20	8	9	9	11	57	40	21	32	25	42	
1999*	39	17	47	9	38	35	49	6	47	52	23	27	
2000*	14	20	31	13	21	6	7	24	99	27	81	32	
2001*	31	8	25	15	8	24	13	64	31	147			
max	74	73	47	51	135	60	120	191	115	147	81	58	135

C.4 Snow, rain and snowcover

Period 1981–1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Siglufjörður													
precipitation, mm	91.7	75.7	80.7	60.5	82.6	55.2	107.9	142.8	211.1	199.2	123.0	98.2	1328.7
rain, %	5%	11%	2%	13%	40%	65%	96%	100%	73%	20%	13%	11%	37%
snow, %	95%	89%	98%	87%	60%	35%	4%	0%	27%	80%	87%	89%	63%
max(rx)	41.5	73.4	31.7	40.2	135.0	58.4	120.2	190.5	107.9	79.4	55.7	55.5	190.5
Skeiðsfoss													
precipitation, mm	109.1	93.7	90.5	56.1	42.7	33.5	65.3	77.5	104.2	122.7	88.2	91.8	975.2
rain, %	6%	12%	4%	17%	40%	83%	98%	100%	63%	33%	15%	10%	40%
snow, %	94%	88%	96%	83%	60%	17%	2%	0%	37%	67%	85%	90%	60%
max(rx)	58.8	44.0	50.8	18.8	33.2	23.7	42.8	91.3	47.4	59.7	30.4	39.7	91.3

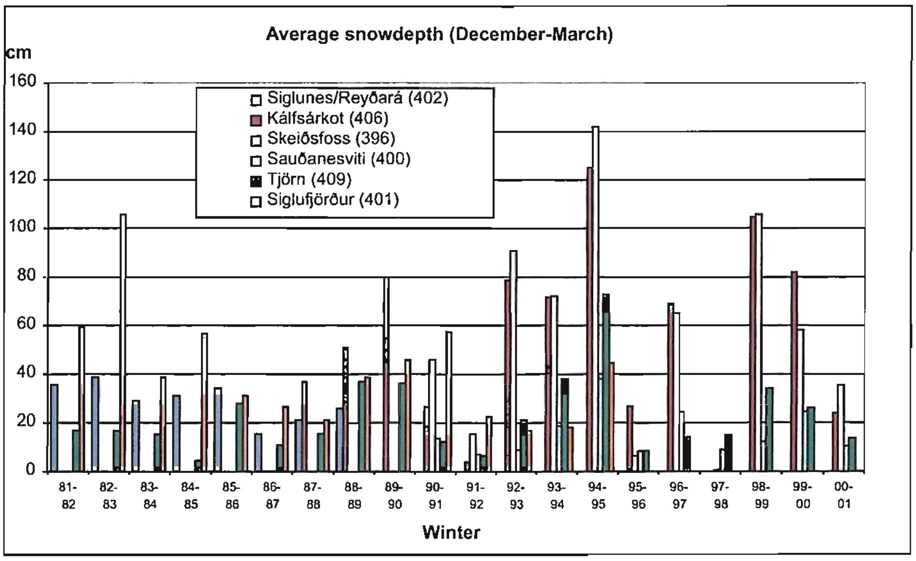
Siglufjörður, no. 401, average snowcover, %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	–	100	100	70	40	–	–	–	–	94	87	90
1982	100	95	94	76	50	0	–	–	–	18	73	98
1983	94	81	94	100	78	42	8	0	4	48	83	95
1984	100	90	80	73	36	0	0	0	3	40	78	85
1985	83	96	87	75	23	0	0	0	3	12	68	100
1986	98	72	92	73	42	8	2	0	0	60	95	99
1987	85	94	83	67	31	0	0	0	3	76	48	65
1988	100	97	100	97	51	18	0	0	19	46	64	67
1989	98	98	100	100	94	25	0	0	3	15	74	59
1990	89	100	100	100	74	14	0	0	7	63	62	73
Mean	94	92	93	83	52	12	1	0	5	47	73	83

Siglufjörður, no. 401, average snowcover, mountain, %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	–	100	100	72	48	–	–	–	–	96	93	95
1982	100	93	93	80	69	–	–	–	–	44	93	98
1983	93	79	94	99	77	58	27	4	–	67	84	98
1984	100	97	80	80	73	–	0	0	39	83	91	97
1985	88	98	89	84	65	36	0	6	37	40	69	100
1986	99	75	93	77	79	44	31	–	10	75	95	95
1987	83	96	88	74	52	20	0	0	20	83	78	87
1988	100	97	100	96	56	25	28	0	31	88	89	85
1989	97	98	100	98	94	32	0	0	36	53	84	69
1990	90	100	100	100	77	31	25	0	23	81	72	81
Mean	94	93	94	86	69	35	14	1	28	71	85	91

C.5 Snow depth



Siglufjörður, mean monthly snow depth (cm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	–	52	67	40	5	–	–	–	–	28	21	30
1982	89	139	161	61	44	–	–	–	–	–	25	28
1983	63	30	33	95	105	6	–	–	–	14	22	59
1984	97	79	24	21	3	–	–	–	–	16	18	20
1985	27	25	13	7	9	–	–	–	–	3	7	37
1986	44	7	34	34	11	1	–	–	–	9	26	40
1987	27	12	9	25	4	–	–	–	–	10	3	9
1988	25	63	27	70	54	–	–	–	2	10	11	10
1989	20	42	112	118	76	–	–	–	–	3	11	18
1990	45	72	102	127	102	–	–	–	–	8	13	17
Mean	49	52	58	60	41	–	–	–	–	11	16	27

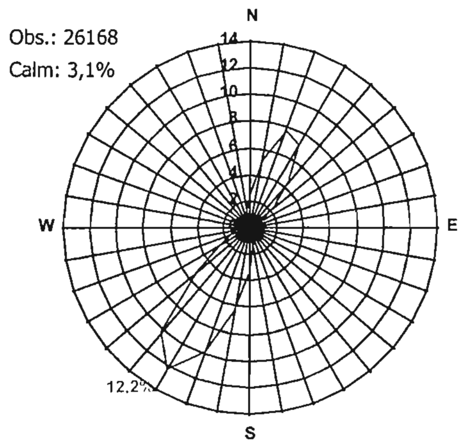
Siglufjörður, daily maximum snow depth (cm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	–	65	85	68	5	–	–	–	–	47	58	71
1982	151	170	168	73	46	–	–	–	–	–	34	40
1983	86	63	54	123	129	7	–	–	–	23	46	67
1984	114	114	49	32	6	–	–	–	–	29	30	30
1985	63	34	20	11	15	–	–	–	–	3	17	53
1986	51	7	66	72	12	1	–	–	–	21	75	85
1987	41	17	20	35	8	–	–	–	–	15	4	22
1988	34	110	41	116	54	–	–	–	3	24	15	15
1989	54	67	136	132	114	–	–	–	–	3	20	25
1990	77	85	124	141	117	–	–	–	–	14	20	59
Highest	151	170	168	141	129	7	–	–	3	47	75	85

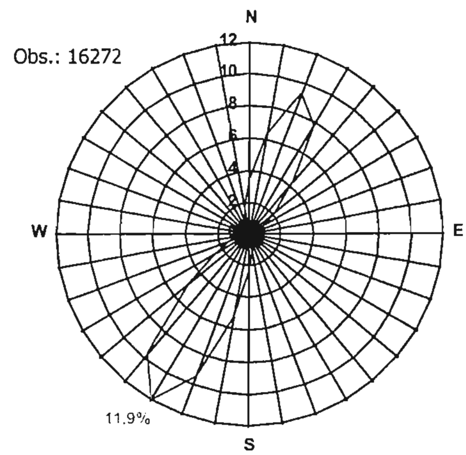
C.6 Wind roses

Siglufjörður, automatic weather station

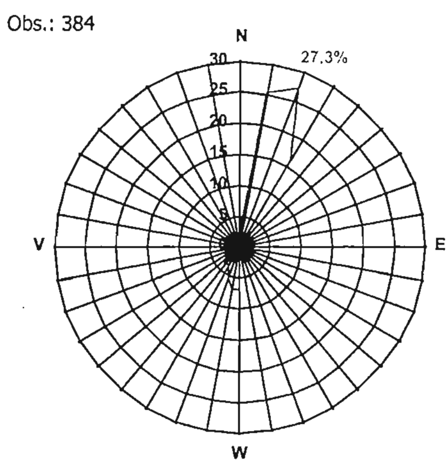
Frequency of wind direction (%),
1.11.1995 - 10.11.2001, Nov-Apr.



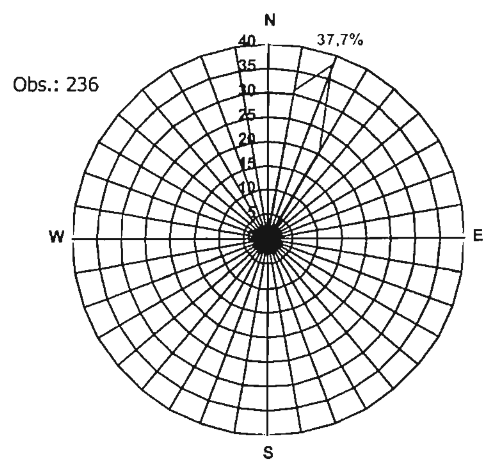
Frequency of wind direction when t =< 1°C (%),
1.11.1995 - 22.11.2001, Nov-Apr.

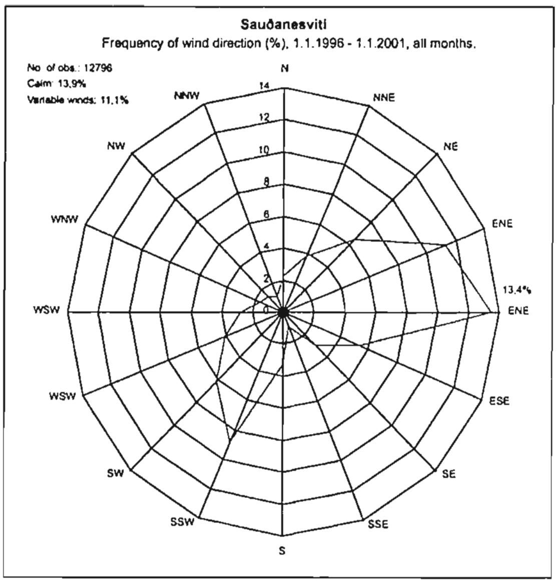


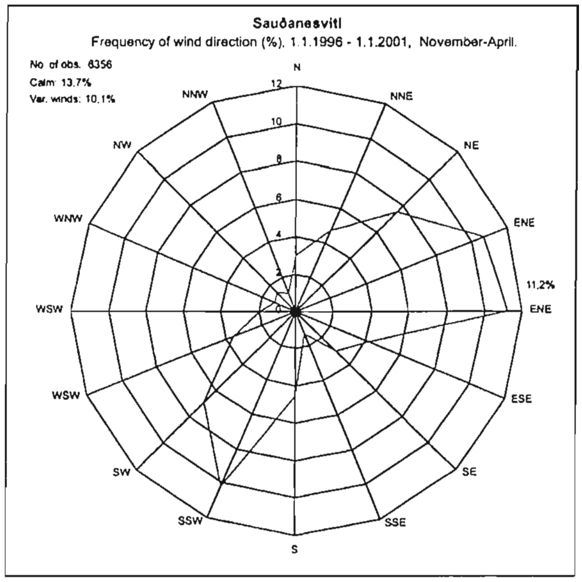
Frequency of wind direction when wind speed >= 15 m/s (%),
19.11.1995 - 23.11.2001, Nov-Apr.

