Accidents and economic damage due to snow avalanches and landslides in Iceland

Tómas Jóhannesson and Þorsteinn Arnalds
Icelandic Meteorological Office, Bústaðavegur 9, IS-150 Reykjavík, Iceland

Abstract — *Snow avalanches have caused many catastrophic accidents and severe economical losses in Iceland since the country was settled in the ninth century. The first reported avalanche accident dates back to 1118 when a snow avalanche killed 5 people in western Iceland. Altogether about 680 deaths by avalanches have been reported in Iceland since then. Unaccounted deaths may be assumed to have been several hundreds, especially during two gaps a total of 250 years in the written records before 1600. Since 1901 altogether 193 persons have been killed in avalanche and landslide accidents in Iceland. Catastrophic avalanches in the villages Súðavík and Flateyri in 1995, which killed 34 people and caused extensive economic damage, have totally changed the view regarding avalanche safety in Iceland. These avalanches made it clear that a substantial number of people in several Icelandic towns and villages live in areas where avalanche risk is unacceptable. Although extensive evacuations may be used to reduce the risk to some extent, this can only be viewed as a temporary measure. Avalanche protection measures or land use changes are necessary for a permanent solution to this problem. Direct economic loss due to avalanches and landslides in Iceland in the 26 year period between 1974 and 2000 is about 3.3 billion IKR (41 million USD). The total cost of defence structures, which have been constructed or are under construction in the towns Flateyri, Siglufjörður and Neskaupstaður since 1995, together with the cost of relocation in endangered areas is about 2.5 billion IKR (31 million USD). The loss includes insurance payments and the cost of rescue and relief operations due to avalanches in towns and villages, and insurance payments due to avalanches in rural areas (damages to farm buildings, power and telephone lines and ski lifts). Other economic losses, especially due to avalanches in rural areas, are substantial, but may be assumed to be much smaller than the loss estimated above. A total of 52 people have been killed by avalanches in buildings, at work sites or within towns during the period 1974 to 2000, while 17 people have been killed by avalanches and landslides outside populated areas during the same period. If the death of a person in an avalanche or landslide accident is included in the economic loss as 100 million IKR (1.2 million USD) per fatal accident, the total cost of avalanche and landslide accidents in Iceland in the last 26 years together with the cost of avalanche protection measures is more than 13 billion IKR (162 million USD). The Icelandic government has drawn up a plan to construct avalanche protection measures for hazard areas and/or to purchase endangered property in order to reduce the death toll and the economic losses caused by avalanches in the future.*

INTRODUCTION

Snow avalanches and landslides have caused many catastrophic accidents and severe economical losses in Iceland since the country was settled in the ninth century. The pioneering work of Jónsson (1957), which was updated in 1992 (Jónsson *et al*., 1992), lists avalanches reported in annals and other sources since the twelfth century. It lists predominantly avalanches which caused damage to inhabited areas and avalanches which caused fatal accidents.

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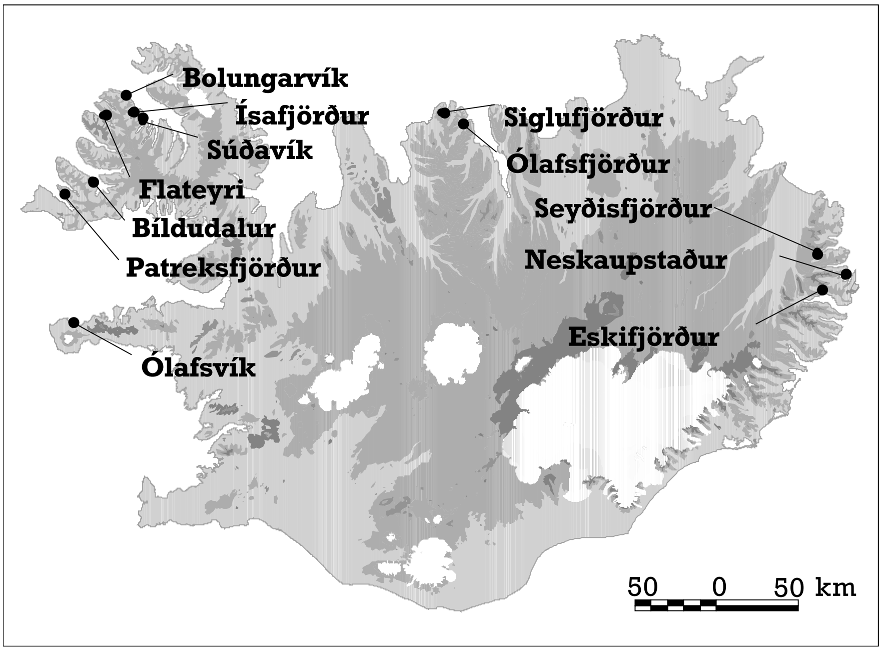

Figure 1. The most important villages in Iceland that are threatened by avalanches and landslides. – *Mikilvægustu þorp og bæir á Íslandi sem búa við hættu á snjóflóðum og skriðuföllum.*

avalanches have been reported in Iceland since then (Jónsson *et al.*, 1992; Björnsson, 1980). Unaccounted deaths may be assumed to have been several hundreds, especially during two gaps of a total of 250 years in the written records before 1600.

Before the middle of the nineteenth century, the population of Iceland lived almost exclusively in rural areas. Many of the accidents occurred on farms, when avalanches hit farmhouses or farm workers working or traveling near the farms. Many accidents also occurred during winter travels, for example from farms to coastal fishing stations and to church. Near the end of the nineteenth century, a number of fishing towns were established in deep fjords in western, northern and eastern Iceland (Figure 1). Parts of these towns turned out to be located in avalanche prone areas and several catastrophic accidents occurred in the years 1880–1920, a period of relatively harsh winters.

