THE AVALANCHE WINTER 1999 IN SWITZERLAND – AN OVERVIEW

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ABSTRACT: February 1999 will be known in Swiss natural disaster history for its record quantities of snow, for more than 1300 harmful avalanches, 17 deaths, cut-off valleys, blocked transport routes, and for total damage costs of over 600 million Swiss francs. Three intensive snow fall periods accompanied by stormy north-westerly winds brought over 5m of new snow within one month to the northern side of the Swiss Alps. This amount of new snow in 30 days has a periodicity of approximately 80-100 years in the central northern part of the Swiss Alps and 40 – 50 years in the other parts of the Swiss Alps. A comparable catastrophic avalanche period of similar size dates happened only in 1951, where 98 people were killed. The avalanche winter 1951 was the beginning of modern avalanche defense measures for the next five decades in terms of paravalanche constructions, avalanche hazard mapping, avalanche warning and silvicultural measures to maintain the protection forest. Considering the growth in public and private investments in mountainous areas, the enormous increase in mobility of the people and the exponentially rising communication needs over the last fifty years, these large investments in avalanche protection measures over the last 50 years have paid off. The paper presents an overview on the weather, snow and avalanche conditions, the direct and indirect damages caused by avalanches and discusses the effectiveness of the integral avalanche protection measures. Finally the necessary improvements for a future integral avalanche risk management are pointed out.

KEYWORDS: Avalanche disaster, avalanche catastrophy, avalanche damages, insurance, integral risk management, avalanche warning, hazard mapping, paravalanche constructions.

1. INTRODUCTION

In February 1999, 28 people were caught in inhabited areas or on roads and 17 of these died (11 in buildings and 6 on roads) and causing economic losses of more than 600 million Swiss francs. Never before in Swiss avalanche disaster history, an avalanche period was as widespread and long-lasting as in February 1999.

The Swiss Federal Institute for Snow and Avalanche Research SLF in Davos worked out a comprehensive report on the avalanche winter 1999 (SLF 2000). This paper summarizes the main results of this report concerning weather, snow, avalanche activity and damages. The effectiveness of protection measures is analyzed with regard to strengths and weaknesses in order to answer the question whether avalanche protection measures were effective and which improvements have to be done in the future.

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2. WEATHER, AVALANCHES AND SNOWPACK

2.1 New snow amounts

Three precipitation periods accompanied by stormy north-westerly winds brought large amounts of snow to the Swiss Alps between January 27th and February 25th (Fig. 1).

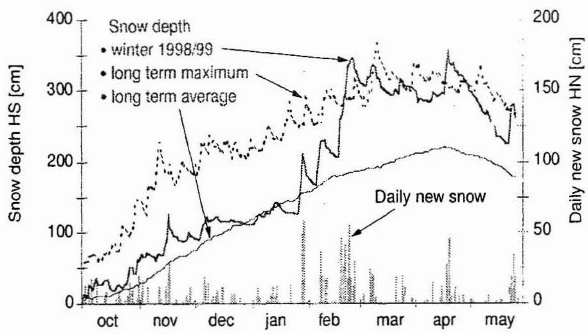

Fig. 1 Time series of total depth of snow cover (HS), compared to the minimum and maximum of 62 prior winters (1936/37 to 1997/98), measured at Weissfluhjoch (2540 m a.s.l.) above Davos. On the second y-axis the depth of daily new snowfall (HN) is noted. Clearly visible are the 3 peaks of HS which correspond with the 3 heavy snowfall periods.

The detailed amounts of new snow in these periods were:

January 27th- 29th	(3 days):	100-150 cm
February 6th-10th	(5 days):	110-220 cm
February 17th-25th	(9 days):	200-400 cm

During 30 days the new snow amount was over 500 cm, in particular on the northern flank of the Alps, i.e. more than the usual amount for the whole winter (Fig. 2). In the central Bernese Oberland and in neighbouring areas the 30-day new snow amount attained a maximum return period of 80-100 years. Many regions of Wallis, Nordbünden and Unterengadin received over 300 cm of new snow, corresponding to a return period of approximately 40 years.