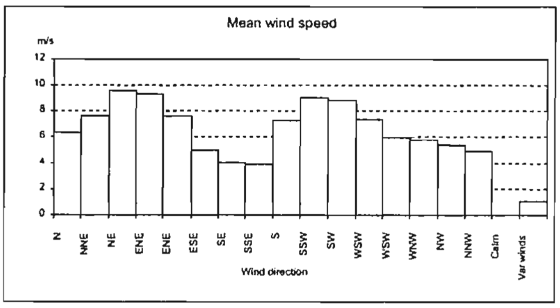


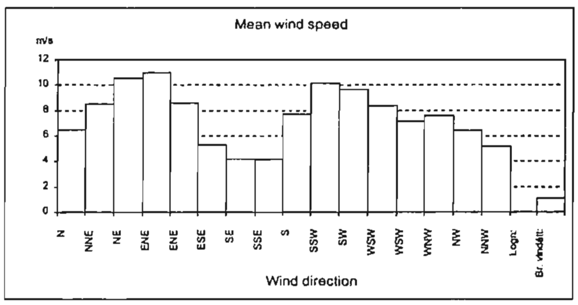
Frequency of wind dirrection when temperature =< 1°C and
wind speed >= 15 m/s (%) 3.1.1996 - 7.11.2001, Nov-Apr.



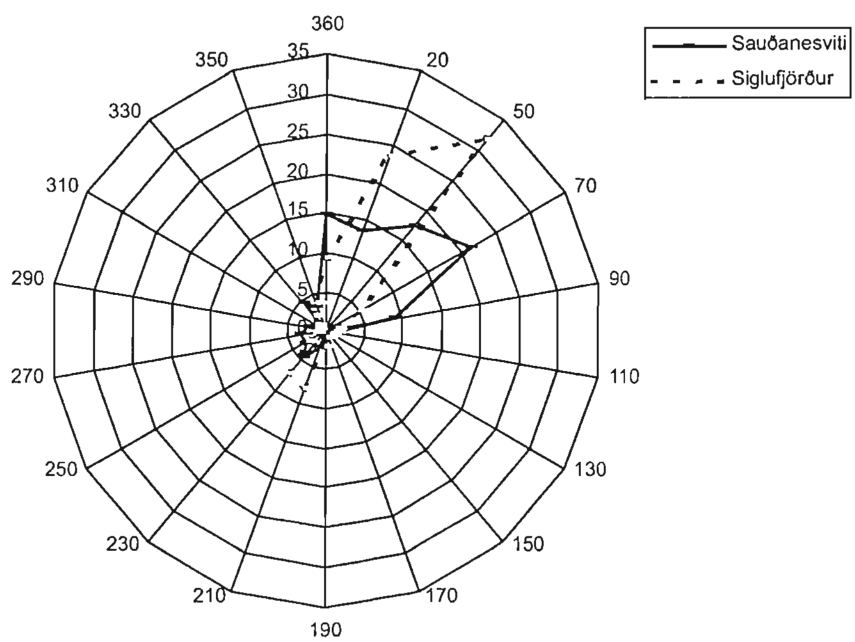




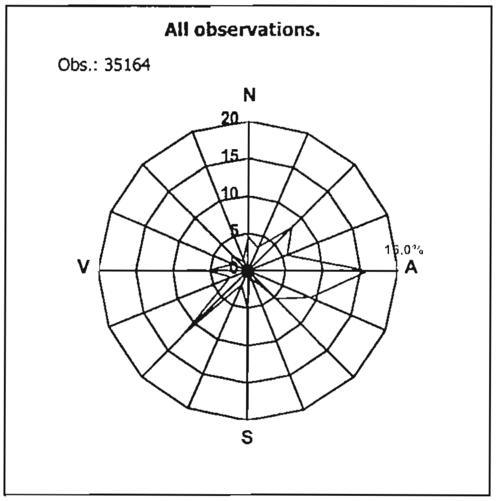


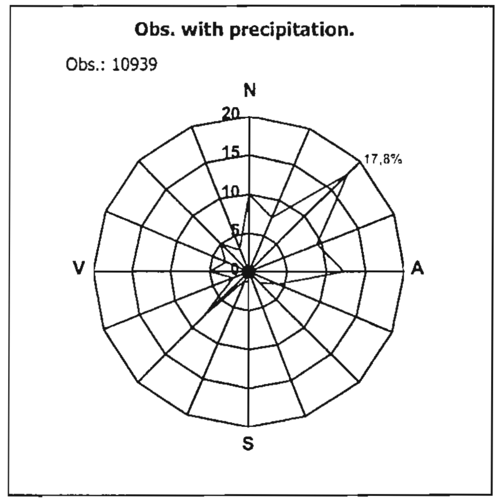


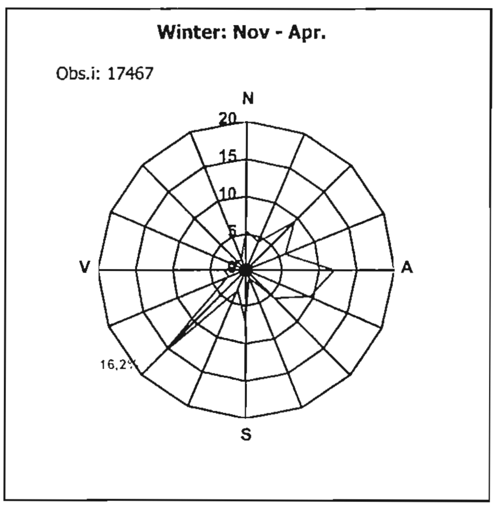
Frequency of wind direction in Siglufjörður and Sauðanesviti, Nov-Apr 1996-2000, when precipitation is observed and temperarture < 1°C at Sauðanesviti.
Total number of obs.1228,

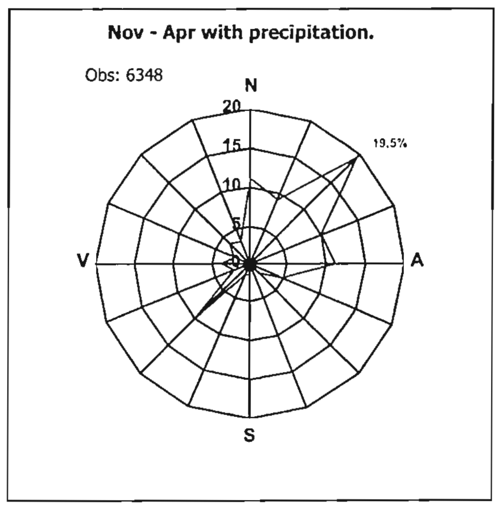


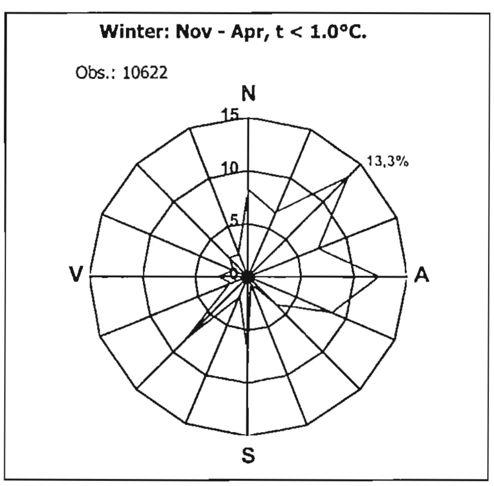
Siglunes/Reyðará, 1.1.1971–31.12.1988

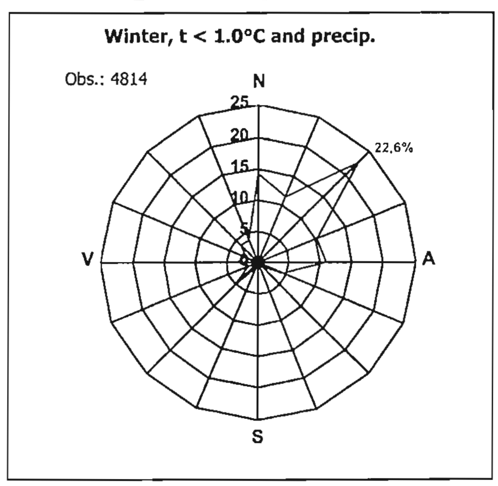






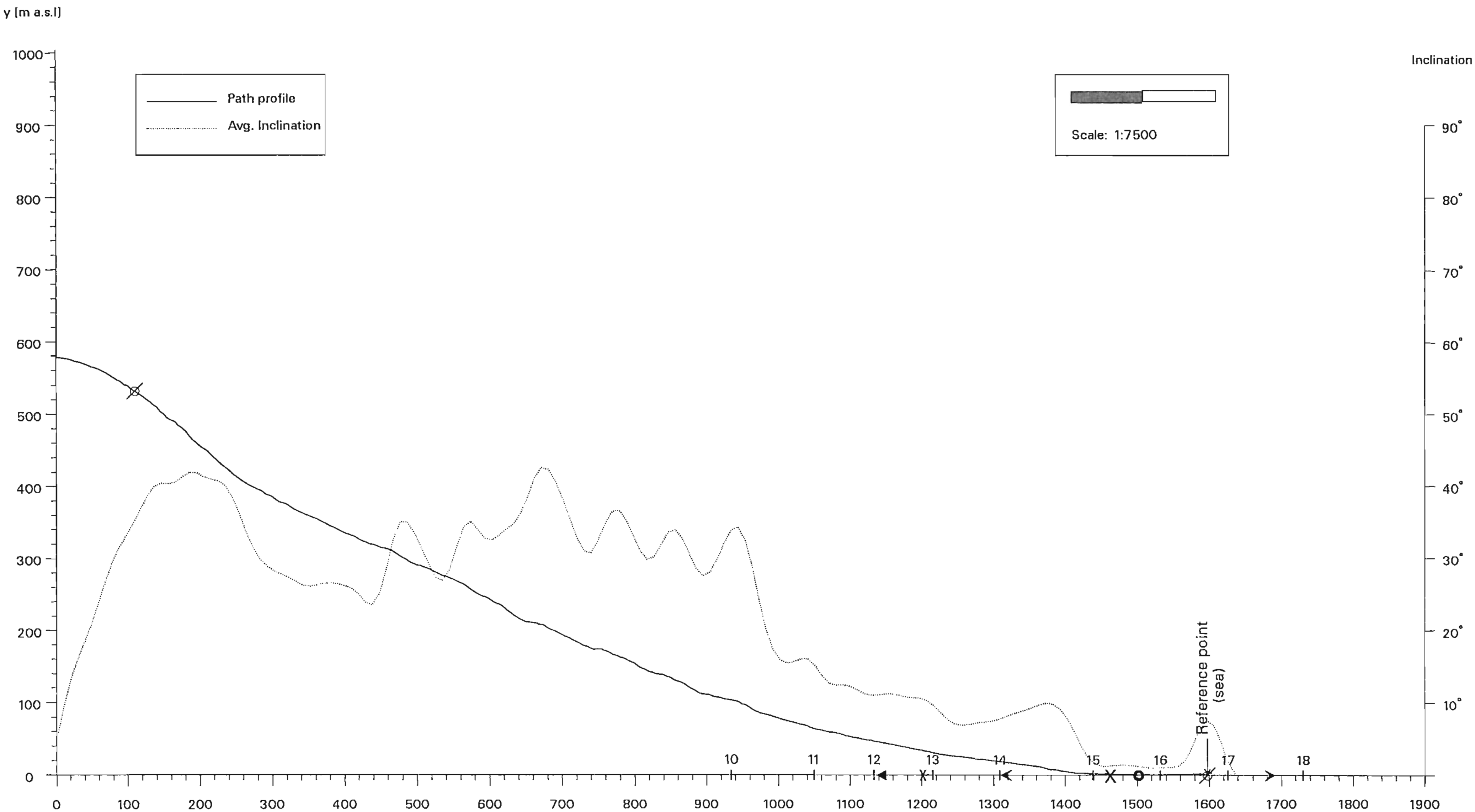






D Profile drawings

Drawing no.	Profile ID	Avalanche path
1	sist06ba	Jörundarskál
2	sist07aa	Jörundarskál
3	sist08ba	Gully between Jörundarskál and Strengsgil
4	sist08aa	Syðra-Strengsgil
5	sist09aa	Ytra-Strengsgil
6	sifi08aa	Fífadalir south
7	sifi04aa	Fífadalir south
8	sifi09aa	Grindagil/Fífladalagil
9	sifi10ba	Fífladalir north
10	sifi07aa	Fífladalir north
11	siha07aa	Gimbraklettar
12	siha08aa	Gimbraklettar
13	siha09aa	Hvanneyrarskál
14	siha10aa	Hvanneyrarskál
15	sigr11aa	Gróuskarðshnjúkur south
16	sigr12aa	Gróuskarðshnjúkur north
17	sigr13aa	Gully north of Gróuskarðshnjúkur