An expansion of the fishing towns in western, northern and eastern Iceland into areas further up into the mountain slopes occurred during the decades from 1930 to 1980 and led to a dramatic increase in the number of buildings in avalanche exposed areas. Records of the avalanche activity in most of these areas do not exist as the areas had not been inhabited, and avalanches which did not cause damage were not recorded in Iceland until recently. Relatively mild climate between 1925 and 1965 led to fewer avalanche accidents during this period compared with the period around the turn of the century. Climatic deterioration after 1965 has brought an increase in the avalanche activity. Several catastrophic avalanche accidents have occurred in recent decades in relatively new neighbourhoods in towns and villages in western and eastern Iceland.

Figure 2 shows locations where avalanches have been reported to cause damage or deaths since the settlement of Iceland in the ninth century (based on Figure 6 in Björnsson (1980)). Although the concentration of the accidents is highest in western, central northern and eastern Iceland as mentioned above, avalanche accidents have occurred at scattered loca-

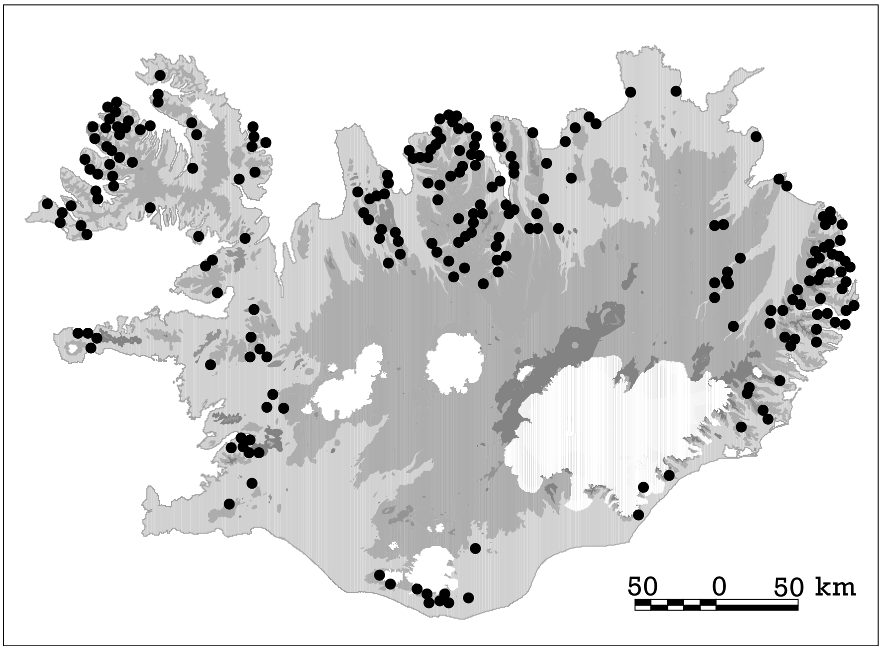

Figure 2. Locations where avalanches have been reported to cause damage or deaths since the settlement of Iceland in the ninth century (based on Figure 6 in Björnsson (1980)). A total of 225 locations are shown. Many accidents may be expected to be missing from the map because the records are not complete and the descriptions of many reported accidents in earliest centuries are not detailed enough to allow plotting their locations. – *Staðir þar sem orðið hafa slys eða tjón af völdum snjóflóða síðan land byggðist á níundu öld (byggt á mynd 6 í Björnsson (1980)). Samtals 225 staðir eru sýndir. Gera má ráð fyrir að marga staði vanti á myndina vegna þess að göt eru í heimildum og einnig vegna þess að lýsingar á mörgum slysa fyrr á öldum eru ekki nægilega nákvæmar til þess að teikna megi þau á kort.*

tions all over the country. Clearly the avalanche problem is relevant to most populated areas of Iceland, although the problem is by far most serious in the western, northern and eastern parts of the country. This point is illustrated by Figure 3, which shows the same data as Figure 2, but without a map of Iceland as a background. Interestingly, the outline of the country is easily recognizable from the locations of reported avalanche accidents alone.

Topographic conditions

Almost all the inhabited areas where avalanches pose a threat to the local population are located close to the coast in western, northern and eastern Iceland (Figure 1). The mountain slopes above the hazard areas usually rise to between 400 and 700 m above sea level. The mountain tops are often flat and formed as large plateaux, especially in the Vestfirðir region (the Northwest peninsula). Mountains in the Austfirðir region (the Eastern fjords) are more often formed as narrow ridges with Alpine characteristics. The plateaux are important as catchment areas for snow drift which can transport large amounts of drifting snow to the starting zones of avalanches under unfavourable circumstances during storms.

Forests are almost non-existent in Iceland. Natural avalanche protection, which is in many countries provided by dense forests covering steep slopes, is therefore not relevant in Iceland. Absence of forests, furthermore, means that information about the age or

