SIXTH FRAMEWORK PROGRAMME
PRIORITY VI
Sustainable Development, Global Change and Ecosystems

SPECIFIC TARGETED RESEARCH PROJECT

irasmos

Integral Risk Management of Extremely Rapid Mass Movements

WORK PACKAGE 5: INTEGRAL RISK MANAGEMENT

DELIVERABLE D5.4

BEST PRACTICE OF INTEGRAL RISK MANAGEMENT OF SNOW AVALANCHES, ROCK AVALANCHES AND DEBRIS FLOWS IN EUROPE

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Summary

Increases in population, higher demand on natural resources, and the desire to experience recreation in pristine natural environments has led to the expansion of human activity into uninhabited mountain regions. Such regions are naturally subject to elevated morphodynamic activity characterized by high rates of erosion, transport, and deposition of water, organic and inorganic matter. Owing to high relief and slope steepness, the downward movement of soil, debris, and rock materials is often the dominant erosional agent. Extremely Rapid Mass Movements are debris flows, rock avalanches, and snow avalanches. These mass movement processes pose varying degrees of risk to land use, infrastructure and personal safety in many mountainous regions and should be handled using a framework of Integral Risk Management. The EU-funded project IRASMOS (Integral Risk Management of Extremely Rapid Mass Movements) was therefore intended to develop a holistic approach to risk management based on the current state-of-the-art. This report summarises some of the findings, particularly those gained from practical application. First the integral approach is developed by integrating existing concepts and ideas for integral management into a new conceptual model called IRMAN. Then the current situation in risk management in the IRASMOS partner countries Austria, France, Italy, Norway and Switzerland is described. This is done more generally based on public documents such as regulations and general overviews; and also to glean more specific insight via workshops held with local risk managers. Subsequently several key elements of the risk management processes are addressed in more detail. The methods of risk assessment such as hazard analysis, vulnerability, risk quantification and evaluation are briefly described. The results of such an assessment are the main input for subsequent planning and the evaluation of countermeasures, and therefore form a pivotal element of risk management. The possibilities for risk management by structural as well as by non-structural countermeasures are then discussed. To illustrate land use planning, France is the primary example in combination with some comparisons with the other countries. Warning and emergency preparedness are explained based on several practical applications such as the avalanche warning centres, new approaches to debris flow warning, alert systems and preparedness and emergency plans. The structural measures are also addressed thoroughly. The alternatives for snow avalanches, debris flows as well as for rock avalanches are briefly outlined and a new procedure for the assessment of effectiveness of countermeasures is presented. In addition to the effectiveness, economic aspects play an important role when decisions have to be made between different alternative countermeasures. Hence, the main methods such as cost-benefit analysis, cost-effectiveness analysis and multi-criteria analysis are introduced. Special emphasis is given to some problems that may appear in practical application and how to solve them. With regard to practical implementation, two case studies representing best practices for risk management are added; one for snow avalanches (Italy) and one for rock avalanches (Norway). The report concludes with some recommendations for applying, implementing and further developing risk management in practice.

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Foreword

Rock avalanches, debris flows and snow avalanches, all grouped under the term *extremely rapid mass movements*, pose varying degrees of risk to land use, infrastructure, and personal safety in many mountain regions. Despite increasing efforts to quantify the risk in terms of potential damage or loss of life, most previous studies have achieved partial rather than total risk solutions. IRASMOS (Integral Risk Management of Extremely Rapid Mass Movements) was therefore intended to direct the focus toward a holistic approach to risk management and away from process-based research. IRASMOS was a research project of the EU Research Framework Programme FP6.

Partners from five European countries, all of them affected by the hazards mentioned, have been cooperating on this project for 2½ years.

- WSL Swiss Federal Institute for Snow and Avalanche Research SLF, Davos, Switzerland (Project Coordinator)
- Cemagref, Grenoble, France
- Centre d'Etudes de la Neige CNRM Météo France, Grenoble, France
- Department of Hydraulic and Environmental Engineering, University of Pavia, Italy
- Institute of Mountain Risk Engineering, University of Natural Resources and Applied Life Sciences Vienna (BOKU), Austria
- Norwegian Geotechnical Institute, Oslo, Norway
- Section of Hydraulic and Water and Coastal Engineering, Politecnico di Milano, Italy
- University Centre for Hydrogeological Protection of Alpine Areas, University of Trento, Italy

Everyone brought specialised experience and knowledge – together we managed to achieve a unified and international perspective.

The research focused on finding effective ways to quantify and mitigate the risk from several phenomena on the basis of current knowledge. However, these findings will only be effective when they are practically applied. The project team was completely aware of the need to transfer knowledge from science to practice; hence a so-called “handbook of best practices” was always intended as a main outcome of the project. Based on an integral understanding of risk management, it outlines the main steps and gives some assistance in practical implementation. We hope that this handbook as well as the other IRASMOS findings will provide a valuable contribution to the development and the application of integral risk management strategies for extremely rapid mass movements.

We would like to thank all the project partners for their involvement throughout the project, which was challenging. We would especially like to say thank you to all the people outside IRASMOS who contributed in discussions, in workshops and during the symposium. Finally, the funding of the project by the European Commission is gratefully acknowledged.

Davos, July 14th 2008 Hans Romang, SLF

Chapter 1

Integral Risk Management

1.1 Damage due to Natural Hazards

Natural hazards represent an enormous threat to the development of the alpine regions. Even though the knowledge of processes as well as the technology and construction techniques of countermeasures have developed, important natural disasters involving extensive damage and casualties regularly occur. Famous events are the landslides in Italy (Vaiont in 1963 (Muller 1968) and Val Pola in 1987 (Costa 1991)) and those in Norway which triggered tsunamis (Tafjord in 1934 (Nadim et al. 2008)), the avalanche winter in the Alps in 1999 (Gruber und Margreth 2001) and the flood events in August 2005 which occurred mainly in Austria, the southern part of Germany and Switzerland, including also some debris flow disasters (Rickenmann et al. 2008). Innumerable further events involving snow avalanches, debris flows and rock avalanches, which are the hazards dealt with within this report, could be added.

All these events equate to loss of lives and quite a remarkable amount of damage. At least for the number of fatalities due to floods and landslides, Weinmeister (2000) showed a decrease in developed mountainous countries such as Japan and Austria, whereas the level remains high in countries such as Nepal. In Switzerland about 3 fatalities per year (1972-2007) result from floods, landslides and debris flows on average (Hilker et al. 2008). The number of fatalities due to avalanches is higher (25 per year, Tschirky et al. 2000) but this figure also includes victims of snow sports. However the loss of life should nonetheless not be underestimated in the management of natural hazards. This is not only because of ethical arguments but also because of the experience that events with a certain number of fatalities used to strongly influence decisions on further strategies and implementation.

Thus natural hazard management focuses more and more on economic damage. In this regard some data showing the increasing importance is available. In Austria the damage only due to torrential events in the period from 1972 to 2002 amounted to 1 billion Euros (Fuchs et al. 2008). This sum also includes torrential floods whereas the Swiss data gives the sum only for debris flows (about 300 million Euros from 1972 to 2007). The damage level seems to increase over time; however, unlike the global evolution (MunichRe 2007) a statistical trend is not yet proven (Hilker et al. 2008). On the one hand this might be due to the fact that the rare but very large events dominate the total damage picture which in turn handicaps a statistical interpretation, and on the other hand the ongoing investments in countermeasures run contrary to this trend and so diminish it (Figure 1). However, the amount of damage, the expenses for protection and particularly their probable evolution suggest that further efforts to reduce and control the risk due to natural hazards would be sensible.

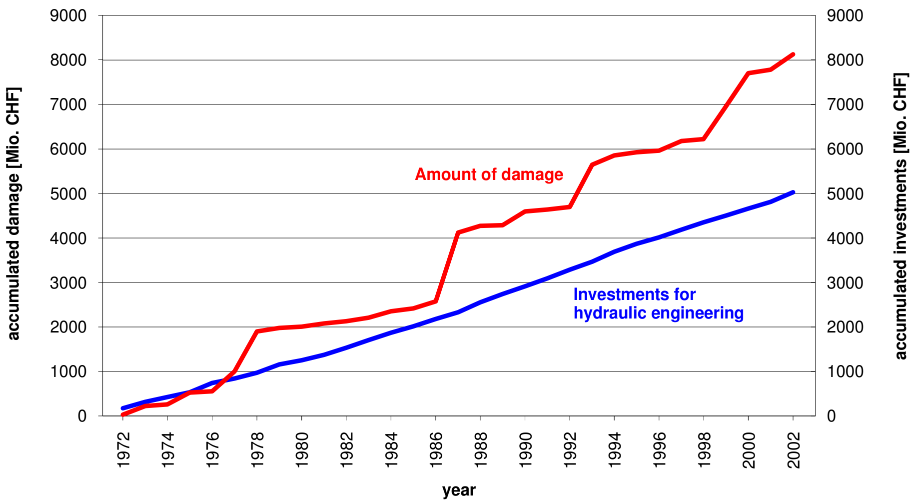

Figure 1: Evolution of damage and investments for hydraulic engineering in Switzerland, 1972-2001 (Romang 2004)

1.2 From Hazard to Risk

Traditionally, natural hazard management focused on the hazardous processes and aimed to reduce or even eliminate them although the repeated disasters and the serious damage clearly showed that the hazard is only one side of the coin. The observed or at least assumed increase in damage may have two reasons: first it may be due to the increased seriousness and intensity of natural events, as a consequence e.g. of climate change (Frei et al. 1998) or of specific anthropogenic factors (road cut, deforestation). Secondly there is economic growth of the territory; e.g. tourism has strongly increased vulnerability, amplifying the results and damages of each event (Fuchs et al. 2005). Hence, to manage natural hazards, a twofold perspective looking at the hazard as well as at the values at risk and respecting their evolution over time is needed. Today, risk management has to look at the natural situation and evolution as well as at the human related conditions and development – otherwise management strategies may result that will not solve the risk problem optimally (Figure 2).

Figure 2: Example of an instable slope triggering debris flows and its evolution within 1 year (at the top) and an alpine settlement and its development over about 100 year (at the bottom). Both aspects produce important issues for risk management. (Photos from Davos, Switzerland, © lower left by documentation library Davos)

Hence, risk does not address the hazard but the damage. A risk describes the potential effects that hazards are likely to cause on specific values such as human beings and assets. No risk exists if one of the two domains "hazards" and "values" is missing. In its most simple form, the risk formula is written as follows:

$$R = p \times A$$

with:
p: probability of damage (combining probabilities of natural occurrence and presence of human assets)
A: degree of damage (combining the natural impact on the objects, their value and vulnerability)

"Risks are not taken for their own sake, but they are an integral part of the activities to satisfy particular human needs or purposes. According to Turner et al. (1990) they should be seen as a segment of a wider perspective on how human beings transform natural into cultural environment with the aims of improving the living conditions and serving human wants and needs." (Ammann 2006: 5). Because risk depends on human activity it does not have to be simply accepted but can be influenced. In mountainous surroundings natural hazards are widespread and a constant human companion. Hence, to live in mountainous areas implies the well-considered handling of natural hazards. Today, this handling and the related tasks are combined in the term "risk management", which has also become a popular approach in the field of natural hazards.

1.3 Integral Risk Management IRM

Risk management at its heart aims to reduce and control risks by planning and implementing countermeasures. The procedure for risk management can generally be divided into the steps identification, evaluation, and controlling of risks (Renn et al. 2007). The risk concept (Figure 3) was developed with respect to this classification. The three main elements of the risk concept can be addressed by posing the following basic questions (Kaplan & Garrick 1981, 1997):

- What might happen? (risk analysis)
- What can be allowed to happen? (risk evaluation)
- What needs to be done? (planning and evaluation of measures)

It is assumed that following this concept systematically and consistently will lead to effective and efficient decision-making and transparent and comparable results.

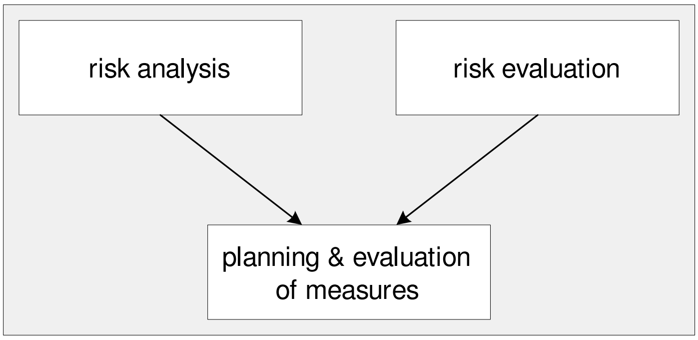

Figure 3: The risk concept (PLANAT 2004)

Risk analysis and risk evaluation, often summarized in the term risk assessment, are very popular tools in different disciplines far beyond natural hazards, such as finances and health, engineering and technology, biodiversity, nuclear technology or terrorism prevention (Bischof et al. 2008). The increasingly widespread use of risk assessment is very useful to support decision-making in complex systems (Hatfield & Hipel 2002) and has become a routine procedure (Klinke & Renn, 2002).

Although the risk concept may be seen as the theoretical basis of risk management, it has to be modified toward a more global view of integral risk management. The crucial point in this context is the word “integral”: what does integral risk management really mean? PLANAT (2004) attempted to embed the risk concept in a strategic framework and to strengthen the risk dialogue aiming for integral management. In addition, it may also be helpful to look at other disciplines which are very familiar with management in general as well as risk management. Rüegg-Stürm (2005) further developed a broadly used integral management model for business economics; the so-called St. Gallen Management Model. There the main criteria for an integral approach are a comprehensive view of the environment (social, technical, economic, ecologic), in which the company or organisation is embedded, well-established communications to this environment or the groups representing it such as stakeholders, customers or the public, and internally well-organised processes, adapted structures and consistent refinement. Finally, in the core discipline risk management the new ISO Standard 31000[1] also focuses on a systematic and integral approach (Figure 4). Based on existing technical guidelines (COSO 2004, AS/NZS

[1] ISO 31000: Risk Management – Principles and guidelines on implementation. Publication planned for 2009. Draft see http://www.broadleaf.com.au/pdfs/iso_31000/iso_iec_rm_princips.pdf, accessed 7.7.08.

2004) it stresses the need for an integration of the risk management process in a general risk framework, because risk management can only be effective if it is a part of all management functions and decisions.

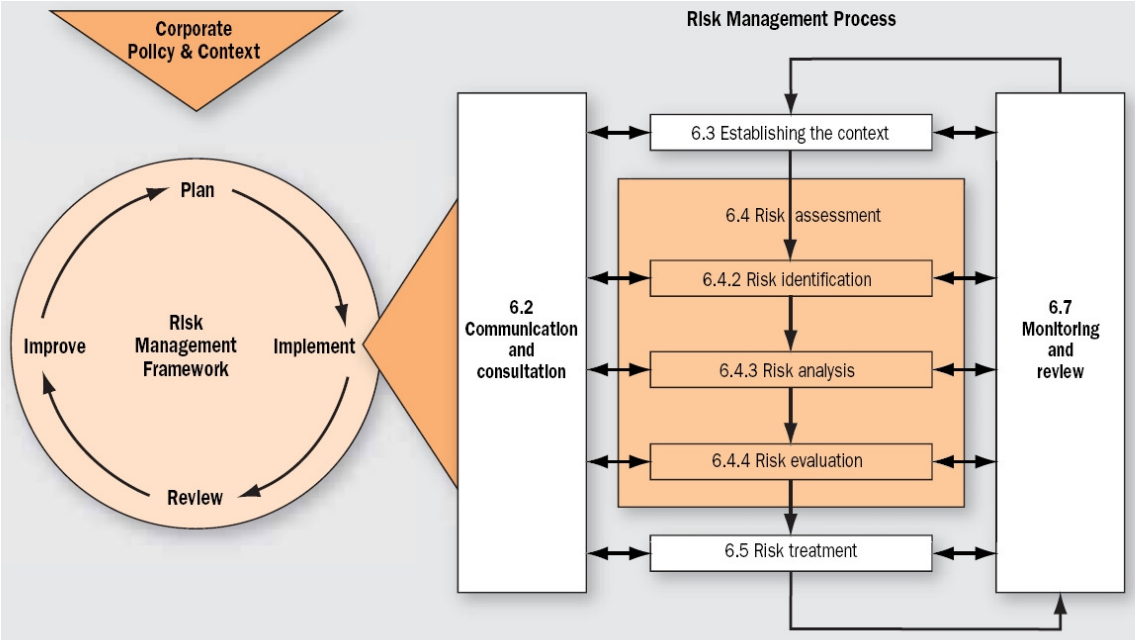

Figure 4: The systematic approach to risk management of ISO 31000 (Jaecklin 2007)

Hence, integral approaches are popular and required not only in the risk management of natural hazards but in all managerial tasks that require dealing with uncertainties, with risks and with decisions on future development. Moreover, it can be seen that the main criteria for integral approaches are similar in all domains. Thus, the requirements for an integral approach to risk management of natural hazards can be defined as follows:

- Every new approach should be based on already existing and well-established concepts and methods such as the risk concept or the standards of risk management such as ISO.
- The risk management processes have to be clearly structured and the different working steps should be well coordinated to support effective, efficient and integrative operations.
- The risk management process have to be actively managed e.g. by setting the strategic framework and defining the objectives, by organising the decision process or by observing and evaluating the results
- The risk management process which has to be embedded in the environment and communication should be promoted actively. This is of pivotal importance e.g. for opinion forming and for decision making.
- Risk management is an ongoing task. Thus, it has to be organised in a consistent way and has to include steps of review and continuous enhancement.

Based on these requirements and the previously discussed existing approaches a new model for integral risk management of natural hazards IRMAN has been developed (Figure 5).

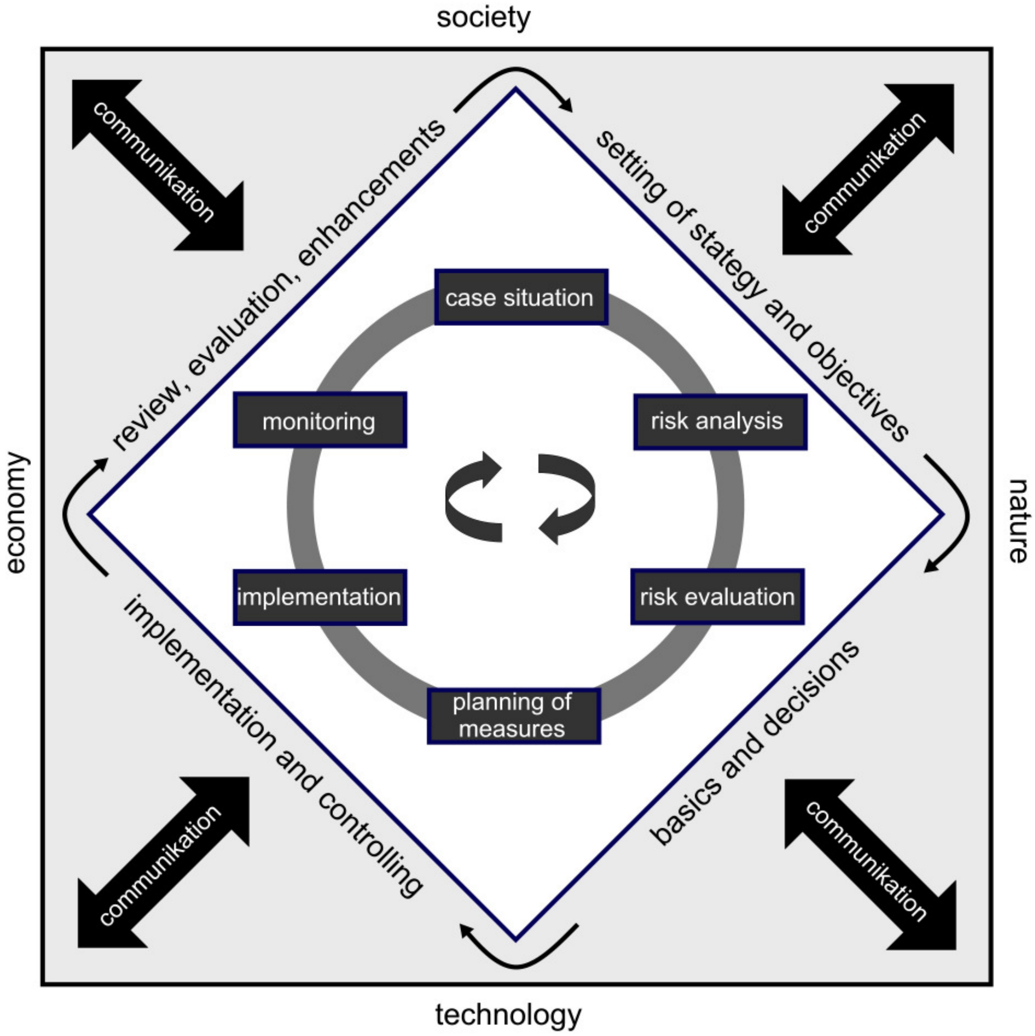

Figure 5: IRMAN – Integral risk management of natural hazards (Romang 2008)

IRMAN consists of three levels:

- First, the risk management process stands in the centre of the model. The terms risk analysis, risk evaluation, etc. are arranged and used the same way as today. Their placement in a cycle underlines on the one hand the never-ending character of risk management and on the other hand the fact that the several steps interlock and have to be coordinated well
- Second, the risk management process is surrounded by the management level. Four main managerial functions can be distinguished: 1) setting of strategies and objectives, 2) preparation and making of decisions, 3) directive for and controlling of implementation and 4) review and improvement.
- Third, the process as well as its management is embedded in the environment. Several trade-offs exist which are represented by the communication.

Based on its design, IRMAN hopefully supports an integral approach to risk management not only on the process level but also by connecting the different levels and groups such as the risk managers, stakeholders and public, all playing an important role in an integral approach.

1.4 Structure of the Report

Chapter 1 gave an introduction to risk management of natural hazards. It illustrated the need for a risk perspective instead of a hazard perspective. Last but not least it explained the importance of the term integral in this context and outlined a new model for integral risk management of natural hazards.

Chapter 2 briefly describes the current situation in risk management in Austria, France, Italy, Norway and Switzerland. On the one hand this is done more generally based on public documents such as regulations and general overviews; on the other hand results of workshops held with risk managers in all the countries give more specific insight.

Chapter 3 addresses the methods of risk assessment. It briefly describes the main working steps such as hazard analysis, vulnerability, risk quantification and evaluation. The results of such an assessment are the main input for subsequent planning and evaluation of countermeasures and therefore a pivotal element of risk management.

Chapter 4 details the possibilities of risk management via non-structural countermeasures. The chapter focuses on land-use planning and on warning systems/emergency management. For the land-use planning, France is the primary example with some comparisons with the other countries, for the warning and emergency part Swiss and Austrian examples are at the centre of focus.

Chapter 5 outlines the structural options for countermeasures. First, the alternatives for snow avalanches, debris flows and rock avalanches are briefly specified. Second, a new procedure for the assessment of effectiveness of countermeasures is presented and third illustrated by its application to a real case.

Chapter 6 focuses on the economic aspects of risk management. The main methods such as cost-benefit analysis, cost-effectiveness analysis and multi-criteria analysis are introduced. Special emphasis is given to some problems that may appear in practical application and how to solve them.

Chapter 7 specifies a typical procedure for risk management in practice. Some important points with regard to practical implementation are discussed. Then, two case studies representing best practice for risk management are added; one for avalanches (Italy) and one for rock avalanches (Norway).

Chapter 8 finally lists some recommendations for applying, implementing and developing risk management in practice.

Chapter 2

Current Risk Management Practices in the IRASMOS Countries

In order to effectively apply risk management and to introduce new methods successfully, the current situation of natural hazards risk management in the countries of concern should first be known. In all of these countries the responsible agencies and persons are already accustomed to dealing with natural hazards, hence new developments and recommendations for further enhancements should fit current practice. If not, they may not be implemented. Additionally the work of IRASMOS should try to benefit from their practical experience and integrate it into the final product. If this is not done, it could remain a research project with a weak link to application.

The risk management practice in the IRASMOS countries was analysed and integrated thoroughly:

- First, an overview on the characteristics of the risk management process in each country was detailed by the IRASMOS partners. This overview is based on public documents such as regulations and public reports as well as from the specific experience of the authors.
- Second, the objectives of risk management were defined for each country. This was mainly done during workshops (see below) and partially completed via general documents.
- Third, workshops with risk managers from the field, administration and science were organised in each IRASMOS country. Based on the knowledge and the experience of the invited experts, the current practice of risk management in the countries of concern have been analysed using the so-called SWOT-method. The results were helpful, not only for the description of the current situation but also to improve perspective as important future issues in risk management were also identified and possible strategies for further development were discussed.

