Impact of rapid mass movement and drifting snow on the infrastructure and development of Longyearbyen, Svalbard

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IMPACT OF RAPID MASS MOVEMENT AND DRIFTING SNOW ON THE INFRASTRUCTURE AND DEVELOPMENT OF LONGYEARBYEN, SVALBARD

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ABSTRACT

The thermal regime and hydrological conditions in arctic regions are a threat and a challenge to human activity. In the Longyearbyen area, Svalbard, snow avalanches, slushflows, debris flows, creep and drifting snow interfere with the location and design of construction works - buildings, roads, ditches, pipes, masts etc., and during winter and spring, popular skiing areas and routes for snowcats can in periods be hazardous. Svalbard Samfunnsdrift A/S has sought professional help from the Norwegian Geotechnical Institute, to evaluate risks and safety measures for existing housing and reduce operational problems caused by drifting snow. Future development will take place in areas which fulfil the safety requirements of the Norwegian Building and Planning Act. A review of problems and recommendations is presented. Limited time-series of relevant meteorological data from Longyearbyen, as well as sparse knowledge of the processes influencing mass stability in permafrost areas, have proved to complicate both risk analysis and accomplishment of mitigative measures. Better knowledge of local wind directions and speed are the key to improve the location and design of roads, production areas and buildings with regard to drifting snow. Research projects within these fields of arctic hydrology are proposed.

INTRODUCTION

Longyearbyen is the administrative centre of the Svalbard archipelago. The built up areas are situated below steep mountain slopes on both sides of the braided river in Longyeardalen, a small side-valley at the head of Adventfjorden (Fig. 1-2). During the last decade the more or less closed mining settlement has developed into an open and expansive centre of arctic education and tourism.

Within this area snow avalanches, slushflows, debris flows, creep, snow drift and floods interfere with the location and design of construction works, such as buildings, roads, ditches, pipes, masts etc., and during winter and spring popular skiing areas and routes for snowcats might in periods be hazardous. In addition, foundation on the permafrost is a practical problem.

Figure 1: The settlement of Longyearbyen, Svalbard. Adventfjorden in front, Nybyen up-valley on the left hand side. The areas mentioned in the text can be identified on the picture. (Photo T. Kjærnet)

Svalbard Samfunnsdrift A/S has sought professional help from the Norwegian Geotechnical Institute (NGI) to deal with problems due to rapid mass movement and snowdrift. NGI undertakes research and consulting within these fields, and our methods are based on up-to-date professional knowledge. Our scientific work has contributed to international competence. Actual references are: Bakkehøi

1987, Bakkehøi *et al.* 1983, Bakkehøi and Norem 1994, Hestnes 1979, 1985 and 1993, Hestnes and Bakkehøi 1993, Hestnes *et al.* 1994, Hestnes and Lied 1980, Hestnes and Sandersen 1989, Lied and Bakkehøi 1980, Norem 1975 a & b, 1985, 1991 and 1993, Norem *et al.* 1985, 1987 and 1989, Onesti and Hestnes 1987, Sandersen 1988, 1992 a & b and 1994.

Altogether 12 consulting reports have been produced during the years 1990-1993. This paper summarize the problems, our recommendations of mitigative measures, and the professional difficulties in handling the problems due to the limitations of local meteorological data and applied research in arctic environment.