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Jörundarskál

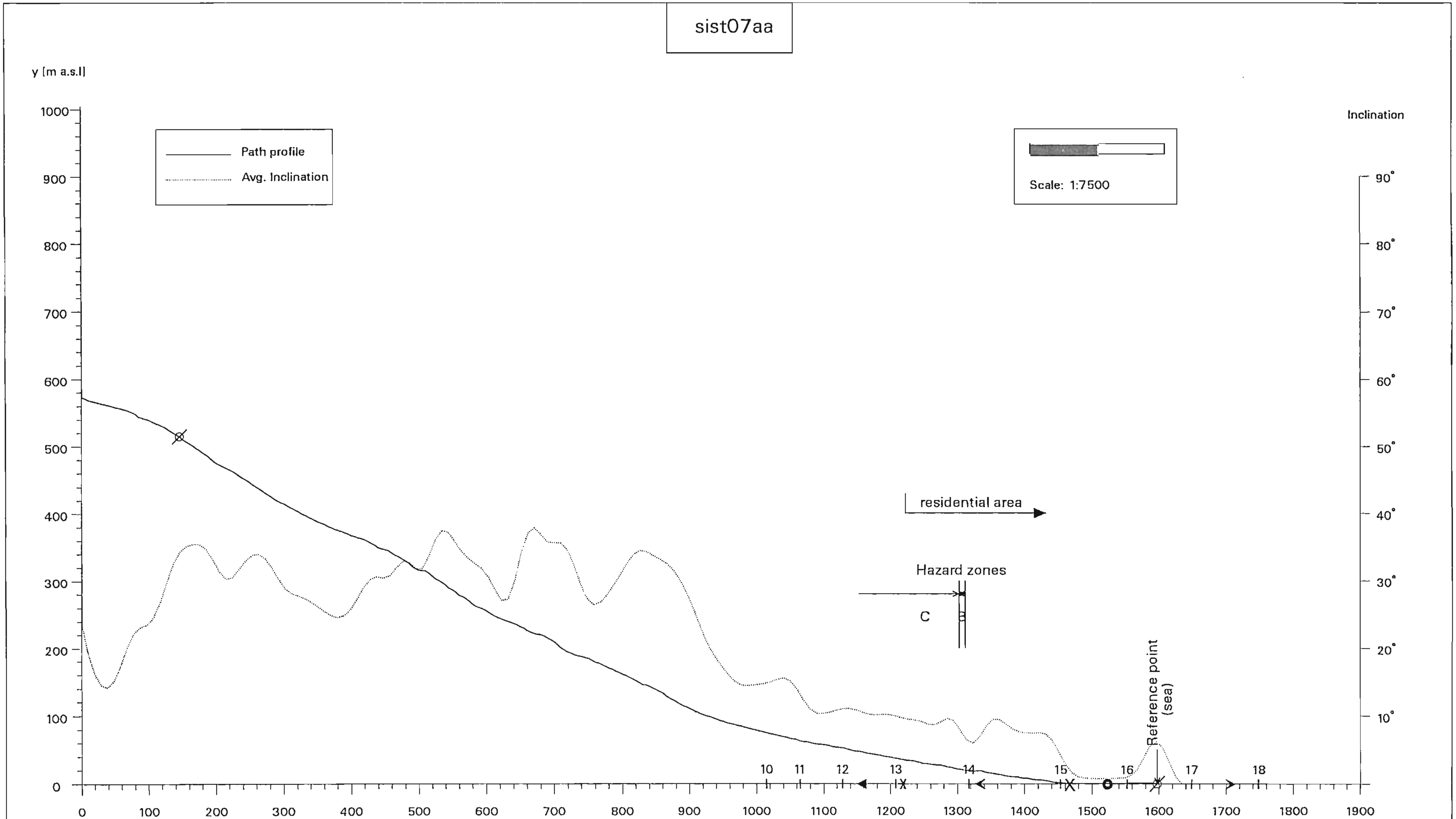
Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
* : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ <: $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂: $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sist06ba
Drawn by: LT
Date: 03.12.2001

Drawing: 1



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Small gully north of Jörundarskál

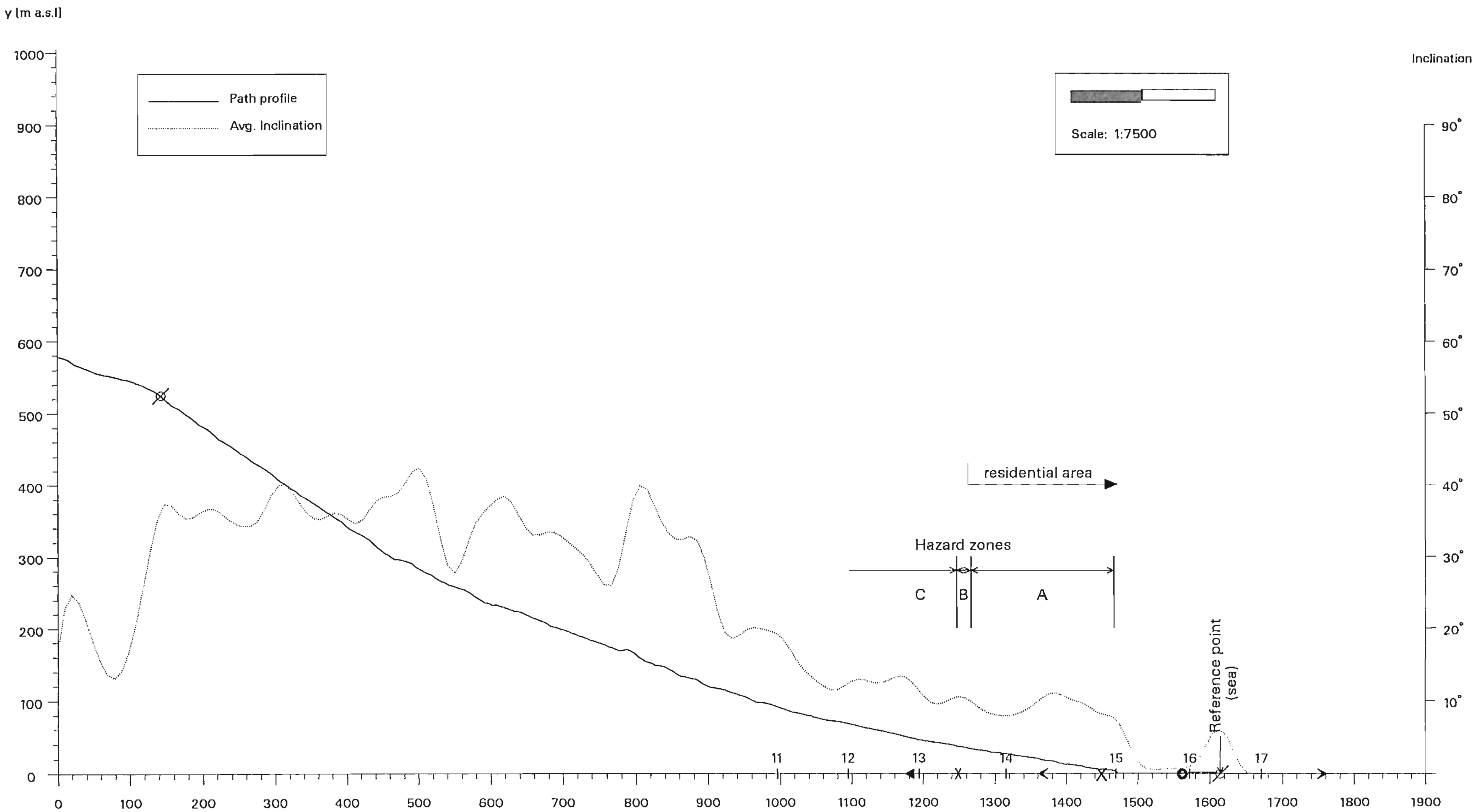
Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
✳ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ <: $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂: $\alpha - 2\sigma$ $\alpha = 2.3^{\circ}$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sist07aa
Drawn by: LT
Date: 03.12.2001
Drawing: 2