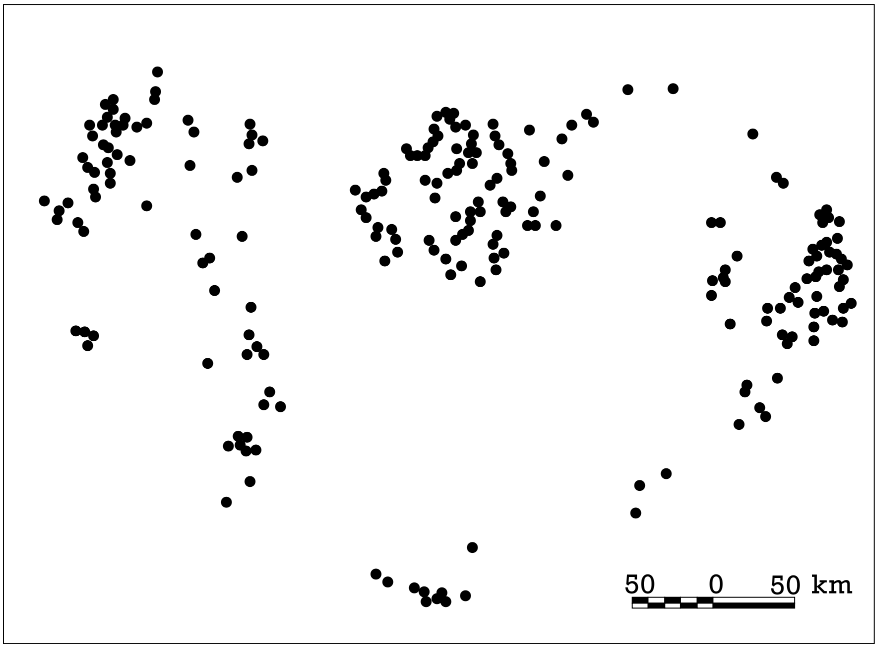

Figure 3. Same as Figure 2 except that a map of Iceland is not drawn as a background. The outline of country can be clearly distinguished from the geographical distribution of avalanche accidents alone. – *Sömu gögn og í mynd 2 nema hvað kort af Íslandi er ekki í bakgrunni. Útlínur landsins má auðveldlega greina út frá landfræðilegri dreifingu snjóflóðaslysa.*

distribution of tree species cannot be used for evaluating avalanche hazard in Iceland. Geological evidence, such as earth profiles and scattered boulders, which are often transported by avalanches, may sometimes be used to estimate the frequency and the maximum historical runout distance of snow avalanches, but studies of such evidence have only recently been initiated.

Meteorological conditions

The most dangerous avalanche cycles in Iceland are associated with intense lows that direct strong north or northeasterly winds to the threatened areas in western, northern or eastern Iceland. Heavy snow fall and accumulation of drifting snow in the starting zones in high winds are important components that lead to the most dangerous avalanche cycles (average wind speeds in excess of 90 knots have been observed in the mountains under such conditions). The snow drift is particularly important where large plateaux are located near steep slopes in which case snow drift during storms can deposit huge amounts of snow in avalanche starting zones adjacent to the plateaux. Björnsson (1980) gives a general outline of avalanche conditions in Iceland and includes a brief discussion of the meteorological conditions associated with the major avalanche cycles of this century. Jóhannesson and Jónsson (1996) and Ólafsson (1998) describe weather before and during several avalanche cycles in the Northwestern peninsula and in Neskaupstaður in the Eastern fjords.

FATAL ACCIDENTS

A total of 193 people have been killed in snow avalanches, slush flows and landslides in Iceland since 1901 (Jónsson *et al.* 1992; sources from the Icelandic Meteorological Office; Pétursson, 1991, 1992, 1993, 1995, 1996; Pétursson and Jónsdóttir, 2000a,b). Of these people, 113 were killed in buildings, at work sites or within towns, and 80 were killed on roads or traveling in backcountry areas. The majority of the fatalities were caused by snow avalanches and slush flows, but a total of 27 of the above mentioned fatalities were caused by landslides (including debris flows and rock falls) as summarised in Table 1.

Table 1. Fatal accidents in avalanches and landslides 1901–2000. – *Dauðsföll af völdum snjóflóða og skriðufalla 1901–2000.*

	Populated areas	Unpopulated areas	Total
Avalanches	107	59	166
Landslides	6	21	27
Total	113	80	193

Since the catastrophic avalanches in Neskaupstaður in 1974, altogether 69 people have been killed in avalanches, slush flows and landslides as summarised in Table 2. Of these people, 52 were killed in buildings, at work sites or within towns, and 17 were killed on roads or traveling in backcountry areas. Rock falls caused 3 of the fatalities during this period.

Table 2. Fatal accidents in avalanches and landslides 1974–2000. – *Dauðsföll af völdum snjóflóða og skriðufalla 1974–2000.*

	Populated areas	Unpopulated areas	Total
Avalanches	52	14	66
Landslides	0	3	3
Total	52	17	69

Figures 4 and 5 show the number of fatalities in snow avalanche accidents in the last 200 years for populated areas and for unpopulated areas, respectively, grouped into 25 year intervals. The number of fatal accidents in unpopulated areas had a steady downward trend from the period 1826–1850 until 1951–1975, but in the period 1976–2000 the accidents seem to start becoming more frequent again. The initial decline reflects improving climate conditions, a reduction in sheep farming in avalanche prone areas and improved transportation facilities that reduced the need for winter travel in the mountains. The rise in the last period reflects increased tourism and winter travel in remote backcountry areas. The number of fatal accidents in populated areas is relatively low in the favourable climatic conditions during the period 1926–1975, but there is a sharp increase in the period 1976–2000, mainly due to the catastrophic accidents in 1995.

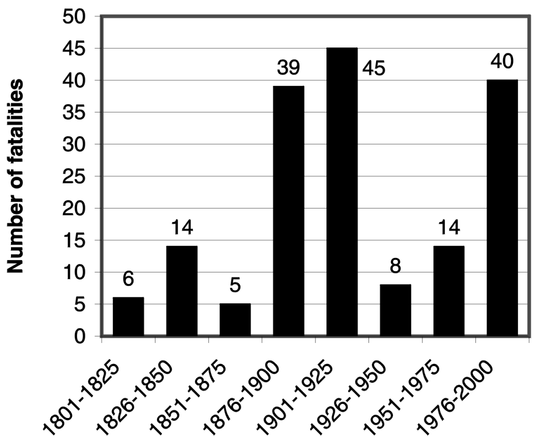

Figure 4. Fatal avalanche accidents in populated areas in Iceland in the period 1801–2000. The numbers include accidents in town and villages and on farms. – *Dauðsföll af völdum snjóflóða í byggð (heimili, vinnustaðir og opin svæði í þéttbýli) á Íslandi á tímabilinu 1801–2000.*

Table 2 shows that since 1974 about 3 times as many people have been killed in avalanche accidents in populated areas compared with unpopulated areas. This ratio is very high compared with other countries in Europe with avalanche problems (McClung and Schaerer, 1993; Tschirky *et al.*, 2000) and reflects the dangerous location of many villages that are situated in avalanche prone areas in Iceland. Table 3 lists the date and location of fatal avalanches hitting towns and farm buildings in Iceland since 1974.