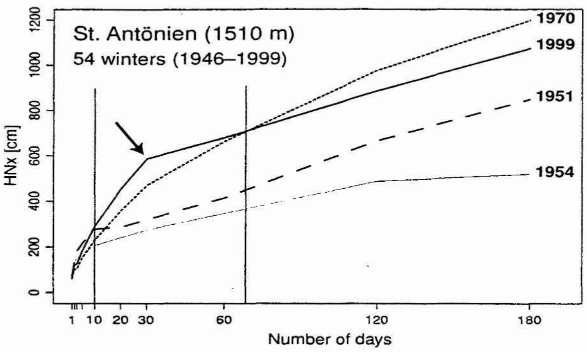

Fig. 2 Maximum x-day new snow amounts (HNx), measured at St. Antönien (1540 m a.s.l.), near Davos. The maximum 10 to 60 new snow amounts as observed in 1999 have never been reached before. Only four winters with heavy snow falls and/or heavy avalanche activity are shown in this figure.

2.2 Avalanche activity and snow pack

The consequences of the extensive snowfalls were very widespread, initiating numerous avalanches (Fig. 3). Approximately 1300 destructive avalanches occurred in the Swiss Alps during this period. Most avalanches occurred in parallel to the three precipitation events with dominant intensity around January 29th, February 9th, and February 22nd.

Compared to earlier years with high avalanche activity, 1999 has produced by far the highest economic losses. Numerous buildings have been destroyed, but still much less than in 1951, a fact which also clearly demonstrates the effectiveness of the avalanche protection measures taken the last 50 years. February 1999 exhibited the most widespread and longest avalanche cycle known and recorded.

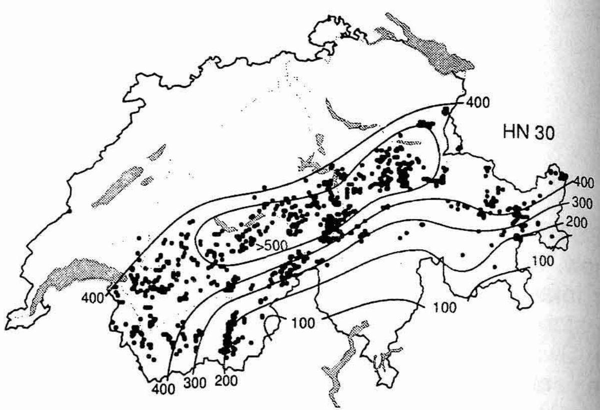

Fig. 3 Spatial distribution of approximately thousand well known destructive avalanches in Switzerland between January 27th and February 25th 1999. In addition the sum of new snow HN_{30} measured in cm during the same time period is marked with isolines.

The primary reason for the large avalanche events in February 1999 were the intense snowfalls in conjunction with low air temperatures. Strong north-westerly winds led to the formation of large accumulations of drifted snow and further worsened the situation. The stability of the snow cover was not poor in the heavy snow accumulation areas. A high overload was necessary before the weak base failed, leading to high fracture depths and big size avalanches. The combination of these effects and a marked rise in air temperature led to the most intense avalanche activity of the winter between February 20th and 23rd. The entire northern flank of the Alps and parts of Wallis and Graubünden were strongly affected.

3. DAMAGES

In addition to 17 avalanche victims, direct and indirect damages of over 600 million Swiss francs were caused. The average damage per destructive avalanche amounts to around half a million Swiss francs.

3.1 Damages to people

An overview of the fatal avalanche events in February 1999 is given in Tab. 1. Six people were killed on roads and eleven in buildings. Compared to 1951 with 98 victims, the number of 17 victims in February 1999 also clearly shows the effectiveness of the different measures taken during this period. The victims are due to several reasons like e.g. a wrong evaluation of the local avalanche situation, a too late closure, etc.

Tab. 1 Overview of the fatal avalanche events in winter 1999 in Switzerland

Date	Commune	Fatalities on roads	Fatalities in buildings	Fatalities total
7.2.00	Lavin	1	--	1
8.2.00	Wengen	--	2	2
21.2.00	Evolène	5	7	12
23.2.00	Bristen	--	1	1
23.2.00	Geschinen	--	1	1

A specific avalanche event with fatal consequences occurred in Evolène, Canton Wallis (Fig 4). Five people were killed on open roads, 7 people were killed in buildings.