The results of these three steps are presented in the following sections (one for each country). Prior to that, the method of SWOT is briefly explained. In the final section of this chapter the specific results for each country will roughly be compared, focussing on important similarities and differences, then some initial conclusions about the implementation will be made and further enhancements of risk management suggested.

2.1 The SWOT Analysis

The SWOT analysis is a strategic planning tool used to evaluate the strengths, weaknesses, opportunities, and threats involved in a project, in a business venture or in any other situation requiring a decision (Simon & von der Gathen 2002). It allows one to relate personal skills to the environmental conditions and to form strategies. Done properly, SWOT offers a “big picture” of the most important factors. A SWOT analysis is simple to understand, but needs some time to develop (Hill & Westbrook 1997). For a successful SWOT analysis the following aspects should be given attention:

- Clearly define the objective or goal. If a SWOT analysis does not start with the definition of a desired end state or objective, it runs the risk of simply being an exercise (i.e. useless). The defined objectives should be SMART (specific, measurable, ambitious, realistic and time-based).
- There must be a clear differentiation between internal and external factors. Internal strengths and weaknesses (S and W) result from the characteristics of the organisation examined and can, over the short-term or at least over the medium-term, be influenced. The opportunities and threats (O and T) result from external conditions such as society, the environment or the market and can only be influenced over the long-term.
- Keep it short and simple. The arguments should be specific and selective. Grey areas should be avoided. In addition, the strengths and weaknesses should be evaluated in a realistic manner. In particular, strengths should not be overestimated and weaknesses should not be ignored.
- A SWOT analysis will only be seen as successful when it is followed by well-defined strategies and implemented using measures that are in line with the goal. However, SWOT analyses only include current conditions from which strategies and actions can be derived.

Although SWOT was developed for and is well known in the business community, its usefulness is not limited to for-profit organizations (Caruso 2006, Olfert 2006, Rauch 2007). SWOT analysis may be used in any decision-making situation when a desired end-state (an objective) has been clearly defined. Thus, it can also be applied in the natural hazard domain. People working in the field of risk management represent a collection of interested parties who seek the same goal – risk reduction and risk control. Therefore, the risk managers in a country can be seen as a body or an organisation with specific S and W, working in an environment with its O and T. Due to their qualitative style, SWOT analyses may be subjectively biased. To minimize this potential danger, a SWOT analysis requires a team effort. Workshops with brainstorming sessions form an ideal platform. Participant selection is an important part for a successful analysis: there should be diversity (e.g. persons representing different parts of an organisation) and openness among the participants (open discussion) and willingness for changes is essential.

SWOT was used within IRASMOS to collect the main factors for risk management in workshops in the five countries. Before the workshops took place, a document with general information on the method and the workshops was sent to the participants so they could prepare. During the workshops the SWOT were collected and analysed as follows:

- The discussion started with the internal factors (S and W) and afterwards considered the external factors. The keywords were written on flip charts and then rearranged in a matrix (Figure 6).
- Next the logical SWOT combinations were identified:
  - Which strengths fit to which opportunities (SO combinations)?
  - Which strengths fit to which threats (ST combinations)?
  - Which weakness fit to which opportunities (WO combinations)?
  - Which weakness fit to which threats (WT combinations)?

  These combinations could then be written with their corresponding description (e.g. S1/O1) in the four strategy fields (Figure 6).

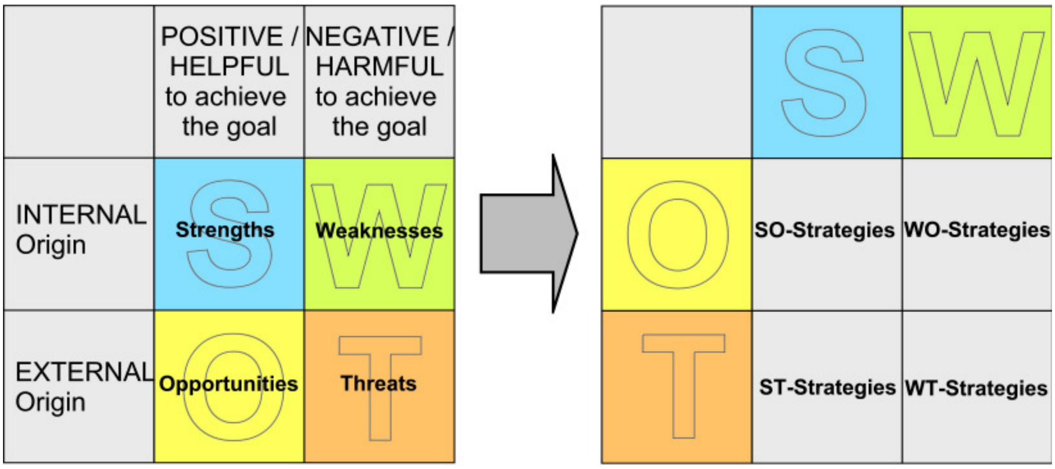

Figure 6: SWOT Matrix (based on Lombriser & Abplanalp 2005)

Finally, on that basis the strategy options were developed, wherein basically four types of strategy are available:

- SO strategies use internal strengths in order to benefit from external opportunities (e.g. to develop new markets)
- WO strategies aim to reduce internal weaknesses or building up strengths in order to benefit from opportunities (e.g. establish strategic partnerships or joint ventures).
- ST strategies make use of strengths in order to reduce or bypass external threats (e.g. setting trends via marketing).
- WT strategies reduce internal weaknesses and avoid threats (e.g. retreat from inactive markets).

The development of the strategy options is the creative part of the SWOT analysis and transitions easily into the strategy development. Due to time limitations, this was not always integrated in the workshop.

In the following chapter the results of the first step, the collection of SWOT, is shown. The further steps leading to strategies for the future will be integrated into the final chapter of this report.

It is important to remember that the SWOT of the countries represents only what was named by the participants and therefore reflects what is seen as most important or typical by them. It may not be a complete list of all possibly relevant points.

2.2 Austria

2.2.1 Objective of risk management in Austria

The objective was discussed in the beginning of the workshop (chap. 2.2.5). The participants agreed on the following objective: natural hazard risk management in Austria should protect areas of human habitation. The protection should be financially, socially and environmentally reasonable, should be integral and should respect technical limitations.

The idea of risk has been a prevalent theme in recent years and is not yet completely recognised when managing the hazards. For example the risk management of the railroad company focuses on safety first. In hazard zoning and similar tasks overseen by the Austrian Service for Flood and Avalanche Control, residual risk today is communicated more and more to the public.

2.2.2 Situation in Austria

Austria has a long experience in dealing with natural hazards both from an implementation-oriented and a scientific point of view. Considerable research has been conducted within the last decades and application of these scientific findings has always been a major task. Therefore, operational practice of natural hazards management is quite far developed. Starting from the management of hazard processes, including forest management, land-use management and the implementation of technical mitigation, dealing with natural hazards includes cost-benefit analyses and governmental consulting by an involvement of multiple stakeholders' interests.

The Austrian state provides a well-established system of natural hazard protection. Multiple legal restrictions exist to regulate the utilisation of endangered areas on different but supplementary federal and Federal State levels as well as community levels. Among others the legal basis for the protection from natural hazards arises from the Forest Act, the Water Act, the Torrent Control Act, the Building Acts and the Development Planning Acts.

2.2.3 Stakeholders

Stakeholders involved in natural hazard management processes are structured on national, federal and municipality levels, plus legwork by the private sector. Each level has different responsibilities and competences, whereas the main responsibility with respect to alpine natural hazards is organised on the national level.

The protection of areas endangered by torrents and avalanches is laid down in Article 10 of the Austrian Constitution. As a result, subsidies were granted by the Republic of Austria in order to implement mitigation measures. In accordance with the regulations of the Forest Act[2], areas endangered by torrents and avalanches have to be protected by preventive mitigation measures, including hazard mapping. On a technical level, the Austrian Service for Torrent and Avalanche Control (WLV) as a subordinated service organisation of the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) is responsible for the operational

[2] Forstgesetz 1975, BGBl 1975/440 idF BGBl I 2005/87

implementation of risk management strategies. Furthermore, WLV advices the provinces and municipalities on different tasks of risk management, and considers applications for mitigation measures. The private sector elaborates risk reduction projects on behalf of the WLV, and provides preliminary work for the different district offices of WLV.

The Austrian federal railway company runs an in-company branch responsible for the protection of the railway lines.

2.2.4 Mitigation strategies

Hazard mapping plays a key role in the Austrian approach. Based on the Decree related to Hazard Mapping[3], catchment areas of torrents and avalanches provide the basis for considering phenomena in the hazard maps. Based on hazard mapping, land-use planning as the major preventive measure is regulated on provincial level. Thereby the level of detail in legal regulations as well as the individual prescriptions differs between the nine Austrian provinces (Hattenberger 2006, Kanonier 2006). The final decision often lies upon the municipal level, i.e. during the assessment of possible new development sites. Finally, cost-benefit analyses are mandatory for preventive measures exceeding capital expenditures higher than EUR 1 million.

Intervention is gaining an increased recognition, and is strongly supported by monitoring and warning tools. However, due to a variety of actors such as the police, civil protection units, fire brigades, emergency task forces, etc., and due to the short lead time, emergency management poses a genuine challenge that needs further development and support.

Insurance companies generally play a minor role in Austria so far. Natural hazards are not (yet) subject to compulsory insurance. However, it is expected that in late 2008 a new legal regulation related to the additional coverage of the house insurance against loss resulting from natural hazard will come into force.

2.2.5 Results of the SWOT-Analysis

A workshop with representatives from the private sector (OeBB), from public administration (WLV) and from scientific institutions (BOKU) was held on April 4th 2008 in Vienna. The SWOT of Austrian Risk Management were collected and strategies were discussed ((Figure 7Figure 7). The SWOT will be further analysed in comparison with the results of the other countries in chapter 2.7.

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[3] Verordnung des Bundesministers für Land- und Forstwirtschaft vom 30. Juli 1976 über die Gefahrenzonenpläne, BGBl. Nr. 436/1976

	POSITIVE / HELPFUL to achieve the goal	NEGATIVE / HARMFUL to achieve the goal
INTERNAL Origin	**Strengths** S1: Long tradition and experience S2: Acceptance by the public (WLV) S3: hazard zoning S4: integral approach of WLV S5: local / regional anchoring S6: exchange science – practice S7: "one big family" due to one national university providing specific formation	**Weaknesses** W1: Missing standards W2: administrative structuring and interface problems W3: closed community (strong self-confidence, little flexibility, missing interdisciplinary) W4: hazard zones not legally binding W5: tendency to inertness W6: missing data (event analysis, state of countermeasures, monitoring)
EXTERNAL Origin	**Opportunities** O1: Natural hazards are top-ranked on the political agenda O2: public perception is high O3: ongoing demand for RM due to tourism O4: Administrative changes (ideas for a stronger collaboration) O5: International exchange O6: Technologically advanced level	**Threats** T1: Increasing demand for public safety T2: decreasing individual responsibility T3: Missing risk perspective T4: framework of RM may rapidly change due to politics T5: More values at risk T6: Belief in technology

Figure 7: SWOT-Matrix Austria

2.3 France

2.3.1 Objective of risk management in France

According to Tacnet & Richard (in prep) eight different objectives of risk management in France can be identified:

- To improve knowledge on natural phenomena and hazards, vulnerability and risk;
- To inform and to educate population;
- To consider risks in land-use planning and applications;
- To reduce vulnerability trough mitigation;
- To monitor and forecast natural events and to warn the population;
- To plan and organise rescue;
- To back-analyse events and crisis management;
- To recover after events and to provide compensation.

This definition of objectives is very large and covers all aspects of risk management for natural hazards. It represents an integral understanding of the problem.

2.3.2 Stakeholders

Stakeholders involved in the management process of rapid mass movements in France are structured in national, departmental and local administration level (Figure 8) plus the private sector. Each level has different responsibilities and competences.

- The public safety of the government and the public establishments (with different administrative formats) such as Cemagref, Météo France, RTM and ONF are situated on the national level. The latter have a centralized direction even if they work also at the departmental level. Risk management activities for rescue and prevention are not unified on the national level. Two Ministries are responsible for managing general risks:
  - The Ministry of the Interior is responsible for emergency measures and rescue plans.
  - The Ministry of Energy, Ecology, Sustainable Development and Land-Use Development (MEEDDAT) is responsible for prevention.

  Other Ministries are also involved in the process such as the Ministry of the Economy, Finance and Industry via the CATNAT financial compensation system. The number of different Ministries involved in the flood risk management system requires coordination. Risk prevention must be considered a global process.
- The departmental authorities mostly determine the operational implementation of risk management. All departments have specialized cells for natural hazards or similar sections.
- The mayors of the municipalities have the responsibility at the city level for implementing the departmental procedures and face immediately to the events (Figure 9). Legally, the final responsibility for civil protection against natural hazards is situated on this level. When an event occurs, they are helped by departmental cells. Within their entire responsibilities, they mainly take influence on land use planning and on emergency management.

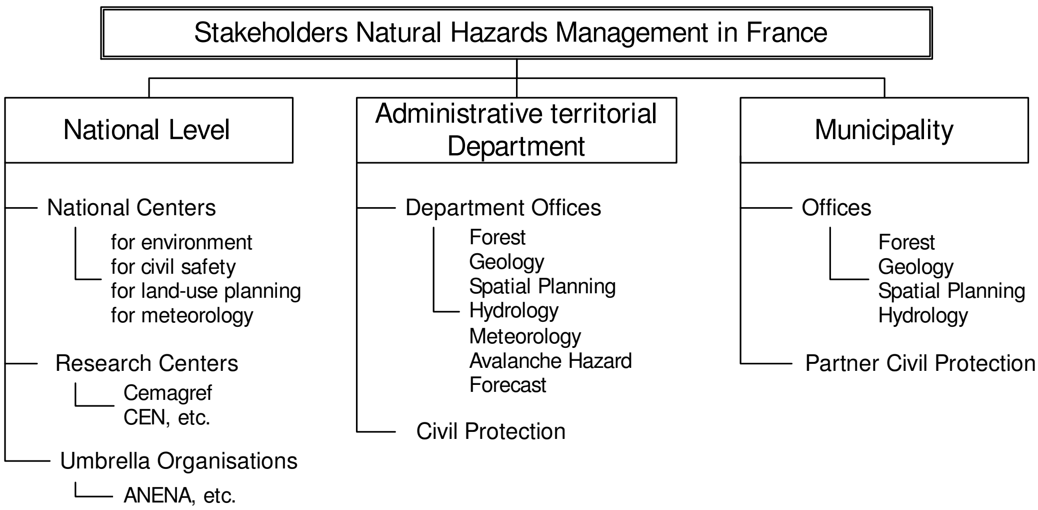


Figure 8: Overview on stakeholders acting in the management of natural hazards in France

2.3.3 Legal system

In France, the role played by the national government and local approaches to risk prevention are defined by laws that cannot be negotiated. The highly centralized French legal system controls land use and implements prevention measures using a wide variety of regulations. […]The top-down approach of the administrative organisation is often criticised (e.g. through PPR implementation)

The main French laws which relate to the limitation of natural and technological risks have only recently been passed. An important law concerning risk management is law number 95-101 of 2 February 1995. It defines the Risk Prevention Plans (PPR) and allows, in certain specific situations, the government to relocate people because they are exposed to natural risks. This solution is available when the cost of defence works exceeds the economic value of the buildings and infrastructures at risk. The law was created to modernise and simplify the legal system and aims to take natural hazards into account in land-use planning on the local and regional level. To date, this law remains the main tool for the government to protect against natural hazards (Tacnet & Richard in prep.)

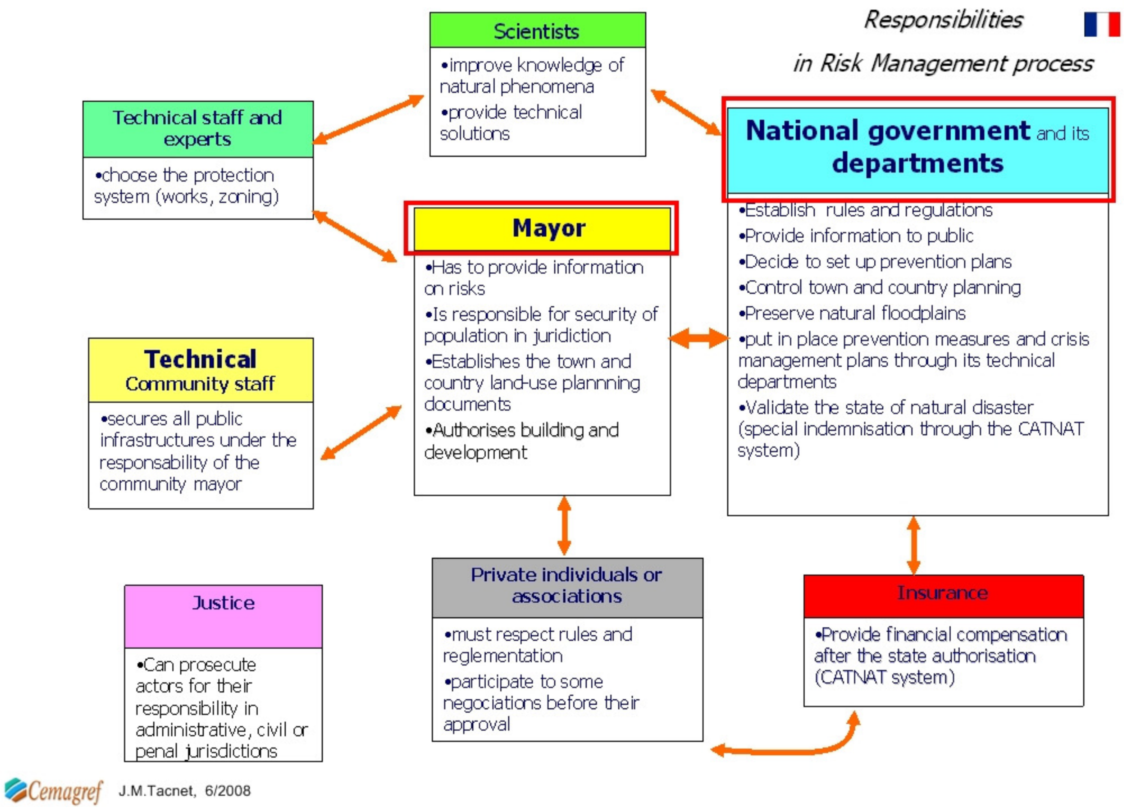


Figure 9: Managing risk chain actors in France: the town mayor and the prefect play major roles in the process (Tacnet & Richard, in prep.)

2.3.4 Results of the SWOT-Analysis

A workshop with representatives from public administrations and from scientific institutions was held on March 26 2008 in Grenoble. The SWOT of French Risk Management were collected (Figure 45). The SWOT will be further analysed in comparison to the results of the other countries in chapter 2.7.

	POSITIVE / HELPFUL to achieve the goal	NEGATIVE / HARMFUL to achieve the goal
INTERNAL Origin	**Strengths** S1: Warning services of Météo France S2: nationally standardised services and experienced professionals S3: role of the municipalities (high responsibility) S4: CATNAT (national fund for compensation) S5: formation (ENA, Ecole nationale d'administration) S6: risk maps PPR (plans de prévention des risques) S7: emergency plans PCS (plan communal de sauvegarde) S8: Event analysis S9: Further methodical developments	**Weaknesses** W1: Administrative organisation (structuring, rivalries) W2: national approach (not adapted to regional or local problems) W3: Missing / ignored hazard maps W4: problems with the Implementation of PPR W5: Overuse / misuse of CATNAT W6: few cost-benefit analyses W7: few standardised methods W8: a lot of small damage
EXTERNAL Origin	**Opportunities** O1: Administrative reorganisation O2: public information / perception O3: Standardisation on European level O4: UN O5: New yellow hazard zone	**Threats** T1: No competence of people to live with risks T2: Rivalries and opposition in administration T3: extremer events due to climate change T4: Insurance companies T5: too distant European level

Figure 10: SWOT-Matrix France

2.4 Italy

2.4.1 Objective of risk management in Italy

The objective was discussed in the beginning of the workshop (chap. 2.4.2). The participants agreed on the following objective: risk management in Italy aims to reduce existing risk and to avoid undertaking new high-risk activities e.g. through hazard zoning. The reduction of existing risks is prioritised according to the following list:

1. human live
2. cultural heritage
3. infrastructures
4. economic activities
5. private properties
6. natural goods

2.4.2 Results of the SWOT-Analysis

A workshop with representatives from the public administrations and from scientific institutions was held on June 19 2008 in Milano. The SWOT of Italian Risk Management were collected and strategies were discussed (Figure 11). The SWOT will be further analysed in comparison to the results of the other countries in chapter 2.7.

	POSITIVE / HELPFUL to achieve the goal	NEGATIVE / HARMFUL to achieve the goal
INTERNAL Origin	**Strengths** S1: good will S2: theoretic know-how (high school level) S3: volunteers S4: public institutions S5: accuracy of regulations	**Weaknesses** W1: waste of funding (misuse) W2: lack of knowledge (e.g. data) W3: difficult application of regulations W4: know-how on administrative level
EXTERNAL Origin	**Opportunities** O1: Governmental and EU funding O2: EU regulations O3: Awareness of climate change	**Threats** T1: Variety of natural hazards T2: Lack of funding T3: effect of climate change on processes T4: Missing risk awareness of people T5: Bad land-use

Figure 11: SWOT-Matrix Italy

2.5 Norway

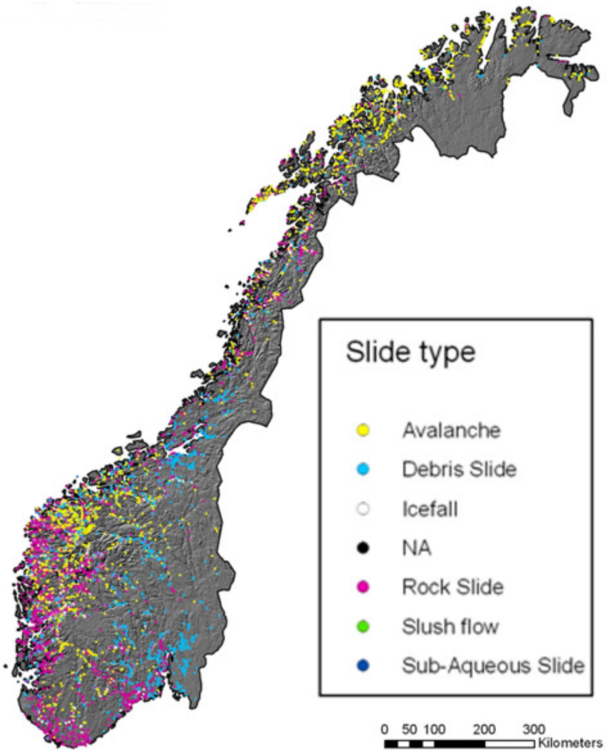
2.5.1 Objective of risk management in Norway

The objective was discussed in the beginning of the workshop (chap. 2.5.6). There is a clear intention that new buildings should not be endangered by events occurring more frequent than every 1000 years. For the traffic infrastructures (roads, railways) a "zero vision" is even proclaimed[4]. It is well known by the experts that this vision cannot be completely met. Among other reasons, the budget to do all of the necessary protection work is not available[5]. Thus, the objective of risk management in Norway is to reduce risks on the long-term to as low as possible taking into account both the technical and financial constraints. With regard to the decreasing number of accidents over recent years, Norway seems to be on the right path toward reaching this objective.

[4] e.g. airport express train: "Target: No-injury through systematic preventive safety work." (www.flytoget.no)

[5] Annually, 500 million NOK are budgeted for safety measures for natural hazards along roads, whereas a more or less complete protection strategy would require 30 billion NOK.

2.5.2 Situation in Norway



Norway has a long experience with natural hazard. Until recently focus has been put on hazard identification by hazard mapping to avoid new settlements to be established in hazardous areas. In the later years focus has also been put on risk management of natural hazards. A lot of research has been conducted within the last decade to find tools for optimal strategies to reduce risk for existing infrastructure as many settlements are located in exposed areas.

The area of main concern regarding rapid mass movements, are located along the western and mountainous part of the entire country, however quick clay slides (included within the debris flow category) may also occur in the flatter eastern part (Figure 12).

Figure 12: Map showing where different types of natural hazards have occurred in Norway

2.5.3 Stakeholders

The stakeholders which are involved in the management of rapid mass movements in Norway are structured in national, county and municipality levels, plus the private sector (Table 1).

