

GIS IN AVALANCHE HAZARD MANAGEMENT

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In 1995, catastrophic avalanches inundated the northwestern Iceland towns of Flateyri and Súðavík killing 34 people. To reduce the possibility of another tragedy, the Icelandic Meteorological Office (IMO) has since increased involvement in avalanche forecasting, evacuations, and hazard zoning for avalanche prone communities around Iceland. A GIS database is currently in development that catalogues both recent and historical avalanche events. As shown in the 1995 accidents, historical avalanches are not sufficient to determine the boundaries of hazardous areas. While past avalanches can concretely delimit hazardous areas, a lack of recorded avalanche activity does not render an area “safe”. Terrain analysis in conjunction with math models can predict possible avalanche runouts that extend beyond historical limits. By determining extreme runouts, boundaries of hazard areas can be defined even when records of past avalanches are limited or nonexistent. At the IMO, GIS is used to record avalanche events, analyze avalanche paths, show results from model calculations, and ultimately to plot hazard zones.

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Avalanche danger threatens many communities around Iceland. The extent of the danger is indicated in figure 1 showing avalanche events in Iceland (Jóhannesson, in press/b, based on Björnsson, 1980) Historical records document deaths, injuries, and economic damages since the earliest settlements. It has recently been estimated that the direct economic loss due to avalanches and landslides in the last 26 years alone is around 3.8 billion IKR. When the cost of defense structures and relocation is added to the economic loss, the direct cost of avalanches and landslides in Iceland is in excess of 6 billion IKR. If the death of a person in an avalanche or landslide accident is included in the economic loss as 100 million IKR 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 (Jóhannesson, in press/b).

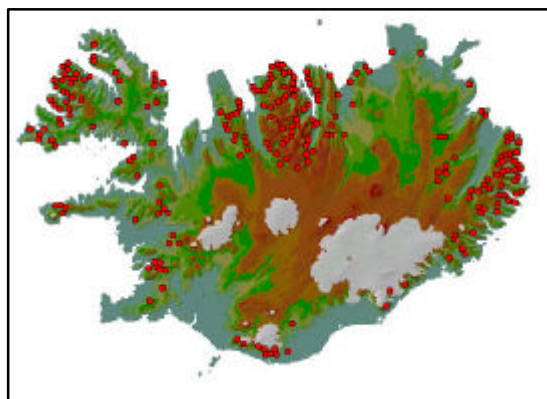


Figure 1. Recorded avalanches that have caused damage or deaths in Iceland.

In 1995, 34 people died in avalanches in the towns of Flateyri and Súðavík in areas that were thought to be safe. Before this catastrophe, avalanche hazard maps had been prepared for several communities, but they were based mainly on recorded avalanches. As settlements expanded up the mountainsides, records of avalanches were scarce. Sadly, lack of records did not equate to lack of danger. The magnitude of the 1995 catastrophe focused attention on

the need for new maps based not only on past avalanches, but also on estimated extreme runouts of possible avalanches.

The deaths of so many people were a catalyst for change in how avalanche danger was addressed in Iceland. The need for a comprehensive national program of land-use planning with regard to avalanche hazard was identified.

As new information flowed into the IMO, an avalanche database began to form (Magnússon, 1993). Annals documenting the avalanche history of the most severely threatened towns were compiled and an SQL database was created to organize data and assist in risk calculations (Arnalds, 1997). Locations, dates, runout lengths, and information about the terrain together with other metadata were recorded. While this database recorded valuable information, spatial data was still relatively inaccessible and relegated to notebook lined shelves.

GIS avalanche database

Prior to the GIS avalanche database, GIS was mainly used to create topo-

The Data
Topographical maps, TIN and contour lines
Rivers and lakes
Buildings and roads
Avalanche outlines
Avalanche paths
Starting zones
Slope of the mountainside
Model results
Hazard zones
Snowdepth stake locations
Snowdepth measurements

graphical maps (Magnússon, 1997). In 1997, the Neskaupstaður avalanche annals were published and ArcInfo GIS was used to create some of the avalanche maps in the book (Haraldsdóttir, 1997). Two years later the development of a comprehensive GIS avalanche database began.

The GIS avalanche database consists of spatial information related to avalanches and terrain. It also includes meta-data that documents data certainty and links to the SQL avalanche database that stores data sources and other meta-data.