RISK ANALYSIS

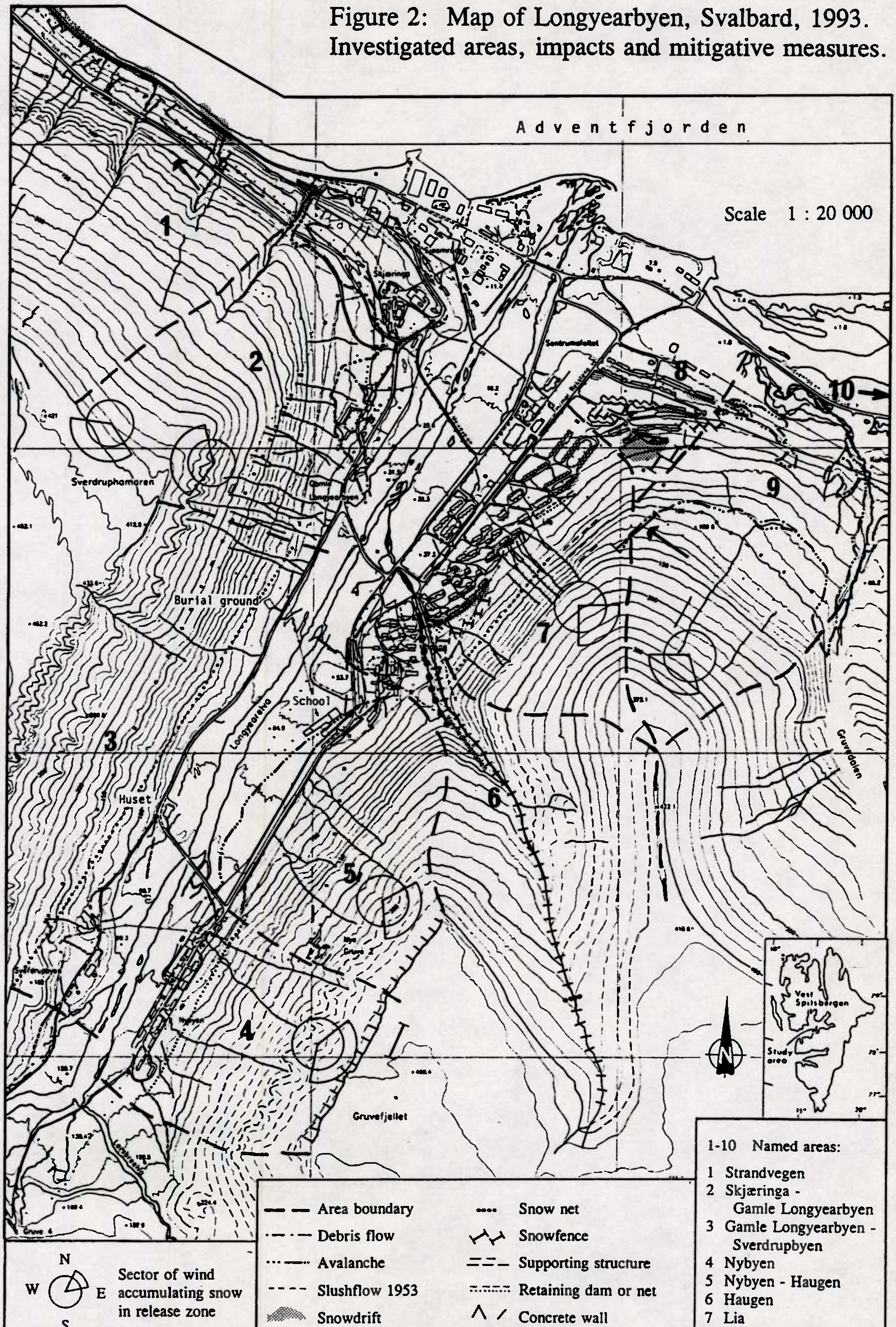
Principal Problems

Drifting of snow due to strong wind is frequent in the area. Negative consequences are reduced visibility, accumulation of snow around buildings and constructions as well as on roads, and the creation of avalanche hazard. Mitigation of these problems is sought by remediation and by optimizing location and design of roads and structures.

Rapid mass movement normally occurs due to extreme weather conditions. The thermal regime and hydrological conditions of the arctic environment do cause some deviations. In area planning, the return period of critical conditions and run out distances, is normally sought. The boundary lines between different risk levels are of primary interest. For design of safety measures, the loads on constructions at certain locations in the hazard zone, are sought.

Evaluation of acute risk is based on current meteorological data and weather prognosis, field investigation of snowpack stability or ground conditions, and observation of current avalanche or debris flow activity. Precautions to prevent accidents may involve evacuation and relocation of people in residential and service areas, and closing and reopening of roads, skiing areas and routes for snowcats. Qualified personnel should evaluate the hazard and representatives of the local authority direct and coordinate the safety precautions.

Figure 2: Map of Longyearbyen, Svalbard, 1993.
Investigated areas, impacts and mitigative measures.



Documentation

Contemporary documentation of avalanches and of debris flows in Longyearbyen is scarce, at least in available documents. The catastrophic slushflow from Vannledningsdalen in 1953 is, however, reported by Ramsli (1953) and Balstad (1955). Mellerud (1980) described local experiences in using different types of snowfences to reduce snowdrift on roads. Larsson (1982) included a short note on the debris flows in 1972, by Mr. G. Christiansen, technical director of the coal mines. During the last years a few events have been notified in the local newspaper (Svalbardposten), by the Governors Office and by Svalbard Samfunnsdrift A/S.

Jahn (1967) described the slushflow in 1953 from a geomorphic point of view. Information on snow avalanches and collapse of cornices is absent in the literature. Maps showing the interrelation between infrastructure and surface processes in Longyearbyen are presented by Lied and Hestnes (1986). A few more scientists have paid attention to debris flows and debris slides, but the conflict between human activity and mass movement has not been focused (ref. Larsson 1982). A recent report dealing with snow drift and climatic adjustment of the development of Longyearbyen is written by Børve (1993).

Meteorological Data

Local meteorological records are available from two synoptic weather stations. 'Longyearbyen', located at Skjæringa, was in operation between January 1957-July 1977, and 'Svalbard Lufthavn' has been in operation since August 1975. Incomplete records from Longyearbyen also exist for approximately 20 of the years between 1916 and 1946.