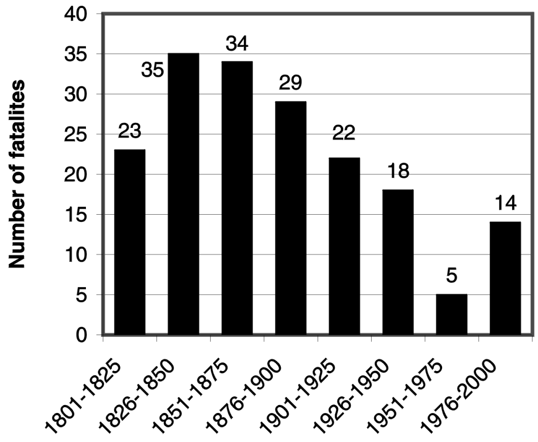

Figure 5. Fatal avalanche accidents in unpopulated areas in Iceland in the period 1801–2000. The numbers include accidents on rural roads and in the mountains. – *Dauðsföll af völdum snjóflóða utan byggðar á Íslandi á tímabilinu 1801–2000. Um er að ræða slys á þjóðvegum og í óbyggðum.*

Table 3. Recent fatal avalanche accidents in populated areas. – *Dauðaslys af völdum snjóflóða á byggð á nýliðnum áratugum.*

Date	Location	Fatalities
20-12-1974	Neskaupstaður	12
22-01-1983	Patreksfjörður	4
05-04-1994	Tungudalur, Skutulsfirði	1
16-01-1995	Súðavík	14
18-01-1995	Grund, Reykhólahreppi	1
26-10-1995	Flateyri	20
Total		52

The number of deaths in avalanche accidents in the 26 year period between 1974 and 2000 may not be representative of the current avalanche risk in Iceland because catastrophic accidents occurred near the beginning and end of the time period. One must, however, note that a considerable number of residential buildings have been built in avalanche hazard areas in Iceland since 1974 so that one may expect the avalanche risk to have increased during this period.

ECONOMIC LOSS

The economic loss that has been inflicted by avalanches and landslides in Iceland has been enormous. It is convenient to divide this loss into three components. First, *the direct loss due to damaged buildings and infrastructure* and properties such as roads or subsurface constructions which may be abandoned after an avalanche accident, *etc*. The direct loss is mainly borne by an insurance operated by the state, the Iceland Catastrophe Insurance. Rebuilding of infrastructure after an accident and compensation for properties, which are not insured by the Iceland Catastrophe Insurance, may partly be financed by funds established from private donations after an accident. Second, the *cost of rescue and relief operations* and other such operational cost associated with an accident. The operational cost is mainly paid by the state. Third, *the direct and indirect economic loss due to the disruption of the local society* where an avalanche accident occurs. This cost is not paid by a definite institute or agency and is not included the analysis presented here.

The direct loss and the cost of rescue and relief operations are summarised in Table 4 (August 2000 price levels and dollar exchange rate (80.43 IKR/USD)).

The table shows that most of the cost is caused by snow avalanches hitting populated areas (about 90%). The bulk of the cost is caused by the three largest accidents in Neskaupstaður 1974 (1030 million IKR, 12.8 million USD), Súðavík 1995 (600 million IKR, 7.4 million USD) and Flateyri 1995 (730 million IKR, 9.1 million USD), which also caused the vast majority of the fatal accidents (46 of the 52 fatalities that have occurred in populated areas since 1974).

The estimated economic loss includes insurance payments due to damaged buildings and infrastructure, the cost of rescue operations, and the cost of various rebuilding financed by the government and funds established from private donations. It is based on information about payments of the Iceland Catastrophe Insurance since 1983 and about the economic damage associated with the accident in Neskaupstaður in 1974. The operational cost is based on

Table 4. Direct loss and cost of rescue and relief operations 1974–2000. – *Efnahagslegt tjón og kostnaður við björgunaraðgerðir 1974–2000.*

Type of accident	Amount (billion IKR)	Amount (million USD)
Snow avalanches, excl. ski areas, power lines *etc.*	3.00	37.4
Damages in ski areas	0.17	2.1
Infrastructure, such as power lines	0.07	0.9
Damages due to landslides	0.09	1.1
Total	3.3	41

information from the Ministry for the Environment for the Súðavík and Flateyri accidents in 1995 and on a rough estimate for other accidents in towns and villages. The largest costs are due to the accidents in Neskaupstaður (1974), Patreksfjörður (1983), Ólafsvík (1984, 1995), Ólafsfjörður (1988), Seyðisfjörður (1989, 1992, 1995), Ísafjörður (1994, 1995), Súðavík (1995), Flateyri (1995) and Bolungarvík (1999) (Figure 1). Insurance payments prior to 1983, other than for Neskaupstaður in 1974, were not available for this study and are therefore not included. Furthermore, the percentage of the loss which is borne by the owner (typically about 5% for private buildings) is not included. The loss estimate includes damage due to avalanches in rural areas (damages to farm buildings, power and telephone lines and ski lifts), but not operational costs associated with such accidents. The unaccounted insurance costs before 1983, the cost borne by the owners of damaged property, and operational costs in rural areas may be roughly estimated as 500 million IKR (6.2 million USD) and are therefore much smaller than the total loss estimated in Table 4.