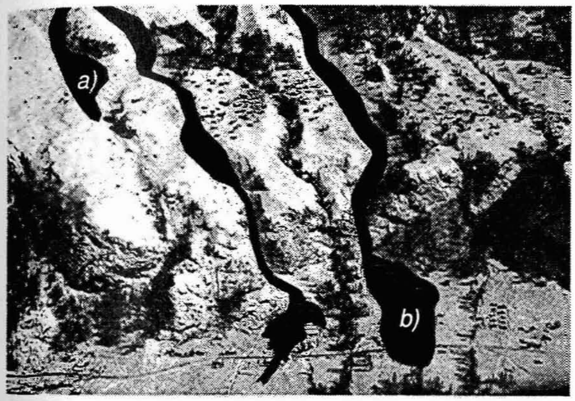

Fig. 4 Fatal avalanche event in Evolène. The avalanche with an initial fracture zone of more than 3 km in length finally led to three main paths. In area a) 3 persons were killed and in area b) 9 persons.

27 buildings were partially demolished, 11 buildings were completely destroyed. Most of the damaged buildings had been build in the last decades, but some of them were older than 200 years. The avalanche tracks were well known, but such a huge avalanche has never been recorded in the past. Neither any people were evacuated nor the affected roads were closed. The need for efficient local avalanche warning services is evident.

3.2 Direct material damages

The direct damages (primarily destroyed or damaged buildings and other structures) caused by avalanches, snow loads and snow gliding reached a total of 440 million Swiss francs (Tab.2). In approximately 60% of the damages buildings and their contents are concerned, in 30% infrastructure and in 10 % natural resources.

Tab.2 Overview of the direct damages induced by avalanches, snow pressure and snow loads.

Damage type		Damage	[mioCHF]
Building	Avalanches	Building Contents	97 34
	Snow loads	Building Contents	97 24
Infrastructure	Transport routes	Roads Railways	63 11
	Supporting struct.		9
	Mountain railways		15
	Electricity		27
Natural Resources	Forest Agriculture		46 14
Total			437

Around 1,700 damaged buildings due to avalanches were reported to the cantonal insurance companies (Fig. 5). The average damage per building due to avalanches was 56,800 Swiss francs. 18000 buildings were damaged due to snow loads and snow gliding which corresponds to a damage of 5,400 Swiss francs per building. Agriculture buildings were mainly affected with approximately 70% of the total number of buildings.

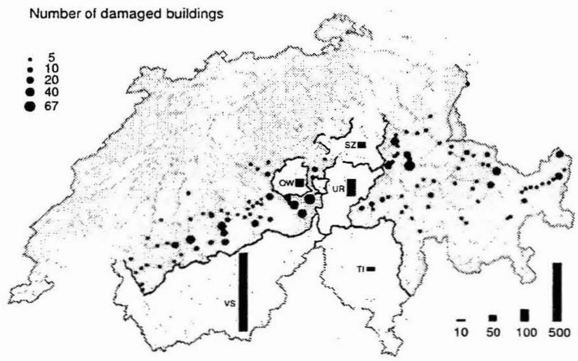

Fig. 5 Spatial distribution of the number of damages to buildings per commune due to avalanches in cantons with cantonal insurance companies (black spots on gray back ground) and total num-

ber of damages in cantons with private insurance companies (black columns on white back ground).

3.3 Indirect damages

The indirect damages due to financial losses in the tourist sector, loss of income in commerce, industry, power supplies and interruptions of road and rail transport facilities reached a total sum of 180 million Swiss francs (Tab. 3). The hotels and the private rail companies were affected most.

Tab. 3 Overview of the indirect damages caused by avalanches.

Trade	Damage [mioCHF]
Hotel industry	80
Private railway companies	98
Miscellaneous	3
Total	181

The total numbers given here as well as the results of a closer analysis of the indirect damages in a community (Nöthiger 2000) have shown, that the indirect damages amount to at least 40% of the direct damages caused by avalanches. The indirect damages are difficult to assess, because an acknowledged method for analysing and assessing the vulnerability of social systems from an economical point of view is still missing.

The losses in the hotel industry were considerable (Fig. 6). The first phase (November, December, January) showed an increase in revenues because of early snowfalls and an early beginning of winter season. In the second phase (February) the direct losses of overnight stays and arrivals with –3% and –8% (a total of 63,894 overnight stays less then the years before) were remarkable. The difference between overnight stays and arrivals at the hotels indicates, that some of the guests canceled their arrangements or were cut off in their resorts and had to stay longer than planned. The positive number shown in Fig. 6 for April were influenced by the fact that Easter-holidays were in April.