Table 1: Overview of stakeholders included in risk management in Norway

National	County	Municipality	Local/private
▪ Ministries ▪ Directorates ▪ Geological Survey ▪ Rescue coordination centre, RCC	▪ Emergency unit ▪ Civil defence ▪ Police	▪ Building authorities ▪ Land use planners ▪ Fire Brigade ▪ Police ▪ Local rescue organisations	▪ Private property owners ▪ Construction firms ▪ Insurance companies

Federal agencies are working on a conceptual and strategic level with responsibility for defining laws concerning accepted risk levels for different activities and for finances. As a special feature, the Directorate for Civil Protection and Emergency Planning in Norway has the responsibility for risk reduction strategic planning on the national level. The Norwegian Geological Survey (NGU) plays an important role in hazard mapping and risk mitigation strategies for rock avalanches. The Norwegian Water Resources and Energy Directorate has been appointed to organise all parties involved in dealing with natural hazards to ensure optimal use of competence and the governmental financial support to this field.

Land use planning performed by the municipalities has to be approved at the county level to ensure that risk assessment has been adequately considered. Additionally, the counties assist and control that the municipalities are working out risk reduction plans for all actions that may involve undesirable occurrences, among them natural hazards.

Legally, the final responsibility for civil protection against natural hazards is situated on municipality level, as the municipalities have the responsibility to take care of safety of their inhabitants.

The private sector works out risk reduction projects on behalf of the municipalities. Generally, expert's opinions play an important role in Norway's risk management. Norwegian Geotechnical Institute is the main consultant company that offers such service, but in addition a few other private consulting companies may also do this, mainly concerning rock falls and debris flow hazards. In addition, insurance companies which are responsible for the disbursement of compensation due to natural hazards, also belong to the private sector.

2.5.4 Mitigation strategies

The management of natural hazards in Norway is mainly treated in the following manners:

- Hazard and risk mapping to avoid new settlements to be located in exposed areas
- Establishment of physical measures for existing settlements
- Emergency and preparedness planning at mainly the municipality level
- Strengthening of the competence by governmental research funding
- Recovering of damage by insurance companies

Snow avalanches, debris flows and rock avalanches are managed separately. Snow avalanches have been dealt with the last 40 years in Norway by the private foundation Norwegian Geotechnical Institute (NGI). In 1972 the Parliament decided that NGI should be the centre for snow avalanche research and consulting in Norway, and since then NGI has received yearly research funding. Rock avalanches generating tsunamis have caused three major accidents the last century with 175 deaths. Investigation of this hazard has been intensified the last decade, and the governmental NGU has taken initiative to establish an early warning system in the most exposed area of Norway by advanced monitoring systems (chap. 7.2).

2.5.5 Finances

The National Fund for Natural Disaster Assistance invested about € 4 million into safety measures in 2005, whereof € 3 million was given to the rock avalanche project at Åkneset. This amount is far too less compared to the national need. For example in the town of Hammerfest in northern Norway the total need for safety measures to protect houses exposed to snow avalanches is estimated to about € 40 mill.

Compensation for damage due to natural hazards is covered by insurance companies and by The National Fund for Natural Disaster Assistance (for non-insured objects). In the period 1996-2007 a total of NOK 7500 million (€ 925 million) was paid out to compensate for damage due to natural hazards in this period, whereof 60 % is damage caused by wind. Rapid mass movements amount to about NOK 450 million (€ 55 million) (Figure 13).

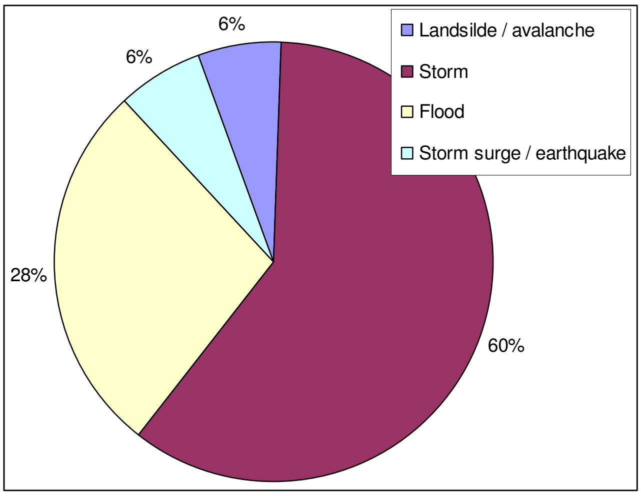


Figure 13: Compensation for different kinds of natural hazards 1996-2007 in Norway

2.5.6 Results of the SWOT-Analysis

A workshop with representatives from public administrations and from scientific institutions was held on May 8 2008 in Oslo. The SWOT of Norwegian Risk Management were collected (Figure 14). The SWOT will be further analysed in comparison to the results of the other countries in chapter 2.7.

	POSITIVE / HELPFUL to achieve the goal	NEGATIVE / HARMFUL to achieve the goal
INTERNAL Origin	**Strengths** S1: Focus on natural hazards S2: Improved education S3: Plans for roads S4: New national directorate S5: Building codes S6: Insurance system S7: Hazard maps S8: International networks	**Weaknesses** W1: Lack of experienced / specialised professionals W2: segregations of duties in risk management of natural hazards W3: Missing expertise on local level W4: Missing focus on county level W5: Lack of funds on municipality level W6: Few detailed hazard maps W7: Difficult determination of 1000-y. event W8: no warning systems
EXTERNAL Origin	**Opportunities** O1: Natural hazards are top-ranked on the political agenda O2: public perception is high O3: open-minded municipalities O4: High susceptibility after disasters O5: developing networks O6: High acceptance of expert's decisions O7: demand for information	**Threats** T1: poor knowledge of the people and , thus, inappropriate behaviour in case of an emergency T2: political changes T3: effects of climate change T4: economic dependency on oil

Figure 14: SWOT-Matrix Norway

2.6 Switzerland

2.6.1 Objective of risk management in Switzerland

The objective was discussed in the beginning of the workshop (chap. 2.6.6). Generally, the objectives that were defined by PLANAT are clear. According to this idea, risk management should aim for an equal level of protection for everyone in Switzerland (risk below protection goals). The risk reduction should be cost-effective, socially acceptable and environmentally sound.

2.6.2 Situation in Switzerland

Switzerland is an international leader concerning integral risk management of natural hazards. A lot of research has been conducted within the last decades. Application of these scientific findings has always been a major task. Therefore, operational practice of natural hazards management is quite far developed. While the beginning of mass movement management was hazard-oriented, in the meantime the risk-oriented approach has been adopted by practice.

2.6.3 Stakeholders

Federal agencies are working on a conceptual and strategic level with responsibility for fundamentals and finances. As a special feature, the National Platform for Natural Hazards (PLANAT) is a non-parliamentary commission and focuses on prevention and risk reduction on a strategic, national level.

The cantons are mainly responsible for the implementation of these concepts. On a technical level, the cantonal authorities mostly determine the operational implementation of risk management: they advice the municipalities on different tasks of risk management, they consider applications for mitigation measures, they approve or reject municipal land use planning, which has to include hazard maps, they take a main responsibility for warning systems, etc. All cantons in Switzerland have departments for natural hazards or similar sections.

Legally, the final responsibility for civil protection against natural hazards is situated on municipality level. This reflects the principle of subsidiary in Swiss federalism, which states that matters ought to be handled by the lowest competent authority. Within their entire responsibilities, they mainly take influence on land use planning and on emergency management.

The private sector finally elaborates risk reduction projects on behalf of the municipalities. Generally, expert's opinions play an important role in Swiss risk management. Therefore, Switzerland has a well developed market of engineering and consulting companies. In addition, insurance companies, which are further major players in risk management, belong to the private sector, too. Last but not least also the population can be seen as a stakeholder of risk management of natural hazards as they bear more than half of the total costs related to natural hazards (chap. 2.6.5).

2.6.4 Mitigation strategies

The integral concept suggests a weighted procedure, where prevention, intervention and recovery are equally used (PLANAT 2004). On the public level priority is still given to prevention, but intervention gains more and more attention. This is mainly due to flooding events in the nearest past, when some experiences illustrated the high potential of well prepared emergency responses. Recovery is mainly covered by insurance companies and by public financing.

Insurance companies generally play an important role in Switzerland. In the field of natural hazards, the building insurances are a remarkable special feature in the stakeholder setting. House owners have to ensure their buildings against natural hazards such as floods, snow avalanches or debris flows, but the insurances are obligated to provide these services with remarkably low costs.

The IRASMOS processes snow avalanches, debris flows and rock avalanches are managed separately and in different depth. Snow avalanches have been dealt with since 70 years in Switzerland and a federal research institute, the WSL Institute for Snow and Avalanche Research SLF, in Davos exists, which is a global leader in snow avalanche research. Furthermore, snow avalanche warning is operational on national basis. Debris flows are investigated since about 20 years, mainly at the WSL Institute for Forest, Snow and Landscape. Operational warning does not yet exist. Most activities related to monitoring and simulation are under development. For rock avalanches no separate research or warning unit exists. Here, monitoring and countermeasures are carried out for individual cases.

2.6.5 Finances

The cumulative expenses for prevention, intervention, recovery and fundamentals such as hazard maps sum up to nearly 3 billion CHF per year (mean value for the period 2000-2005) (Wegmann et al. 2007), which represents 0.6 % of the Gross Domestic Product (GDP. The costs are paid by the public sector (40%) and by the private sector (60%). About half of the expenses concerns prevention, a third concerns recovery and a sixth concerns intervention.

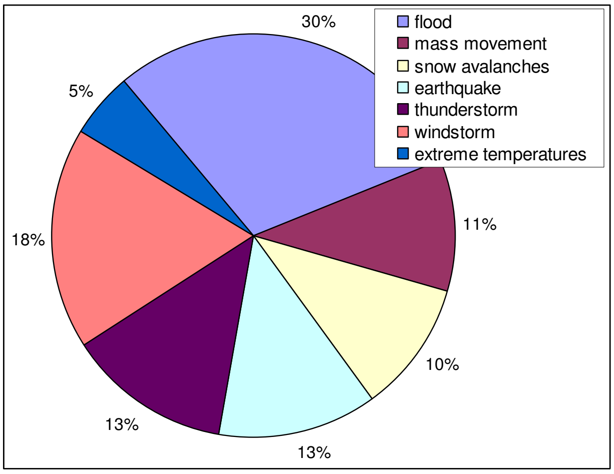


Figure 15: Distribution of expenses for Switzerland (Wegmann et al. 2007)

2.6.6 Results of the SWOT-Analysis

A workshop with representatives from the public administrations and from scientific institutions was held on February 22 2008 in Zurich. The SWOT of Swiss Risk Management were collected and strategies were discussed (Figure 16). The SWOT will be further analysed in comparison to the results of the other countries in chapter 2.7.

	POSITIVE / HELPFUL to achieve the goal	NEGATIVE / HARMFUL to achieve the goal
INTERNAL Origin	**Strengths** S1: Long tradition and experience S2: National standards S3: Knowledge and techniques S4: Strong in snow avalanche RM S5: Good data S6: Professional networks S7: Attitude of professionals S8: Compulsory building insurance	**Weaknesses** W1: Risk quantification is complicated W2: No inclusion of benefits W3: Not yet integral nor risk-oriented W4: Weak knowledge on rock avalanches W5: Generally incomplete information W6: Event-driven W7: Dealing with very rare events not specified W8: Administrative difficulties W9: Weak controlling W10: Weak formation of the people concerned
EXTERNAL Origin	**Opportunities** O1: Natural hazards are top-ranked on the political agenda O2: public perception is high O3: increasing demand for RM O4: Societal environment O5: People O6: Administrative changes O7: Economic strength O8: Technologically advanced level O9: Favourable climatic conditions O10: Internationally growing demand	**Threats** T1: Increasing demand for public safety T2: decreasing individual responsibility T3: framework of RM may rapidly change due to politics T4: Short memory T5: Increasing mobility and extension of settlements T6: Socio-political conflicts T7: No legal definition of risk T8: Federalism T9: Administrative processes are slow

Figure 16: SWOT-Matrix Switzerland

2.7 Comparison of the country-specific Views with particular Consideration of the SWOT Results

2.7.1 Strengths

The strengths of the risk management process in the different countries are similar. All countries have quite a long experience with natural hazards. To a greater or lesser extend they have national organizations and use some standards and tools such as hazard maps, they are adequately skilled and show a high motivation to solve the problems. In all countries there exist different administrative levels from the national level to the municipalities. The latter always take a high responsibility to guarantee safety for the population. All countries also have their specialties such as the WLV in Austria or the high importance of volunteers in Italy. But in general the level of the key players in risk management in the different countries and of the organizations they are working for are comparable. This is a favourable condition to suggest common strategies and methods and to further enhance the work processes in all countries.

2.7.2 Weaknesses

Concerning the weaknesses quite a lot of aspects where mentioned only in one country and really might be individual such as:

- a too closed community of experts in Austria,
- problems related to a centralised national approach in France,
- a non-optimal use (not adequate to the severity of the problem) of funding in Italy,
- the lack of specialised personnel in Norway or
- a weak controlling in Switzerland.

The weaknesses often are influenced by a rather subjective and emotional perception of the current state and the possibilities of enhancements because they reflect the desired development. Thus they may be rather unique. However, some of the keywords were mentioned in a similar way in different countries:

- Some problems arise with respect to the implementation of hazard maps in spatial planning. In France, difficulties with the implementation of the PPR were stated. Perhaps these difficulties become more obvious in France, because there exists a standardised procedure of implementation including elected representatives. In Austria, although hazard maps have a long tradition, they are not legally binding. Alternative ways were found to enforce their consideration (chap. 4.2.2) but problems might remain immanent. In Norway, the implementation is limited simply because detailed hazard maps are often missing. And in Italy existing technical regulation are difficult to transfer to hazard maps and spatial planning.
- In all the countries the segregation of duties and responsibilities between different administrative entities handicap risk management. Different authorities may be concerned with prevention and intervention. During emergencies a lot of players such as fire brigades, police, civil protection, army and political bodies are active and claim responsibility. Last but not least also the different administrative levels nation, region and municipality need coordination.
- Knowledge and methods are still incomplete. Therefore several needs for improving event analyses, information on countermeasures and monitoring (Austria), standard methods (Austria, France), measured data (Italy), education (Norway) and knowledge on processes (Switzerland) were stated.

2.7.3 Opportunities

The big opportunity for risk management in all the countries is the high perception of natural hazards in politics as well as in public. Recent events and the discussion on climate change are effective awareness builders. In addition, the demand for risk management and safety is increasing. In combination with the generally favourable conditions (e.g. technological level, societal stability in the countries of concern, financing, acceptance of experts’ decisions) risk management can be carried out in a positive framework. This framework could become even better on the one hand due to international exchange and standardisation (e.g. EU regulations) and on the other hand due to the administrative reorganisations that are in progress or already finished in the countries and raise high expectations.

2.7.4 Threats

The most important threat is the poor knowledge of the people about natural hazards and their missing competence to live with risks. This may lead for example to a non-adequate behaviour in case of an emergency or to problems in the implementation process of countermeasures and of land-use planning. This threat is somehow contradictory to the opportunity "high awareness". But this contradiction opens the doors for communication and education initiatives.

Another immanent threat for risk management results from its public character and thus its dependency on political decision. The political framework may change rather rapidly and this may have important consequences on the strategic level and especially on financing.

Whereas the increasing demand for risk management and safety can be seen as an opportunity, it might also change to a threat. This would be the case if the requirements would be too ambitious to fulfil. This might become a problem in particular with respect to the decreasing individual responsibility. If people expect protection without doing anything to help themselves, risk management might meet its limits.

Other threats are related to possible changes in the variables defining the risk such as the extension of settlements and the increasing mobility leading to more values at risks or the consequences of climate change possibly leading to more intense and more frequent events.

2.7.5 Conclusions

The opportunities and the threats are similar in all countries. The general conditions to manage risks due to natural hazards are generally favourable and benefit from a high perception in politics and in the public. But people do not really know much about the theme and political opinions and needs may change quite quickly. Therefore for all the countries it seems necessary to strengthen information and communication among stakeholders and the public. In this way, the awareness can be deepened and probably becomes more sustainable.

The strengths and the weaknesses describe the internal factors of risk management in each country. Unlike the opportunities and the threats they can be influenced directly by the community of risk managers. Comparing the different countries, the following general rules could help to develop strategies to further profit from the strengths and to reduce the weaknesses:

- If strengths and weaknesses are similar in several countries possibly high affinities exist and joint strategies could be developed. An important precondition for joint strategies is the fact that opportunities and threats are similar in all countries.

  ➔ e.g. further develop knowledge and techniques in international consortia; face the challenge of respecting hazard maps in land-use planning; match the national standards.
- If strengths and weaknesses are just the opposite way round in two or more countries it might be reasonable to learn form each other and to enforce exchange.

  ➔ e.g. anchoring on the local level, compensation of losses, standardised methods.
- If strengths and weaknesses are really specific for one country it might be reasonable either to keep this individuality or – especially in case of weaknesses – to reduce it.

Chapter 3

Risk Assessment

3.1 Introduction

This chapter concentrates on risk analysis and risk evaluation (Figure 17) as important steps within the risk management process (chap. 1.3). Risk analysis and risk evaluation can be summarized with the term risk assessment.

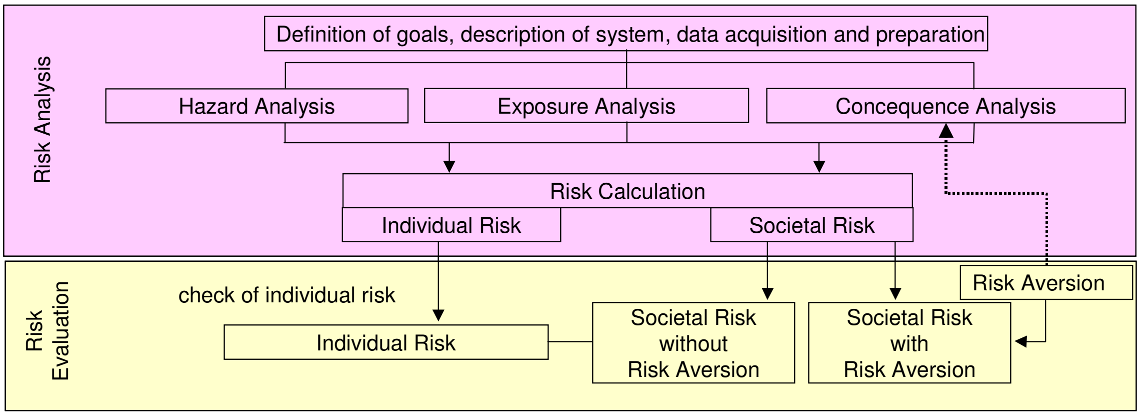


Figure 17: The main elements of risk analysis and risk evaluation

The term risk is in this report defined as "a measure of the probability and severity of loss to the elements at risk, usually expressed for a unit area, object, or activity, over a specified period of time" (Crozier & Glade 2005). Expressed in a mathematical equation this definition can be written as (AGS 2000, Crozier & Glade 2005, Fuchs et al. 2007c):

$$R_{i,j} = p_j \cdot p_{i,j} \cdot A_i \cdot V_{i,j}$$

with:

$R_{i,j}$	=	Risk to object i due to scenario j
p_j	=	probability (frequency) of scenario j
$p_{i,j}$	=	probability that an object is present, while scenario j is occurring
A_i	=	value of object i
$V_{i,j}$	=	vulnerability of object i due to scenario j

3.2 General Aspects of Hazard Analysis

The hazard analysis is the fundamental basis of a risk analysis since it defines the type of processes, which might occur, its probabilities and the dimensions of the physical impact. The physical impact is described according to the characteristics of a process and can be denoted as intensity. A hazard analysis can be divided into two components, which address the probability and the characteristics on the one hand and the intensity on the other hand. The first part is done in the event analysis and the latter in the intensity analysis. The final results of a hazard analysis are intensity maps which reflect the possible courses of a dangerous event.

3.2.1 Event analysis

According to Kaplan & Garrick (1981) the goal of an event analysis is to define the relevant scenarios with its probability of occurrence, which describe a possible damage. In order to formulate realistic scenarios, all available information about the area under investigation has to be collected. This can be:

- data relevant for the triggering of the process (e.g. recurrence interval for certain amounts of rainfall or runoff);
- historical photographs about past events;
- process inventories;
- technical reports;
- air photographs;
- results of terrain analyses;
- newspaper articles;
- reports of the local population and experts.

Using these information, three categories can be distinguished which allow to estimate the probability of occurrence of a scenario (Merz 2006)

- statistical analysis of historical events and observations;
- modelling of damage scenarios, e.g., with event trees or complementary scenarios;
- expert opinions.

3.2.2 Intensity analysis

In the intensity analysis the spatial distribution and variability and the physical impact of a process is determined. The physical impact varies depending on the process. According to guidelines from different European countries the intensity of the processes snow avalanches, debris flow and rock avalanches are defined as shown in Table 2.

The spatial variability of the intensity is visualised by intensity maps. Intensity maps can be created with physically based models. The resolution of the model output is determined by the resolution of the digital terrain model. Typical resolutions are in the range of 10 to 25 m. In a model output each raster cell is denoted with a calculated intensity value. For application in practice the calculated intensities are classified with intensity classes (Figure 18). Intensity maps are calculated for every of the considered scenarios. The results have to be carefully analysed by experts to correct the deficiencies of the model.

Table 2: Physical impact expressed as intensity of the processes snow avalanches, debris flow and rock avalanches and the corresponding units. For snow avalanches the intensity is expressed in most of the cases as impact pressure, in fewer cases it is expressed as velocity

Process	**Physical Impact**	**Unit**
Snow avalanches	impact pressure	*kPa*
	velocity at front	ms^{-1}
Debris flow	velocity at front	ms^{-1}
	flow height	*m*
Rock avalanches	energy	*kJ*

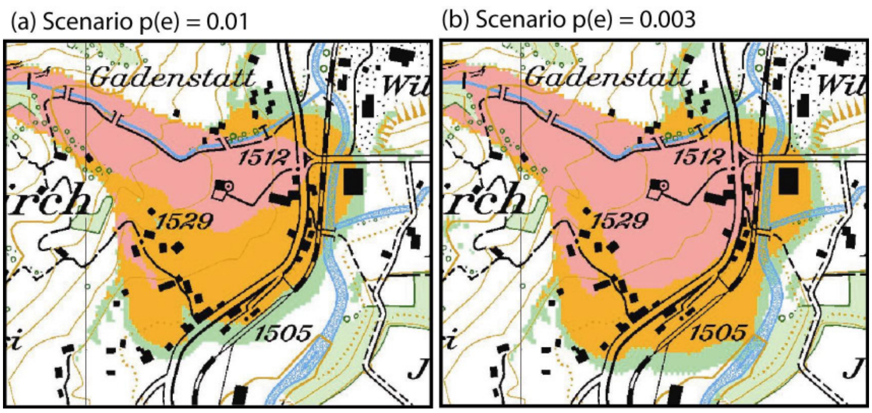


Figure 18: Example of an intensity map for snow avalanches for two scenarios. Case (a) represents a scenario with an exceedance probability of p(e) = 0.01, case (b) one with p(e) = 0.003. For both scenarios the intensity classes low, medium, strong are indicated with colours. The intensity classes fit the recommendations of the Federal Office for the Environment (BFF & SLF 1984). Green denotes an impact pressure p(i) < 3 kPa, orange denotes an impact pressure 3 kPa < p(i)< 30 kPa, and red marks an impact pressure of p(i) > 30 kPa

Intensity maps are the basis for the calculation of damage and risk in which the exposed objects are overlaid with the calculated intensity maps. However, the result of the hazard analysis is the first and probably the most important source of uncertainty in a risk analysis.

3.3 Hazard Analysis of Debris Flows

3.3.1 Introduction

Situated amongst landslides, rockfall, and floods (Rickenmann 2002, Rickenmann et al. 2006) debris flows are mixtures of water and sediment, ranging from clay sized particles to boulders of several meters of diameter. They frequently include woody debris. The coarse sediment is usually concentrated in the upper layers and at the front of the flow. The sediment concentration is often between 40 and 70 % by volume. The specific bulk density of the mixture amounts to 1.7-2.4. The event volumes of debris flows vary considerable between several thousand to some hundred thousand cubic metres. The destructive nature of debris flows is mainly due to high possible values of density, velocity and discharge. Front velocities exceeding 20 m/s have been observed (Costa 1984, Rickenmann 1999) and peak discharges one or two orders of magnitude larger than normal floods in the same catchment have been estimated.