sist08ba



Icelandic Meteorological Office

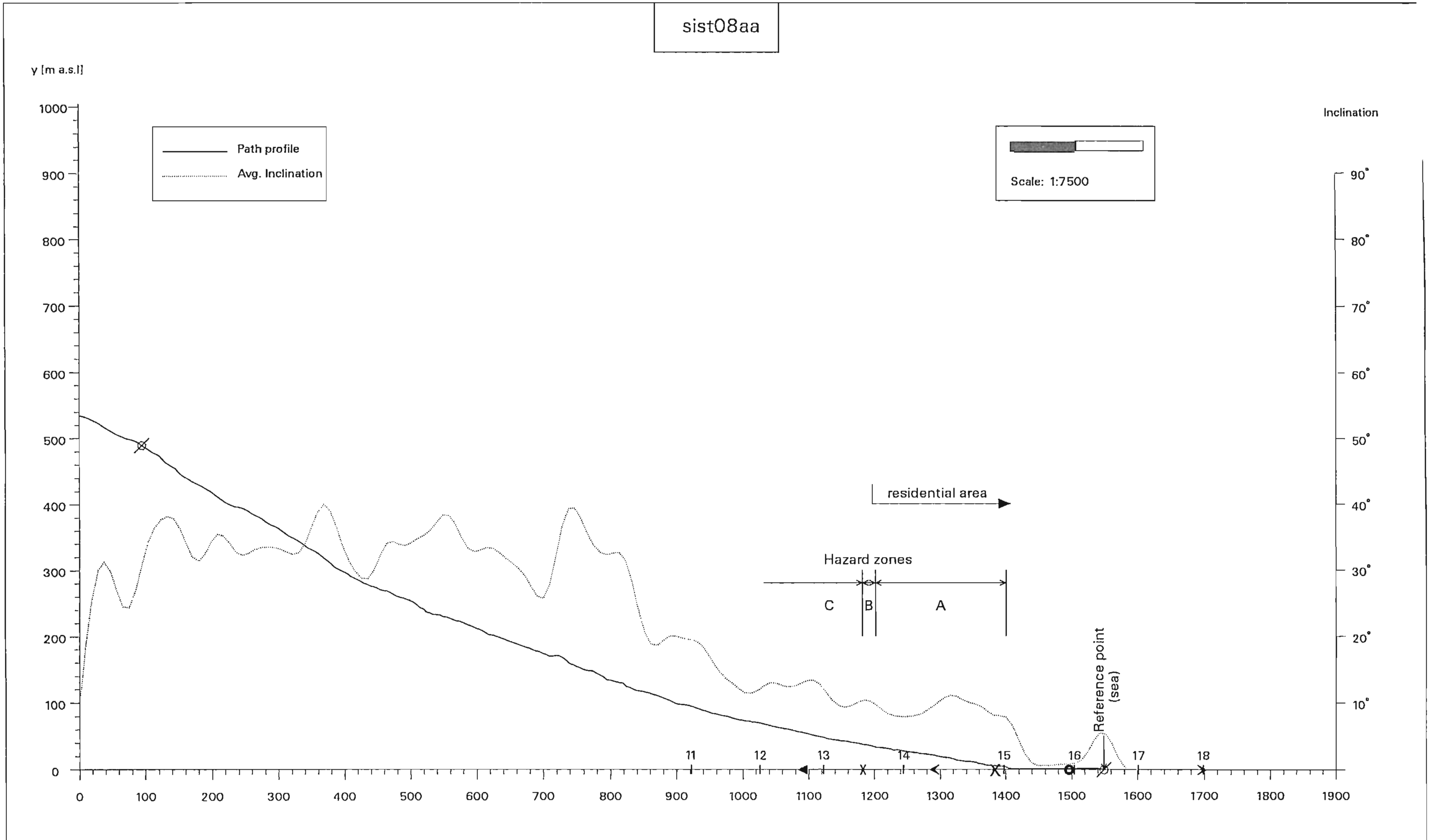
Hazard evaluation
Runout model and hazard zones
South of Syðra-Strengsgil

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
✳ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ <: $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂: $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sist08ba
Drawn by: LT
Date: 03.12.2001
Drawing: 3



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Syðra-Strengsgil

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

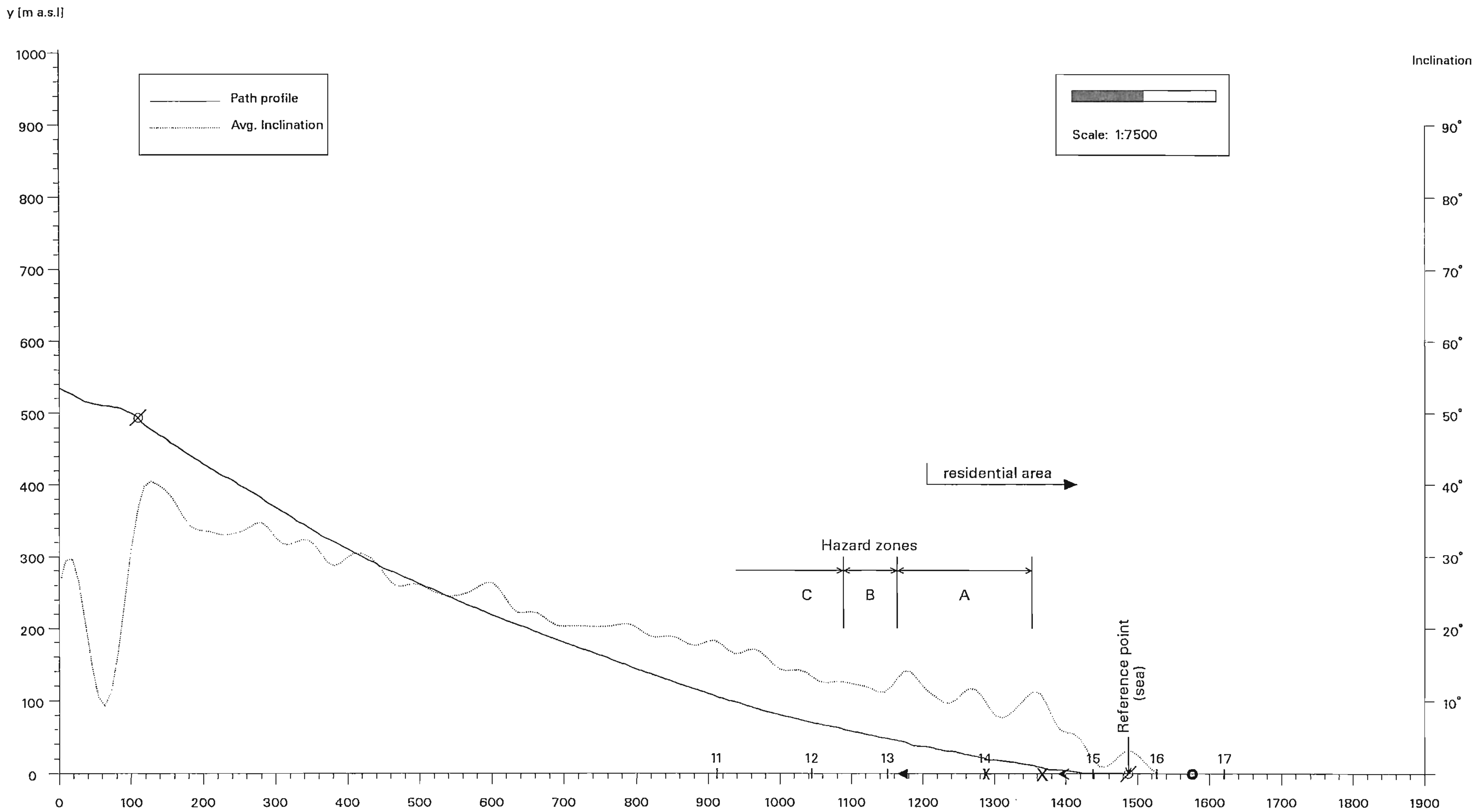
α/β model
✳ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
‹ : $\alpha + \sigma$ ‹ : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sist08aa
Drawn by: LT
Date: 03.12.2001

Drawing: 4

sist09aa



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Ytra-Strengsgil

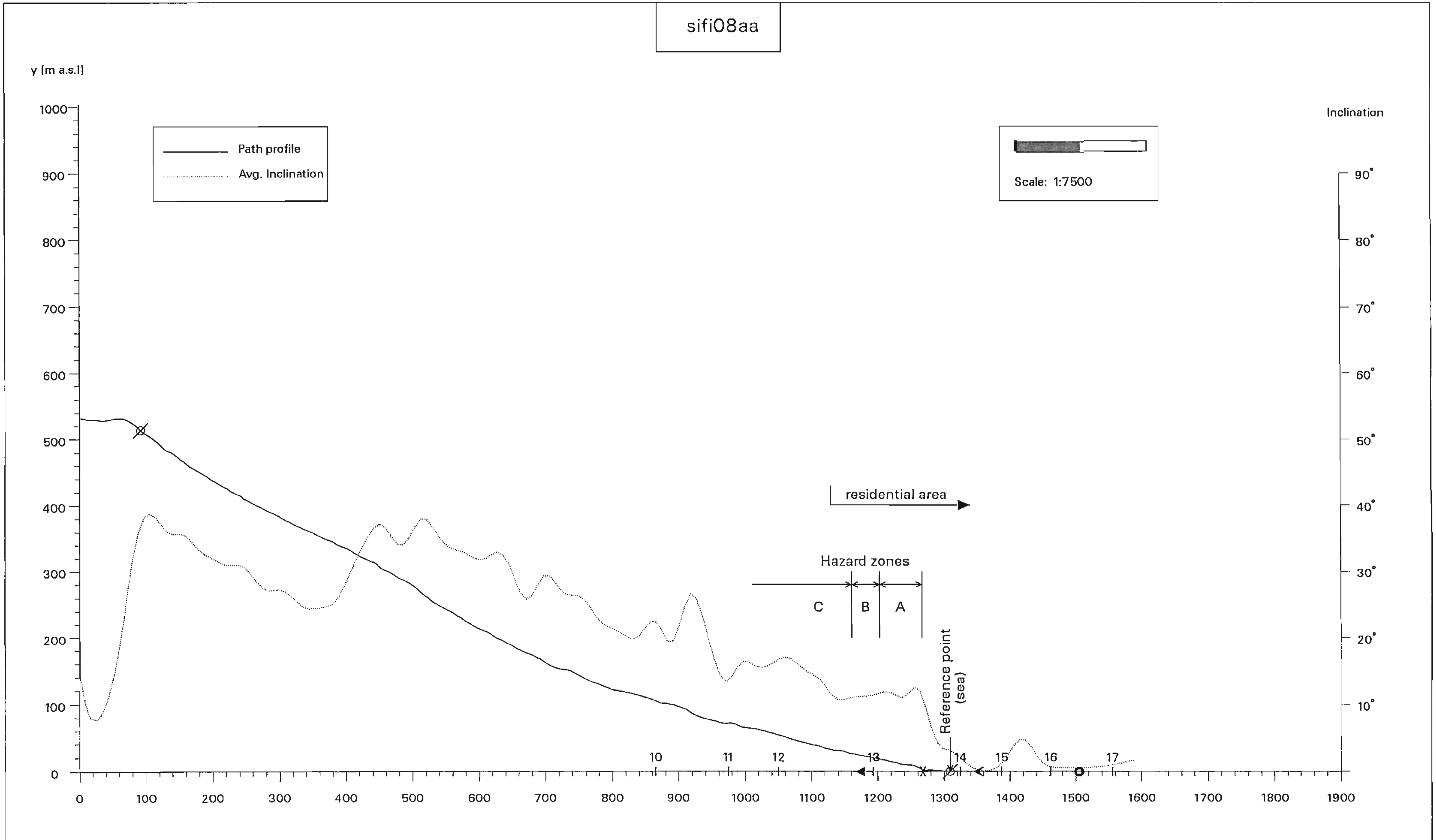
Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
∗ : β, Angle from the start to where the slope is 10°.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ $\sigma = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sist09aa
Drawn by: LT
Date: 03.12.2001

Drawing: 5



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Mið-Skriðulækjargil, upper starting point