The loss due to the disruption of the local society following an avalanche accident is not explicitly estimated here. It involves a more or less total disruption of all ordinary activity in a society of several hundred people for several weeks. It also involves a prolonged recovery period where a significant proportion of the society is absorbed in planning the recovery, participating in rebuilding of damaged property and taking part in other activities connected with the accident.

COST OF PROTECTION MEASURES

After the avalanches in 1995, a government fund that finances protection measures in the threatened areas was strengthened considerably. The Icelandic Avalanche Fund finances up to 90% of the cost of protection measures for avalanche and landslide hazard. The remaining 10% are borne by the local community, except that communities which need comparatively costly measures relative to their size can apply for additional support from the government. A report was compiled in 1996 about the need for avalanche protection measures in Iceland (Jóhannesson *et al.*, 1996). Based on this report, the local communities together with the Ministry of the Environment made a plan for the construction of protection measures where the communities agreed beforehand on the priorities of the different areas under consideration.

The cost of the construction of avalanche defence structures and relocation in endangered areas since the catastrophic accidents in 1995 is summarised in Table 5 (August 2000 price levels and USD exchange rate).

In addition to the projects listed in Table 5, appraisals of avalanche protection measures have been carried out for Seljalandshlíð in Ísafjörður (Hnit and NGI, 1996), the Bjólfur area in Seyðisfjörður (VA and NGI, 1998), Geirseyrargil in Patreksfjörður (VST and NGI, 1998), the settlement of Bolungarvík (Orion, VA and NGI, 1999) and for Siglufjörður north of Strengsgil (Margreth, 2001), but construction of defence structures has not been started in these areas. The cost of these studies, the cost of a pilot project in

Table 5. Cost of relocation and avalanche defence structures 1995–2000. – *Kostnaður við uppkaup, flutning byggðar og byggingu varnarvirkja 1995–2000.*

Location	Cost (billion IKR)	Cost (million USD)
Súðavík (relocation)	0.81	10.1
Hnífsdalur (purchasing of buildings)	0.23	2.8
Flateyri (dams[1], completed in 1998)	0.44	5.5
Siglufjörður (dams[2], completed in 1999)	0.33	4.0
Neskaupstaður (dams and supporting structures[3])	0.55	6.8
Various costs	0.13	1.6
Total	2.5	31

[1] Sigurðsson *et al.* (1998). [2] VS and NGI (1997). [3] Tómasson *et al.* (1998).

Siglufjörður to evaluate the use of supporting structures for Icelandic conditions (Jóhannesson and Margreth, 1999) and some other miscellaneous costs are listed as various costs in the last line of Table 5.

The table shows that the cost of defence structures is now about 60% and the cost of relocation and purchasing of buildings in hazard areas is about 40% of the total cost.

The new defence structures at Flateyri and in Siglufjörður have already been hit by avalanches on four separate occasions in the three winters since the deflecting dams were completed (Jóhannesson *et al.*, 1999; Jóhannesson, in press). Figures 6 and 7 show outlines of the avalanches that hit the deflecting dams at Flateyri in 1999 and 2000 and Siglufjörður in 1999 and 2001. The 1999 avalanche from Skollahvilft above Flateyri was substantially smaller than the catastrophic avalanche in 1995 (Figure 6). It would thus probably not have caused damage in the absence of the dams, because buildings in this area of the village were devastated by the avalanche in 1995. It is possible, on the other hand, that the avalanche in 2000 from Innra-Bæjargil (Figure 6) would have reached the current settlement and destroyed several domestic houses. It is also possible that the avalanche in 1999 from the gully Ytra–Strengsgil in Siglufjörður (Figure 7) would have reached the current settlement if it had not been directed away from the village by the deflecting dam which was then under construction below the gully.

OTHER LOSSES AND COSTS

An additional loss component, which is difficult if not impossible to determine economically, is the loss of lives in accidents. Although it is not particularly meaningful to attach a certain sum of money to each lost life, one may try to approach this question from the viewpoint that the society spends money on lifesaving operations in hospitals, by building more secure traffic infrastructure *etc*. There is general willingness in the society to spend a certain but not a very well defined amount of money on saving a life, and this amount is definitely not unlimited. If a life is lost in an accident, which could have been prevented with a much lower cost than is often spent on saving the lives of patients in hospitals or on other lifesaving operations in the society, then this may be considered a failed opportunity to prevent an accident. This view will be adopted here and it is assumed that the society is willing to spend on the order of 100 million IKR (1.2 million USD) to save the life of one person that otherwise might be lost in an accident.

The deaths due to avalanche and landslide accidents in Iceland over the last 26 years thus correspond to an economic loss of 69·100 million IKR (86 million USD) in the above sense that the society is assumed to have been willing to spend this amount of money on measures for preventing the accidents in addition to the cost of the more direct economic damage which was estimated above.