The main objective of a hazard analysis is the evaluation of debris flow hazards in a particular torrent catchment, including the spatial identification of the debris flow process and the estimation of magnitude and frequency. Once the dominant torrent process is classified as debris flow or debris-flow like, a hazard assessment has to consider the following points:

- the determination of relevant local conditions in order to recognise the process accordingly. This comprises the analysis of geomorphic evidence, of aerial photographs, and topography, as well as the collection of historic records within the catchment;
- the precise and accurate description of collected data;
- the analysis of whether or not debris flow triggering is possible. This includes the assessment of slope angles, the analysis of material that might be available for (re-)mobilisation, and the analysis of the soil moisture content and precipitation patterns;
- the estimation of debris flow magnitudes and, when possible, probabilities of occurrence;
- the determination of relevant process scenarios and possible debris flow volumes;
- the selection of an appropriate method for debris flow runout prediction (empirical vs. numerical simulation);
- the generation of intensity maps; and
- the consideration of uncertainties associated with the methods selected and data used.

3.3.2 Qualitative approaches for event analysis

Several methods have been proposed to estimate the likelihood of debris flow occurrence in a particular torrent catchment (Aulitzky 1984, Nakamura 1980, Rickenmann & Zimmermann 1993, VanDine 1985). However, there are no rigorous methods that allow a strict assessment to determine an exact probability of debris flow occurrence so far, neither based on physically measured characteristics of a catchment nor based on statistical analyses. The information available on past debris flow events is often the most reliable indication (Rickenmann 1999).

For hazard assessment the determination of frequency must be accompanied by an estimation of magnitude for the potential debris flow event, which is a matter of scale (Fuchs et al. 2008).

Heuristic approaches are mainly based on a priori knowledge, local experiences as well as expert judgements and spatial information related to debris flow occurrence. Commonly, such information includes topographical, hydrological, geological, geotechnical or geomorphical factors, as well as information on vegetation coverage and land use patterns.

Qualitative methods provide preliminary estimations of debris flow susceptibility and hazard. This information is used at different scales within qualitative risk analyses and is based on descriptive or numeric rating scales to describe the magnitude of potential consequences (Tropeano & Turconi 2003).

3.3.3 Quantitative approaches for intensity analysis

Quantitative methods can be divided into two different approaches: On the one hand statistical and probabilistic prediction analysis, and on the other hand process-based analysis. In contrast to qualitative methods, quantitative approaches draw comparisons and/or classifications of different debris flow events in a more comprehensible style. Thus, quantitative methods are widely applied for hazard analyses on a regional scale.

Statistical and probabilistic prediction analysis

The statistical methods have been extensively developed in connection to landslide hazard assessment, and have been also adopted for debris flows (Corominas et al. 2003, Fell et al. 2005). Information describing geology, soil, and topography (e.g., slope angle, horizontal and vertical curvature, aspect, distance to divide, etc.) is combined and compared with debris flow distribution from inventory maps, and a spatial debris flow density is calculated.

Various statistical analyses are used to compare each individual factor with the hazard locations. As a result, weighting factors are computed for every factor. Further statistical methods providing probabilistic prediction models (e.g. Bayesian probability, fuzzy logic, etc.) can also be used to calculate these susceptibility maps (Chung & Fabbri 1999).

At this level of detail, rough quantitative assessment of susceptibility is possible, but no detailed information about event parameters such as volume, flow velocity, or runout length is available. A useful approach to designate different debris flow hazard classes to torrent catchments has been proposed by Rickenmann (1995).

Process-based and numerical analysis

At a catchment scale, the magnitude of channel-based hazard processes can be expressed by geomorphic features, such as potential debris volume, mean flow velocity, peak discharge, and runout distance. For this purpose, empirical and semi-empirical equations may be used. As an alternative, dynamic (often numerical) simulation models might be considered to assess the flow properties and the depositional behaviour (Hungr 1995).

With respect to hazard evaluation, the potential debris flow volume is the most important parameter. Many attempts had been made to estimate a maximum debris flow volume for a given torrent catchment using empirical relations. A compendium on such empirical relationships for debris flows was published by Rickenmann (1999). He showed that such attempts may overestimate the actual debris flow volume up to a factor of 100, and he therefore recommended to conduct a geomorphologic assessment of the catchment to estimate the possible volume of material to be susceptible to mobilisation. Subsequently, the debris flow volume can be used to derive an estimate of the associated peak discharge, the total travel distance, and the runout distance on the fan.

Dynamic simulation models are used to calculate the spatial distribution of debris flow susceptibility within user-defined boundary conditions based on a mathematical formulation defining the material (flow) behaviour (e.g., rheological or friction models, single or multiphase flow models, etc.). A variety of flow resistance laws describing the flow behaviour of debris flows have been proposed and are still subject of research (see e.g. discussion in (Iverson 1997, 2003). Several 1-D and 2-D numerical models exist such as the commercially available software Flo-2D (O'Brien et al. 1993). Detailed comparisons of different model approaches can be found in Naef et al. (2006) and Rickenmann et al. (2006).

In general, numerical simulation based on basic rheologic models is a helpful tool in hazard assessment as long as necessary coefficients can be measured or back-calculated from past events in the same channel (Coussot et al. 1998, Kaitna et al. 2007). However, the main weakness is the high demand for precise data, which is often not available in view of the costs involved, the complexity of the natural terrain as well as the properties of the flowing material.

3.3.4 Conclusion

However, hazard assessment requires experience, which only can be obtained by continuos training. Generally, catchments are subject to continuous modifications, in particular regarding the sediment budget. The steady alteration of sections characterised by erosive, accumulative or transportation processes influence the possibility to predict developments within the catchment. Due to this fact, regular inspections of the catchment area as well as the channel system considering the boundary conditions of the hazardous processes are indispensable.

Usually, a particular design event serves as the base for planning mitigation measures against natural hazards. Calculation methods leading to this design event are not only very complex, they also require the continuous adaptation to current technical developments. Furthermore, due to a limited lifetime and therefore an increasing complexity of maintenance in high-mountain regions, future implementation of technical structures is restricted due to a scarceness of financial resources provided by responsible authorities. If maintenance is neglected, mitigation measures will become ineffective and can even increase the catastrophic potential of natural hazards.

3.4 Hazard Analysis of Rock Avalanches

3.4.1 Introduction

The process of rock avalanching is the extremely rapid (>30 m/s), flow-like movement of large volumes (>10^6 m^3) of rock particles, which are being increasingly fragmented during the runout process (McSaveney 2002). Rock-avalanche motion typically takes places within less than one to several minutes, and the displaced masses attain a total runout of 1 to 20 km (Abele 1974). There is very little observational evidence of this phenomenon. Judging from rock-avalanche deposits that have run up obstacles or opposite valley flanks, the maximum travel velocities of rock avalanches are estimated to range between 20 and 130 m/s. These extreme velocities together with the long runout make rock avalanches some of the most highly mobile and destructive geological processes on the Earth's surface.

The lack of accurately predicting the location, initial volume, and maximum travel distance for a given rock avalanche is one of the key problems in hazard assessment. Rock avalanches are relatively rare types of landslides, and many conventional methods in use for quantitative landslide hazard assessments have not been fully tested or verified for rock avalanches. Therefore, a production of hazard or intensity maps for rock avalanches is currently not feasible like it is possible for debris flow or snow avalanches. We will therefore only provide general approaches for hazard analysis of rock avalanches. For further details we refer to D3.1 in WP3 “Hazard Analysis” in IRASMOS.

3.4.2 Event analysis

Historical data

Like for debris flow and snow avalanches the most important basis for an event analysis are sufficiently large and complete time series of known past events. The empirical basis is an inventory of former rock avalanche events used for describing the relation between magnitude and frequency by a power law-relationship (Hungr et al. 1999). Studies carried out in the Central Southern New Zealand Alps (Whitehouse & Griffiths 1983) attempt to derive the annual probability of occurrence of catastrophic rock avalanches from a dataset of rock avalanches in the Holocene. By analysing this dataset it was possible to derive a return period of roughly 2,070 yr for a rock avalanche in the size of $5 \cdot 10^7$ m^3.

A major drawback for estimating rock-avalanche hazard with scaling relationships is the lack of absolute age controls on many rock-avalanche deposits. Thus, although size-scaling relationships may be established mainly on the basis of rock-avalanche deposit area or volume, there is little additional information about the frequency with which these events occur in time. Altogether, very few rock-avalanche inventories allow putting more tight temporal constraints on the observed relationship between frequency density and volume (Figure 19).

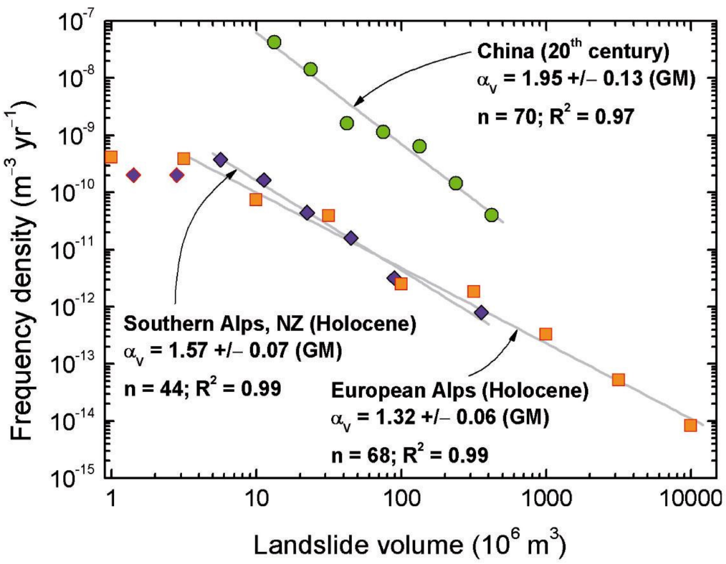


Figure 19: Average annual frequency density as a function of landslide volume of n = 70 large catastrophic landslides (including rock avalanches) that occurred in China during the 20th century (Wen et al. 2004), n = 44 Holocene rock avalanches in the Southern Alps of New Zealand (Whitehouse 1983), and n = 68 Holocene landslides in the European Alps (Abele 1974, Korup et al. 2007, Prager et al. 2008). Geometric mean (GM) regression lines indicate inverse power-law relationship (with exponent value α_v) over more than three orders of magnitude (in the case of the European Alps), and may be used to quantify to first order rock-avalanche hazard in these study regions

The magnitude-frequency relationship thus derived from a sample of n = 68 documented catastrophic landslides with volumes between 10^6 and 10^{10} m^3 (mainly rock avalanches documented in (Abele 1974, Korup et al. 2007, Prager et al. 2008, and other references) that had occurred in the European Alps during the last 10,000 yr (Figure 19) indicates that, for example, events with a volume of 10^7 m^3 were on average ~21 times more abundant than events with a volume 10^8 m^3. In other words, smaller events have occurred more frequent than larger ones during the Holocene, where the consistent factor of ~21 for each increase/decrease in order of magnitude of landslide volume is set by the scaling exponent α_v. Using a larger sample of n = 110 late glacial and Holocene landslides that have occurred in the Alps during the last 16,000 yr produces the same scaling exponent $\alpha_v = 1.32 \pm 0.08$ ($\pm 1\sigma$). In this case, the number of samples does not seem to significantly influence the observed scaling relationship (Figure 19).

The preceding examples show that the limited amount of data allows only estimation on frequency on a regional scale. For the period of the last 10,000 years in the European Alps, large events with volumes of $2 \cdot 10^7$ m^3 have a maximum return period T ~ 300 yr anywhere in the Alps, although judging from the number of undocumented or undated events it is much more likely that T ~ 100 yr.

A similar approach was used by Blikra et al. (2005) to estimate the frequency magnitude relationship of a rock avalanche event in Storfjorden, Norway (Table 3).

Table 3: Cumulative frequency of rock avalanche event in Storfjorden, Norway, derived from Blikra et al. (2005)

Volume (10^6 m^3)	**>0.5**	**>1**	**>2**	**>5**	**>10**	**>20**
number of events	59	30	17	7	4	3
frequency/year	0.0059	0.0030	0.0017	0.0007	0.0004	0.0003

Site dependent data

The second important component of an event analysis is the analysis of site dependent data. The analysis can consist of:

- analysis of the geological and geomorphological conditions;
- analysis of "silent witnesses"', like e.g. tense roots, rocks of different sizes in the surroundings;
- analysis of the geological structure of the terrain, like block segmentation, number, size and orientation of cracks etc.
- analysis of the hydrological system (fonts, subterraneous transportation routes of water);
- analysis of movements, if measurements (e.g. by GPS, photogrammetry, extensometers etc.) or observations are available .

This information allows to describe the potential release area, the depth of the potential rockslide (rock avalanche) and the volume. Measurements in boreholes can help to quantify the depth of the sliding surface. The block model and the estimations of the depth of the sliding surface can be used to estimate the volume of the rockslide and to describe different volume scenarios.

3.4.3 Intensity analysis

For the determination of the intensity of a rock avalanche, which is closely related to the run-out distance there are presently a number of physical based models that simulate rock-avalanche dynamics and mechanics, with a focus on attempting to explain the extraordinary run-out and required low friction coefficients. Most of these models explain the extreme mobility of the moving mass by invoking, among other theories, groundwater-saturated valley fills, increased porewater pressures in basal shear bands, acoustic fluidisation, or dynamic fragmentation (Davies & McSaveney 2002, Denlinger & Iverson 2004, Iverson et al. 2004, Pirulli 2004). Augmented or even calibrated with empirical data, many of these models provide more or less reliable predictions of run-out for a given failure volume.

The key problem of modelling rock avalanches is the calibration of parameters in a way that it is possible to successfully model other events than those used for calibration. It is quite common that one set of calibrated parameters yields over- or underestimates of the deposit morphology, when applied to rock avalanches that initiated even under very similar conditions. Hence, dynamic rock-avalanche modelling should be preferably used for hillslope-scale hazard mapping, and only if there is sufficient certainty about the calibrated parameter set.

The sensitivity of such models to changes in initial conditions may be considerable. Typical parameters that may affect the results are:

- Initial location of the failure mass (e.g. ridge crest);
- Planform geometry (i.e. extent of headscarp and lateral release scarps);
- Three-dimensional geometry of unstable rock block;
- Occurrence and orientation of rock-mass discontinuities; and
- Initial loading conditions (e.g. cleftwater pressures, creep velocities, additional horizontal earthquake acceleration).

Given these sensitivities, it is more appropriate at a first order to quantify the annual probability of rock avalanching within a defined study area on the regional scale.

3.5 Hazard Analysis of Snow Avalanches

3.5.1 Introduction

Avalanches are defined as a snow mass with usually a volume greater than 100 m^3 and a minimum length of 50 meters, that slides rapidly downhill (SLF 2008). Snow avalanches can be distinguished into dense flow avalanches and powder snow avalanches. If avalanches hit buildings, infrastructure or other obstacles, heavy damages can occur due to large impact pressures. Avalanches can also transport debris or wood that can increase the damage causing effects of avalanches (McClung & Schaerer 1993).

3.5.2 Event analysis

There are several steps to be done in an event analysis for snow avalanches.

- Analysis of existing avalanche inventories and historical information;
- Analysis of the terrain, development of the map of the phenomena;
- Analysis of the meteorological conditions;
- Development of the avalanche frequency and / or derivation of scenarios.

The first step is a routine in event analysis for every natural hazard process and is described also in chapter 3.2.1. For the definition of scenarios or frequencies all available information of past events have to be analysed. Direct, long-term observation of avalanche run-outs allows defining the frequency at certain locations in the area under consideration. Additional scenarios, which might not be observed in the past, can also be taken into account.

The second step is the terrain analysis. It takes into consideration the slope angle, aspect, terrain characteristics, roughness, vegetation, protection measures and the indications for avalanche release like e.g. signs at trees or vegetation in the release zone, the transit zone and the deposition zone. Dendrochronological investigations sometimes allow to determine the return period of avalanches (Stoffel & Bollschweiler 2008). All observations are documented in the map of the phenomena (Heinimann et al. 1998).

The third step addresses the meteorological conditions and the return period of release depths of avalanches. The release depth is often assumed to coincide with the snow depth precipitation in the three days before the event, or three days snow fall depth, P_{72} (Burkard & Salm 1992). The value of P_{72} is calculated by evaluating the “increase in snow pack depth during a period of three consecutive days of snow fall" (Barbolini et al. 2004b, Sovilla 2002). The value of P_{72} for every year is taken as the greatest observed value of the positive difference in snow depth calculated using a three days wide window, moving by one day steps (Barbolini et al. 2004b). This is evaluated with respect to a flat area and then properly modified for local slope conditions and snow drift overloads (Barbolini et al. 2003, Barbolini et al. 2002, Salm et al. 1990).

Finally, this information is used to define the avalanche frequency and to define the relevant scenarios, which should be taken into consideration in a risk analysis. In the following intensity analysis the extent and the impact pressure (and/or velocity) are determined by avalanche modelling.

3.5.3 Intensity analysis and avalanche modelling

The dynamics of avalanches are complex, involving aspects of fluid, particle and soil mechanics. Also aspects of submarine slide models are applicable. However, no universal avalanche model exists. The limited amount of data available from real events makes it hard to evaluate or calibrate existing models. Thus, the use of several models based on differing descriptions of the flow is a common strategy. Various models have been proposed in technical literature and applied in practice, both empirical procedures using topographical/statistical and comparative models for run-out distance computations, and dynamics models for avalanche motion simulations.

Empirical procedures are based on statistical and comparative models for estimation of avalanche run-out distance. In topographical/statistical models the run-out distance relations are normally found by regression analysis. Comparative models are based on methods for evaluating the similarity between path profiles. An alternative approach is to present pure limiting criteria for flow behaviour, as recognised from considerations of sub-aerial debris flow behaviour. Empirical procedures are normally applied to dense flows.

Models for dense snow avalanche base on one-dimensional rigid body models or two-dimensional depth-averaged deformable body models. Rigid body models describe the slide initiation well. Due to their simplicity they are also widely applied to the rest of the avalanche motion. Deformable body models describe the dense snow avalanche as a continuum. The main problems of dense snow avalanche dynamics models are related to the understanding and description of material properties; these differ considerably between flow and deposition.

Upon reaching speeds of approximately 10 m/s, dense-flow avalanches develop an aerosol 'cloud', and a "powder snow avalanche" (PSA) develops. The majority of avalanches are a mixture of dense flow avalanches and powder snow avalanches. There are models, which describe only the turbulent particle flow and disregard the interaction with the dense flow. Thus, they are not able to model the early stages of PSA formation. Nevertheless, for practical applications the recent numerical PSA models seem to be able to reasonably simulate run-out zone motion and stagnation pressure distributions.

Coupled models try to describe both the dense and powder components of the avalanche, as well as the coupling between them. In principle, the complete avalanche could be described by a universal two-phase model for air and snow particles valid over the encountered range of particle volume fractions: from the high values of the dense layer to the very low values of the powder layer. Unfortunately, such two-phase models are very complex and still affected with uncertainties, especially at high particle volume fractions. In practice, separate models for the dense and powder flow components are applied.

3.5.4 Definition of avalanche intensity

Buildings and other structures in mountain terrain could be hit by avalanches and it is routine for engineers to consider potential impact forces of avalanches in design; nevertheless, according to current Alpine regulations, avalanche impact pressure is commonly used as measure of avalanche intensity for mapping purposes.

Impact forces due to moving snow are usually assumed to be proportional to the avalanche speed squared (v^2) and the flow density of the moving material (ρ):

$$I \propto \rho \cdot V^2$$

Impact forces of avalanches might range from relatively harmless blasts from powder clouds to the high destructive forces of a full-scale dry flowing avalanche capable of destroying reinforced concrete structures. Generally, dry flowing avalanches have the highest product of speed squared and flow density so their destructive potential is usually the highest.

Table 4 gives typical impact pressures expected for avalanches in relation to their destructive effects, whereas in Table 5 most commonly used intensity classes for mapping purposes are presented.

Table 4: Correlation between avalanche impact pressure and potential damages

Impact pressure (kPa)	**Potential damages**
1	
5	Push in doors
30	Destroy wood-frame structures
100	Uproot mature spruce
1000	Move reinforced concrete structures

Table 5: Typical intensity classes in avalanche hazard mapping

Intensity class	**Impact pressure**
Weak	$I < 3$ kPa
Moderate	3 kPa $< I <$ 30 kPa
Strong	$I > 30$ kPa

3.5.5 Uncertainty in hazard analysis

There are several uncertainties in hazard analysis, which are relevant for risk analysis. Beside the uncertainties due to missing historical information, which can give hints concerning the frequency and the extent of events, the assumptions for the modelling of processes are to a large degree based on expert experience and are therefore subjective and uncertain (see also D3.1 in WP3 of IRASMOS). These uncertainties relate to the definition of the initial conditions and to the definition of the model parameters. They represent one of the main weaknesses in dynamical models for practical application (Barbolini et al. 2002). A way to deal with these uncertainties is to provide a confidence interval for the run-out length for certain scenarios. Concerning the calculated risk this means that a lower and an upper boundary for risk is calculated (Fuchs et al. 2005).

3.6 Elements at Risk

3.6.1 Introduction

After the hazard analysis the next step of a risk analysis is the exposure analysis. The goal of the analysis of exposure is the identification of vulnerable objects and their temporal and spatial presence in the likelihood of a coincidence with a certain hazardous event (Ammann 2006). For the estimation of a potential damage, the type, number, value and the vulnerability in dependence of the process intensity have to be known. The type of elements, which have to be taken into consideration and the regarded level of detail, depends on the scope of the risk analysis (Bell & Glade 2004). A characterization of each specific element at risk is often connected to an extensive data collection. Therefore, it must be decided whether each single object should be recorded or whether objects could be grouped to object classes. Generally, the elements at risk can be determined into the following categories:

- static objects: their presence does not change over time and in place (e.g. buildings);
- variable objects: their presence does change over time and in place (e.g. vehicles);
- persons: their presence can change over time and in place, they can be present in definite or variable objects or outdoor;
- future development: changes in presence of objects and/or persons.

In the following chapters the categories of vulnerable elements are defined and described. The values of these elements depend on the country's specific price level and have to be determined individually.

3.6.2 Static objects at risk

Within this step of analysis of exposure the static (immobile) objects like buildings, infrastructures, as well as agricultural and forest areas are assessed. The location can be obtained by analysing topographical or zoning maps, aerial photographs, object registers and / or field campaigns where every object is characterised at its location. Additional information, such as year of construction, type and replacement values can be obtained by asking the owners or by using insurance data if available. The number of endangered permanent residents can be derived from the number of domiciles, using statistics. Since all these data are spatial data the use of a geographical information system (GIS) might be an appropriate way to handle them. The characterisation of the damage potential should include the following assessments:

- Location of values at risk, e.g. buildings, infrastructures;
- Type and use of these values at risk, e.g. residential homes, agricultural buildings;
- Type of construction, e.g. concrete constructions, wooden barns;
- Value of objects and personal belongings;
- Land use, e.g. agricultural or forest land.

Gathering all the necessary data can be very time consuming. Therefore the level of detail of data should be in relation to the strived level of detail for the whole risk analysis.

Objects at risk can be distinguished in following categories:

- buildings, e.g. houses, hotels, industrial buildings, shopping centres, schools;
- roads and traffic lines, e.g. highways, regional roads, road bridges, railways;
- infrastructure, e.g. electricity lines, water reservoirs, transportation lines;
- communication lines, e.g. antenna poles, telephone lines.

The category building can be divided into several building types. The range of value and vulnerability of these building types is strongly varying. In most cases it will be necessary to determine the specific value of a building in a risk analysis. For a simple approach a rough estimation of the value can be made using data from building insurances and to express the value of a building as a fraction of the building volume. In addition to the value of the structure of a building, the assets inside a building have to be taken into account. As a rule of thumb the value of assets can be roughly approximated with 25 percent of the structure value (Wilhelm 1997).

The damage to structure and assets is expressed in monetary value per building and the damage to persons as number of fatalities and / or number of injured persons. The elements at risk can be analysed with respect to their spatial location and extension using a geographical information system (GIS). This method allows attributing information on every single element at risk in a system. Such analyses are based on digital maps, providing detailed spatial information as for example the location and perimeter of every building, the number of stores, the number of accommodation units, the insured value of buildings, etc. (Fuchs et al. 2005). Additional information, such as year of construction, type and replacement value can be provided by municipality offices.

3.6.3 Persons and mobile objects at risk

The central focus in most risk analyses is put on damage to persons. Persons affected by rapid mass movements can either be injured or killed. Persons, who are present in an endangered area, can either be outdoor or they can stay inside a building, inside a vehicle on a road or inside a train and thus be somewhat more protected. Consequently, the vulnerability to persons differs depending on their current whereabouts during an event.