Avalanche Outlines

One of the main purposes of the GIS database is to record avalanche outlines. The outlines come from many sources with varying degrees of certainty. Information about the oldest avalanches is obtained from newspaper articles, interviews, books, and town records. While some points along the outline may be certain (i.e. when the avalanche damages a structure), most outlines of the oldest avalanches must be estimated from the available evidence.

Many outlines of recent avalanches are more certain than the oldest ones. The shape of the tongue may be sketched on a map or a number of witnesses agree on the extent. As with the other avalanches, the tongue of the avalanche is usually more certain than the starting zone or track.

The highest level of certainty is given to some of the most recent avalanches. Snow observers in avalanche prone communities photograph and measure significant avalanches. Sections of avalanches measured with GPS are designated with the highest level of certainty though dangerous conditions and inclement weather can prevent such accurate measurements of an entire avalanche.

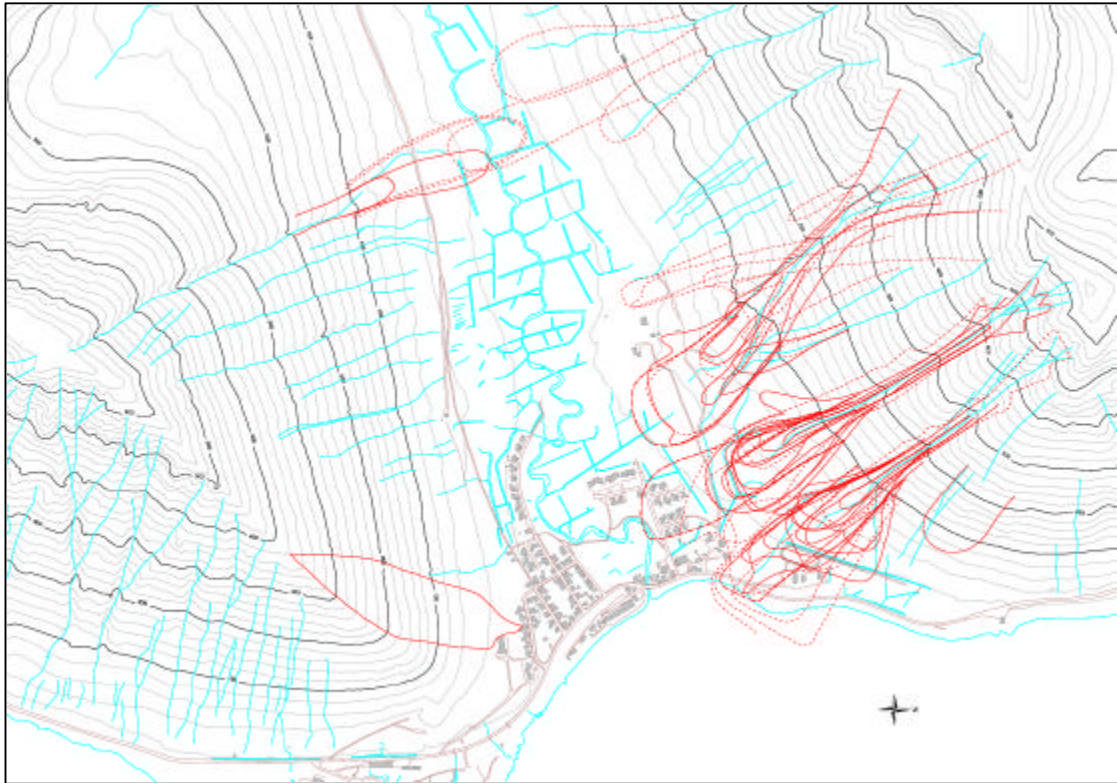


Figure 2. Avalanche outlines of varying certainty in Hnífsdalur, northwest Iceland.

The certainty of avalanche outlines are shown graphically through the use of varying line types as shown in Figure 2. As indicated above, a single avalanche outline can consist of segments of varying uncertainty and the certainty is often related to location on the mountainside.