The regional climatic conditions in the area have been surveyed based on data from all the arctic weather stations, operated by the Norwegian Meteorological Institute (DNMI). Essential documents dealing with these problems are Steffensen (1969, 1982) and Hanssen-Bauer *et al.* (1990).

DNMI has put the meteorological data from the arctic stations at NGI's disposal, and they have been consulted on special analytical problems. Supplementary information has been passed to NGI by the meteorologist at Svalbard Lufthavn.

PRINCIPLE LEGISLATION

The Norwegian Building and Planning Act is not put into force in Svalbard. Even so, Svalbard Samfunnsdrift A/S has decided that future development should take place according to these standards (ref. Hestnes 1990 and 1991).

The safety requirements of the different types of buildings and their surrounding areas varies according to the probable risk of personal injury. There are three safety classes (Table 1). The highest nominal annual probability for hazards to buildings in safety class 3 ($< 10^{-3}$) should be decided by the local authority, for each case. The higher the consequences the lower probability of natural hazard should be allowed. Buildings and their surrounding areas may also be dimensioned or otherwise secured so that the specific standards are fulfilled.

There are no safety requirements for existing buildings. However, buildings of safety class 2 and 3 in hazardous areas can only be rehabilitated or rebuilt if the

Table 1: Safety requirements for the location of buildings

Safety class	Consequences of structural failure	Highest nominal, annual probability of natural hazards	Categories of buildings
1	Less serious	10^{-2}	- Garages for max. 2 cars, boat houses etc. - Storage sheds occasionally in use - Halls of plastic-based fabrics - Agricultural buildings etc., if frequently used class 2 or 3
2	Serious	10^{-3}	- Buildings not exceeding two storeys of moderate span and in normal use - Industrial and storage buildings of one storey not accessible to general public, with ≤ 5 persons per 100 m^2. Distance to other buildings, roads etc. $\geq$ height of the facade - Tall masts, independent towers, silos and chimneys outside of built up areas
3	Extremely serious	$< 10^{-3}$	- Buildings not included in class 1 and 2

highest nominal annual probability of hazards is less than $3x10^{-3}$ in class 2 and 10^{-3} in class 3. Buildings of class 2 and 3, which have a higher risk than these minimum standards, would normally be appraised for securing (Hestnes 1990 and 1991).

The Norwegian Working Environment Act has regulations stating that employers are obliged to take precautions to prevent avalanche accidents at all exposed locations in potentionally hazardous areas. The avalanche risk to access roads, camp locations and construction sites has to be evaluated by an avalanche expert. The expert shall prescribe the necessary safety and standby measures, and work out an action plan and/or appropriate precautions to be followed in hazardous situations. The builder or main contractor is responsible for directing and coordinating the safety precautions.

IMPACTS AND MITIGATIONS

Introduction

The scope of the assignments was defined by Svalbard Samfunnsdrift A/S. The substance and extent of site investigations and use of professional methods, were decided by NGI. The actual mitigative measures were normally discussed with the client before they were recommended.

In the following review Longyearbyen is divided up into smaller geographical units, and the objectives within each unit are summarized (Fig. 2). Within these areas there are of course additional scientific and practical problems not requested by the client. Such questions have only been looked into when relevant to the assigned problems.

Strandvegen

Strandvegen is the road between the airport and Longyearbyen. Just outside the settlement the road runs along the foot of a natural terrace for approximately 1.5 km. During winter the prevailing wind blows snow off the escarpment onto the road. The funnel effect of gullies and small scars in the rim is striking. The snow drift causes visibility problems and heavy snow accumulation on the road, which is dangereous, and also critical to the flow of traffic. Consequently, maintenance of the road is time-consuming and costly (Fig. 2).

The suggested mitigative measure for the problem was to relocate the road to a new embankment in the shallow shore water. The embankment should be given a streamlined design, in order to achieve good visibility and reduce the tendency of drifts to form on the road. Snowfences located above the escarpment were an alternative. The objective of the fences would be to break the windspeed across the gullies and scars, in such a way that snow accumulated in them, instead of creating a funnel effect. Location and design should be adjusted to the specific sites.

Skjæringa - Gamle Longyearbyen

Central service functions are located in the lower parts of this area. It is also an area of potential development. Snow avalanches are known to occur both in the upper part of the northeast facing hillside, and in the chutes above Gamle Longyearbyen (Fig. 1-2). Old debris flows are observable on the lower slopes, and are especially well developed to the south. Snow drifts are primarily created by man made road cuttings, embankments and housings. The only problem to existing activity in the area, noted by client, is snow accumulation on the road caused by a guard rail. However, it is obvious that the kindergarten is situated on rather fresh debris flow deposits and the church close to others.

The risk evaluation indicates that destructive snow avalanches of an average return period of 1000 years, might almost come down to the built up area north of the church. Southwards from the church, debris flows are the critical hazard. In the area of Gamle Longyearbyen, south of the museum, disastrous debris flows and avalanches can reach the river plain. The problems caused by the drifting snow could be reduced by removing the guard rail, enlarging the roadbank to 3 metres and giving it a specified form. The safety of the traffic would be maintained and the road maintenance simplified.