One main problem in estimating the risk to persons is their probability of presence. Best ways to define the presence of vulnerable persons is using average values or situations of exposition.

Using average values, the number of endangered permanent residents can be derived from the number of domiciles or from statistics. E.g. for Switzerland the statistics indicate 2.24 persons per residential unit in the year 2000 (BfS 2008). The number of exposed persons in hotels, guest houses and hospitals can be quantified by the number of beds and be multiplied by the degree of utilisation.

For variable objects, such as vehicles, mobile homes, tents, etc. it has to be determined, if their presence coincides with the occurrence of a hazardous process. If this coincidence is reasonable and the value is of relevance, the values of these objects have to be considered within the risk analysis for the corresponding area.

The effective number of present persons is determined if the average number of persons taken from statistics and the probability of presence is combined. If we consider the average number of residents in Switzerland with 2.24 persons per residential unit (N_p= 2.24) and their average daily presence in a building is 12 hours per day (presence probability p_{Pr} = 0.5) then the assumed effective number of persons in the considered building ($N_{p\text{-}eff}$) is 1.12 persons.

A second possibility to estimate the number of present people is to consider different situations with a varying number of persons in objects. The assumption of these so-called "situations of exposition" depends on a specific situation. If the number of persons, present in the endangered area, is strongly varying and if risk peaks should be taken into account, then situations of exposition should be considered. More information about this is given in the D5.2 "Technical report" of the IRASMOS project.

3.6.4 Indirect consequences

In addition to the direct consequences, there are also indirect consequences, which can often only be described in a qualitative way, and which hardly be directly quantified.

Indirect consequences arise due to incomplete operation of objects (e.g. damaged or closed roads, interrupted industrial processes). For some objects the loss due to indirect consequences can be much higher than due to direct damage. For example the interruption of a railway line can cause the need for a rail replacement service, which is very costly and might even cause compensation payments. In this example, the direct costs due to damage caused by e.g. snow avalanches or rock fall are minor in comparison to the indirect consequences. Some examples of indirect consequences are listed in Table 6. It is very difficult to measure the indirect consequences; therefore a clear and comprehensible reporting of all consequences of an event is necessary.

Table 6: Indirect consequences and their characteristics

Asset	**Indirect consequence**
buildings and special objects, infrastructures	costs of service interruption
roads, railways, mechanical ascent support	costs of service interruption
cable lines, logistics	costs of service interruption
agriculture	crop failure
forest	missing protection against natural hazards
recreation area	service breakdown

3.6.5 Future development of values at risk

Values at risk and thus the damage potential are dynamic parameters, which may change over time. To incorporate the timely development of the risk due to natural hazards within the lifetime of a countermeasure, not only the actual conditions have to be determined, but an assessment of the future development of the damage potential should be undertaken. In this assessment the following parameters should be considered:

- modification of number of buildings;
- modification of infrastructure;
- modification of number and length of traffic lines (roads, railways);
- modification of lines of energy supply, communication, water and waste water;
- modification of frequency of vehicles on roads and railways;
- modification of number of persons present in buildings and on traffic lines;
- time of expected increase.

There are several possible approaches to deal with the development of damage potential in the considered area. One possibility is to assume one or two additional scenarios, which reflect the development, e.g. in five or ten years. However, it is recommended to determine the damage potential for the actual situation and the future scenarios separately.

3.7 Consequence Analysis

In the consequence analysis, the exposed objects (chap. 3.6) are overlaid with the intensity maps obtained from the hazard analysis (chap. 3.2 to 3.5). There are several assumptions and factors, which have to be taken into account for the calculation of damage or loss. The term "loss" denotes the damage to assets (unit in monetary terms) and the damage to persons (number of dead or injured persons) in case of an event. In the following the characteristics of the factors of the risk equation are described.

3.7.1 Vulnerability

The term vulnerability is used in hazard and disaster management in a large number of ways (Thywissen 2006). Vulnerability is related to the consequences of a natural hazard. These consequences are generally measured in terms of damage or losses, either on a metric scale (e.g., as monetary unit), or on an ordinal scale based on social values or perceptions and evaluations. Consequently, two diverse perspectives on the concept of vulnerability exist; (1) the perspective from social science and (2) the perspective from natural science. In this report we focus on the perspective from natural science and define vulnerability as " … the expected degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomena of a given magnitude." (Glade et al. 2005).

The approaches for evaluation of vulnerability vary significantly in detail of analysis and resulting numerical value. Concerning the process debris flow, rock avalanches and snow avalanches, the approach to determine the vulnerability and the knowledge is different. For rock avalanches the vulnerability of affected buildings, infrastructure and persons in the perspective of this report can be regarded as one, which means that we can assume a total loss. For the two other processes there are different approaches and values, which are shortly presented here. Detailed information on vulnerability is given in D4 and D5.2 "Technical report" of IRASMOS.

Vulnerability due to debris flow

Values quantifying vulnerability of buildings towards torrent processes have so far been empirically estimated using relatively rare event documentation or assumptions. Moreover, the vulnerability was often estimated rather than based on damage collected in official authorities' or insurers' databases. A comparison of different studies is difficult due to missing information on construction types and building categories. Thus, studies conducted in Australia (Fell & Hartford 1997) are hardly comparable to studies carried out in Switzerland (Borter 1999b) due to differing resilience of the values at risk. So, it can be agreed to the statement of (Glade 2003) that neither a unique method nor a vulnerability function is currently available for vulnerability assessments in landslide risk analysis. In particular with respect to torrent processes such as debris flows and hyperconcentrated flows, sound suggestions are still outstanding, even if these processes caused major losses in the Alps in recent years (Fraefel et al. 2004, Romang 2004).

Fuchs et al. (2007a, b) carried out a case study in an Austrian torrent catchment aiming at the establishment of a preliminary vulnerability function for buildings (detached houses) towards debris flows. The presented method followed a spatial approach, and was based on process intensities volumes (as a proxy of process intensity), on elements at risk and on average reconstruction values in dependence of the surface area on an object basis. The relationship between debris flow intensity and vulnerability of buildings was found to fit best to the data by a second order polynomial function for all intensities 0.33 ≤ x ≤ 3.06 m (Figure 20).

$$f(x) = \begin{cases} 0 \;\; if \;\; x < 0.\overline{3}m \\ 0.12x^2 - 0.04x \;\; if \;\; 0.\overline{3} \le x \le 3.06m \\ 1 \;\; if \;\; x > 3.06m \end{cases}$$

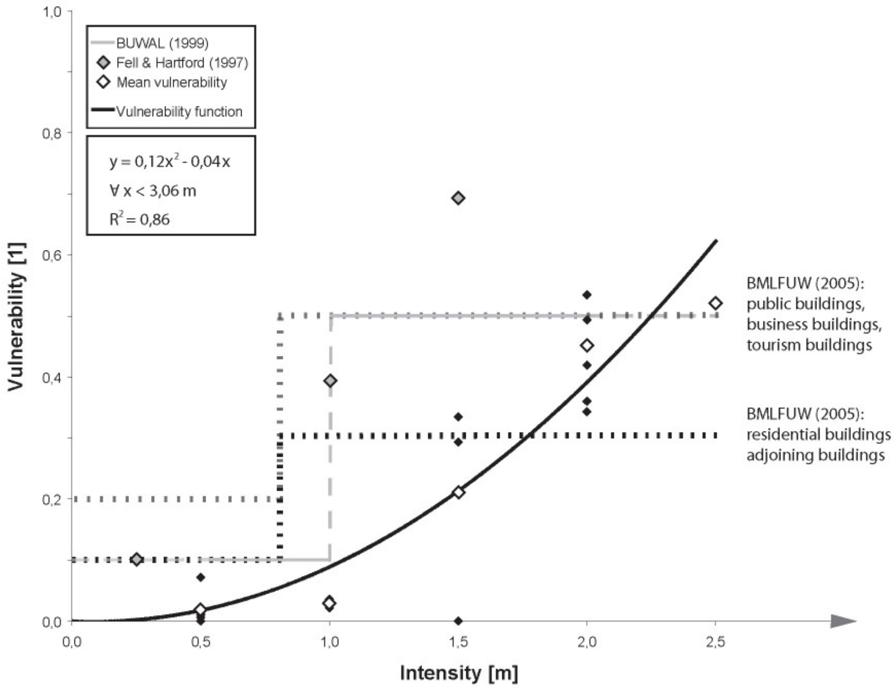


Figure 20: Relationship between process intensity and vulnerability of exposed residential buildings; for comparison, vulnerability functions published in Borter (1999b) (dashed grey), Fell and Hartford (1997) (grey rhombi) and (BLFUW 2005) (black and grey dots) are shown (modified from Fuchs (2007a, b)

However, for a wider application of this function more data is needed for validation. By definition, vulnerability ranges from 0 and 1. Consequently, for process intensities higher than approximately 3 m, vulnerability cannot be satisfyingly mirrored by such a polynomial. On the other hand, such high process intensities generally result in a total loss of the building since the arising efforts to repair the damage will exceed the expenditures necessary for a completely new construction. The vulnerability function developed by Fuchs (2007a, b) seems to be consistent with the suggestions of Borter (1999b) for accumulation heights < 1.0 m, even if for relatively small intensities no sound statements are traceable. For accumulation heights between

1.0 m and 1.5 m, the values of Borter overestimate the function developed within the study of Fuchs (2007a, b), a sudden increase in vulnerability of 0.4 related to an intensity of 1.0 m is not supported by the findings within the Austrian test site. The values suggested by Fell and Hartford (1997) and BLFUW (2005) seem to be considerable higher than those values resulting from the studies by Fuchs (2007a, b). Recent investigations from several sites in the Swiss Alps showed comparable results (Spichtig & Bründl 2008). Similar values are also used for the calculation of cost-effectiveness of countermeasures with the software "EconoMe" in Switzerland (Arge-EconoMe 2008). However, these comparisons are biased by the different characteristics of the buildings in the regarded studies. Table 7 shows a compilation of different suggestions related to an assessment of vulnerability of structural elements with respect to debris flows.

Table 7: Compilation of different suggestions related to an assessment of vulnerability of structural elements with respect to debris flows (Fuchs 2007a, b)

			Intensity							
			qualitative				(semi-)quantitative			
			low	medium	high	very high	low	medium	high	very high
			not specified	not specified	not specified	not specified	not specified	h < 1 m or v < 1 m/s	h > 1 m and v > 1 m/s	not specified
Vulnerability	qualitative	Leone et al. (1995, 1996); Finlay (1996)	not linked to process intensity							
Vulnerability	qualitative	Cardinali et al. (2002)	superficial	functional	structural	structural				
Vulnerability	quantitative	Fell and Hartford (1997)	0.1	0.4	0.7	1.0				
Vulnerability	quantitative	Michael-Leiba et al. (2003)	0.1 (distal)		1.0 (proximal)					
Vulnerability	quantitative	Bell and Glade (2004)	0.1	0.2	0.5	not specified				
Vulnerability	quantitative	Romang (2004)	not specified	0.1 - 0.2	0.5	not specified				
Vulnerability	quantitative	BUWAL (1999) [for channel debris flows]					not specified	0.1	0.5	not specified

Vulnerability due to snow avalanches

There are several vulnerability relations for use in snow avalanche risk assessment, which has been proposed by Wilhelm (1997), Johnson & Rodine (1984), Jonasson et al. (1999) and Barbolini et al. (2004a). Focusing on buildings and people exposed, some additional references suggested average vulnerability values for use in avalanche risk assessment (Borter 1999a, b, Bell & Glade 2004, Kraus 2006).

A distinction between vulnerability curves has to be made with respect to the elements at risk. So, different functions exist for structural elements (e.g. buildings) and for persons inside buildings. A further distinction could be made with respect to the avalanche type.

Vulnerability functions for structural elements

With respect to dense flow avalanches, Wilhelm (1997) provided five different vulnerability curves that were empirically determined by an analysis of approximately 50 damaged buildings in Switzerland. According to different building categories - (1) light construction, (2) mixed construction [chalets], (3) masonry, (4) concrete buildings with reinforcement, and (5) reinforced buildings - vulnerability functions were provided in dependence on avalanche impact pressure (Figure 21).

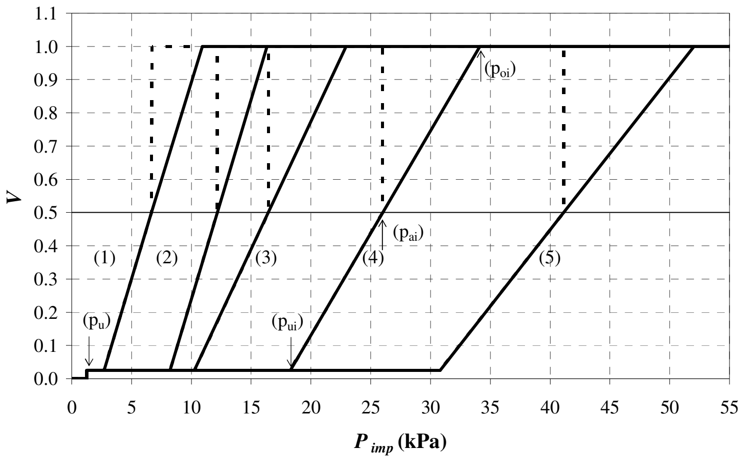


Figure 21: Vulnerability functions for different buildings types (classes 1-5) in function of the impact pressure (Pimp); p_u denotes the general damage threshold, p_{ui} the specific damage threshold of a building type, and p_{ai} the threshold above which a building must be rebuild. The parameter p_{oi} means the total damage (V=1). (modified after Wilhelm 1997:72)

Additionally, Borter (1999a, b) defines vulnerability values for masonry buildings of 0, 0.5 and 1.0 for low, medium and high avalanche intensities, which can be used in a first approximation. Empirical investigations with case studies from the Swiss Alps showed comparable results (Spichtig and Bründl 2008). Similar values are also used for the calculation of cost-effectiveness of countermeasures with the software "EconoMe" in Switzerland (Arge-EconoMe 2008).

Vulnerability functions for people inside buildings

- Several suggestions for an assessment of vulnerability due to dense flow avalanches exist. Jónasson et al. (1999) presented a study linking avalanche speed to survival probability inside a building. The vulnerability relation f(x), indicating the probability of death as a function of the avalanche velocity x, is given in equation 4.3, where k = 0.00130, c = 0.05, a = 1.151, b = 18.61 and x_1 = 23.0 m/s. The vulnerability goes progressively to zero when the avalanche velocity decreases to a null value, and has an upper limit of 0.95 when the avalanche velocity increases indefinitely high. Therefore it has been implicitly assumed that a loss of life is always possible with a non-zero velocity and that regardless of the avalanche speed some proportion of people will always survive.

$$f_{(x)} = \begin{cases} kx^2 & if\ x < x_1 \\ 1 - c - \dfrac{a}{x-b} & if\ x > x_1 \end{cases}$$

- Based on works by Keylock et al. (1999) and Keylock & Barbolini (2001), Barbolini et al. (2004b) presented a vulnerability function with thresholds accounting for lower and upper limits of avalanche speed x, where the vulnerability is set to 0 and 1, respectively.

$$f_{(x)} = \begin{cases} 0 & \text{if } x \leq 3.5 m.s^{-1} \\ 0.001x^2 + 0.0096x - 0.0426 & \text{if } 3.5 < x \leq 28 m.s^{-1} \\ 1 & \text{if } x > 28 m.s^{-1} \end{cases}$$

  However, the data used for the derivation of this equation originates from destructive avalanches in Iceland, where buildings have other structural features than in alpine countries. Hence, an application to alpine-type buildings might be difficult.
- With respect to powder avalanches, a vulnerability function as relation between vulnerability f(x) and avalanche impact pressure was suggested by Barbolini et al. (2004a).

$$f_{(x)} = \begin{cases} 0 & \text{if } x \leq 5kPa \\ 0.0094x - 0.0508 & \text{if } 5kPa < x \leq 34kPa \\ 1 & \text{if } x > 34kPa \end{cases}$$

Vulnerability functions for persons outside buildings

- In Barbolini et al. (2004a), a vulnerability function f(x) is provided in dependence of the degree of burial (avalanche flow depth x):

$$f_{(x)} = \begin{cases} 0 & \text{if } x \leq 40cm \\ 0.0039x - 0.1546 & \text{if } 40cm < x \leq 210cm \\ 0.65 & \text{if } x > 210cm \end{cases}$$

3.7.2 Protection factor of buildings

The vulnerability of buildings is reduced of direct protection measures are implemented (Holub & Hübl 2008). The effect of these measures can be taken into account with an object protection factor ε_i for objects. Objects, which have a high resistance against a process, have a high object protection factor ε_i. The factor ε_i can have a value between 0 (no protection) and 1 (full protection, no damage).

3.7.3 Spatial probability of process

In most cases the processes snow avalanches and debris flow affect only a part of the potential run out area. There are two approaches to take this effect into account.

The first is to analyse past event and to estimate (or calculate) the probability an object can be hit. A suitable method is to develop an event tree model. By this method it is possible to take site-specific characteristics of the terrain and of the object into account.

The second approach is to assume a factor, which reduces the whole run out area. We denote this ratio spatial probability, meaning that the probability that the whole run out area is affected is lower or equal one (Figure 22). Therefore, the value ranges between 0 and 1. For rock avalanches this value is 1, because of the large area, which is covered by rock avalanches.

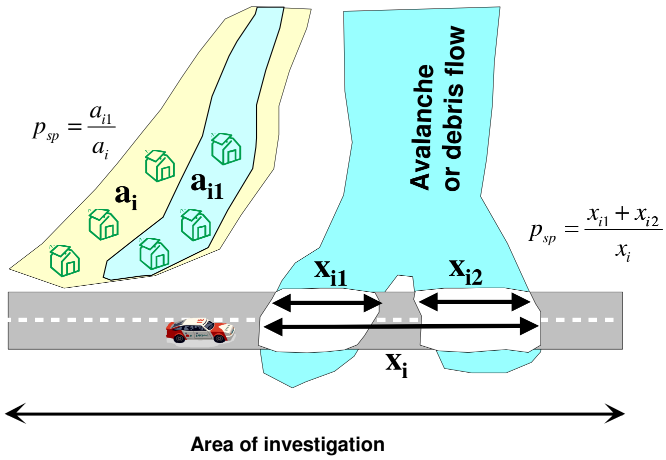


Figure 22: Schematic illustration of the spatial probability of a process. The left part shows that only a part of the potential run out area(yellow area) is assumed to be affected (a_{i1}), the right shows that only a part of the road section is hit by the process (x_{i1}, x_{i2})

3.7.4 Probability of presence

Persons and mobile objects are not always present when a process releases. The probability of presence indicates the ratio of the effective time span e.g. a person is present in relation to the total time a process can happen (see chap. 3.6.3). The consideration of this factor decreases the expected damage.

3.7.5 Calculation and presentation of damage

For the calculation of damage the described factors have to be linked with the exposed objects under the considered scenarios. For every object it is checked:

- if it is affected, and
- in which intensity area it is located.

The damage is calculated for every object and every scenario. The results can be summarized in a table (Table 8).

The loss is calculated for those objects, which are actually exposed in a particular case. Summarized this can be:

- Loss to buildings
- Loss to persons in buildings
- Loss to static objects along roads
- Loss to persons along roads
- Loss to static objects along railways
- Loss to mobile objects along roads
- Loss to persons along railways
- Loss to power and communication lines and water lines
- Loss to agriculture and forest

The generic formula for the calculation of damage is:

$$L_{ij} = p(sp)_j \cdot p(pr)_{ij} \cdot (1-\varepsilon_i) \cdot C_i \cdot V_{ij}$$

with:

L_{ij}	=	Loss to object *i* in scenario *j*;
$p(sp)_j$	=	spatial probability of a process in scenario *j*;
$p(pr)_{ij}$	=	presence probability of object *i* in scenario *j*;
ε_i	=	protection factor object *i*;
C_i	=	value of object *i* or, for persons number of persons β;
V_{ij}	=	vulnerability of object *i* in scenario *j*.

The factor $p(pr)_{ij}$ for persons depends on the time a person (or a group of persons) is present in the endangered objects. Assuming a presence time of 12 hours during 7 days a week and 52 weeks results in p(pr) = 0.5. For buildings p(pr) is set to "1". For mobile objects or persons on traffic lines p(pr) is calculated with:

$$p(pr)_{ij} = \frac{F_{ij} \cdot g_j}{v_i}$$

with:

F_{ij}	=	frequency of object *i* in the endangered area in scenario *j*, e.g., mean daily traffic frequency;
g_j	=	length of the endangered section of the traffic link in scenario *j*;
v_i	=	velocity of object *i* in the endangered section of the traffic link.

For trains the length of the train has to be considered, so that:

$$p(pr)_{ij} = \frac{F_{ij} \cdot g_j}{v_i} \cdot \left(\frac{l(t)}{g_j} + 1 \right) \text{ with } \left(\frac{g_j}{l(t)} \leq 1 \right)$$

with *l(t)* being the length of the train.

A detailed description of all formulas for the calculation of damage is presented in D5.2 "Technical report" of IRASMOS.

The total loss of all elements at risk is calculated by summing up all the loss to the individual objects. Special concern has to be given to the calculation of loss to persons. In order to sum up the loss to assets and persons to the total risk, a monetary value has to be assigned to one person. A way to monetize persons is to take the value of statistical life (VSL, chap. 6). This value is an indicator for the societal willingness to pay to avert a fatality. In Switzerland this value is in the range of 3 to 6 million Euro (PLANAT 2004), which is in good agreement with values from other countries (e.g., for Austria see Leiter & Pruckner 2008). This means that the loss to persons expressed in monetary terms is calculated with:

$$L(pm) = L(p) \cdot VSL$$

where *L(pm)* is the loss to persons expressed as monetary value, e.g. Euro, *L(p)* the loss to persons expressed as number of fatalities and *VSL* denoting the value of statistical life.

An overview on the damage is presented in a table where the loss of all objects in all scenarios is illustrated. Table 8 shows an example of a loss matrix as an empty table.

Table 8: Matrix presenting the expected loss L to objects i = 1 … n in all scenarios j = 1 … n

Loss L to object i	**Scenario 1 (s_1)**	**Scenario 2 (s_2)**	**Scenario 3 (s_3)**	**Sum object i**
object 1	…	…	…	ΣLo_1
object 2	…	…	…	ΣLo_2
…	…		…	ΣLo_i
Sum scenario *j*	ΣLs_1	ΣLs_2	ΣLs_3	*L*

3.8 Calculation and Presentation of Risk

3.8.1 Calculation and presentation of societal risk

The risk is calculated by linking the frequency of scenarios with damage, which is expected to be the consequence of the scenarios. Taking the loss of the different scenarios the total societal risk is calculated by:

$$R_j = p_j \cdot L_j \quad \text{with} \quad p_j = P_j - P_{j+1}$$

$$R = \sum_j R_j$$

with:
R_j = societal risk in scenario *j*;
Pj = frequency of scenario approx. as difference of the exceedance probability of two adjacent scenarios P_j and P_{j+1};
R = societal risk of all scenarios.

However, according to Kaplan and Garrick (1981) the societal risk can not be expressed only as a single number. Therefore, the risk is usually presented with a FN-diagram (Figure 23). A FN-diagram is constructed by sorting the scenarios by their frequency and the corresponding losses and plotting them in a FN-diagram with log-log scale. The result is a step function. The area below the curve represents the societal risk given the assumed loss. The graph shows at which probability a certain damage is exceeded.