Not only are outlines often uncertain, the date of the avalanche is also uncertain. The SQL database addresses the extent of date uncertainty (Arnalds, 1997), but in the GIS database, 3 dates are assigned: a Julian date, an Icelandic date as text, and an English date as text. While the text dates are used as labels, the Julian date is stored in the internal format of the SQL or GIS database centered in the time interval when the avalanche is known to have occurred. For example, an avalanche known to have occurred in January 1945 is given the date 15.01.1945. Because at times the most accurate possible date is “the late

1700’s,” the Julian date is purely for query purposes and facilitates mapping date ranges.

Terrain analysis with GIS

The slope of the hillside is directly related to the possibility of avalanches. If the hillside is very steep, snow cannot accumulate. If the slope of the hillside is too small, snow can accumulate, but will not fall. Using TIN or contour lines to create a grid, a slope map can be calculated as shown in Figure 3. Areas of yellow and purple indicate the extreme slopes where avalanche triggering is unlikely. The increasing shades of red point to the areas where the slope of the hillside could allow the triggering of avalanches. The results of such maps are twofold. It suggests areas to focus field research, and shows potentially dangerous areas on the hillside through color to those unfamiliar with contour maps.

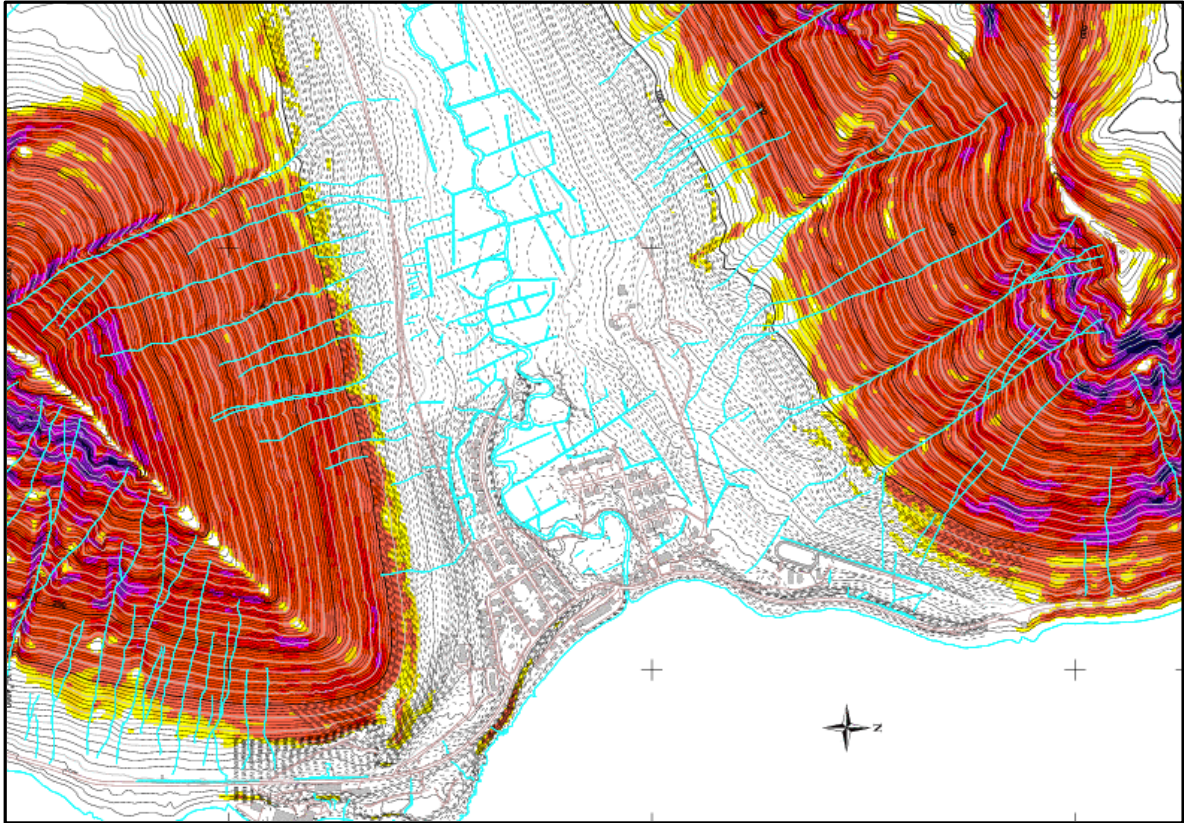


Figure 3. Slope map indicating starting zones in Hnífsdalur, northwest Iceland.