Gamle Longyearbyen - Huset - Sverdrupbyen

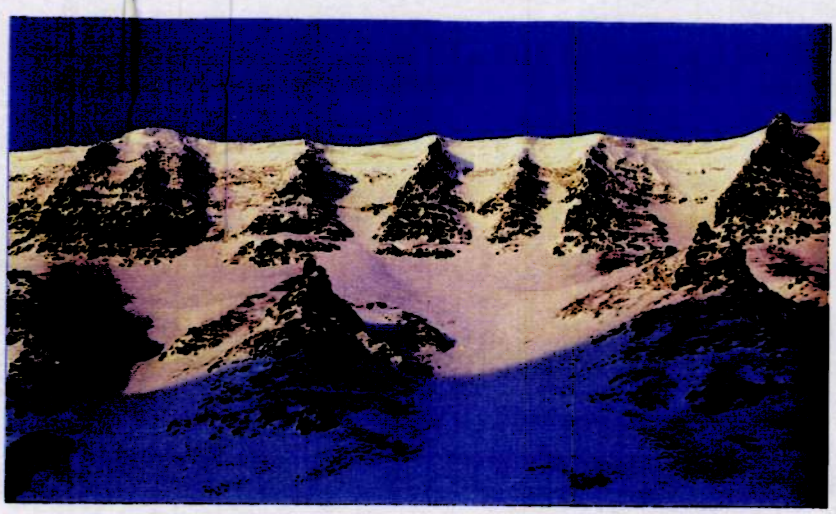
The community centre (Huset), the burial ground, and at least parts of the deserted Sverdrupbyen, as well as the road between these sites, lie in the hazard zone of avalanches, debris flows and rockfalls (Fig. 1-2). Only opinions about the acute avalanche hazard to the road and the community centre, due to current meteorological conditions, have been requested in this area.

Nybyen

Nybyen, todays oldest residential and service area in Longyearbyen, is located on screes and glacifluvial deposits along the foot of Gruvefjellet (Fig. 1-2). Snow avalanches, collapse of cornices, debris flows, rockfall and floods are potential threats to the built up area. Recent incidents have reached the buildings in the northern part. NGI has given advice concerning problems related to cornices and acute avalanche hazard.

Every winter huge cornices are built-up along the rim of the top plateau, due to the prevailing wind from the southeast (Fig. 3). If parts of these cornices collapse

Figure 3: Some of the cornices along the rim of Gruvefjellet. The starting zones of avalanches in the lee-slopes below.



during winter or spring they may release snow avalanches in the steep lee-slopes below, or come all the way down as big blocks. Either way can be hazardous to man and constructions. Some years ago the mining company took precautions against these cornices by releasing them with explosives before they were supposed to be a threat.

Release of cornices above Nybyen by explosives is not recommended as a mitigative measure by NGI. The reason is that detonations normally cause break-offs and avalanches that otherwise might not occur, and they will be larger than if released naturally. Thus, the probability of an unwanted consequence would be higher, not lower. A calculated risk may, however, be taken in a critical avalanche situation, to secure necessary human activity in the area.

Snowfences on the top plateau may reduce the size of the cornices and the snow accumulation in the upper part of the avalanche release zone. The ideal location and height are related to the expected wind direction and speed. Due to uncertainties about windspeed, a step-wise development is recommended. The first fence is suggested to be 100 m long, 4,5 m high and located 80 m from the rim above the northern part of Nybyen.

Nybyen - Haugen

The river plain between Nybyen and Haugen is supposed to be a potential development area (Fig. 1-2). Break-offs from the cornices, snow avalanches, debris flows and rockfalls are known to have reached the road along the hillfoot. The boundary line of the potentially dangerous area and the acute avalanche hazard to the road during a critical weather situation, have been evaluated.

The run-out of snow avalanches determines the limit of the hazard area with an average return period of 1000 year (Fig. 2). Insignificant amounts of water and debris may, however, drain further, but are not supposed to represent a significant hazard according to the Building Regulations. Parts of the hazardous area might be developed if secured by safety measures.

The sports ground north of the school is located outside the hazard area. There is no objective safety standards for sports grounds, and it is unlikely that people would use it during extreme weather conditions. Therefore, due to shortage of areas suited for development, it is indicated that the sports ground can be relocated in the potential hazard area south of the school. The sports ground, as well as the road along the hillside, might be closed off if the current safety is questioned.

Haugen

Haugen is the residential and service area located on the fan built by the river Vannledningselva. The rather steep and deeply incised tributary, drains a small basin in Gruvefjellet. Slushflows are the primary threat to this area, the adjacent houses on road 222, and the roads and pipelines below (Fig. 2, 4). According to Ramsli (1953), informants said that there had been at least 5 huge slushflows from Vannledningsdalen earlier this century, before houses were located on the fan. The air-pressure from one of these slushflows was said to have broken windows in one of the buildings (bakery or cow-stable/museum) on the opposite riverbank.