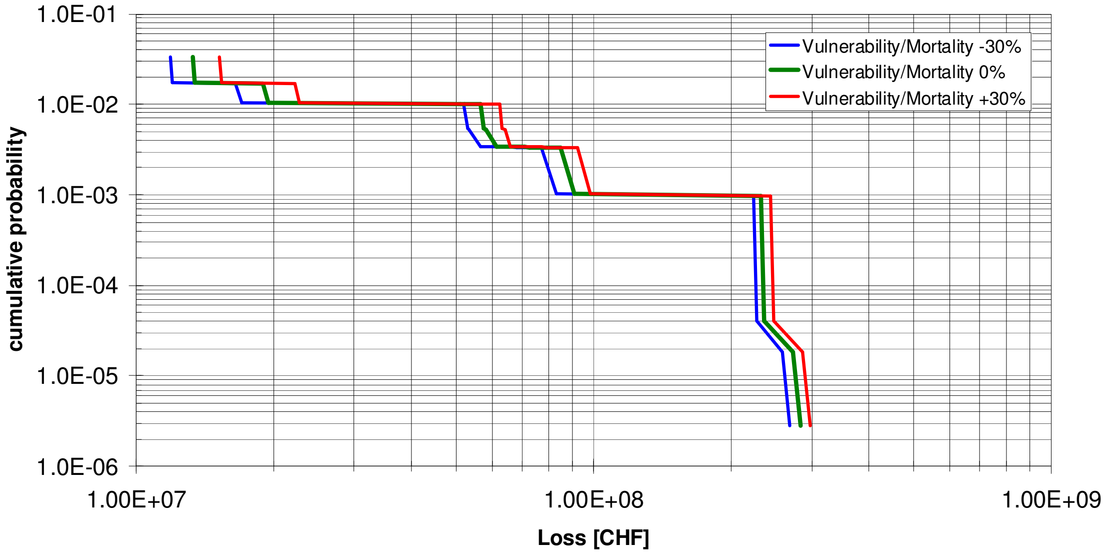


Figure 23: FN-diagram illustrating the societal risk. The red and the blue line shows the uncertainty of the factors vulnerability and mortality of persons

3.8.2 Calculation and presentation of individual risk

The individual risk is an indicator how much risk a single, identifiable person has to bear as a consequence of the assumed scenarios. The total societal risk allows no statement whether the risk of an individual person is above or below the protection goals. Therefore, the risk to individual persons has always to be calculated separately. The relation between societal and individual risk can be explained by the following example. Fewer persons with a high individual risk can result in the same societal risk as many persons with a low individual risk. For the individual risk it is important whether a given threshold is exceeded or not.

The individual risk to persons is calculated according to the generic formula presented in chap. 3.8.1). For persons along roads the number of crossings per day has to be included. More detailed information, how the individual risk is calculated is given in D5.2 "Technical report" of IRASMOS.

3.9 Risk Evaluation

3.9.1 Evaluation of societal risk

The evaluation of societal risk follows two principles:

- Economic approach to valuate societal risk
- Engineering approach to valuate societal risk

Economic approach to valuate societal risk

The economic evaluation of societal risks is based on the paradigm of expected utility. Following the dictum of expected utility maximization, society should reduce risks only as far as the marginal gain by a unit of risk reduction provides more utility than any other application of the funds necessary to finance this unit. Following this theory, the society will optimize between a decreasing wealth and an increasing amount of safety (or decreasing mortality). The preferences between wealth and mortality can be illustrated with an indifference curve, which is convex to the origin and slopes downwards. The slope of the curve equals the marginal rate of substitution between wealth and mortality (or risk reduction) and is termed the value of statistical life (VSL). The values for VSL are typically between 1 and 5 million Euros for natural hazards according to several studies in Europe (Leiter and Pruckner 2008).

The VSL can be used as the marginal cost criterion to optimize risk reduction. The optimal amount of safety is determined as the point on the risk reduction curve, where the VSL equals the slope of risk reduction curve (see Figure 24). With a consequent application of this criterion an optimal and proportional allocation of financial resources for risk reduction is guaranteed. A more detailed explanation of the scientific background for the VSL is presented in D5.2 "Technical report" of IRASMOS.

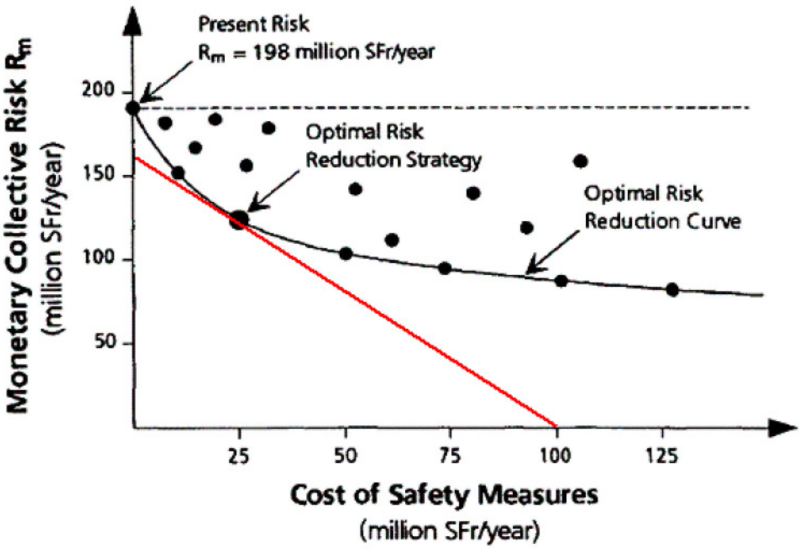


Figure 24: Optimisation of risk reduction by using the VSL as marginal-cost-criterion (Bohnenblust & Slovic 1998)

Engineering approach to valuate societal risk

In the engineering approach the protection goals for societal risk is formulated in a similar way as for as for individuals at risk. The basis for evaluation is the FN-diagram. In Figure 25, the dotted intolerable line demarks such a protection goal. The region above this criterion line represents risks of the system, which are judged unacceptable whereas the region below the line is called the ALARP region indicating that risks in this reason should be as low as reasonably possible. The slope of the criterion line indicates how much weight is given to the number of fatalities implied with different hazard scenarios.

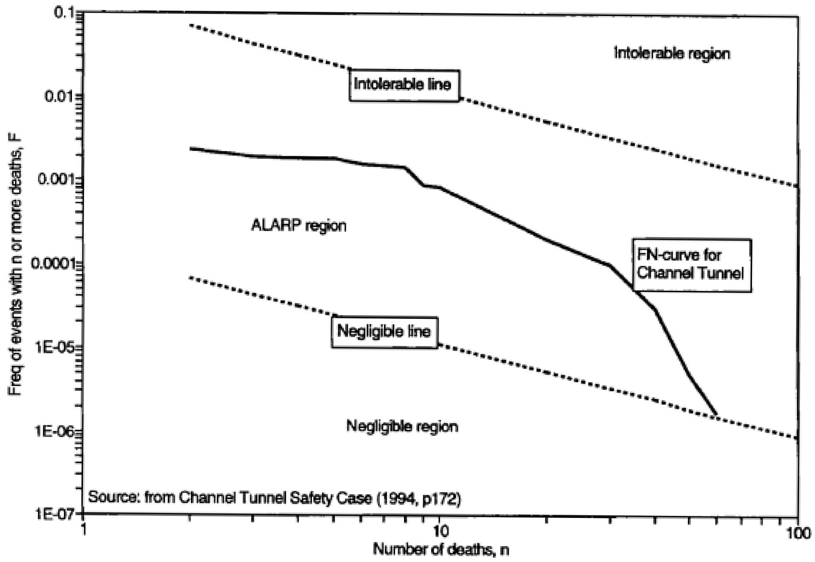


Figure 25: FN-diagram example from (Evans & Verlander 1997) presenting the FN-curve for the Channel Tunnel (continuous line) and the dotted lines delimiting the region of unacceptable or intolerable risk and the region of As Low As Reasonably Possible (ALARP) risk

3.9.2 Evaluation of individual risk

The individual is evaluated with risk acceptance criteria. These protection goals are defined by experts and public administrators and can be applied to very different risk sources, defining different standards of acceptable or tolerable risk. Based on a review by (Jonkman et al. 2003) we give an overview on some of the standards for acceptable individual risk (safety goals) in Table 9.

Table 9: Protection goals for individual risks from different fields of application (Jonkman et al. 2003)

Individual risk	**Basis of calculation**	**Field of Application**	**Source**
$< 10^{-6}$ / yr	Probability of death for most exposed off-site individual	Hazardous installations in the UK and the Netherlands	(HSE 2001; VROM 1988)
$< \alpha \times 10^{-5}$ / yr	Probability of death for: most exposed workers ($\alpha = 10$), most exposed off-site individual ($\alpha = 0.1$), maximum cancer risk ($\alpha = 1$),	Industrial facilities in the US, UK, Norway, the Netherlands	(Pate-Cornell 1994)
$< \beta \times 10^{-4}$ / yr	Probability of death for: voluntarily borne risk ($\beta = 10$), risk with large self-control ($\beta = 1$), risk with small self-control ($\beta = 0.1$), involuntarily borne risk ($\beta = 0.01$).	Floods, Aviation, Traffic	(Vrijling et al. 1995)
$< \delta \times 10^{-4}$ / yr	Probability of death for: voluntarily borne risk ($\delta = 10 – 100$), risk with large self-control ($\delta = 2 – 10$), risk with small self-control ($\delta = 0.3 – 2$), involuntarily borne risk ($\delta = 0.3 – 0.04$).	Natural hazards in Switzerland	(PLANAT 2004)
$< \gamma \times 10^{-5}$ / yr	Probability of death for: road services ($\gamma = 10$), road traffic ($\gamma = 1$), railway traffic ($\gamma = 0.5$).	Protection of traffic routes from snow avalanches in Switzerland	(Wilhelm 1999)
$< 10^{-5} – 10^{-6}$ / yr	Probability of death for involuntarily borne risk	Gravitational hazards in Switzer-land	(Borter 1999a)

Chapter 4

Non-Structural Countermeasures

4.1 General Aspects of the Planning and Evaluation Process

When risks are too high or might be reduced with a reasonable effort, countermeasures to reach the desired level of safety have to be identified, selected and applied. This evaluation of countermeasures as well as their implementation may be seen as the core element of risk management. It represents the working step in the whole cycle where risks are really reduced. But risk management should always be seen integrally as shown in chapter 1. With respect to the planning and the evaluation of countermeasures, the term ‘integral’ means that

- all possible countermeasures such as technical, biological or organisational measures should be included in the evaluation process and should be combined optimally;
- all phases of the risk cycle (Figure 26) should be kept in mind and preventive, interventive and recovering measures should be treated equally, appropriate to the situation;
- not only safety aspects are relevant for the planning but also other needs such as economic restrictions, sustainability or acceptability should be met.

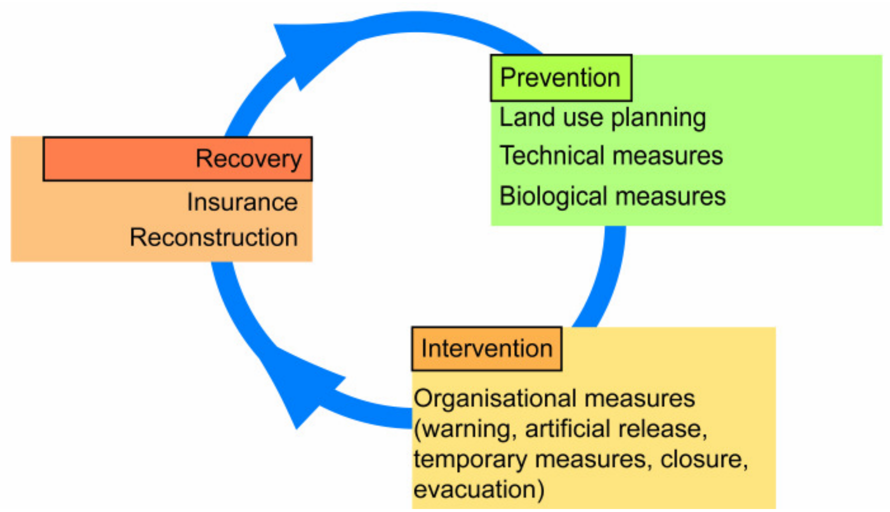


Figure 26: The risk cycle and possible measures for risk mitigation (PLANAT 2004)

Hence, an integral planning of countermeasures means that all possible countermeasures reducing risks according to the risk cycle should be evaluated and optimally combined to reach the intended level of safety, respecting general conditions such as economic commensurability, social acceptability and environmental compatibility.

As a vision, this definition is generally applicable already at this stage. When planning countermeasures the different criteria may be kept in mind and may be respected at least on a qualitative level. In many cases combinations of different measures prove to be most effective and efficient as well. Typically, structural measures (limited e.g. for financial reasons or the protection of the landscape), organisational measures to prepare for and act during an event that exceeds the dimensioning of the structural measures and land-use planning as the general framework are combined. However, the effectiveness of such a combination has to be proven for each single case. But the methods for a comprehensive and transparent assessment are still under development. Today, the evaluation of countermeasures focuses on the one hand on technical aspects such as the technical feasibility or the effectiveness in risk reduction and on the other hand on direct economic consequences such as construction costs or the benefit in the sense of avoided damage. Moreover, in the majority of cases preventive measures are dominating in the evaluation process as well as when it comes to financing. Thus, on the level of practical implementation but also on the level of methodical development, the stage of a real integral planning and evaluation of countermeasures is not yet reached.

Though, practice always has to accept compromise. On the one hand a thorough and comprehensive analysis of the situation, the hazard and the risk as well as an open-minded evaluation of countermeasures is necessary. On the other hand also rules of thumb, some general conventions and last but not least common sense is also needed to select the best possible solutions.

Chapter 5 and chapter 6 present methods for sound analyses as well as examples and experiences from practice. The two chapters are separated with regard to the two main groups of countermeasures, structural and non-structural measures. Structural measures aim at preventing disasters from occurring whereas non-structural methods are targeted on activities to reduce the consequences of a disaster. Structural measures are related to constructional works or to biological structures. They are mainly applied in the field of prevention but not exclusively limited to it. Non-structural measures include a variety of measures where construction do not play a major role (but of course may also be involved). They may be applied equivalently along the whole risk cycle, e.g. land-use planning in prevention, warning and rescue in intervention and loss compensation by insurance companies in recovery.

Non-structural measures are invoked for two main reasons:

- To reduce the consequences of hazardous events to people, existing buildings and infrastructure;
- To avoid new buildings and infrastructure in exposed areas.

In the following the different opportunities of non-structural measures will be described shortly. Several examples of application are used to show the practical implementation.

4.2 Land-use Planning based on Hazard Maps

4.2.1 Overview

In the long-term perspective careful land-use planning taking into account natural hazards might be the most cost-effective measure to reduce risk. Thus, all IRASMOS countries respect natural hazards in their land-use planning. However, the implementation varies and faces some problems:

- Natural hazards are only one aspect of land-use planning. Though, even if they are respected at the best, compromises will be necessary.
- Land-use planning is highly influenced by strong economic, political and social interests. Hence it is not always easy to achieve acceptance of limitations due to natural hazards.
- The consideration of natural hazards in land-use planning is mostly hazard-oriented. Risk aspects such as vulnerability are considered less, which may lead in the long term to more risks that intended.
- Land-use planning is made for the future and is not able to solve current risk problems. In this sense it may be difficult to communicate the risk management effect of spatial planning.
- Land-use planning needs very simple and clear indications of hazards. Varying regulations for different processes as well as for different regions complicate the transfer from hazard to spatial planning and may lead to a non-adequate and unbalanced land-use.

Due to such limitations, Fleischhauer et al. (2007) state that the role of land-use planning in risk management tends to be overestimated and that the planning should be seen as only one actor of many in risk management. Despite the problems, risk managers have to deal with natural hazards in land-use planning. The current practice in the IRASMOS countries may give some hints to cope with this challenge. In the following the examples of Austria, France and Norway are briefly discussed. Further information for Italy as well as for many other European countries can be found in Fleischhauer et al. (2006). The Swiss approach was addressed by ARE (2005), land-use planning in Switzerland, Italy and France was also analysed by Gillet et al. (2007).

4.2.2 Hazard zones in Austria

The Austrian hazard maps delineate red and yellow hazard zones, specific reserved areas and areas for information. If existing, red and yellow hazard zones and blue reserved areas have to be displayed, whereas the delineation of brown and purple areas for information is optional. Thereby the outline of those areas is only based on technical criterions and not on the outline of the land plots.

The red hazard zone includes all areas endangered by torrents and avalanches in a degree that a permanent use for settlement and traffic purpose is not possible due to the estimated damage resulting from the design event; or where the use would only be possible with disproportional subsidies by the public sector in protection measures. The yellow hazard zone includes all areas influenced by the effects of torrents and avalanches if used for settlement or traffic purpose.

The basis of the red and yellow hazard zones is given by the design event, which is an event with a recurrence interval of approximately 150 years. However, with respect to avalanches, this design event is specified further within the instructions of the Ministry to the subordinated government departments of the Torrent and Avalanche Control Service.

Blue areas to be reserved include all those areas (i) needed for the implementation of technical or forestall protective measures or the maintenance of such areas and (ii) needed for a certain form of land management due to an implemented mitigation measure. Brown areas include all areas affected by natural hazards apart from torrent processes and avalanches, such as rock fall or landslides. Purple indicates those areas where the protective function is dependent on the conservation of soil or terrain properties.

According to the legal regulations, hazard maps are evaluated and refereed reports of the summary outline of all possible design events and therefore have been judged by the Austrian administrative tribunal as qualified report with a prognostic character. Thus, the consideration of hazard maps in all planning activities by communes and citizens cannot be obligatorily enforced (a weakness according to SWOT, chap. 2.2.5). Therefore, the BMLFUW introduced the so-called estoppel, in which a non-consideration of hazard maps will exclude statutory corporations from governmental subsidies for countermeasures against torrent and avalanche hazards.

The text component completes and comments on the cartographic part of the hazard map and therefore ensures the comprehensibility of the hazard plan. Correspondingly, all map bases and data used are included, as well as a justification of the assessment and depiction of endangered areas, and special notes for spatial planning activities, construction and safety purposes. The data to be considered include maps, outlines, aerial photographs, references used and reports taken into account during the procedure of hazard mapping. Furthermore, descriptions of all areas with respect to avalanches and torrent processes, and the related catchment characteristics such as area, discharge and potential bed load during a design event have to be described in the written part of the hazard plan. This description has to be carried out using a standardised official form. Additionally, for every catchment area an inspection sheet has to be compiled, including all observations relevant with respect to an assessment of those watersheds, such as possible sources of bed load. The written part of the hazard assessment is completed with suggestions of how to incorporate the mapping results in the local development planning and with potential construction requirements or restrictions for the yellow hazard zone.

4.2.3 Risk Prevention plans PPR in France

Text according to and cited from Tacnet & Richard (in prep.).

To consider natural hazards in spatial planning, PPR (plans de prévention des risques) are required and a legal procedure in France (chap. 2.3). To date, 6426 PPR have been approved (Figure 27) in a total of 12,000 communities considered to be exposed to natural hazards (FFSA 2002). The main objectives of PPR are: make the risk known, increase risk awareness and preparedness and reduce the vulnerability of the population, assets and activities threatened by a potential hazard. PPR implementation implies four steps: 1) hazard assessment and mapping, 2) exposure analysis for inhabited zones, 3) risk zoning and 4) regulations (building codes etc.). The zoning map (3) and the regulations (4) are the two main documents making up the risk prevention plan.

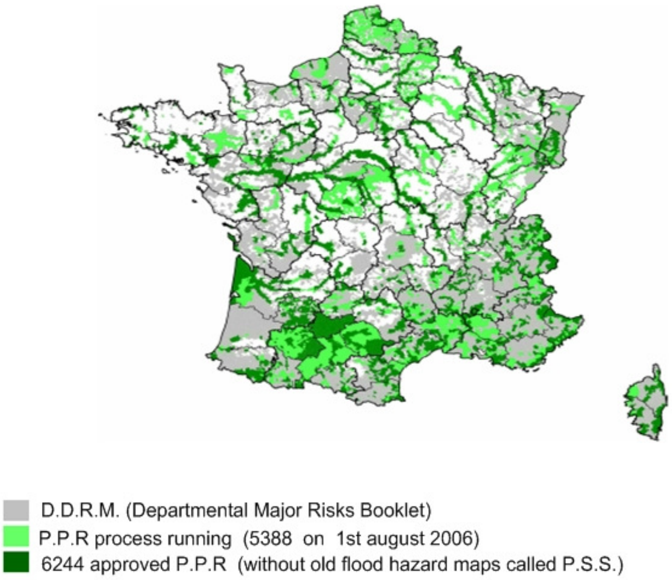


Figure 27: Approved risk prevention plans in France – May 2008 (Tacnet & Richard, in prep)

At present, most of risk prevention plans are produced relying on a rather qualitative expert process concerning hazard and risk assessment (Figure 28). This process is accepted because it is based on an economic approach. It would be impossible to use modelling for every PPR.

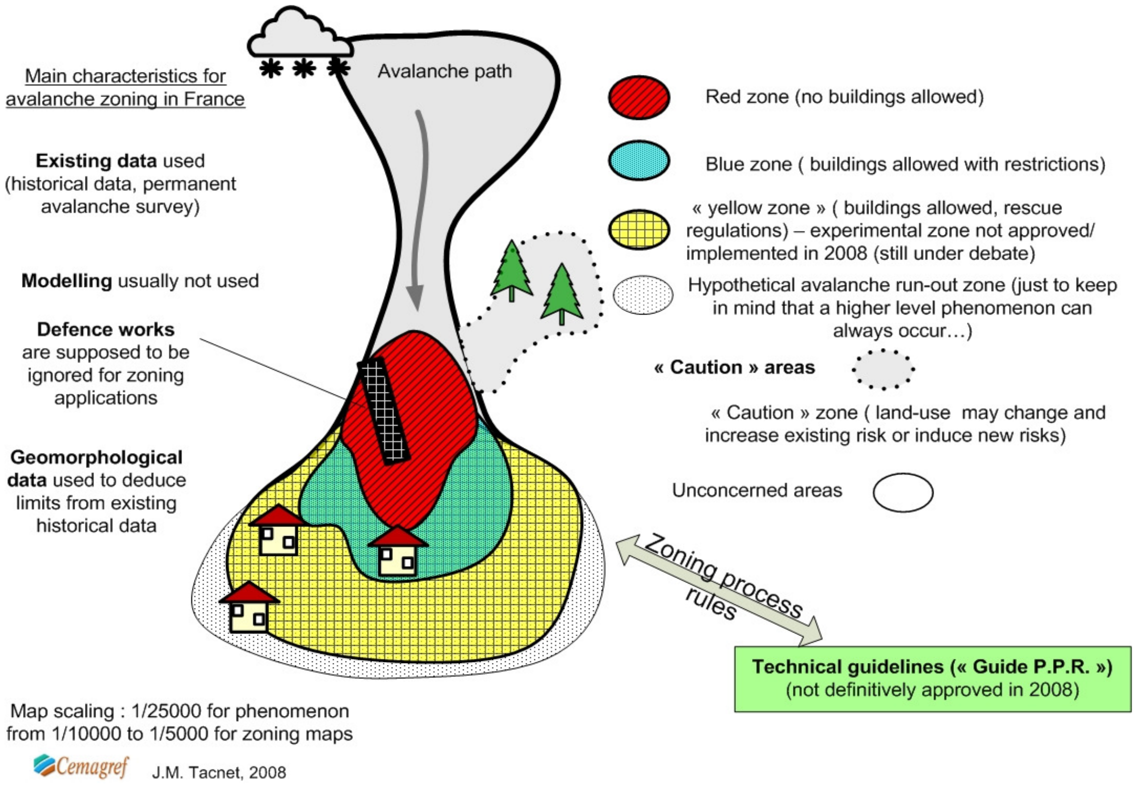


Figure 28: Risk prevention plans are mainly based on qualitative and existing data: historical information, testimonies, and geomorphologic approaches (Tacnet & Richard, in prep.)

To improve the hazard-related quality of PPR, for snow avalanche assessment two types of reference hazard are proposed (Figure 29):

- A 100-year return period reference hazard to protect buildings at risk. This reference avalanche is described by a global avalanche extension zone which is divided into several zones depending on the intensity of the avalanche.
- The maximum plausible avalanche to protect human beings. The induced avalanche envelope corresponds to the worst situation that could be imagined (forest destruction, defence works failures, etc.). This principle has been proposed recently to protect the population and to emphasise the need for local rescue plans (Plans Communaux de Sauvegarde, PCS) in those areas. This maximum plausible avalanche has not yet been implemented and there the political and technical debate is ongoing because of the constraints that it implies for local community mayors in terms of induced responsibility.

Due to the lack of knowledge e.g. on avalanche pressures and its relations to structural vulnerability, the evaluation of the hazard level may remain quite subjective and dependent on expert knowledge. The pressure thresholds are currently used, but the actual corresponding avalanche is not clearly known.

Reference hazard (estimated probability) / **Intensity level** : avalanche pressure estimation (on exposed buildings or infrastructures)	**100-year** return period *rare* event	**Maximum plausible avalanche** exceptional event
(estimated) pressure ≥ 30 kPa	**A3**	**AMV**
1 kPa < (estimated) pressure < 30 kPa	**A2**	
0 < low pressure < 1 kPa	**A1**	

Figure 29: Avalanche hazard levels versus intensity levels (Lievois et al. 2005)

The hazard map is transformed into a zoning map establishing red, blue and white zones (Figure 30). In red zones all buildings are prohibited whereas in blue zones building is possible but only in certain conditions (Lievois et al. 2005). The transformation takes into account the hazard as well as the exposed values. Whereas in non-urbanised areas (espaces non-urbanisés) new buildings and thus the development of settlements are prohibited, in already urbanised areas (espaces urbanisés) the zoning is differed based on the seriousness of the threat and the existence of countermeasures. In non-protected areas (non protégés) the restrictions are more severe than in protected areas.