Fieldwork and model results

Avalanche outlines comprise only a small amount of collected spatial data. GIS layers also store results of model calculations, fieldwork and hazard zoning.

Some models demand an estimate of the mass of the snow in the starting zone. Figure 4 shows an example of starting zones. While slope maps can point to potential starting zones, the polygons in figure 4 are based on extensive fieldwork by avalanche experts with consideration of terrain and meteorological conditions. These zones indicate areas where snow is likely to accumulate on the mountainside. Using snow depth measurements and the area of the polygons, the volume and mass of snow in the starting zone can be estimated.

As shown in the 1995 disasters, maps of previous avalanches are not sufficient to determine the extent of avalanche

hazard. It is also necessary to estimate extreme possible runouts through the use of models such as so-called runout indices shown in figure 5 (Jónasson, 1997) and the α/β -model in figure 6 (Jóhannesson, 1999). Most models are one-dimensional and require a set of paths as shown in the previous figures. Each path suggests the course an avalanche could trace down the hillside. A starting point, reference point, and name are attached to each path.

The model results are stored as layers in GIS and indicate the size and length of avalanches that could occur along the various paths. These results combined with avalanche outlines form the main inputs to the delineation of hazard zones.

Hazard zoning

While models and historical avalanche maps can indicate the location of hazardous areas, the level of risk that a

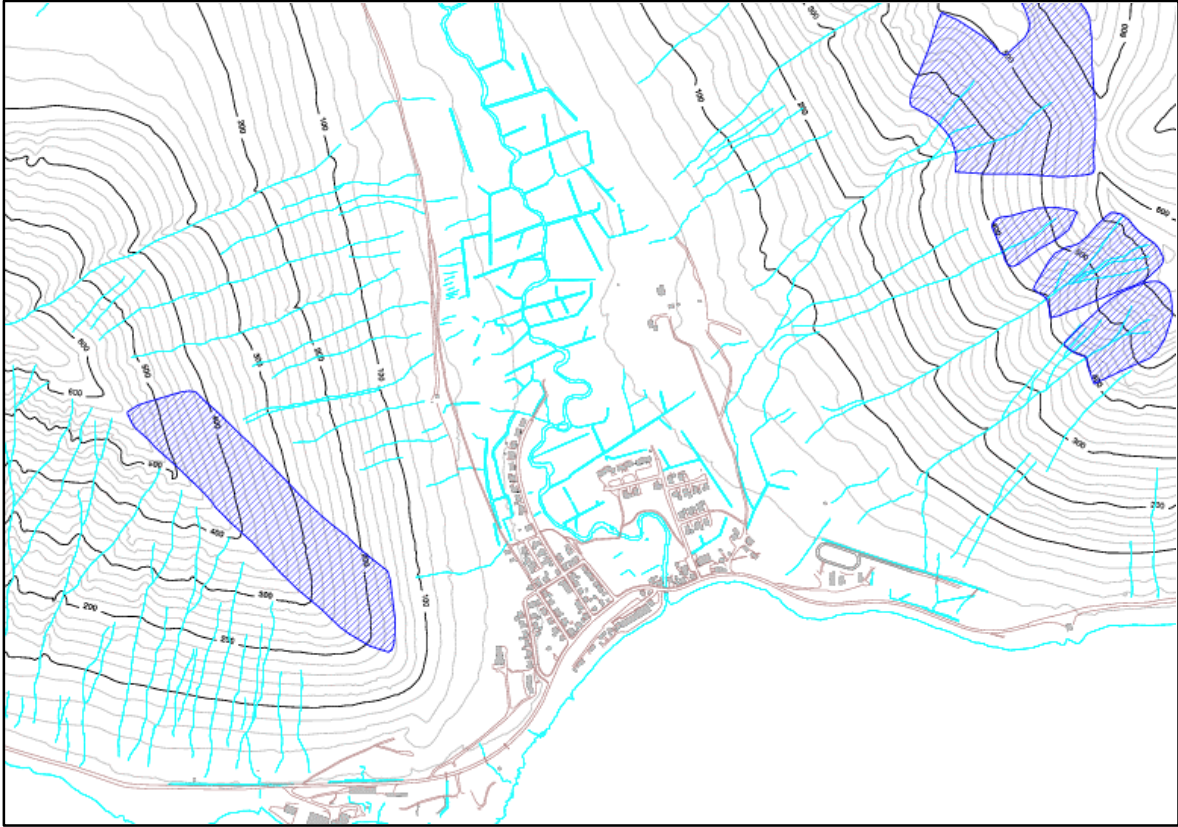


Figure 4. Starting zones in Hnífsdalur, northwest Iceland.