A deflecting dam was constructed to protect the buildings on the fan after the

Figure 4: Haugen, 1985. The river channel is partly filled with debris.
Figure 5: The manmade channel is blocked by uneven snowdrift, 1990.

disastrous slushflow in 1953. This safety measure was supplemented by removing the snow from the drainage channel by bulldozer every spring - except in 1989. Another destructive slushflow occurred that year, partly because the dam was in bad shape. Luckily, the slushflow was small this time, and the damage was less. After this event, NGI was commissioned to review the mitigative measures and recommend future methods.

The exposed houses on the fan and along road 222 may attain a level of safety which complies with the requirements for rehabilitating the houses (ref. Principle Legislation). Two main alternatives are outlined: i) Passive measures - protect the exposed houses by new and rebuilt embankments, supplemented by stabilizing potential water-saturated snowpack in the upper part of the drainage area by a wire net across the outlet of the level plain; ii) Passive and active measures - protect the exposed houses by embankments and remove the snow from the drainage channel by bulldozer every spring.

It is stressed that a consequence of the first alternative will be frequent slushflows across public roads, which is not recommendable. The second alternative is an improved version of todays practice. The risky aspect of this alternative is the problem of reopening the channel if it is blocked anew by a later snowfall. There is no simple way to get the bulldozer up to the top again (Fig. 5). Remedial methods to overcome this problem have been discussed.

Lia

Lia is the residential area north of Haugen. Both snow avalanches and debris flows are a threat to the houses lying closest to the steep hillside. Debris flows are frequent in the south and middle part, avalanches in the north. Critical situations have been reported. The access to the same houses is often blocked in winter, when snowdrift occurs (Fig. 6-8).

Permanent protection of the houses in the northern part is considered, including supporting structures, retaining dams, concrete walls and snow fences (Fig. 2, 6). The snow fence will reduce the frequence of avalanches from the most prominent release zone, but not eliminate the hazard. Deflecting walls are recommended where other alternatives seem unrealistic due to cost or avalanche velocity.

Routines for keeping up with the current weather and snowpack development related to acute avalanche hazard, as well as hazard evaluation and operative organization, are also recommended. Reliable information on current windspeed and precipitation in Lia are vital to the hazard evaluation. Evacuation of the residents in critical situations is an alternative to permanent safety measures.

Mitigation of the snowdrift about the roads 222 and 226 is planned by means of snowfences (Fig. 7). The location and dimensioning of the fences are based on

Figure 6: The avalanche hazard is high in the northern part of Lia.

Figure 7: The access to houses along road 222 is frequently blocked by snowdrift.

the wind speed records from the former meteorological station in Longyearbyen. The orientation are adjusted to the observed wind direction on site (Fig. 2).

The obvious debris flow hazard in the area is notified, but neither routines for acute hazard evaluation nor safety measures have so far been requested (Fig. 8).

Figure 8: Houses along road 226 are located on debris flow deposits.

Veg 232-236

Drifting of snow is a problem for road maintenance and access to some of the houses in this residential area, primarily along the southeastern border. The design of the apartment buildings also causes local turbulence in the entrance areas. The snow accumulations are caused by the prevailing southeasterly wind from Advent-dalen. The wind interferes with the buildings and local terrain features, as well as some road embankments and pipeline constructions. Wind from Longyeardalen also causes some minor snowbanks (Fig. 2).

It is possible to almost eliminate the existing problems by use of snowfences. Combining fences with two additional buildings may be even better. Location and design have been indicated. Expansion eastward will, however, alter the snowdrift formation patterns along the present border. Thus, NGI has recommended that remedial measures should be planned as an interactive part of future development of the area.

Gruvedalen

The sloping terraces between the settlement and Gruvedalen is a potential development area. Traces of old and fairly recent debris slides and debris flows are observable on the mountain side and the upper terrace. Instability of the active layer along basal structures, low slopes, drainage lines and less obvious causes on the lower terrain, are also prominent. The rocky mountain slope, which is smoothed by drifting snow every winter, is an ideal release zone for snow avalanches. However, only storms from the southwest may cause a hazard. Small avalanches may also occur in some steep slopes in the lower part of the area (Fig. 1-2).

The critical hazard in this development area is avalanches. They may reach approximately 100 meter below the old cableway in the southeastern part, and have to be taken seriously in the low-lying slopes as well. Debris flows from the high mountain side may reach further out in the central area, but their destructive effect can easily be hindered by an earthfill dam on the lowgrade slope above.