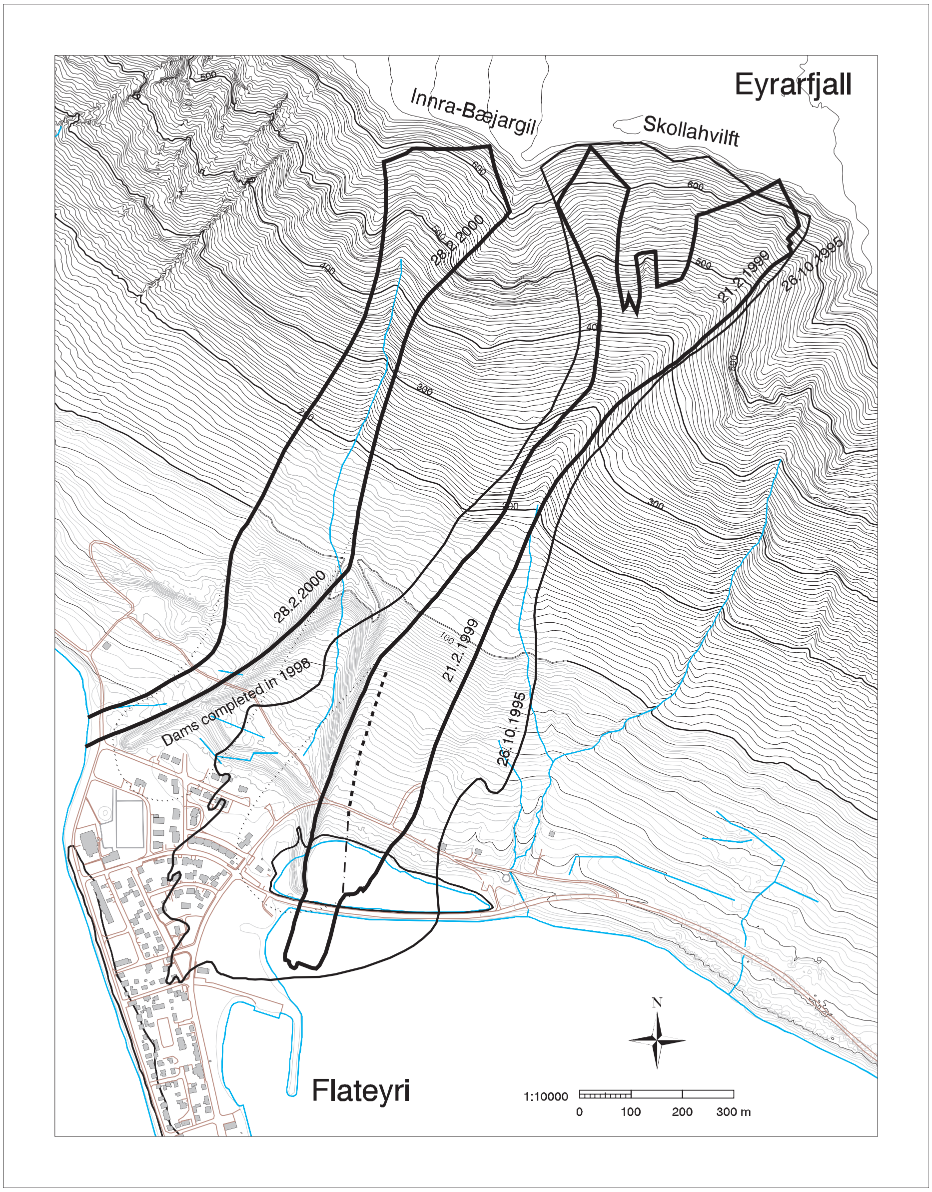

Figure 6. The outlines of avalanches that were deflected by the deflecting dams at Flateyri in 1999 and 2000. The outline of the catastrophic avalanche in 1995 is also shown. The channelized flow of the 1999 avalanche from Skollahvilft along the deflecting dam is indicated with a dashed curve. Hypothetical outlines of the avalanches in 1999 and 2000 in the absence of the deflecting dams are shown as dotted curves. – *Útlínur snjóflóða sem féllu á leiðigarðana á Flateyri 1999 og 2000. Útlínur mannskaðasnjóflóðsins 1995 eru einnig sýndar. Næst varnargarðinum flæddi flóðið 1999 í stríðari og þykkari streng en fjær garðinum og er þessi hluti flóðsins sýndur á myndinni með slitinni línu sem næst samsíða garðinum. Áætlaðar útlínur flóðanna 1999 og 2000 ef varnargarðarnir hefðu ekki verið til staðar eru sýndar með brotnum línum.*