3.3 Financial damage handling

The public financing and the contribution from the cantonal and private insurance companies amounts to about 85% of the direct

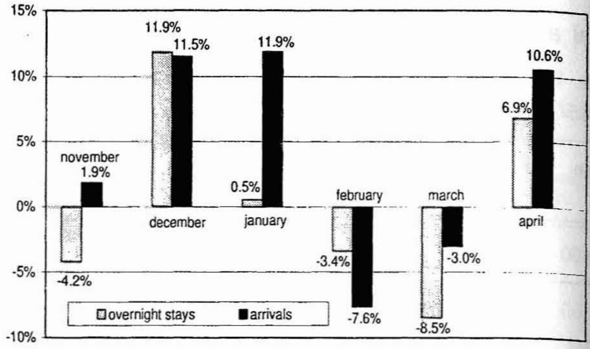

Fig. 6 Variability of the number of overnight stays and arrivals in the hotel industry in mountain resorts over 1,000 m a.s.l., mainly ski resorts. The numbers of the winter 1998/99 are compared with the average number of the period 1993/94-1997/98.

damages(Tab.4). In nineteen cantons of Switzerland the insurance of buildings by the public cantonal insurance companies is obligatory (see Fig. 5). In the remaining seven cantons the private insurance companies are present.

Tab. 4 Classification of the financing of direct, indirect and total damages on a national, cantonal and local level (Nöthiger 2000).

Financing level	Direct costs	Indirect costs	Tot. costs
National	36.7 %	0.4 %	22.3 %
Cantonal	49.0 %	6.6 %	32.3 %
Local	14.3 %	93.0 %	45.4 %

A completely different situation concerning the financing of indirect damages has been analyzed by Nöthiger (2000). The insured amount of indirect damages by public and private insurance companies on a national and cantonal level is only around 7%. The remaining 93% of the indirect damages had to be taken by private companies and individuals.

The long term development of damages is an expression of the public risk acceptance. The line in Fig. 7 shows the increase of the insurance values for buildings, which results in 1999 five times higher than in 1971. The damage ratio with 29 Rp/1,000 CHF insurance value seems to be high at first view, but this indicator was even five times higher in the canton Graubünden in the mentioned avalanche winter 1951 (not to be seen in Fig. 7).

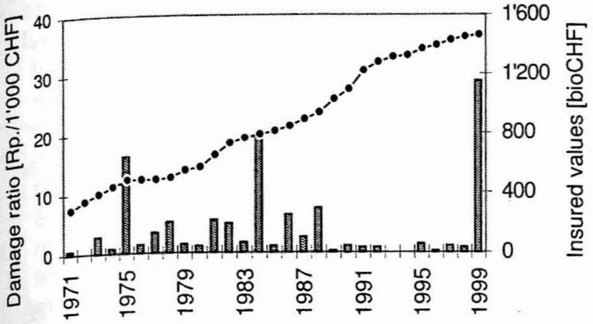

Fig. 7 Development of the insurance values for buildings [bioCHF] in nineteen cantons (line) and damage ratio [Rp/1,000 CHF insurance value] from 1971-1999 (columns). The damage ratio in 1999 is not that high, regarding the intensity and the high return period of the avalanche cycle in 1999.

Considering the increased insurance values and the huge intensity and high return period of the avalanche cycle in 1999, the damage ratio for 1999 in Fig. 7 can be interpreted as a first indicator for good effectiveness of the long term avalanche protection measures.

4. AVALANCHE PROTECTION MEASURES

4.1 Integral avalanche protection

Integral avalanche protection means that protection measures involving forestry operations, land use planning, technical and organisational measures are coordinated and applied in an optimal manner. The optimal level of security can then be reached with least cost and it guaranties an optimal resource allocation. This interplay of protective constructions, avalanche hazard maps, protective forests, systems for early warning, forecasting and alerting, closing off and securing areas, evacuations and artificially triggering avalanches is shown in Fig. 8. The optimisation includes the duration time of the measures as well as the intervention strategy.

4.2 Avalanche forecasting - organisational measures

In Europe avalanche danger is divided in five levels (level 1 for low danger to level 5 for very high danger). In 1999 the two highest levels of the European avalanche danger scale were used for the first time and over longer periods of time since the introduction of the scale in 1993 (the level 'very high' on 6 days). In mid-April 1999 the avalanche danger was judged as 'high' again.