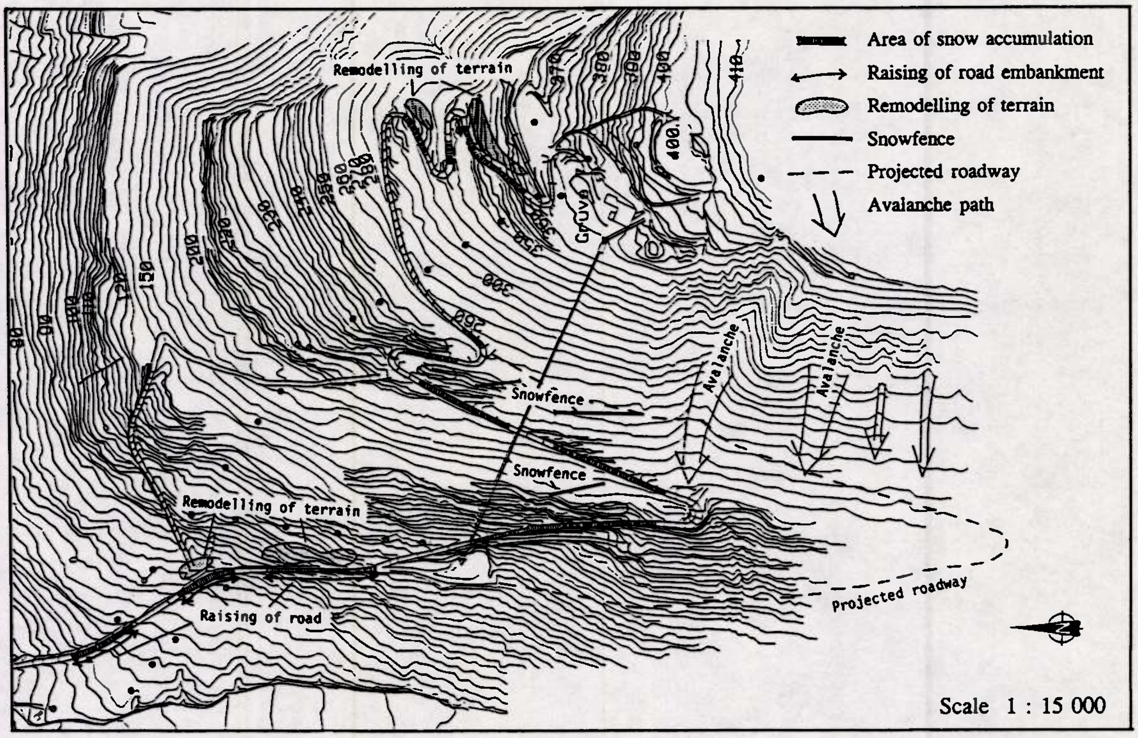
Stability management of the active layer within the area should be planned as an interactive part of the future development, as suggested for the snowdrift problems. The key measures are road embankments, ditches and drainage control down to the plain below.

Gruve 7

The access road to Gruve 7 climbs the steep lee slope of a hill. The easterly wind from Adventdalen blows down the slope causing extensive snow accumulation on the road. Constructions and guard rails increase the accumulation. The problem is critical to the traffic, and makes the road maintenance time-consuming and costly.

Mitigative measures have been recommended. The methods involved are primarily redesign of the road embankment, remodelling of terrain features causing snow accumulation and use of snowfences. In some places the problem might be eliminated, in others greatly reduced (Fig. 9).

Figure 9: The main snow accumulation areas along the road to Gruve 7, and suggested mitigative measures.



Outdoor Activities

During winter and spring the population uses snowcats for transport and enjoyment, and children are fond of skiing and playing in the snow.

Avalanches sometimes interfere with the attractive routes and recreation areas. Within Longyearbyen the ground above the houses in Lia is an arena for intensive activity. The track alongside the road from Haugen to Nybyen is also among the threatened areas (Fig. 1-2). Outside town many attractive routes go through valleys, ravines and cross slopes of potential avalanche hazard. The unwary may also meet hazards outside the traditional routes.

Hazard to outdoor activities is primarily an acute risk problem caused by storms and heavy snowdrift. The snowpack will start to stabilize as soon as the weather calms down. Acute risk evaluation is based on the normal procedure, including checking on snowpack stability and observation of current avalanches on slopes having the same aspect.

The primary effort to avoid accidents would be public education about avalanche hazard in schools, social organizations and the media. Signs should identify critical areas and, if possible, traffic prohibited during periods of increased risk. Specific locations with high hazard levels might also be blocked off during the whole season.

LIMITING DATA AND RESEARCH

The limitations in local meteorological records and applied research in arctic environments, influence the precision of professional work. Some examples of the basic problems are given below.