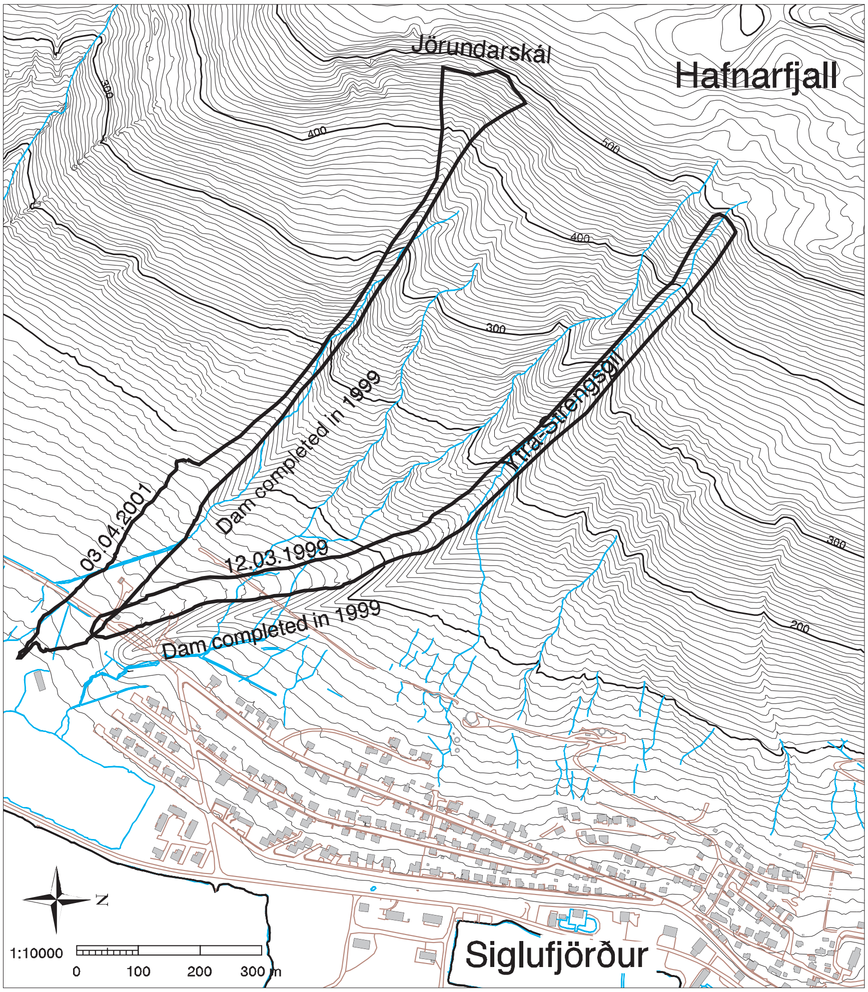

Figure 7. The outlines of avalanches that hit the deflecting dams below Ytra–Strengsgil and Jörundarskál in Siglufjörður in March 1999 and April 2001. – *Útlínur snjóflóða sem féllu á leiðigarðana undir Ytra–Strengsgili og Jörundarskál á Siglufirði í mars 1999 og apríl 2001.*

Yet another aspect of the loss caused by avalanches, which is also almost impossible to estimate in economic terms, is the disruption and inconvenience caused by impending avalanche danger even when no avalanches fall. The most obvious effect of this type is the inconvenience cause by frequent evacuations of buildings in avalanche hazard areas. Insecurity and anxiety among the local population in the endangered areas is also an important negative aspect of the avalanche problem which cannot be expressed in economic terms.

THE TOTAL COST DUE TO AVALANCHES AND LANDSLIDES

Based on the above estimates, it is found that the total direct and operational loss due to avalanche accidents in Iceland following the accident in Neskaupstaður in 1974, together with the cost of purchasing buildings and the construction cost of defence structures, is about 5.8 billion IKR (72 million USD). This includes the cost associated with the relocation of Súðavík, the purchasing of houses in Hnífsdalur, the cost of defence structures for Flateyri and Siglufjörður, and the estimated cost of the structures which are under construction in Neskaupstaður. About 3.3 billion IKR (41 million USD) of the total is direct economic loss due to avalanches and landslides, whereas the cost of defence structures and the cost of relocation in endangered areas amounts to about 2.5 billion IKR (31 million USD). Unaccounted costs may be roughly estimated as an additional 500 million IKR (6.2 million USD).

When the hypothetical cost of the 69 fatal avalanche and landslide accidents in Iceland in the last 26 years as estimated above is added to the economic loss and the cost of avalanche protection measures, the total cost of avalanches and landslides in Iceland during this period is found to be more than 13 billion IKR (162 million USD).

AVALANCHE HAZARD AND ACCEPTABLE RISK

Avalanche hazard zoning is the basis of most other work on improving avalanche safety, including local community planing and the design of avalanche protection measures where settlements have already been located in dangerous areas. Some initial work was done on evaluating the avalanche hazard for settlements in Iceland after the Neskaupstaður accident in 1974 (see for example de Quervain, 1975), but this work did not lead to a fundamental change in the rules and regulations regarding avalanche safety in Iceland. It was not until after the accidents in 1995 that it was fully realised that a substantial number of people in several Icelandic towns and villages live in areas where avalanche risk is unacceptable. This realisation led to a strengthening of the avalanche work group at the Icelandic Meteorological Office (Magnússon, 1996, 1998, in press) and the office was given the responsibility for avalanche hazard zoning in Iceland.

In 1995 shortly after the catastrophic accident in Súðavík research into hazard zoning was strengthened. A research project was started at the University of Icelend to establish the statistical foundations af hazard zoning. The result of this effort was that it would be advantageous to delineate hazard zones based on individual risk. A technique for estimating the risk due to avalanches was also proposed (Jónasson *et al.*, 1999).

The acceptable risk for individuals living in avalanche hazard areas was considered by avalanche professionals, government officials and the local authorities of the affected communities. Avalanche risk is non-voluntary and avalanche accidents have a high "risk aversion factor". It is therefore desirable that avalanche risk in inhabited areas is significantly less than for example risk due to fatal traffic accidents or the total risk of death by accidents for children. This line of argument leads to an acceptable risk level due to avalanches on the order of 0.2 to 0.5 fatal accidents per year per 10 000 persons assuming that a risk aversions factor in the range 5 to 2 compared to traffic accidents is adopted. Similar results can be obtained by considering the value of life discussed above (based on willingness to pay analysis) and finding a risk level that should be virtually negligible for most persons.

A new regulation about hazard zoning and the use of hazard zones in Iceland was issued in 2000 (Ministry for the Environment, 2000). This regulation specifies three different hazard zones which are designated with the letters "A", "B", "C". The zones are based on the concept of "local risk", which is defined as the yearly risk of death faced by an individual who stays all year round in an ordinary building at a specific location. The actual risk experienced by inhabitants of hazard areas depends on the proportion of time they stay in different types of buildings and on the additional safety provided by exceptionally strong buildings. This will typically be about 75% of the specified "local risk" for domestic houses and on the order of 40% of the specified "local risk" for commercial buildings. The three hazard zones are defined in terms of the "local risk" according to Table 6.

Table 6. Hazard zones of the Icelandic regulations issued in 2000. – *Hættusvæði samkvæmt reglugerð um ofanflóðahættumat frá árinu 2000.*

Hazard zone	Lower limit of risk (10^{-4} per year)	Upper limit of risk (10^{-4} per year)
A	0.3	1.0
B	1.0	3.0
C	3.0	—

New settlements can only be planned outside hazard zones according to the new regulation. The regulation specifies the following restriction on the use of hazard zones in already existing settlements.