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

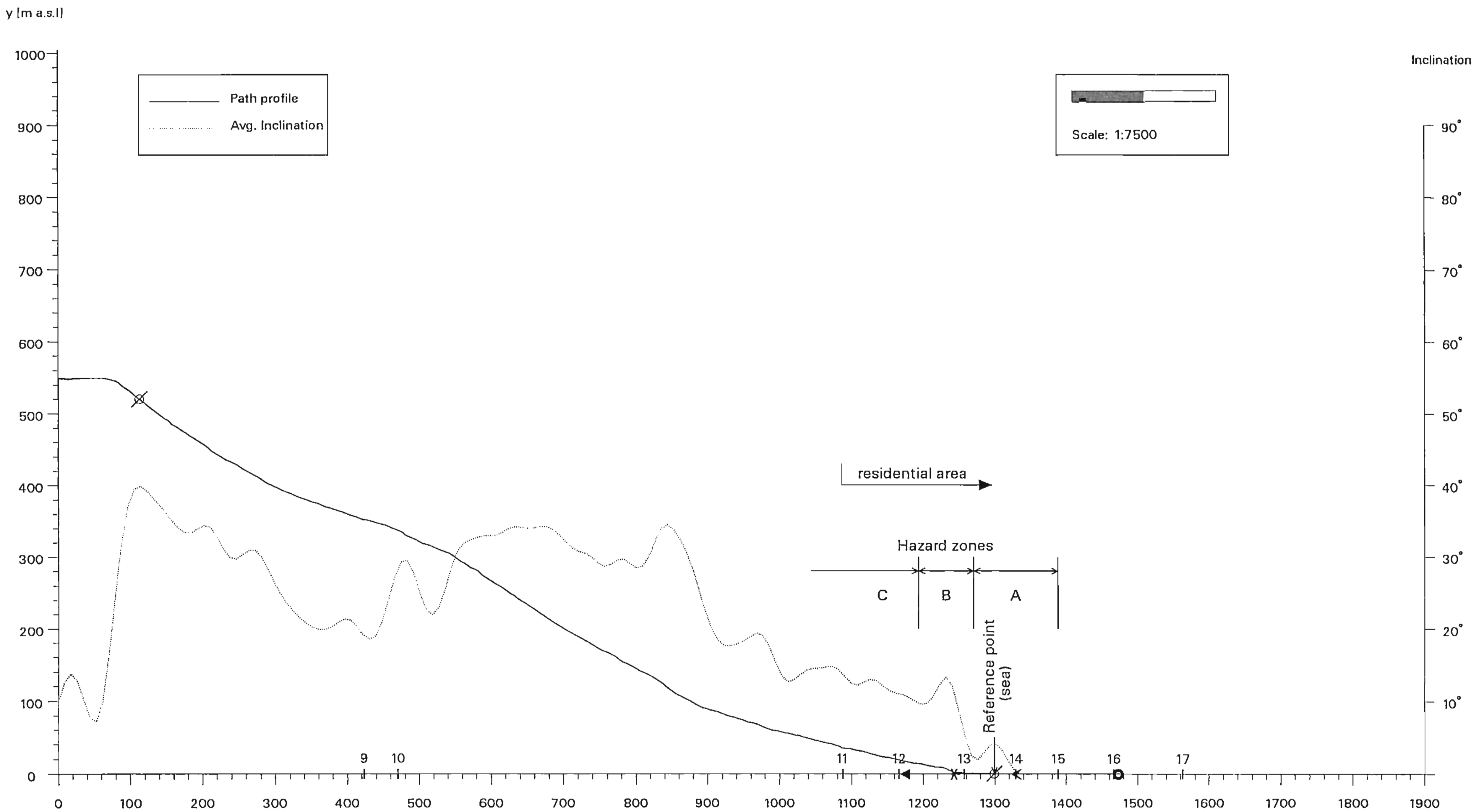
α/β model
✳ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◄ : $\alpha + 2\sigma$ ◄ : $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sifi08aa
Drawn by: LT
Date: 03.12.2001

Drawing: 6

sifi04aa



Icelandic Meteorological Office

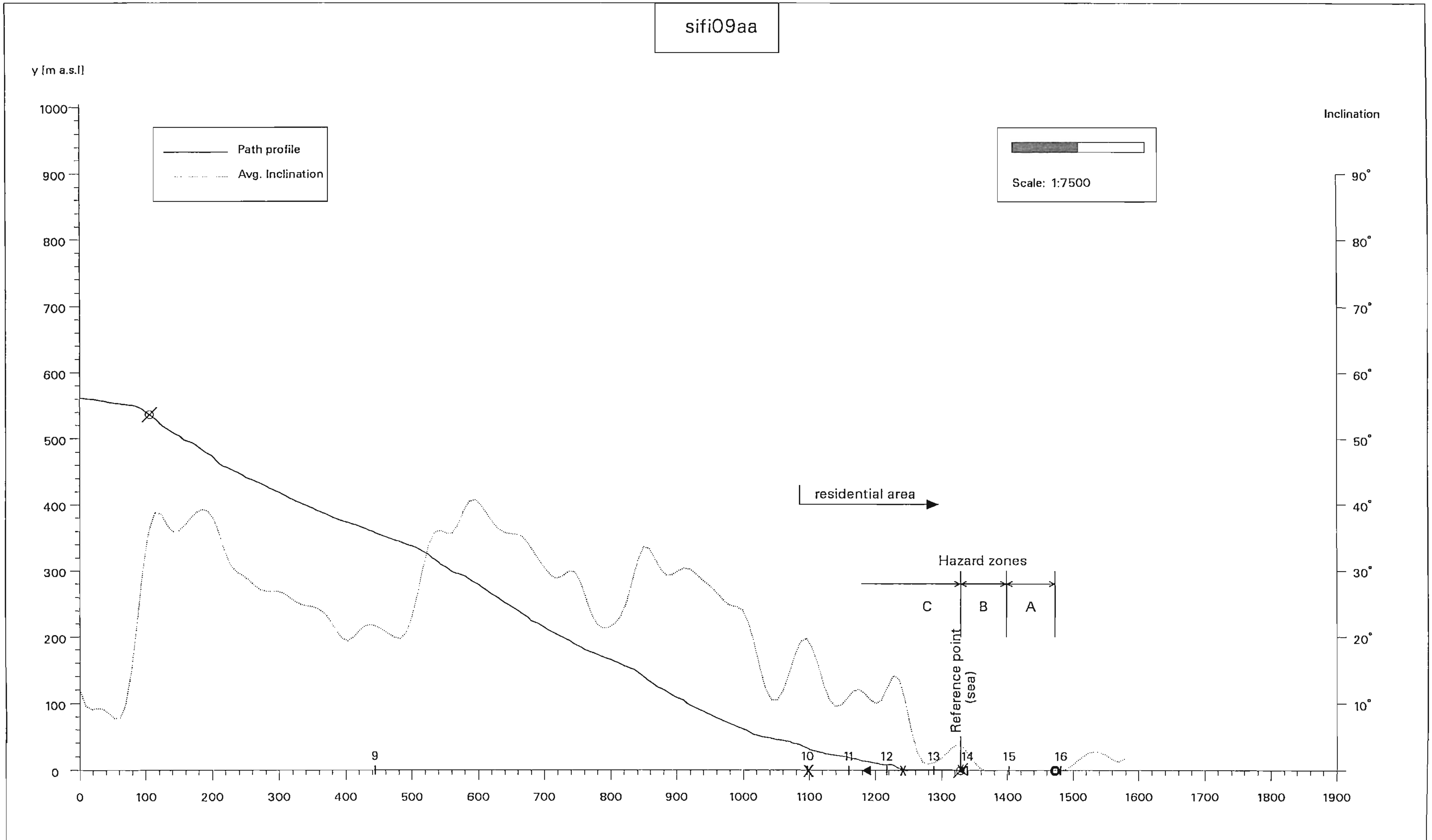
Hazard evaluation
Runout model and hazard zones
Sunnan Fifladalagils, upper starting point

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
* : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sifi04aa
Drawn by: LT
Date: 03.12.2001
Drawing: 7



Icelandic Meteorological Office

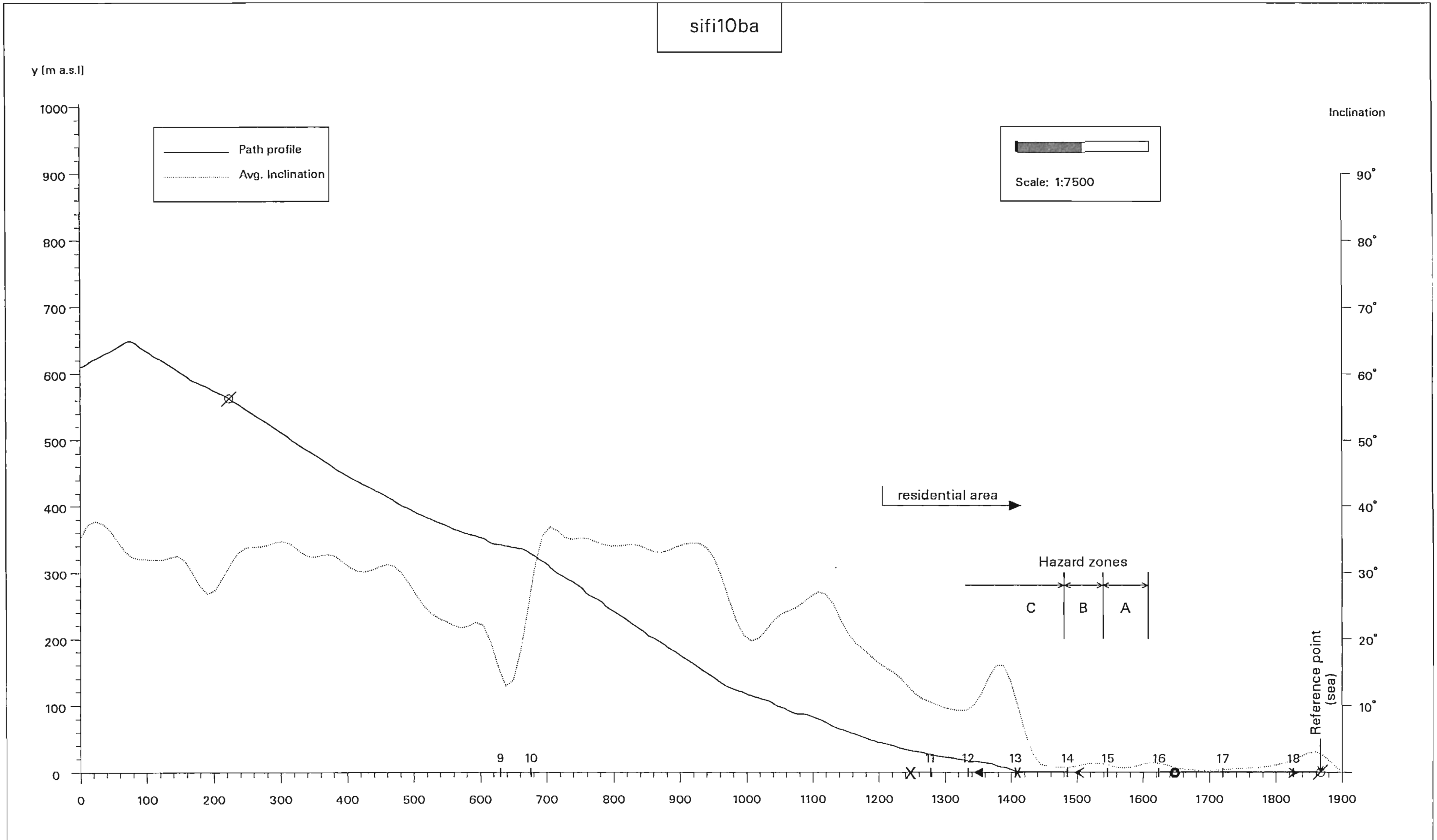
Hazard evaluation
Runout model and hazard zones
Grindagil, upper starting point

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
* : β, Angle from the start to where the slope is 10°.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sifi09aa
Drawn by: LT
Date: 03.12.2001
Drawing: 8



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Fifladalir, middle starting point