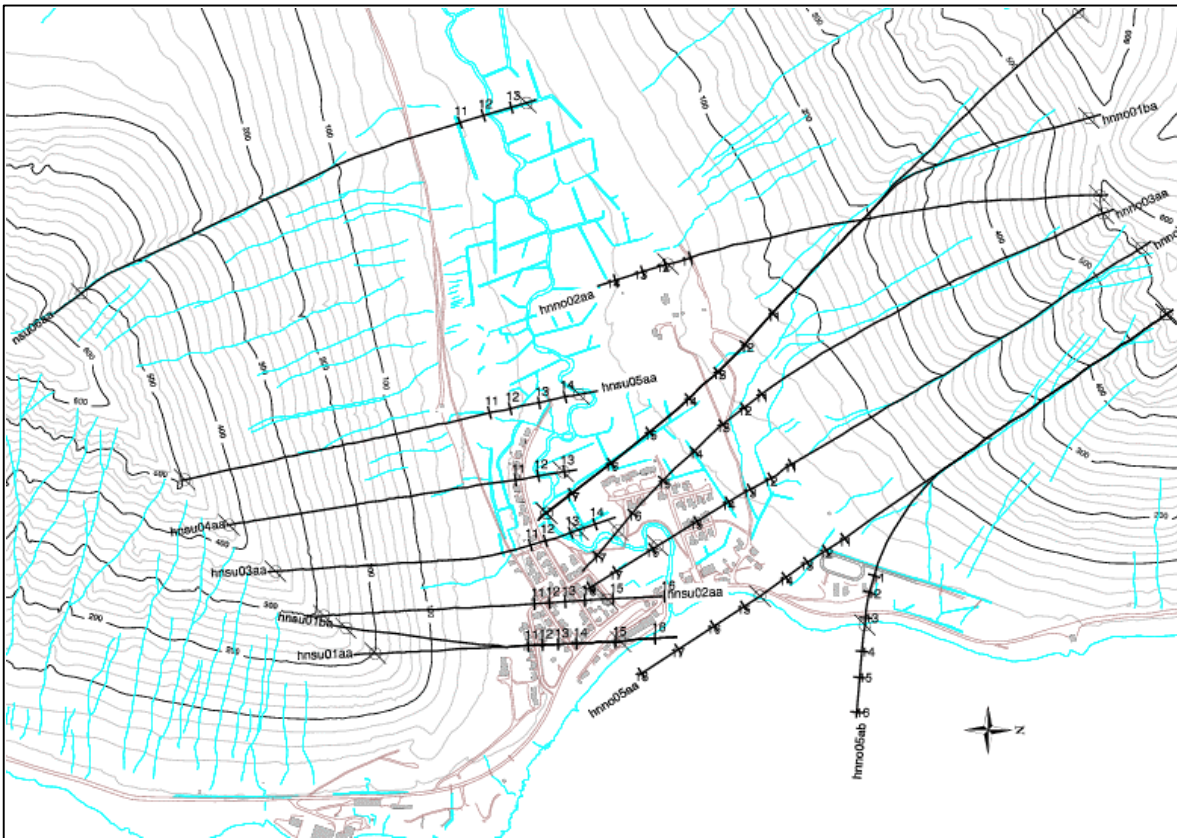


Figure 5. Runout indices in Hnífsdalur, northwest Iceland.