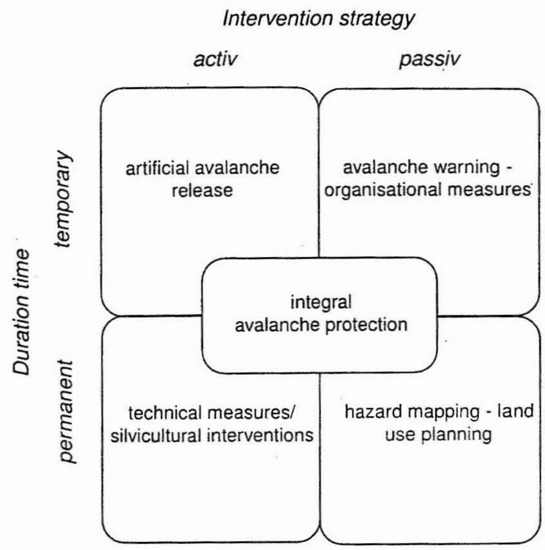

Fig. 8 Integral avalanche protection in the form of an optimal combination of various measures.

Observed avalanches can be taken as a verification tool for the evaluation of avalanche forecasting at high and very high danger (Fig. 9). However, during a 5 day storm not all of the avalanches could have been observed due to poor visibility. Since the number of days with very high danger is very low (7 days in about 1400 forecasts between 1993 and 2000) the experience for forecasting the avalanche activity is very low respectively. Decision support tools are in preparation and already in use for test purposes (Brabec et al. 2000, Gassner et al. 2000).

Overall the forecasts during the avalanche period of 30 days were good. Only on one day the real danger in many areas was underestimated; on most days the avalanche frequency and hazard level showed corresponding results. However, avalanche forecasts are not verified systematically in Switzerland. Therefore a precise score can not be given.

Organisational measures for protection play an important role – both for prevention and in acute situations. As a result of the Swiss federal structure, these measures are organised separately at the cantonal and communal levels. The authorities and the general public receive the necessary information from the Swiss Federal Institute for Snow and Avalanche Research (SLF) in Davos.

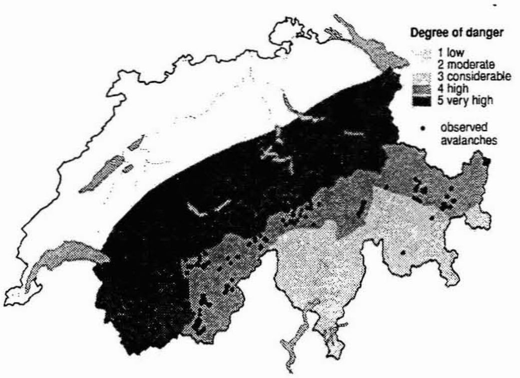

Fig. 9 National avalanche bulletin from February 9th 1999, issued at 9 a.m. compared with the total number of observed medium or large avalanches from February 8th and February 9th (black dots). The map shows that the forecast was good in most areas. In some areas like around Zermatt the hazards may have been underestimated.

In the winter 1998/99 a snow and avalanche early warning message system was established by SLF and the Swiss Meteorological Service SMA. A early warning message is edited 3 days in advance to expected heavy snow fall periods, exceeding 1m new snow with a probability of 75%. This early warning suggests also a probability for very high avalanche danger in different areas of the Swiss Alps. In addition to the national avalanche bulletin, regional avalanche bulletins were made for Central Switzerland and for North and Central Graubünden.

The analysis of the SLF avalanche warnings and of the crisis management in the five most affected cantons shows that the collaboration with organisations at the local, regional and cantonal level in this extraordinary situation proved to be efficient. Further improvements must nevertheless be done in this field. The various avalanche commissions are differently equipped with decision making aids. The qualification of the members of the avalanche commissions is also very variable and should be improved.

These analyses emphasised two important points: firstly, a complete network of avalanche specialists should be established, and secondly, an information and crisis management system is required. This should guarantee exchange of information between the numerous decision makers and information sources and also keep the public well informed. This system can also be used to counter other catastrophic situations such as floods and storms.