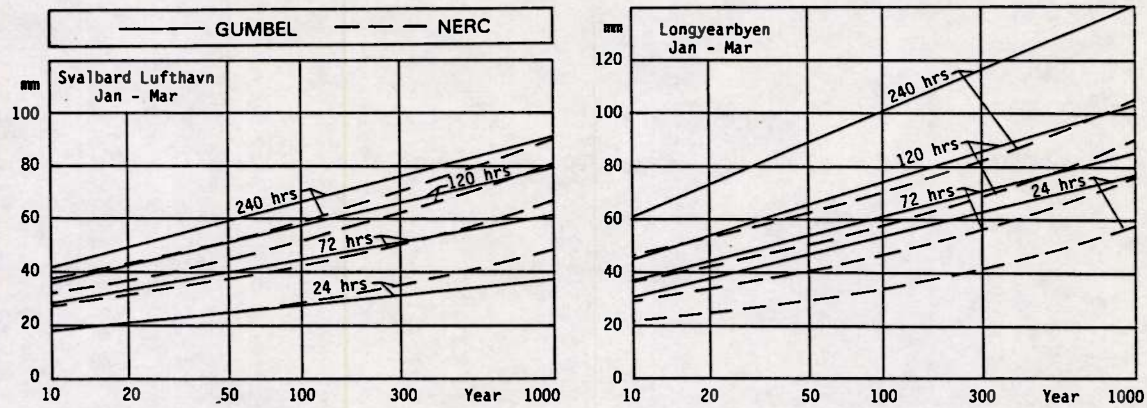
Weather Extremes And Their Return Period

Debris flows, slushflows and snow avalanches, hazardous to housing and development areas, are primarily caused by extreme weather conditions. The analysis and weighting of principal parameters differ, but back-calculations of critical situations and prognosis of return periods have to be based on the records from the two DNMI stations, Longyearbyen and Svalbard Lufthavn.

The ordinary recording time of both stations is approximately 20 years. Unfortunately, there are only two years of overlap between them, so homogenization has not been accomplished. The extreme values from Longyearbyen are supposed to be the most representative for the settlement.

However, the reliability and representativity of the records are questioned. For instance: The recordings of precipitation at Svalbard Lufthavn are known to be too low. On the other hand, could the rain gauge at Longyearbyen have caught too much during heavy storms? The Gumbel and NERC prognosis of Svalbard Lufthavn have almost identical elapse, while the observed extreme values of Longyearbyen fit with the Gumbel prognosis, but not with the NERC prognosis. The deviation in January-March is between 10-38% (Fig. 10). Consequently, uncertainties concerning the return period of extreme precipitation arise when the basis for the prognosis is questioned (Førland 1987).

Figure 10: Precipitation prognosis according to Gumbel and NERC.



The probability of extreme avalanches in the mountains of South Norway is approximately 50% if 50 mm of precipitation, accompanied by wind ≥5 m/sec, is recorded in 3 days (Bakkehøi 1987). The questions are: What might be the return period of avalanches in Longyearbyen (ref. Fig. 10 & Table 2) ? And what would be the return period of avalanches in specific locations (Fig 11) ?

Table 2: Approximately return period of heavy precipitation in Longyearbyen

January - March		GUMBEL	NERC
1 day	40 mm	25 years	250 years
3 days	50 mm	40 years	150 years
5 days	60 mm	35 years	125 years
10 days	70 mm	15 years	100 years

Stability Of Snowpack And Active Layer

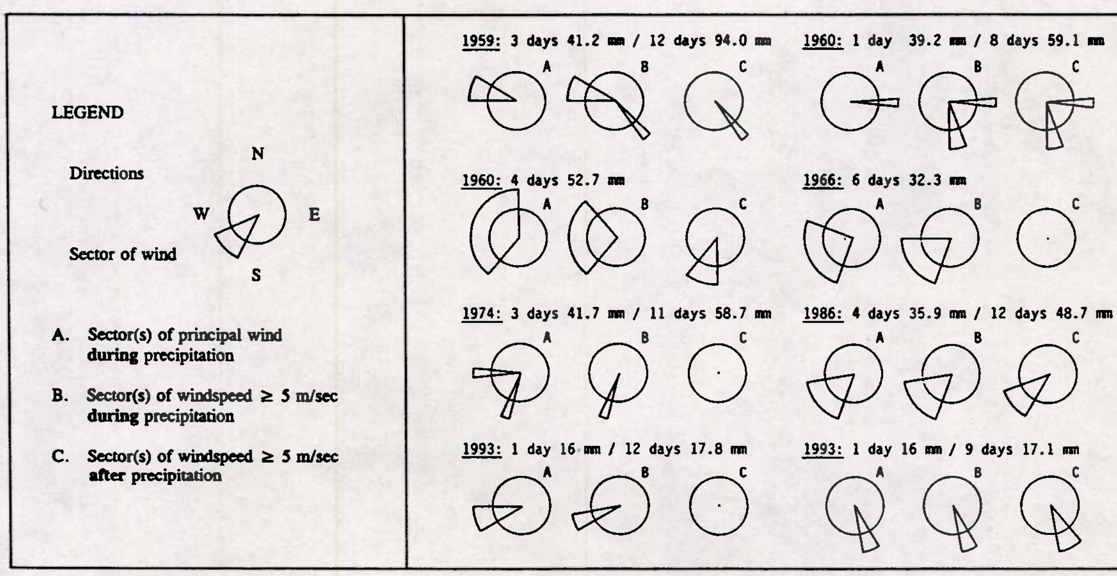
The stability of the snowpack and the active layer prior to storms or intense spring thaw, is of vital importance to acute hazard development. Basic knowledge of the influence of meteorological factors on the hydrological processes in snowpack and ground in arctic regions is, however, almost absent. Thus, the release mechanism of debris flows, slushflows and avalanches in these environments are not fully understood.