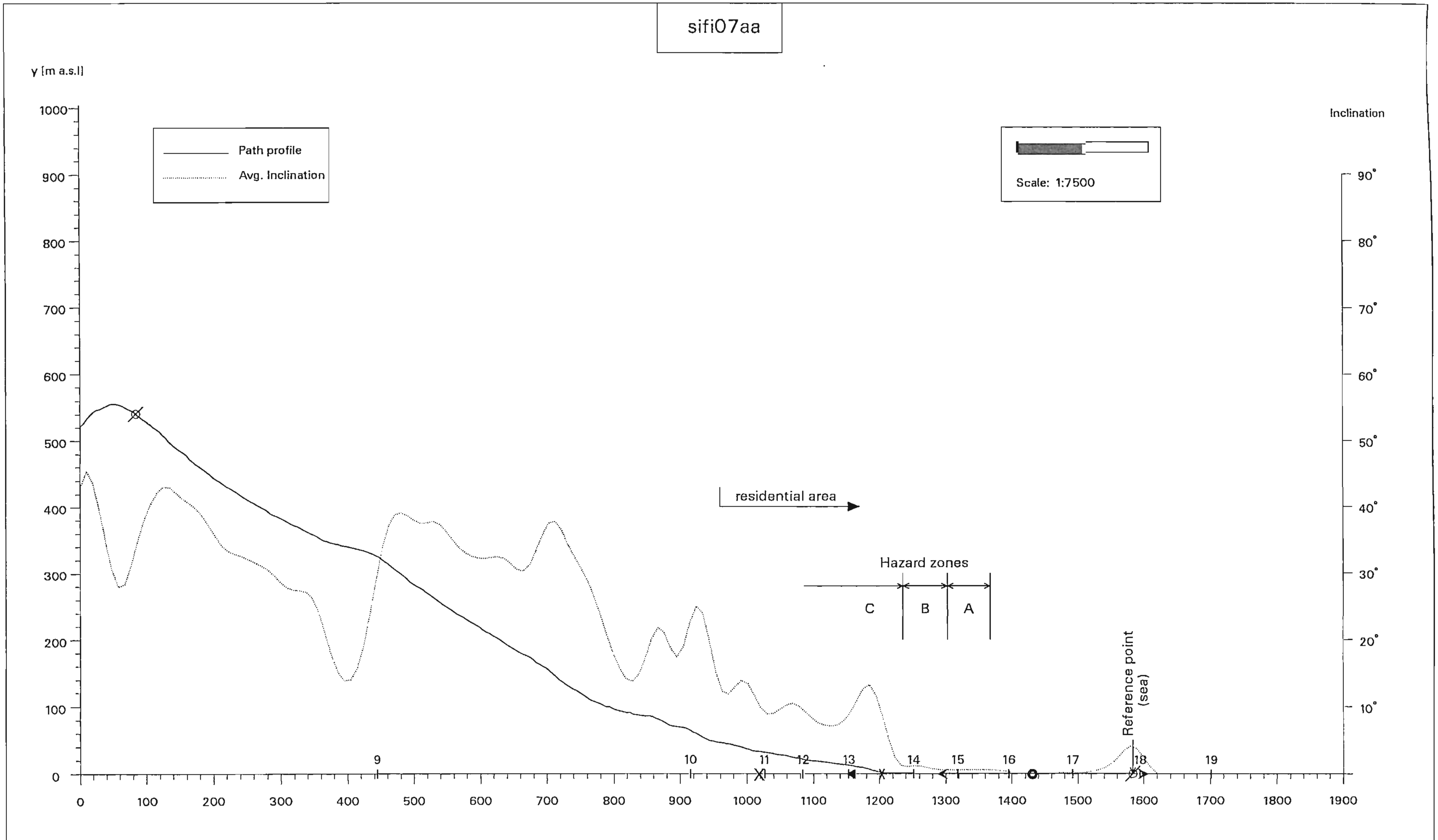
Hazard zones
C: Risk more than $3 \cdot 10^{-4}$
B: Risk between $3 \cdot 10^{-4}$ and $1 \cdot 10^{-4}$
A: Risk less than $1 \cdot 10^{-4}$
According to hazard zones regulations implemented in July 2000.

α/β model
* : β, Angle from the start to where the slope is 10°.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$
$\alpha = 2.3^\circ$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sifi10ba
Drawn by: LT
Date: 03.12.2001

Drawing: 9



Icelandic Meteorological Office

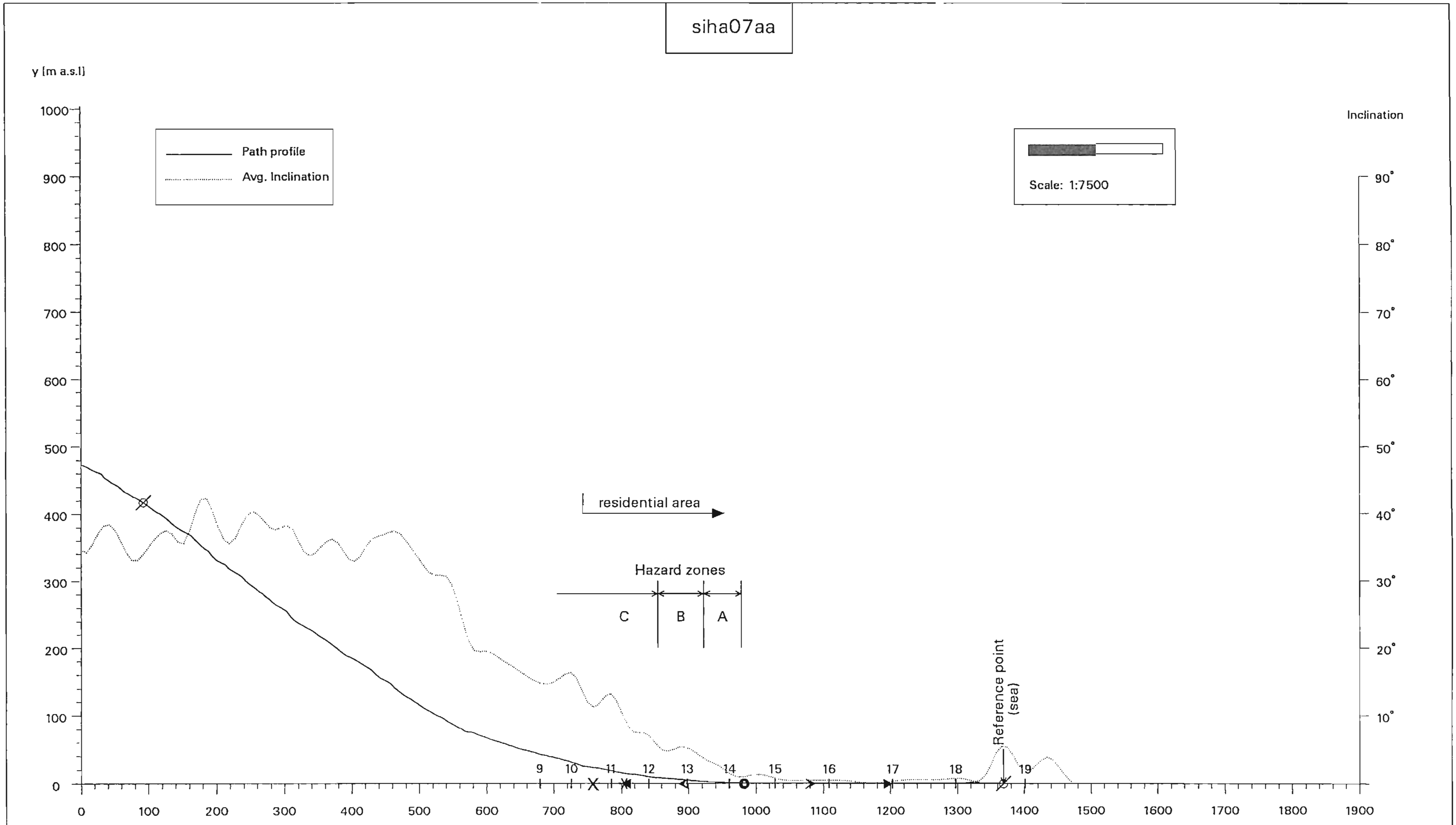
Hazard evaluation
Runout model and hazard zones
Fifladalir north, upper starting point

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
✱ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◄ : $\alpha + 2\sigma$ ◄ : $\alpha - 2\sigma$ $\alpha = 2.3^\circ$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sifi07aa
Drawn by: LT
Date: 03.12.2001
Drawing: 10



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Hafnarhyrna, Gimbraklettar, southern part

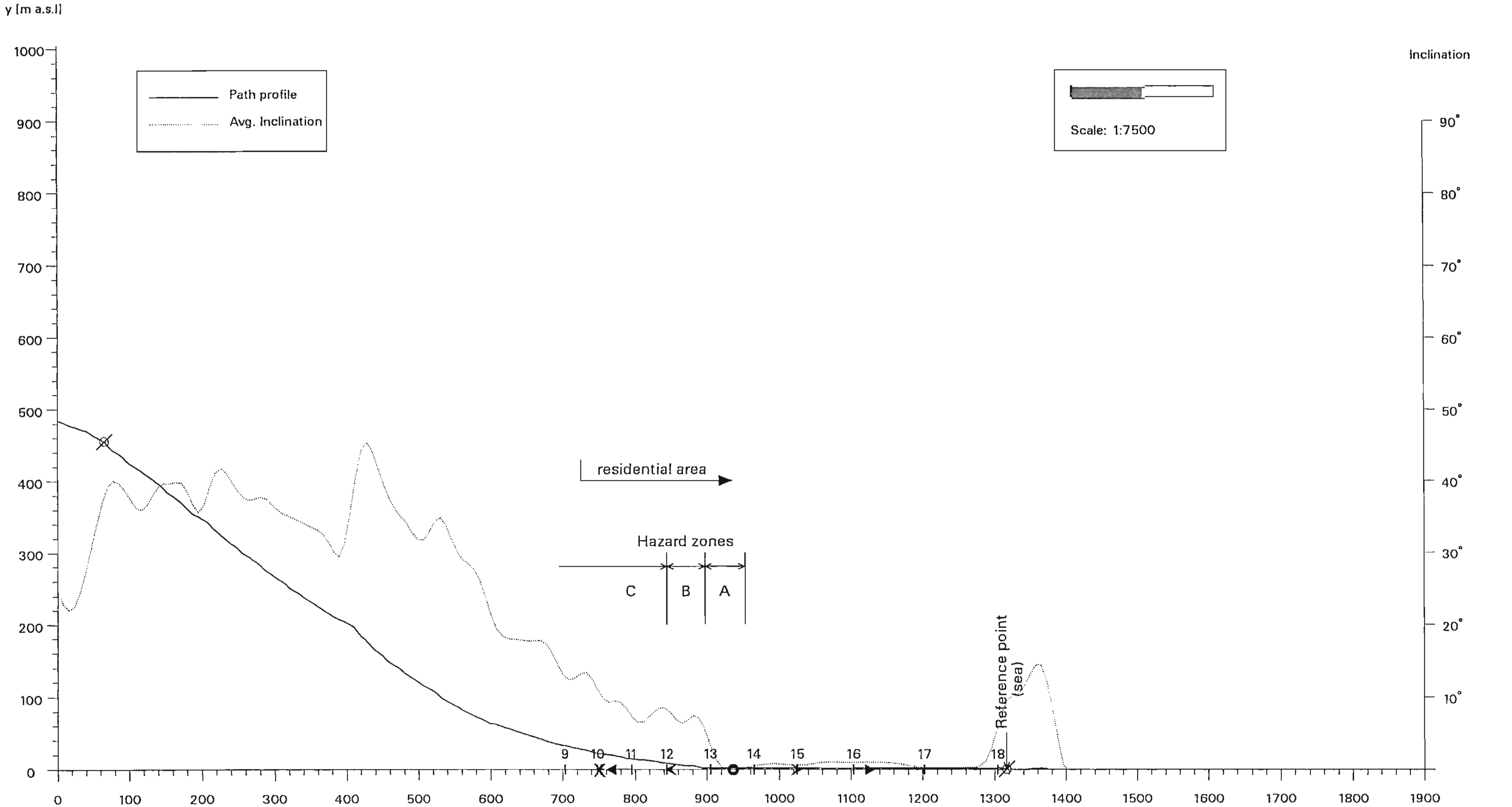
Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
* : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ <: $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂: $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