A New residential houses and commercial buildings can be built in hazard zones "A" in existing settlements, but schools, hospitals, apartment buildings and similar buildings must be reinforced to withstand the impact of a design avalanche in these areas.

B Residential buildings must also be reinforced in hazard zones "B", but not common commercial buildings. New schools, hospitals, *etc.* are not allowed.

C No new buildings where people are expected to stay on a permanent basis are allowed in hazard zones "C", neither residential nor commercial buildings. Changes and maintenance of existing buildings is allowed in these areas, but subject to the restriction that the safety of people should be improved by the changes.

The regulations require that local governments aim to fully eliminate the use of hazard zones "C" for residential buildings by the year 2010 by the construction of protection measures and/or purchasing of buildings in hazard zones in cases where the construction of defence structures is not practical or economical. A plan has been made to construct avalanche protection measures for hazard areas and/or to purchase endangered property to reach this goal. The support of the Icelandic Avalanche Fund is also available to local authorities for the construction of avalanche protection measures for zones "B" and "A".

The approach to use individual risk as a criteria for hazard zoning is quite different from the traditional practice in other countries in Europe, such as Norway and the Alpine countries, where the greatest experience in avalanche hazard zoning has accumulated. Therefore a comparison was made between Icelandic and Norwegian and Austrian hazard zoning methods (Arnalds, 2001). Three separate groups of experts delineated hazard zones in Seyðisfjörður, eastern Iceland, based on Icelandic, Norwegian and Austrian regulations and methods. The results indicate that the Icelandic regulations are somewhat stricter than the Norwegian and Austrian regulations. The safety level imposed by the Icelandic regulations may be about three time higher than for the other two countries.

After the regulations on hazard zoning were finalised a hazard map has been proposed for the community of Neskaupstaður (Arnalds *et al.*, 2001a; Hættumatsnefnd Fjarðabyggðar, 2001). The technical work related to the hazard zoning for Neskaupstaður was done parallel to hazard zoning for Ísafjörður and Siglufjörður (Arnalds *et al.*, 2001b). The regulations specify that in addition to the four abovementioned towns hazard zoning should be completed before the end of 2001 for the towns Ólafsvík, Patreksfjörður, Bíldudalur, Bolungarvík and Eskifjörður (Figure 1).

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ÁGRIP

Slys og tjón af völdum snjóflóða og skriðufalla á Íslandi

Snjóflóð hafa valdið mörgum hörmulegum slysum og stórfelldu efnahagslegu tjóni hér á landi síðan byggð hófst á níundu öld. Fyrstu heimildir um mannskaða af völdum snjóflóða eru frá árinu 1118 þegar snjóflóð í Dölum hreif með sér 5 menn og fórust þeir allir. Samtals er getið u.þ.b. 680 dauðsfalla af völdum snjóflóða á Íslandi síðan þá. Gera má ráð fyrir nokkur hundruð óskráðum dauðsföllum til viðbótar, einkum á tveimur samtals 250 ára löngum tímabilum fyrir 1600 þegar göt eru í annálum. Á tuttugustu öld fórust samtals 193 af völdum snjóflóða og skriðufalla hér á landi.

Hörmuleg snjóflóðaslys í Súðavík og á Flateyri árið 1995, sem kostuðu 34 mannslíf og ollu miklu efnahagslegu tjóni, hafa gerbreytt afstöðu Íslendinga til snjóflóðahættu. Slysin opnuðu augu manna fyrir því að snjóflóðahætta er langt umfram það sem hægt er að sætta sig við á stórum þéttbýlum svæðum í nokkrum þorpum og bæjum á landinu. Rýmingar er hægt að nota til þess að draga að vissu marki úr slysahættu af völdum snjóflóða. Engu að síður verður að líta á víðtækar rýmingar sem tímabundna ráðstöfun meðan unnið er að lausn vandans með byggingu fullnægjandi snjóflóðavarna og með breytingum á skipulagi og landnýtingu.

Beint efnahagslegt tjón af völdum snjóflóða og skriðufalla hér á landi á 26 ára tímabili frá 1974 til 2000 er um 3,3 milljarðar kr. Heildarkostnaður við varnarvirki, sem byggð hafa verið á Flateyri, Siglufirði og í Neskaupstað síðan 1995, ásamt kostnaði við uppkaup og flutning byggðar frá hættusvæðum, er um 2,5 milljarðar kr. Tjónið felur í sér tryggingarbætur og kostnað vegna björgunaraðgerða vegna ofanflóða í þéttbýli og tryggingarbætur vegna flóða utan þéttbýlis (þar er m.a. um að ræða tjón á sveitabæjum, rafmagns- og símalínum og skíðalyftum). Annað efnahagslegt tjón, sérstaklega vegna snjóflóða utan þéttbýlis, er umtalsvert, en gera má ráð fyrir að það sé miklu minna en heildartjónið sem nefnt er hér að framan.

Samtals hafa 52 látið lífið í snjóflóðum sem fallið hafa á heimili, vinnustaði eða á opin svæði í þéttbýli á tímabilinu 1974 til 2000, en 17 hafa látist af völdum snjóflóða og skriðufalla á ferðalögum eða í óbyggðum á sama tímabili. Ef hvert dauðaslys af völdum ofanflóðs er metið sem 100 milljóna kr. „tjón" þá er efnahagslegt umfang ofanflóða á Íslandi síðustu 26 árin meira en 13 milljarðar kr. Stjórnvöld hafa gert áætlun um uppbyggingu snjóflóðavarna og uppkaup húsnæðis á hættusvæðum til þess að draga úr slysum og tjóni af völdum snjóflóða og skriðufalla í framtíðinni.

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