An illustrative documentation of this problem is shown in Table 3. Unexpected avalanches have occurred 4 times within 3 years in Lia (Fig. 6). Some of them might have been triggered by a snowcat, but it is very likely that some were also naturally released. This is very unusual during persistent cold weather. The reason has to be sought in the climatic conditions.

Table 3: Data from Svalbard Lufthavn prior to avalanches in Lia, Longyearbyen

Date of avalanche	Precipitation mm				Average wind direction & speed and max. temperature deca-grades · metre/sec · °C		
	24hrs	48hrs	120hrs	240hrs	0-24 hrs	24-48 hrs	48-72 hrs
05.04.91	0.7	0.7	0.7	13.4	16 · 11.0 · -13.5	15 · 9.0 · -17.3	14 · 5.0 · -18.2
19.11.91	0.5	2.6	2.7	6.5	30 · 5.0 · - 3.5	25 · 8.5 · - 2.1	15 · 4.5 · -10.0
05.11.92	0.0	0.1	10.1	11.5	15 · 5.0 · -14.4	15 · 4.5 · -10.0	28 · 6.0 · - 2.1
16.03.93	0.1	0.2	16.6	17.7	16 · 9.0 · - 6.0	16 · 8.5 · - 5.8	16 · 8.5 · - 5.4

Figure 11: Recorded intensity of snow and corresponding wind during 6 extreme weather periods between 1957-1993, and recorded precipitation and wind during 2 avalanche periods in 1993.



Local Wind And Precipitation

The current wind and precipitation data from Svalbard Lufthavn are not adequate for evaluation of acute risk in Longyearbyen, at least not for avalanches. Location of supplementary instruments as well as observation routines have been suggested.

The effect of snow fences is sensitive to the windspeed and direction. Due to uncertainties about the wind conditions in Lia and further north, a stepwise building of fences is recommended in the two areas, as well as constructions with the possibility of adjusting the height. The wind is also critical to the loads and thus the design and cost of fences.

Better knowledge of the local wind is also the key to optimize future location and design of road embankments, buildings and constructions.

The Run-out Of Avalanches And Debris Flows

Knowledge of the critical run-out of debris flows, slushflows and avalanches is vital in area planning. The lack of methods adjusted to the climatic region may affect the precision of the boundary lines. Hopefully, the errors are acceptable.

Some calculations of avalanche run-out have, however, been questioned by the client. Fortunately, evaluation of avalanche run-out always includes correlation between three different statistical models, and one of these models only involves topographic parameters. The result should therefore be fairly reliable. Only unforeseen differences in snow properties between the high mountains of mainland Norway and Svalbard, may influence the validity.

Motion And Impact Of Rapid Mass Movement

The volume, density and speed of rapid mass movement are essential to the location and design of safety measures. Motion and impacts of snow avalanches are fairly accurately derived from the existing models. Adequate models for assessment of the potential speed and loads of debris flows and slushflows are missing.

Debris flows of limited size, comparable to those observed around buildings and in planning areas in Longyearbyen, could, however, easily be handled. The potential slushflow problem of Vannledningsdalen is worse. Field measurements of huge slushflows are scarce. No registrations of speed, super-elevation in curved tracks, density profiles of flows, or impact measurements, are available. Thus, the efficiency of the existing deflecting dam on Haugen has been questioned by NGI.

CONCLUDING REMARKS

Rapid mass movements and drifting snow interfere with the infrastructure and development of Longyearbyen.

The methods used in handling the problems are based on up-to-date professional knowledge. The accuracy of the professional work is, however, influenced by limitations in meteorological data and the lack of applied research within these fields in arctic regions. This state of affairs will be a source of uncertainty until local meteorological data are available and local research is carried out.

The problem of estimating return periods of snow avalanches of extreme run-out is primarily connected to the reliability of meteorological recordings. The evaluation of acute avalanche risk is linked to location, seasonal development of snowpack and current weather conditions. A research project on this second aspect is being discussed by NGI.

Three applied research projects within arctic hydrology have been at the planning stage for some time (Hestnes 1993). The preliminary titles of the three projects are: i) Analysis and remediation of construction and operational problems caused by drifting snow in arctic regions; ii) The flowpattern of arctic slushflows is the key to slushflow control; and iii) Hydrological processes initiating slope instability in permafrost areas.

NGI is looking for financial support for these challenging projects.

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