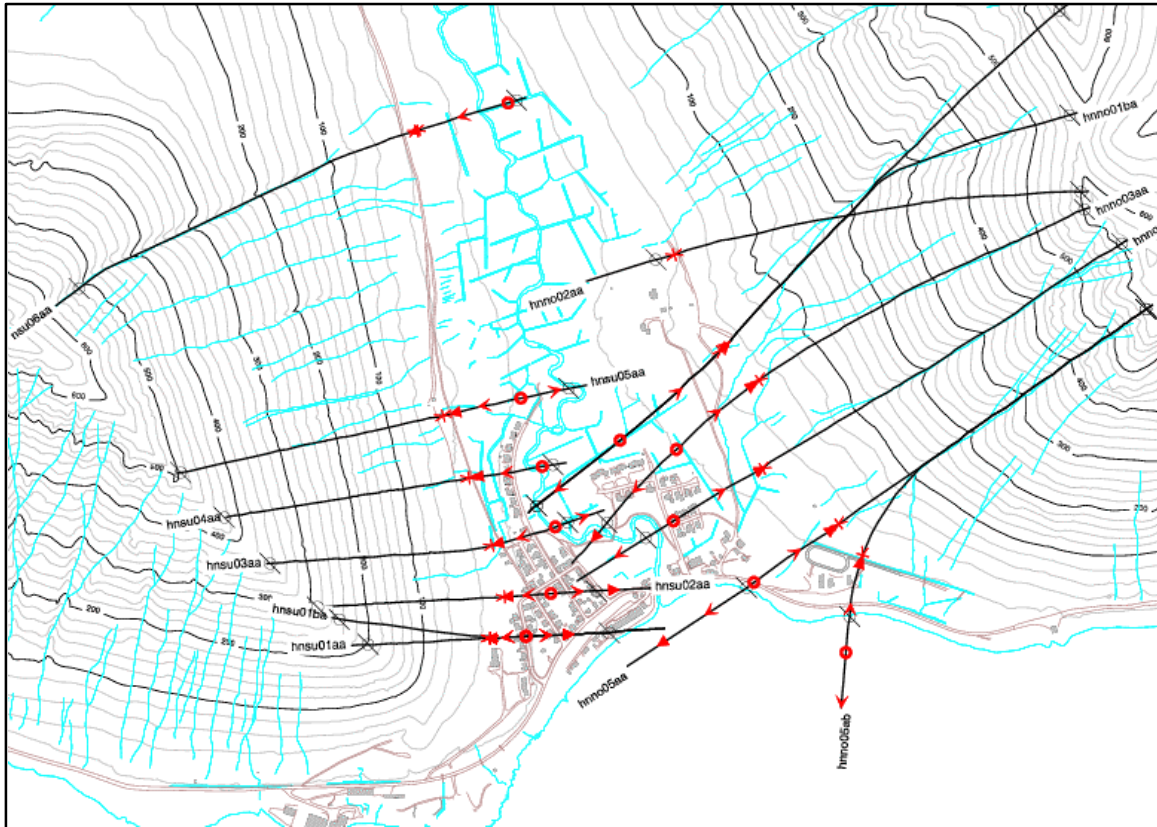


Figure 6. α/β -model results in Hnífsdalur, northwest Iceland.

community is willing to accept is a political issue. In Iceland, risk is defined by the probability of death due to avalanches (Jónasson and others, 1999). Zoning decisions are based on acceptable risk levels that have recently been formalized by law and regulation. Although hazard zones are not calculated within GIS, they are stored as layers and easily mapped

Future plans

As the avalanche database takes form, future goals become more ambitious. While maintaining the current database, more spatial information will be added and applications written to access and analyze the data.

The database will expand to include more than the current few communities. New avalanches will be added consistently as they occur and automated annual updates will be a feature. Spatial data such as snow depth measurements

will be added. Geological maps and aerial photographs should also be included when possible with the goal of increasing accessibility to all available information. Applications will be written to access the precipitation stations and estimate snow accumulation. These layers and grids will in the future be incorporated into an application to assist hazard monitoring and evacuation decisions.

GIS and the community

As length of time following a catastrophe increases so does the tendency to relax. A natural resistance can form to changes demanded by outsiders in a community that has existed for hundreds of years. Following the 1995 accident in Flateyri, it was decided that a huge earthen structure would be built above the town. At that time, not everyone agreed with the plan, but the map in figure 7 showing the performance of the