4.3 Hazard mapping – land use planning

In a small, densely populated country like Switzerland, land-use planning has an important function to reduce the risks due to natural hazards. The analysis of the application of avalanche hazard maps show that there are large discrepancies between the different cantons. In some potentially endangered communes there are no avalanche hazard maps. The use of an avalanche cadastral map is not established in all cantons. In these extreme avalanche situations, the avalanche cadastral and hazard maps were also used as an important basis for the planning of road closures and evacuations (Gruber and Margreth 2000).

Many avalanches in February 1999 had enormous fracture heights and lengths, often corresponding to the total potential fracture area. Nevertheless, existing hazard map contours were overflowed only in about 40 avalanche situations. The overflow was mainly due to the powder snow avalanches part. In many cases multiple avalanches occurred within a few days. The refilling of the starting zones was a consequence of heavy wind storms. In some cases this led to a lateral overflow of existing deviation dams.

The return periods of the individual avalanche events are sometimes very difficult to determine and accordingly the assessment of the hazard maps show some uncertainties. This was also the case for Evolène (Fig. 10). Although avalanche dynamic calculations in the past had shown the potential run out of avalanches as it occurred in February 1999, the extent of the red and blue zones in the hazard map were reduced meanwhile. A main reason was the existence of some houses which were several hundred year old. As a consequence after the avalanche event in winter 1999, the red and blue zones were extended again.

In general land-use planning and hazard mapping proved to fulfil its function satisfactorily on the whole.

4.4 Technical measures

No large avalanches were triggered between snow supporting structures – they fulfilled their function efficiently. Despite the fact that these structures were completely filled in many places, they withstood the very high loads (Fig. 11). Total Damages to structures amount to 8 million Swiss francs and are relatively low. They occurred mainly in areas where avalanches flowed over the structures. Structures located on the ends of rows and in areas with strong snow gliding were found to be rather scarcely dimensioned (dimensions according to the BUWAL/WSL guidelines, 1990) and higher loads may have to be considered in future.

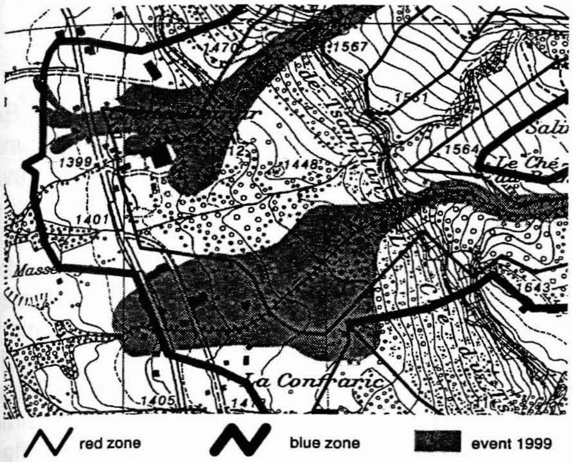

Fig. 10 Avalanche hazard map in Evolène before the avalanche event of 1999. Although the exact return period of the avalanche event in 1999 couldn't be determined, the zones were extended afterwards again.

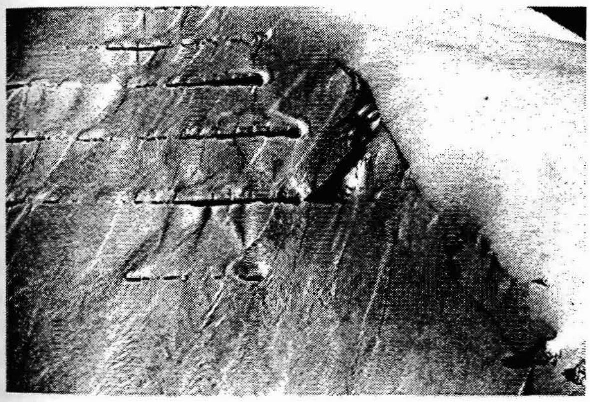

Fig. 11 Avalanche supporting structures at Chüenihorn above St. Antönien/GR, photographed on February 25th, 1999. The photo shows clearly the effectiveness but also the limits of supporting structures with several lose snow avalanches on the surface of the snow pack (Foto SLF).