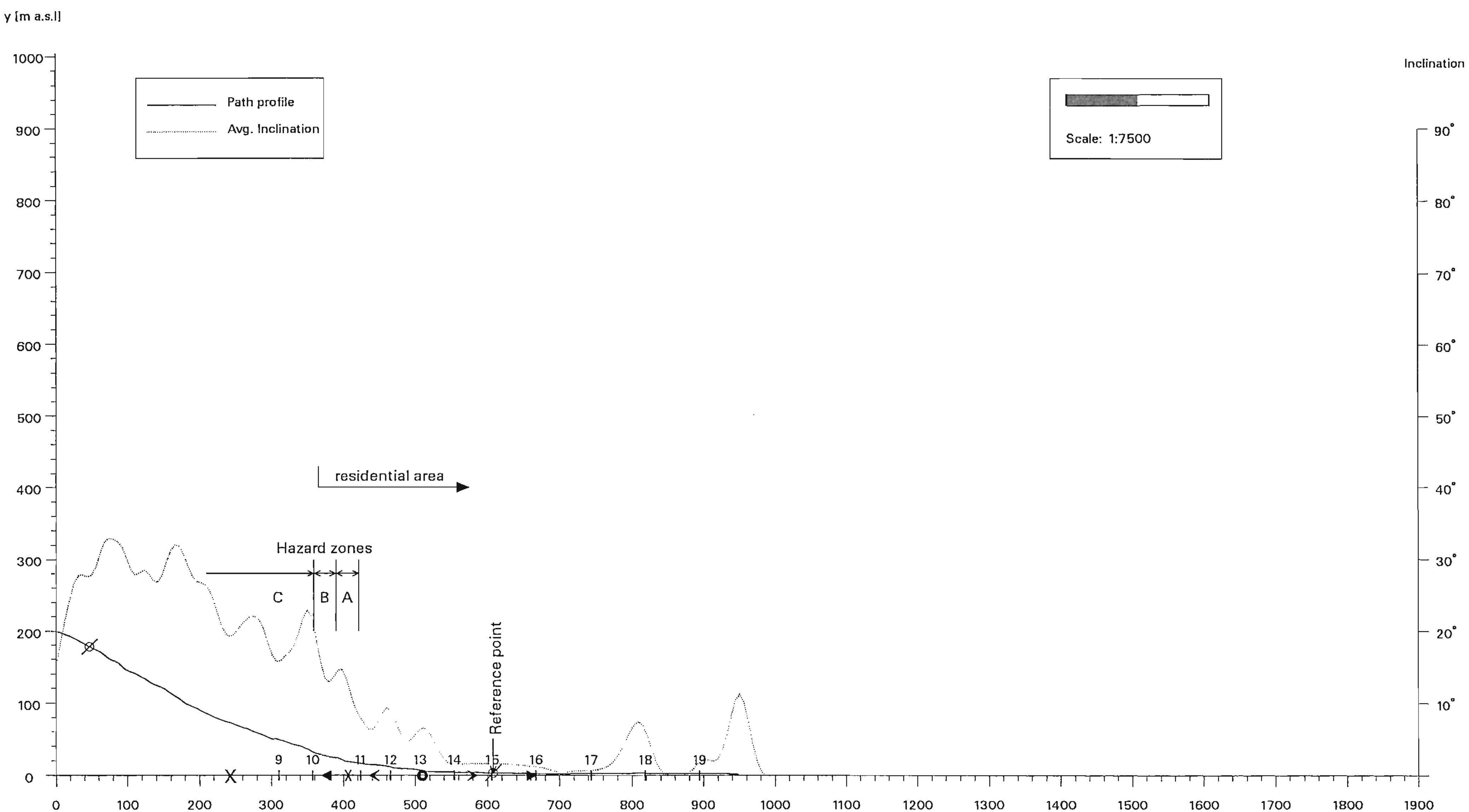
Path: siha07aa
Drawn by: LT
Date: 03.12.2001
Drawing: 11

siha08aa



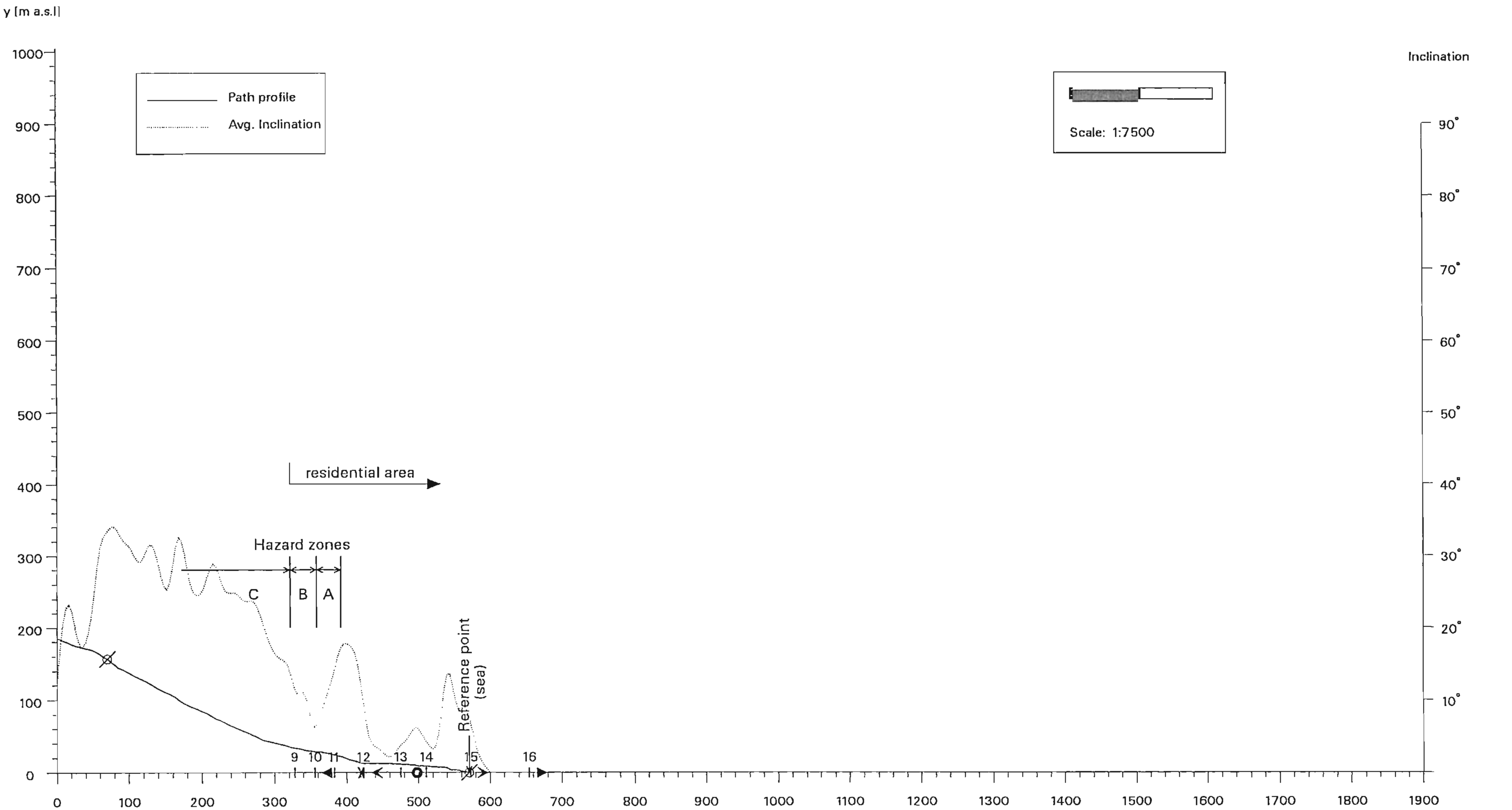
Icelandic Meteorological Office	Hazard evaluation Runout model and hazard zones *Hafnarhyrna, Gimbraklettar, northern part*	Hazard zones C: Risk more than 3 · 10-4 B: Risk between 3 · 10-4 and 1 · 10-4 A: Risk less than 1 · 10-4 According to hazard zones regulations implemented in July 2000.	α/β model ✳ : β, Angle from the start to where the slope is 10 °. o : α, Angle from runout to the start. $\alpha = 0.85\beta$. < : $\alpha + \sigma$ <: $\alpha - \sigma$ ◂ : $\alpha + 2\sigma$ ◂: $\alpha - 2\sigma$ $\alpha = 2.3°$	Runout indices 11, 12, ...20 See VÍ-R99001-ÚR01 Longest avalanche runout: X	Path: siha08aa Drawn by: LT Date: 03.12.2001 Drawing: 12

siha09aa



Icelandic Meteorological Office	Hazard evaluation Runout model and hazard zones *Lower Hvanneyrarskálar, southern part*	Hazard zones C: Risk more than 3 · 10-4 B: Risk between 3 · 10-4 and 1 · 10-4 A: Risk less than 1 · 10-4 According to hazard zones regulations implemented in July 2000.	α/β model ✱ : β, Angle from the start to where the slope is 10 °. o : α, Angle from runout to the start. $\alpha = 0.85\beta$. < : $\alpha + \sigma$ < : $\alpha - \sigma$ ◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ $\alpha = 2.3°$	Runout indices 11, 12, ...20 See VÍ-R99001-ÚR01 Longest avalanche runout: X	Path: siha09aa Drawn by: LT Date: 03.12.2001 Drawing: 13