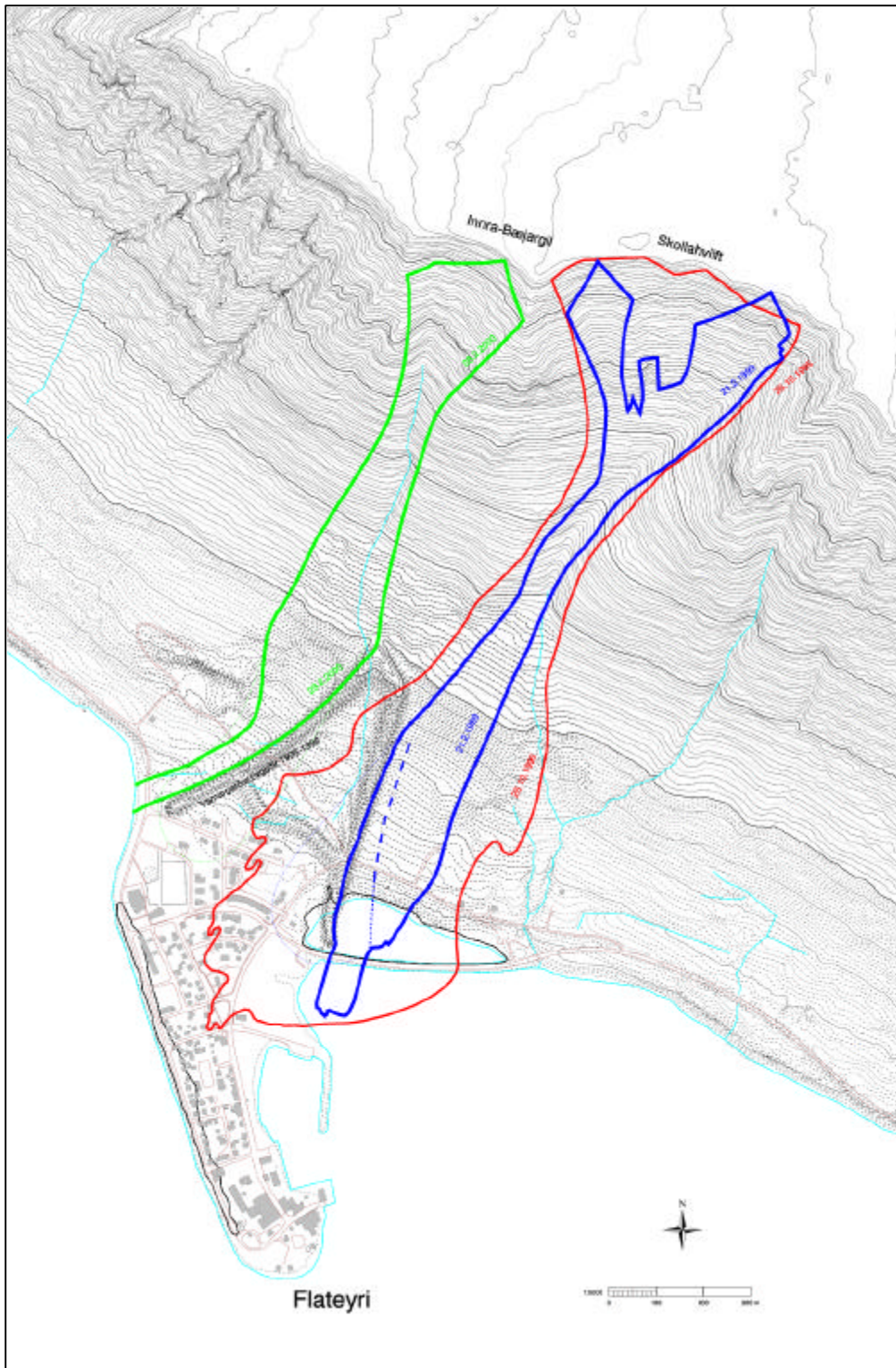


Figure 7. The dams at Flateyri, the catastrophic 1995 avalanche (red), and two avalanches that have been deflected by the dams since its completion in 1998 (blue and green).

dam just 2 years after its completion clearly reinforced its value (Jóhannesson, in press/a).

The zoning process is equally controversial. While the risk of avalanche is a great concern, the loss of value in a home located in a new hazard zone is painful. The avalanche hazard label can also be perceived as a slur on a community that struggles to maintain its existence.

As more data becomes available and updated maps are generated, the public should have at least limited access to information. Through GIS and internet, avalanche annals and outlines can be made publicly available while easily updated. By publishing information in this visual and accessible format, the residents of avalanche prone communities can be more aware avalanche hazard and more importantly, be knowledgeably involved in the hazard management process.

Acknowledgements

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