The zoning map is drawn in association with elected representatives. According to the SOWT analysis of the French risk management remarkable problems related to PPR are related to this implementation process (chap. 2.3.4). Improvements seem to be desirable.

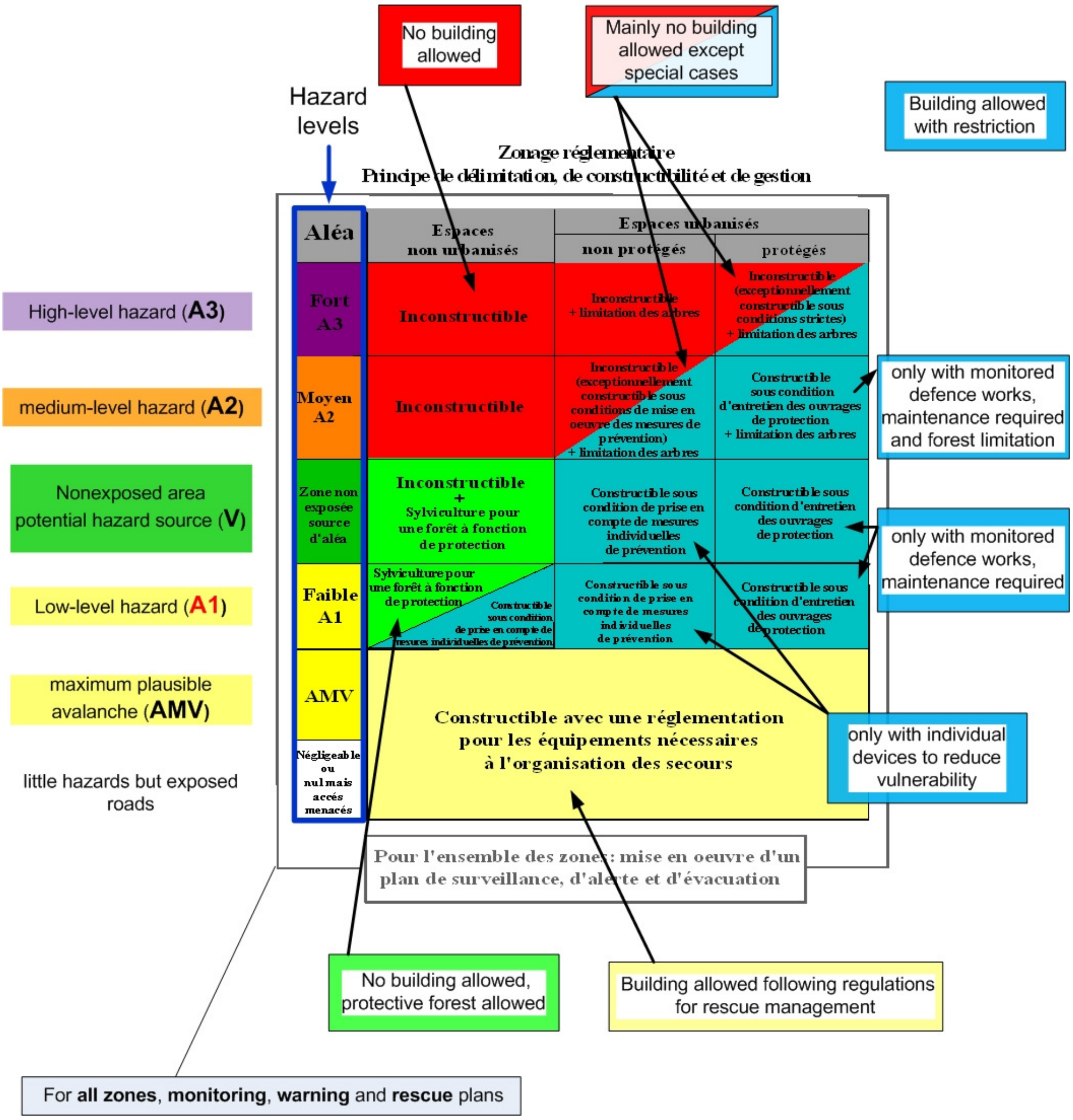


Figure 30: Determination of the zones of a PPR for snow avalanches (adapted and translated by Tacnet & Richard (in prep.) from Lievois et al. 2005)

4.2.4 Hazard and risk mapping in Norway

Hazard and risk mapping in Norway is carried out at three different levels:

- Overview susceptibility maps at 1:50.000 scale
- Overview hazard maps at 1:10.000 scale
- Detailed hazard and risk maps at 1:5.000 scale

Overview susceptibility maps have been covered by governmental funding the last 25 years. These maps are made for the land use planners and the municipalities. If exposed areas are to be developed, detailed investigations are required. Two different hazard map series have been made; one covering snow avalanches and rock falls and the other covering quick clay slides. For snow avalanches and rock falls currently 2/3 of the country have been investigated. For quick clay slides the most exposed areas have been covered, and the last five years detailed risk maps have been constructed.

Hazard and risk maps at more local scale the municipalities are responsible for the mapping, but only a few of the exposed areas have so far been investigated, mainly for economical reasons. The responsibility for the municipalities to conduct risk and vulnerability analyses will be included in the Norwegian building codes currently under revision. The Directorate for Civil Protection and Emergency Planning in Norway is making guidelines for how this risk assessment should be performed.

The building code prescribes safety classes for buildings in areas exposed to natural hazards (Table 10). No pressure criteria are used in Norway. The building codes are under revision, and it will be considered if pressure criteria should also be included as in many of other European countries.

Table 10: Building code in Norway

Safety classes/consequences	Maximum probability per year	Example on type of structure
1 Small	10^{-2}	Garage, boat house
2 Medium	10^{-3}	Dwelling house
3 Large	$<10^{-3}$	Hospitals, schools etc.
4 Very large	No danger at all	Oil refineries

Special guidelines for land use in areas subjected to quick clay hazard have recently been prepared to instruct the municipalities, land use planners, consulting companies and entrepreneurs how to operate in hazardous areas at different levels in the planning. These guidelines can also be adapted to other natural hazards such as snow avalanches and debris flows.

4.2.5 Effectiveness of land-use planning

The effectiveness of countermeasures is a decisive parameter for decision on alternatives of countermeasures. But the effectiveness of spatial planning is difficult to assess, because the effects only arise in a long-term perspective, and they may be considerably superposed by economically and socially induced developments of the settlements. Thus, the effectiveness of land-use planning could only be estimated by a scenario analysis with different assumption on future development. The effectiveness is not determinable similar to the one of countermeasures with an immediate effect. The only risk reducing intervention that might be allocated to land-use planning with a direct effect is the relocation of buildings. Here the determination of effectiveness is possible.

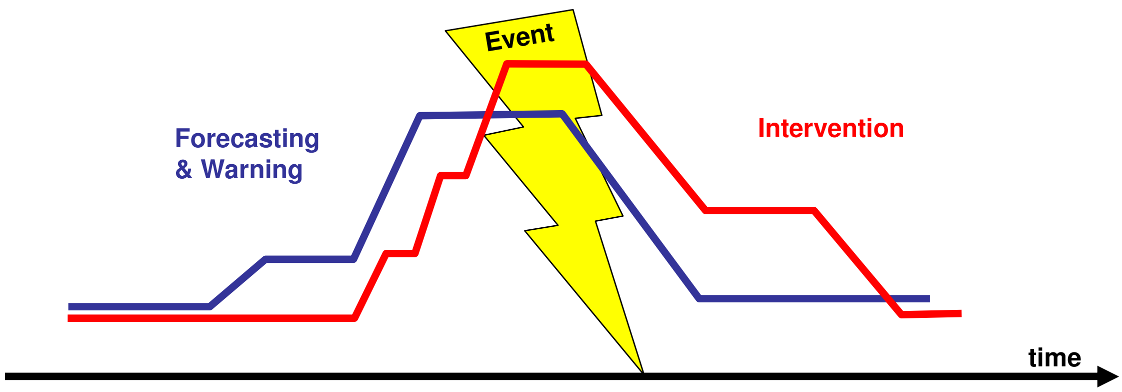
It seems reasonable to treat land-use planning separately. If the risks are already too high today, other countermeasures than spatial planning are needed. But the planning should still be integrated with the long-term perspective. If the risks are acceptable, spatial planning is the designated way to make sure that they will not increase unregulated in future.

Hence, and-use planning is essential to control risks in the long-term. As long as there exist alternative locations for settlement development that imply fewer problems than the ones situated in hazard prone areas, a rather strict application of hazard zones seems reasonable. Else a careful consideration of all aspects such as threat, economic development, social needs, political responsibility and (opportunity) costs should go along with the decision process for the selection of new sites.

4.3 Emergency Management: Forecasting, Warning and Intervention

4.3.1 General overview

Emergency management depends on various actions. It is most important not to focus too much on one element out of the chain, but to search for an optimal combination. Although the action is generally focusing on a rather short moment of some hours to days (the event), first, the preparation is of pivotal importance. All the tasks and aspects that are not settled and clarified here will be not ready for the emergency. Second, the forecasting and warning is an ongoing task for the responsible services (Table 11). Near the event the intensity of observation, interpretation and communication increases, possibly resulting in an alert. Based on the warning and possibly on other local information, third, the intervention starts preferably before the event occurs or reaches its maximum. Depending on the hazard and the available information, it is a very difficult job for responsibles to decide on the right moment to act. The intervention phase is rather short and highly dynamic. It strongly depends on people who are able to act reasonable even under stress and who are ready to take the responsibility. Missing preparedness will have a considerably adverse effect especially in this phase. Fourth, the after-event phase is not only dedicated to recovery but also to learn and to make further progress.



Preparation	**Warning**	**Intervention**	**Lessons leared**
- monitoring - organisation - formation - awareness-building - planning of intervention - training - ...	- increasing level of awakeness - decision criteria - pre-warning / warning / alert - ...	- decision - action - taking responsibility - information / communication - coordination - ...	- documentation - evaluation - enhancements - …

Figure 31: The main working steps of emergency management

Emergency management can be applied to all the IRASMOS processes, but there exist quite important differences:

- Snow avalanches: Forecasting and warning on the one hand and interventive measures such as artificial release, closure of roads or evacuation are broadly used. The accuracy of forecasting greatly depends on the quality of recording systems (e.g. spatial distribution and frequency of recordings) and the knowledge (availability of empirical data) of the relationship between the monitored factors and avalanche initiation.

- Rock avalanches: Based on the nature of failures in rock slopes the most and normally the only method of managing the risks associated with a rock slope movement, is the development of an effective warning system (chap. 7.2). Suitable emergency planning is then the only effective tool to reduce the consequences by means of evacuation, road closure and other active measures.
- Debris flows: The possibilities for forecasting and warning are limited because the time period is very short and the process knowledge (e.g. small scale meteorology, hydrologic and geomorphologic processes) and therefore the prediction of the local development are highly uncertain. Because of these limitations no general, national or regional forecasting for debris flows like for other hydrological processes e.g. for large scale floods exists. However, an initiative in Switzerland tries to develop such a system based on the experiences from snow avalanches (chap. 4.3.3).

Table 11: Possibilities to get information on upcoming events for the management of short-term emergencies (e.g. periods of high avalanche danger due to heavy snowfall) and of long-term risks (e.g. continuously creeping slopes) as well

Monitoring	Continuous observation of a system or measurement of characteristic parameters of a system over days, month and years.
Forecasting	A prediction several hours or days in advance which describes the characteristic phenomena of an expected weather situation or weather related situation (e.g. avalanche situation). A forecasting is generally broadcasted to the public via many different communication channels.
Early warning	Warning against dangerous natural hazard events hours to days in advance. An early warning is targeted to safety services and professionals and is distributed via specific, mostly protected communication channels.
Warning	Warning against dangerous natural hazard events more than 36 to 6 hours in advance. A warning is targeted to safety services and professionals and is distributed via specific, mostly protected communication channels.
Alert/Alarm	An acoustic, optical or mechanical signal which informs about a dangerous event shortly before its occurrence. An alarm may be targeted to the public, too.

Today, emergency management is mainly used in the following situations:

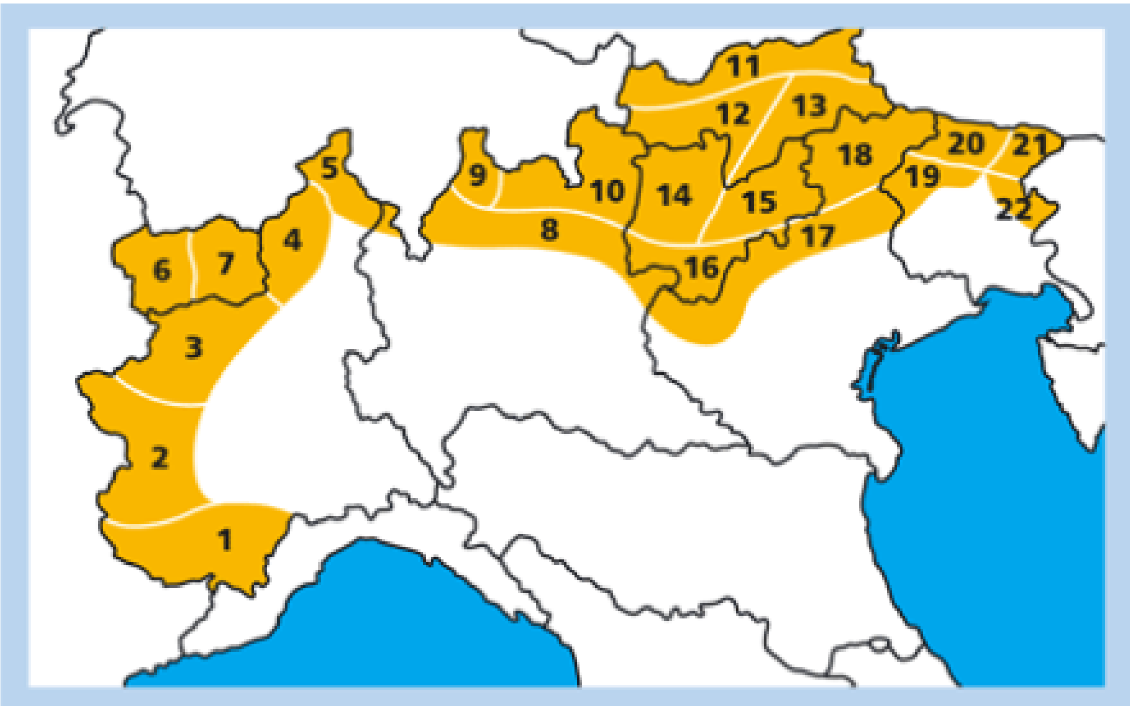
- To lower the risk for people outside the settlements and off the traffic lines (e.g. by avalanche warning)
- To minimise the risk for people in winter sports areas (e.g. by artificial release)
- To assure the safety and the reliability of traffic lines (e.g. by monitoring systems for slope / rock movements, alert systems for debris flows or snow avalanches, forecasting / warning and closure)
- To handle rather extreme weather situations with potential threat in settled areas (e.g. by evacuation)
- To reduce damage when structural countermeasures such as dams are overtopped
- To deal with situations where there exist no other possibilities (e.g. for rock avalanches)
- To face every unexpected situation

Given the evidence that risks due to natural hazards are not declining but possibly rather rising, and the fact that the risks cannot be reduced by structural as well as planning measures alone, the importance of effective emergency management becomes even more evident. However, emergency management is a major challenge. The crucial point in this regard is time. In situations with short reaction times, emergency management poses a particular challenge. Finally, time may be too short, decisions may be wrong and measures may fail. Thus, residual risk always has to be taken into account.

4.3.2 Avalanche Warning in European Countries

National avalanche centres

In the IRASMOS countries warning centres take the responsibility to provide accurate information for snow avalanches. These centres are organised either centrally providing information on the whole country (France, Switzerland, Norway) or regionally (Italy (Figure 32), Austria). Information on these centres and their work can be found on www.avalanches.org and in the deliverable D1.3 of IRASMOS.



1 Alpi Liquri e Marittime
2 Alpi Cozie
3 Alpi Graie meridionali
4 Alpi Pennine orientali
5 Alpi Lepontine
6 Alpi Graie settentrionali
7 Alpi Pennine occidentali
8 Alpi Orobie
9 Alpi Retiche
10 Alpi Retiche centrali orientali
11 Alpi Venoste e Aurine
12 Gruppo Ortles Cevedale
13 Dolomiti settentrionali
14 Dolomiti di Brenta e Adamello
15 Dolomiti occidentali
16 Prealpi Trentini
17 Prealpi Venete
18 Dolomiti orientali
19 Prealpi Carniche
20 Alpi Carniche
21 Alpi Giulie
22 Prealpi Giulie

Figure 32: Regional and sub-regional division of Italian Alps for avalanche bulletin (www.aineva.it)

To collect und to process different data – the synoptic method

Daily avalanche bulletins are a main outcome of national avalanche warning services. They are mainly elaborated following the synoptic method (Figure 33). Within this approach, local information is important and therefore field measurements and observations are a precious base for the forecaster even though they are time consuming and require relevant effort.

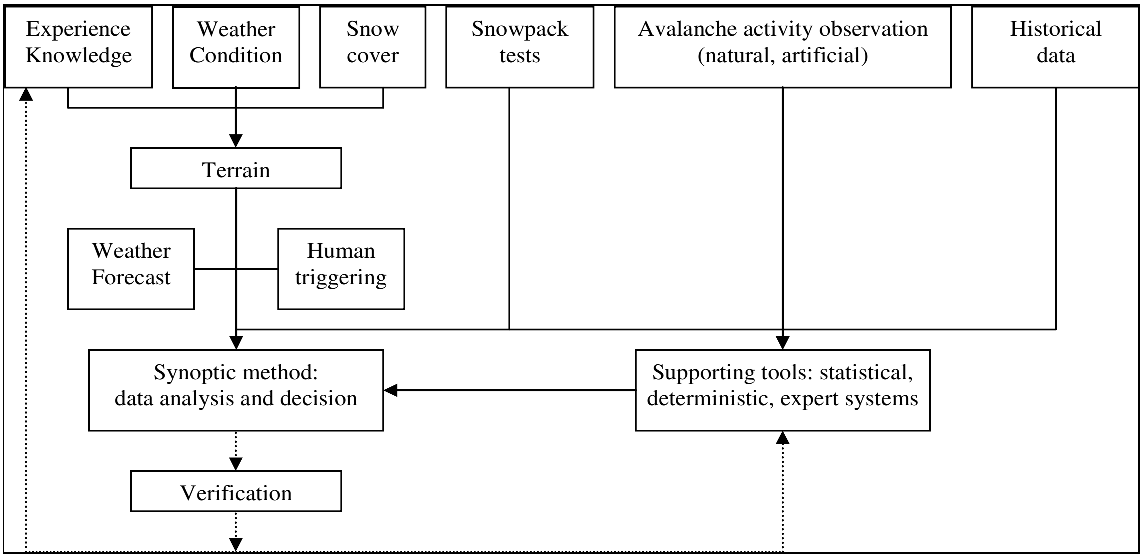


Figure 33: The synoptic method for forecasting the avalanche hazard (Schweizer & Föhn 1994)

Even if none of the supporting tools are, so far, reliable enough to substitute the human expert, they become more and more important:

- Numerous operational systems based on the statistical approach were developed in several countries and are widely used (McClung and Tweedy 1994) both for local and for regional avalanche forecasting. The two most popular methods are the discriminant analysis and the nearest neighbours (McClung and Schaerer 1993).
- Models such as SNOWPACK (Lehning et al. 2000) allow to simulate the evolution of the snowpack on the basis of meteorological parameters (wind speed, radiation, snow and air temperature, fresh snow amount) observed by automatic sensors, offering information even regarding sites that are partially or totally inaccessible during winter.
- Expert systems simulate the decision making process of an expert. Most of them are symbolic computing systems using rules which were formulated explicitly by human experts (Giraud 1991, Bolognesi 1993).
- Combinations such as the SAFRAN/CROCUS/MEPRA-system in France (Durand et al. 1999) simulate all elements for operational avalanche forecasting. The first model called SAFRAN estimates relevant meteorological parameters affecting snow pack evolution. The second model, CROCUS, is a snow numerical model which simulates the physical processes inside the snow pack and its stratigraphy. The last model, MEPRA, is an expert system; based on assessment of snow pack stability, it deduces natural and accidental avalanche risks.
- Not only numerical instruments should be considered. To improve the avalanche forecasting it is possible to act on all the part of process: for example the step of verification of the prediction could be more efficient. Pedrazzoli et al. (1999) tried to systemise

the phase of valuation of the forecast systematic giving specific guidelines to the evaluator. In this way the subjective factors in the verification should be eliminated and the field work should be optimised since they are one of the most expensive phases in the process.

Avalanche bulletins and the European avalanche hazard scale

The resulting avalanche bulletins are classified according to international code (Figure 34, Table 12). This standardised scale is a big step towards a common understanding of hazard and warning scales, which facilitates communication among avalanche specialists as well as to the public.

Europäische Lawinengefahrenskala

Escala Europea de Perill d'Allaus

Medzinárodná stupnica lavínového nebezpecenstva

échelle Européenne de risque d'avalanche

	GB	SL	I	E	D	F	SK
1	low	majhna	debole	feble / débil	gering	faible	malé
2	moderate	zmerna	moderato	moderat / moderado	mäßig	limité	mierne
3	considerable	znatna	marcato	marcat / marcado	erheblich	marqué	zvýšené
4	high	velika	forte	fort / fuerte	groß	fort	veľké
5	very high	zelo velika	molto forte	molt fort / muy fuerte	sehr groß	très fort	veľmi veľké

Evropska petstopenjska lestvica nevarnosto proenja sneznih plazov

Escala Europea de peligro de aludes

European avalanche hazard scale

Scala Europea del pericolo di valanghe

Figure 34: European avalanche hazard scale

Table 12: Signification of the different hazard scales

1	low	The snowpack is generally well bonded and stable. Triggering is possible only with high additional loads on a few very steep extreme slopes. Only a few small natural avalanches (sluffs) possible.
2	moderate	The snowpack is moderately well bonded on some steep slopes, otherwise generally well bonded. Triggering is possible with high additional loads, particularly on the steep slopes indicated in the bulletin. Large natural avalanches are not likely.
3	considerable	The snowpack is moderately to weakly bonded on many steep slopes. Triggering is possible, sometimes even with low additional loads. The bulletin may indicate many slopes which are particularly affected. In certain conditions, medium and occasionally large sized natural avalanches may occur.
4	high	The snowpack is weakly bonded in most places. Triggering is probable even with low additional loads on many steep slopes. In some conditions, frequent medium or large sized natural avalanches are likely.
5	very high	The snowpack is generally weakly bonded and largely unstable. Numerous large natural avalanches are likely, even on moderately steep terrain.

Effectiveness of avalanche warning

The need for avalanche warning is out of question. But it would be interesting to know more about the effectiveness. The effectiveness of warning services and similar applications cannot be defined directly. As shown, it is not only a question of the quality of the warning information, but also of its communication to the end-users and, finally, of its implementation in practice. The capability to act accordingly to the situation is not only limited to specialists but largely concerns also to the public. Therefore this aspect is strongly related to education and information and will be treated in chapter 0. However, the rather steady number of fatalities due to avalanches (Tschirky et al. 2000) compared to the continuously increasing people sojourning in potentially avalanche-threatened areas (SLF, 2000) allows the assumption that avalanche warning in combination with the mentioned activity may substantially reduce the risk.

Reliability of the avalanche warning

Nairz (2003) compared the daily avalanche bulletin in Tyrol with the feedback from end-users, own field measurements, photos, stability checks and feedback from the professional avalanche observers. For the winter 2002/03 he found a hit rate of 86 %. In these cases the avalanche bulletins fitted perfectly to the avalanche conditions all over Tyrol. A similar study from the DAV-Summit Club (also mentioned in Nairz 2003) resulted in a hit rate of 91 %. A current survey of the Swiss Institute for Snow and Avalanche Research SLF reveals a hit rate in the range of 80 %, too (evaluation not yet finished). This result confirms former surveys. Hence, for the national and regional avalanche bulletins in the IRASMOS countries a success rate of about 80 % seems to be within reach.