In order to estimate the number of avalanches prevented in February 1999 with defence measures, the avalanche activity was analysed for the Davos area and an appraisal for whole Switzerland was made (Margreth et al. 2000). The rough estimation shows, that in about 350 controlled tracks destructive avalanches were successfully prevented and in about 170 tracks the extent of the avalanches was reduced. If we consider, that the majority of the defence measures had been built to protect villages, the prevented damage per prevented avalanche is several times higher then the average damage of 0.5 mioCHF per observed avalanche.

It should be determined in future research work, how the efficiency of defence structures and the residual risks can be quantified – and by which criteria rezoning can be undertaken when defence structures are built according to the official guidelines. Avalanche galleries also proved to be very efficient. Maintenance of the numerous defence structures must be ensured in future, and this requires an appropriate organisation.

4.5 Protection forests and silvicultural measures

The absence of avalanche fractures in forests in winter 1999 was obvious. Weather and snow cover conditions had a positive influence on the avalanche activities so that the forests probably did not have to prove their protection role. Hardly any avalanches started in forests, even in potentially dangerous areas. Although the efficiency of forest structures cannot be established satisfactorily, avalanche activity could be observed on clearings in the forest (Fig. 12). It seems that the protection forest fulfilled its function properly.

One positive aspect for avalanche protection is definitely the constantly increasing surface area of forests and their growing density. The surface area of forests increased between 1870 and 1999 for more than 50%. Even in the last decade an increase of 4% is observed.

The avalanches caused the formation of new potential dangers, for example, the presence of lying trees in stream beds. Clearing avalanche debris timber is not always meaningful or possible. However, priority should be given to the clearing of river beds which threaten to be dammed by timber.

4.6 Artificial avalanche release

Artificial avalanche release had an important role in winter 1999. Regular triggering avoided the formation of large avalanches in many areas. The method was generally useful; however, there were also significant damages to buildings and diverse infrastructures, confirming that there is risk involved. It can not be avoided that triggered avalanches are larger than expected or that avalanches that were not successfully triggered release later. Estimation of possible extreme run-out areas and organisation of large-scale closures proved to be essential for avoiding damages, particularly in cases where avalanches reach valley bottoms.

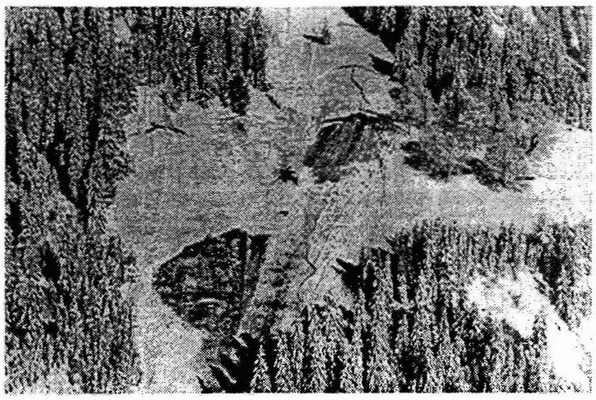

Fig. 12 Avalanche fractures in clearings within the forest photographed on February 12th, 1999. Compared with the avalanche activity in the open field, the protection forest in general proofed to fulfil its function (Foto SLF).

The result of artificial releases must be verified in order to make the method a useful instrument for increasing the safety of roads and infrastructures. If the result is not clear, experiences in winter 1999 showed, that it is very delicate to cancel preventive measures such as road closures. The security staff, including mine throwers and rocket shooters, must be well qualified and have attended obligatory courses guaranteeing this.

5. RISK MANAGEMENT – THE ANSWER

Finally, it appears that integral avalanche protection in the form of an optimal combination of various preventive and crisis management systems was successfully put to the test in February 1999. The winter 1999 confirmed that complete protection is impossible due to technical, economic and ecological limitations. The analysis of the winter 1999 (SLF 2000) shows that the level of security offered to settlements today is very high. Not yet satisfactory is the protection of traffic routes. It has not been possible to adjust the extent of protection compared to the heavy increase of traffic over the past few decades. The avalanche winter of 1999 showed very clearly how vulnerable today's mobile society is to extreme natural events.

Existing avalanche defence structures should be completed if necessary. The limited existing financial resources should be used in an optimal manner for integral risk management, i.e. for protection strategies which combine various different and complementary methods of protection. Within this strategy, the organisational means of protection will be of greater importance in future. Risk assessment methods and methods for the evaluation of the economic efficiency of means of protection have priority. Integral risk management should also be applied increasingly to other natural hazards such as floods and storms in future.

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