siha10aa



Icelandic Meteorological Office

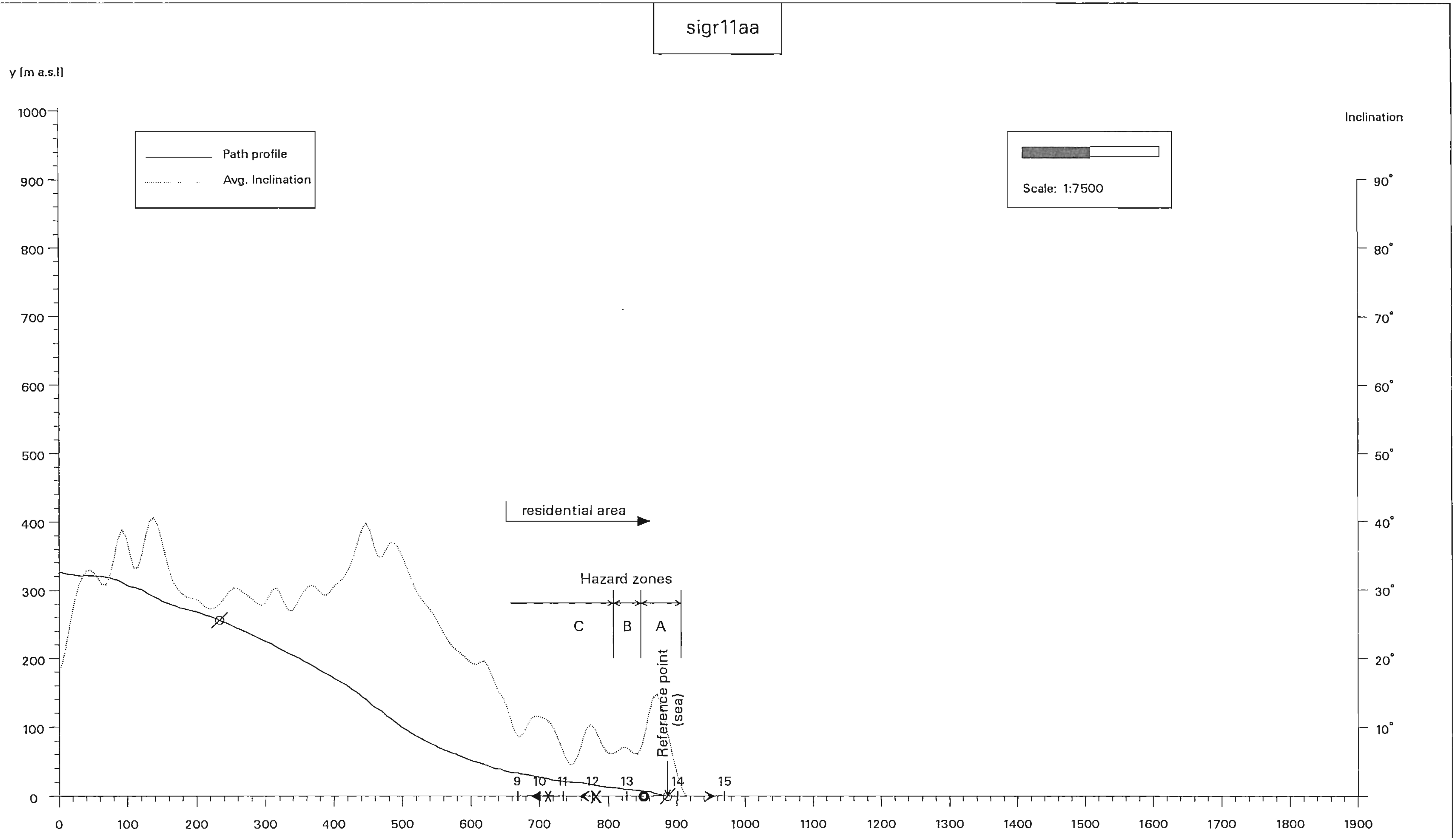
Hazard evaluation
Runout model and hazard zones
Lower Hvanneyrarskálar, northern part

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
✱ : β, Angle from the start to where the slope is 10 °.
O : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ $\sigma = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: siha10aa
Drawn by: LT
Date: 03.12.2001
Drawing: 14



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Gróuskarðshnjúkur, southern part

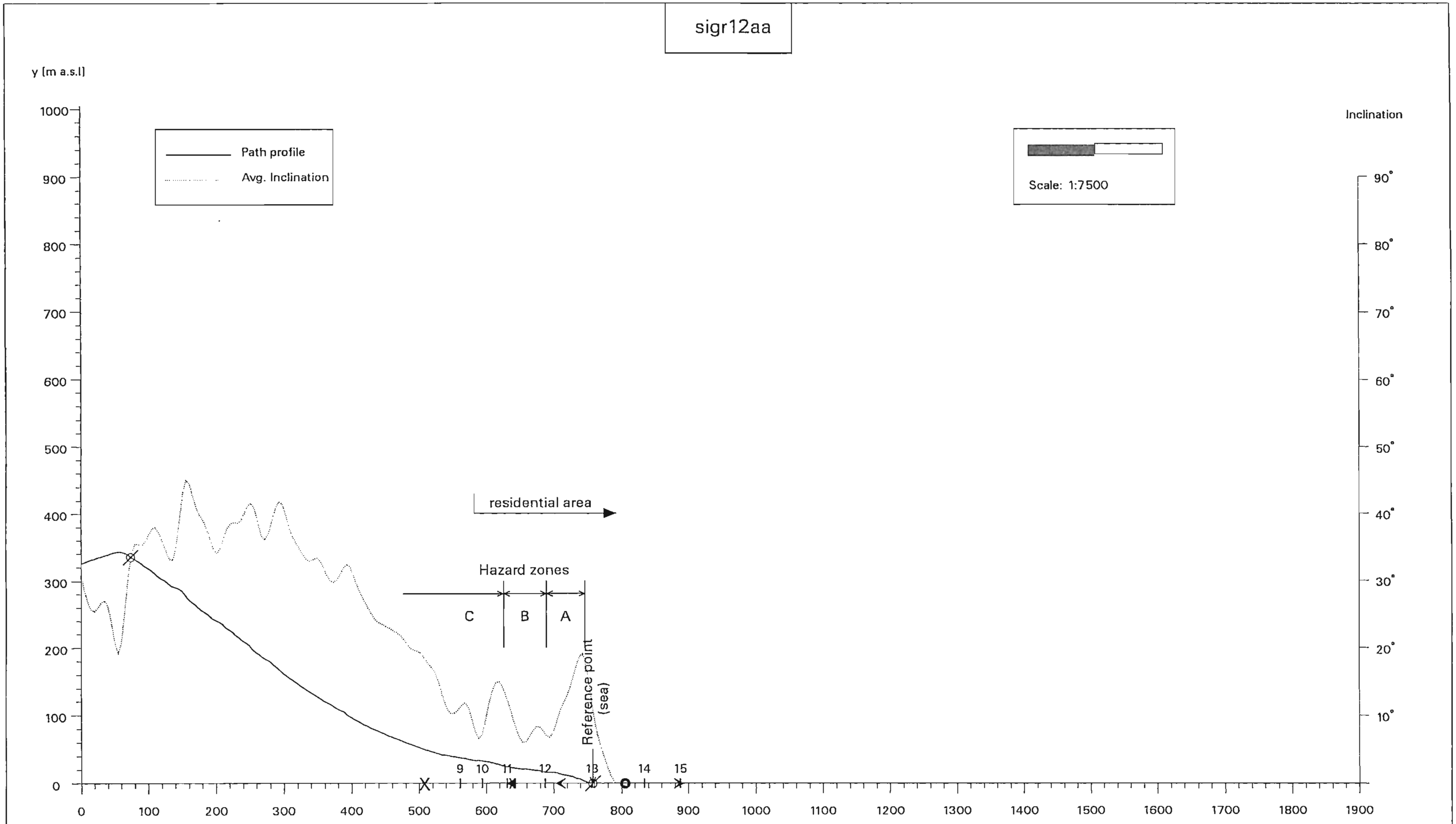
Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
∗ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ } $\sigma = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sigr11aa
Drawn by: LT
Date: 03.12.2001

Drawing: 15



Icelandic Meteorological Office

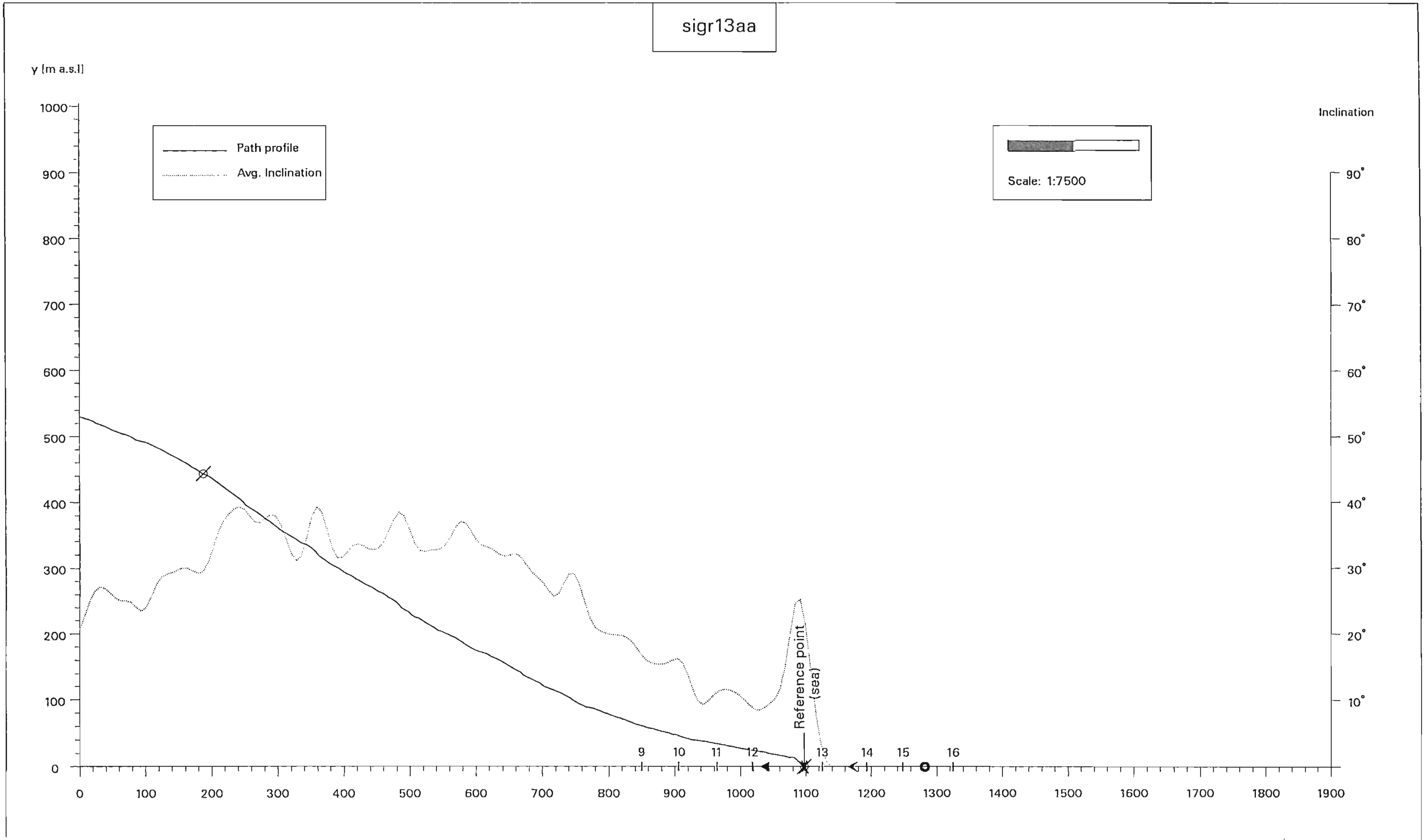
Hazard evaluation
Runout model and hazard zones
Gróuskarðshnjúkur, northern part

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
✱ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ } $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sigr12aa
Drawn by: LT
Date: 03.12.2001
Drawing: 16



Icelandic Meteorological Office

Hazard evaluation
Runout model and hazard zones
Gully north of Gróuskarðshnjúkur

Hazard zones
C: Risk more than 3 · 10-4
B: Risk between 3 · 10-4 and 1 · 10-4
A: Risk less than 1 · 10-4
According to hazard zones regulations implemented in July 2000.

α/β model
✱ : β, Angle from the start to where the slope is 10 °.
o : α, Angle from runout to the start. $\alpha = 0.85\beta$.
< : $\alpha + \sigma$ < : $\alpha - \sigma$
◂ : $\alpha + 2\sigma$ ◂ : $\alpha - 2\sigma$ $\alpha = 2.3°$

Runout indices
11, 12, ...20
See VÍ-R99001-ÚR01
Longest avalanche runout: X

Path: sigr13aa
Drawn by: LT
Date: 03.12.2001
Drawing: 17