Communication to the end-user

Warning is useless if it is not communicated. To reach the end-user, the messages have to be adjusted to his needs and capabilities. A lot of tools are in use today and cannot be discussed here in detail. Just two examples show the variety of possibilities:

- On the one hand there is a persistent need to make information as simple as possible. Therefore icons were developed to make an avalanche bulletin even easier to read (Figure 35).
- On the other hand professionals need detailed information. In Switzerland, the web-platform InfoManager presents the national and the regional avalanche forecasting bulletins and all data, observations and model results which are relevant for safety decisions (Figure 36). It is the fundamental basis for the safety services to decide on closure of traffic routes, evacuation of buildings, etc. Thus, it is a sophisticated tool dedicated to experts.

Future needs

Based on the already well developed methods and organisations for avalanche warnings, future enhancements will concentrate on the following points:

- Enhance existing approaches and knowledge e.g. related to models
- Take advantage of new technologies such as seismic avalanche detection
- Extend the knowledge and the tools to the local scale and to short-time forecasting

- Improve weather information (models, measured data)
- Develop decision supporting tool customised to the needs of the end-users
- Improve education.

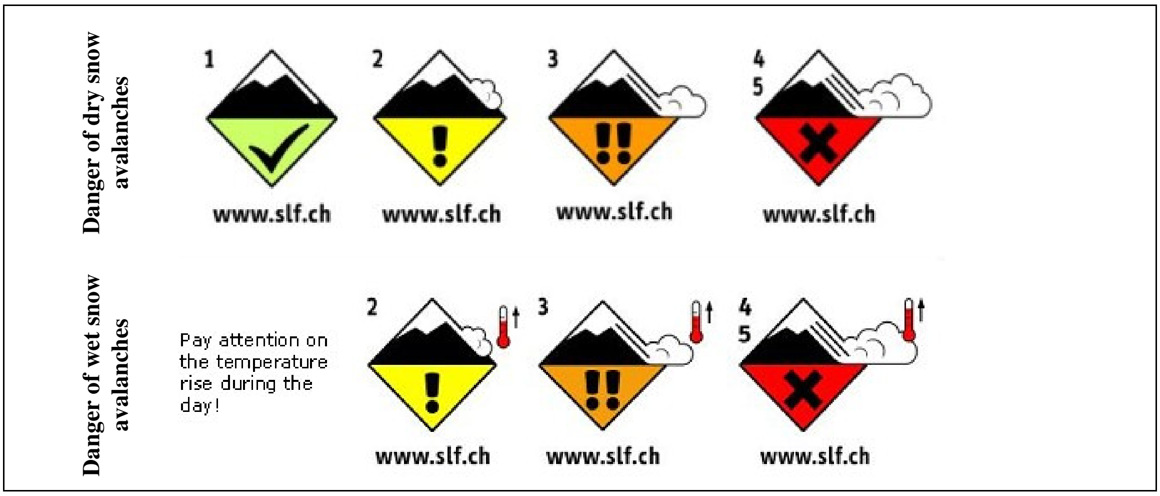


Figure 35: Avalanche danger level icons for daily information on current avalanche danger in Switzerland

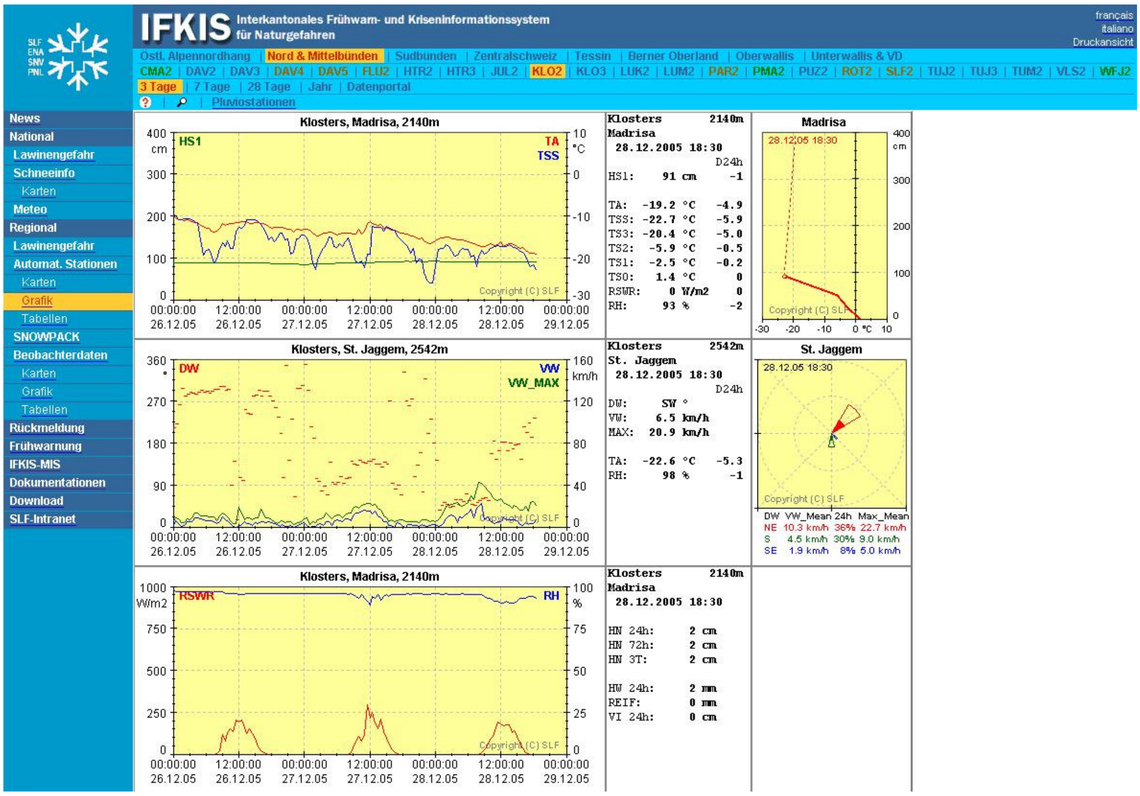


Figure 36: Screen shot of the InfoManager

4.3.3 Example of a Debris Flow Information System

Comparing to avalanche forecasting, there is no forecasting of debris flows. The most important prerequisite for debris flows are intensive precipitations, sufficient erodable material and a steep, channelled terrain (> 25 %). Rapid increases of air temperatures, a high zero degree line with the consequence of an accelerated snow melt are favourable factors. A very important basis for warning is the weather forecast. If the meteorological factors and the amount of erodable material in the starting zone are very well known, the probability for debris flows in a certain area can be roughly estimated by local experts. But this estimation is much more uncertain than it is for snow avalanches.

One approach for a rough prediction of debris flow triggering is based on rainfall-debris flows relationships. The goal of this method is to identify the meteorological events which can cause the triggering of soil slips and debris flow. The validity of the relationships is limited to the regional areas where the curves where inferred (Figure 37). On the basis of this concept, some real time systems were set up, in several part of the world. For example rainfall thresholds have been used for regional real-time landslide warning in the San Francisco Bay region (Keefer et al. 1987), Hong Kong (Hanson et al. 1995) and Rio de Janeiro (Ortigao et al. 2003).

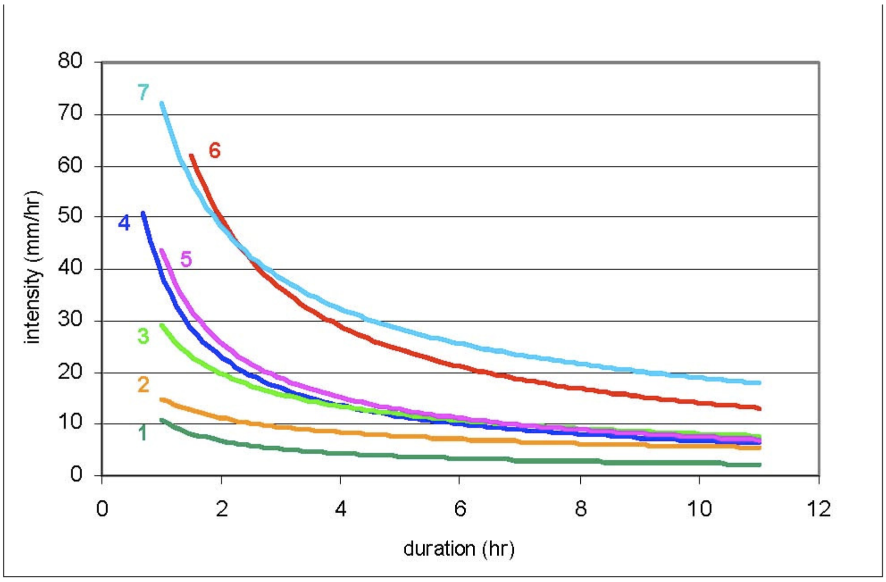


Figure 37: Comparison of different duration / intensity curves for shallow landslides in several areas of the world 1) California (Wieczorek and Sarmiento, 1988); 2) general (Caine, 1980); 3) general (Jibson, 1989); 4) Apuan lower curve (Giannecchini, 2006); 5) Valtellina (Cancelli and Nova, 1985); 6) Apuan upper curve (Giannecchini, 2006); 7) Porto Rico (Jibson, 1989)

Further progress towards early warning system for flash floods and debris flows were made in the 1980s in California (Wilson et al. 1993). The results finally led in 2005 to a farsighted initiative for a debris flow warning system (NOAA-USGS 2005). In other regions of the world too, some early warning systems for smaller catchments, debris flows and landslides have been studied (Georgakakos 1986, Chan et al 2003, Aleotti 2004).

In Switzerland, a project was initiated in 2004 aiming at developing an information and warning system for hydrological hazards in small and medium scale catchments. The system was based on significant experience from the avalanche warning system IFKIS (Bründl et al. 2004) and was therefore named IFKIS-Hydro (Romang et al. 2008a). Several systems have been installed or are under development (Figure 38) including the highly instrumented and well-known debris-flow catchment Illgraben in the Canton Valais (Badoux et al. 2008).

The processes of data collection, data processing, interpretation and dissemination have been standardised within the IFKIS system. Similarly to the avalanche warning, IFKIS-Hydro combines the available information based on the synoptic method (Figure 33). For communication purposes and adapted version of the InfoManager is in use (Figure 36). To understand and possibly predict hydrological events in smaller catchments, local information is of pivotal significance. Therefore, observers play a major role in the concept of IFKIS-Hydro. People working in the field are often effective and efficient providers of event information. Observers can be flexibly deployed and even barely measurable factors such as slope instabilities, debris flow activity, floating wood or bed load can be gathered and later interpreted. Moreover, the inclusion of specialised local personnel is a must as they have so much responsibility, both for the interpretation of the data and the realization of the intervention.

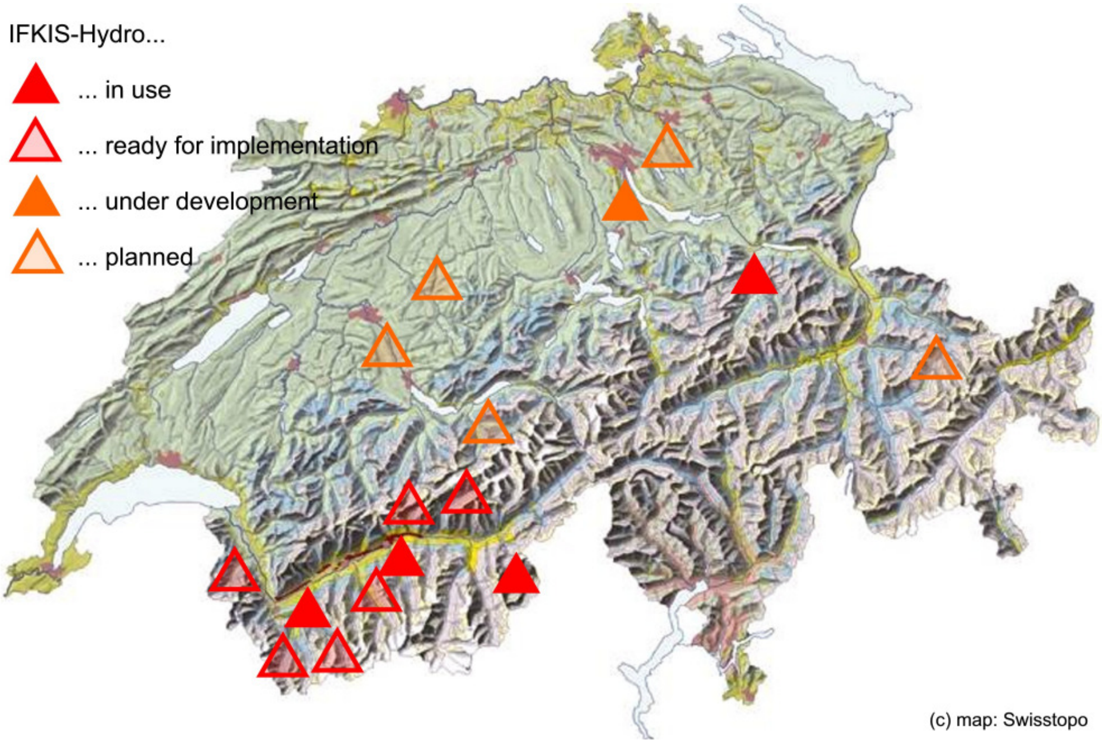


Figure 38: Pilot regions of IFKIS-Hydro

The application of IFKIS-Hydro in the test regions showed both successful use of the system and its possible limits. The requests for extending the system to other regions in Switzerland show the positive evaluation by the users. Generally, there is a particular interest among the stakeholders involved in Switzerland to further advance IFKIS-Hydro and related tools for warning and intervention.

Further progress should focus on the following aspects:

- to advance weather forecast and decision support methods as well as process models focusing on small scale and short-term predictions (e.g. thunderstorms);
- to improve knowledge of hydrological processes (e.g. discharge formation, debris flow initiation) and to develop operationally running models[6];
- to strengthen local competences by creating optimal conditions for emergency management (e.g. responsibilities, resources) and by providing advanced training courses for safety managers; and
- to bring together all the players in the field of emergency management (e.g. at the local, regional and national level) and to establish networks to exchange and to share information.

4.3.4 Alert systems

When debris flows or snow avalanches are already in motion, alert systems recognizing the hazardous process are used in some catchments (Arattano 1999, Gubler 2000, Badoux et al. 2008). These systems are especially helpful when people can easily be evacuated from endangered areas or prevented from entering in it. Thus, a typical application of detection systems is in the traffic control system; e.g. that the traffic to threatened areas can be stopped early enough by traffic lights. For debris flow detection there are sensors available which combine an acoustic, a seismic and a pressure sensor. This sensor is typically integrated in an alarm station and allows the detection of a debris flow event or in winter of an avalanche. Another typical application are rock avalanches because no other countermeasures are feasible (chap. 7.2)

<u>Ritigraben, Switzerland</u>

A debris flow alarm station in the Ritigraben protects the cantonal road from the village Visp up to the Matter valley in the canton of Valais. The station consists of two seismic sensors in the starting zone, hard- and software for controlling and data analysis as well as for alarm triggering. When an alarm is triggered, an electronic signal switches two traffic lights to red and a telephone alarm is transmitted to the police station in Visp. After 15 minutes the traffic lights switches to a blinking, yellow signal. During these 15 minutes the police checks whether the alarm was correct and conducts necessary measures. The station exists since summer 1995 and proved to be effective.

<u>Embd, Switzerland</u>

There are several avalanche detection and alarm systems in use in Switzerland. At the alarm station Embd avalanches from four starting zones are detected. The station is located at 2250 m a. s. l. and measures snow movements, forces on the detection cables (mechanical sensor) and concussions of the detection cables. When an avalanche is detected, alarm is released via radio and the traffic lights are switched on. In addition a message is transmitted to the head office in Sierre.

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[6] Extended information on these topic can be find in the IRASMOS deliverables D1.2 and D1.3.

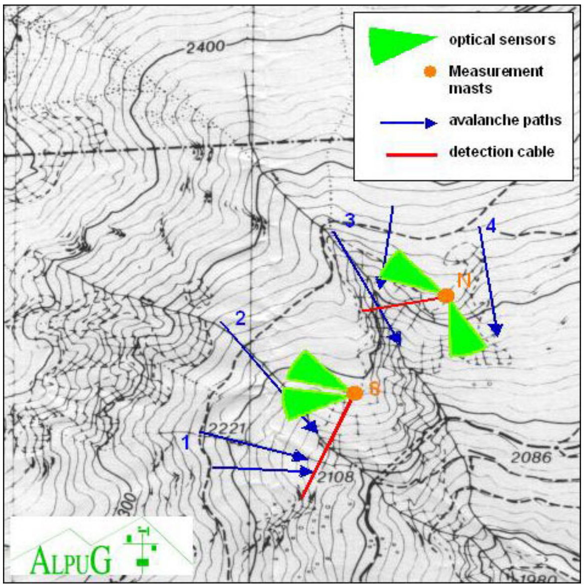


Figure 39: Alarm station Embd in the canton of Valais, Switzerland (source: AlpuG)

<u>Pians, Austria</u>

The protection concept of the village of Pians (Austria) at the outlet of Lattenbach catchment is based upon temporary road closures in case of occurring debris flows. A coupled system of monitoring instruments was installed in the catchment, comprising of (i) two climate stations in the upper part, (ii) geophones and ultrasound flow measuring devices in the lower reaches, and (iii) a real-time event documentation located at the gorge portion directly adjacent the fan, including geophones and ultrasound flow measuring and digital video equipment. The energy for the climate stations and the measurement station in the lower reaches is supplied by solar panels while the power supply for the real-time event documentation is taken from the public electricity network and supplemented by a battery in case of power breakdown. The data communication is based on radio transmission, and the data is stored locally in the master station. In case of an alert based on the exceedance of pre-defined thresholds in the measured data, the road is automatically blocked by traffic signs, warning lights and the video documentation are put into operation, and an additional SMS alert is transmitted to responsible authorities. Additionally, data is transmitted on a diurnal basis using DRS techniques to the control centre at the University of Natural Resources and Applied Life Sciences in Vienna, Austria.

Some problems associated with such warning and alert systems have to be highlighted. First of all, the systems used have to provide fail-proof measurements in the mountain environments they are used, not only with respect to power supply but also with respect to high temperature ranges and extreme mountain climate. Second, the data transmission has to be reliable, hence, GSM coverage has to be guaranteed by the telecommunication network provider or a sound radio transmission is inevitable. Third, the most sophisticated alert and warning systems are useless if the information transfer to the targeted stakeholder groups is not guaranteed. Thus, not only technical and scientific aspects of warning have to be considered, but also psychological and sociological aspects. It is essential that these systems are applied by the stakeholders involved, such as the regional and local authorities and the population. The acceptance of such systems remarkably decreases if the amount of false alerts or alarms increases.

4.3.5 Preparedness and emergency plans

When information on upcoming events is available appropriate intervention has to follow (chap. 4.3.5). This intervention has to be prepared in advance. Preparedness and emergency plans are often used to anticipate the emergency case. They include measures implemented mainly to reduce the consequences of natural disasters and consist of several elements:

- Evaluation of danger level: The activities have to be adapted to the different levels of danger. Hence, the quality and the frequency of information on meteorology, on the current process activity (e.g. observation of avalanches) in the area of interest, etc. should allow detecting the variability in the current danger level. In many cases the municipalities have the responsibility to perform the daily danger evaluation based on objective criteria. When critical conditions occur and risk becomes high, specialists should be involved.
- Identification of exposed areas: The next basic input to the activity plan should be hazard or risk maps. Based on these maps the elements at risk are identified, including buildings, roads, infrastructure and areas used for recreation. For each of these elements the acceptable risk levels when actions should be effectuated have to be defined. The higher the vulnerability (e.g. concentration of people outside) the lower hazard level should be accepted.
- Detailed activity plan: The different activities for the different hazard levels should be described with clear recommendations for the different elements at risk and with reference to the zones on the hazard map. The activity plan could for example be structured by defining activity lists for each danger level (Figure 40).
- Organization and responsibilities: There is a strong need for detailed descriptions of responsibilities for the different actions in the activity plan. The persons included in the plan should cover all levels in the community and involve all agencies having responsibility for safety e.g. mayor, representatives from the police, representatives from the inhabitants, natural hazard or specialists for information and dissemination. The number of persons included in the organization should reflect the risk level and the size of the affected areas. The plans should also take into consideration whether it have to be treated on a local, regional or national scale.
- Implementation and dissemination: Effective preparedness management relies on thorough integration of the plans at all levels of government and non-government involvement. Activities at each level (individual, group, community) affect the other levels and therefore needs careful planning. Plans for how information and dissemination of all decisions to the public and the media must also be included. The importance of dissemination of information is often neglected in preparedness planning, but all experience demonstrates that this part should be given high priority in the planning.
- Application and enhancements: There is a strong need for regular exercises to make sure that the plans work according to the intentions. Such exercises will demonstrate shortcomings and need for improvements in the planning both in the activity and organizational parts.

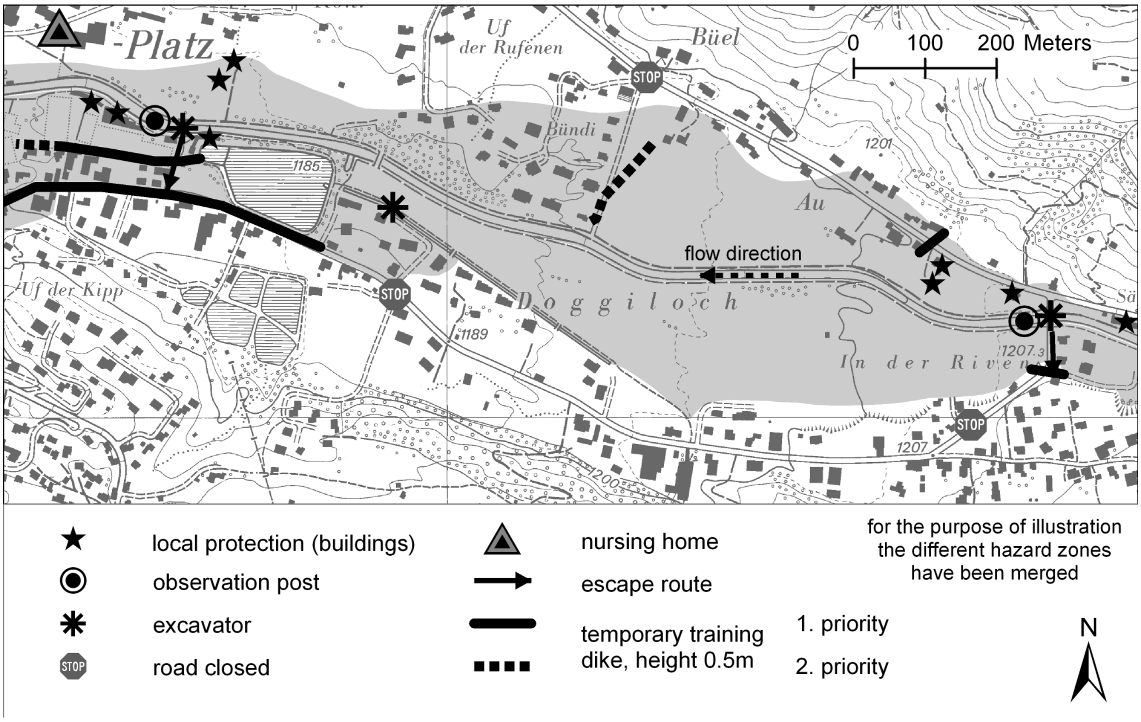


Figure 40: Example of an intervention plan from Switzerland (Romang & Wilhelm 2008). The intervention plan combines hazard and intervention measures. It is specific to a spatially defined object. During an event, this defined area is covered by a unit of the emergency services with one officer in charge. The design of the intervention plan is simple. The front page of the plan shows the hazard zones, special objects at risks, and the measures recommended. On the back side, additional text lists the material needed for the operation, provides important phone numbers and defines the rules for handling an intensification of the situation (event phases)

On November 15 2003 at 10 a.m. the order for immediate partial evacuation of the Cogolo village (Italy) due to imminent avalanche danger was given (Figure 41). Fortunately, this was only a drill of the Trentino civil protection drill carried out in Val di Pejo. The operation was organised by the Disaster Prevention Service of Provincia Autonoma di Trento through the AINEVA office with the collaboration of the Pejo municipal administration.

In the last ten years, three evacuation drills have been carried out for landslide danger prevention, and the Pejo drill was the first where danger was represented by unstable snow masses. In this way it was possible to verify and test the efficiency of rescue plans in case of avalanche and make villagers aware of the potential risk they may have to face.

Despite the need, in general such exercises are carried out to scarcely. To boost emergency management it would be absolutely necessary to put more emphasis on this point,

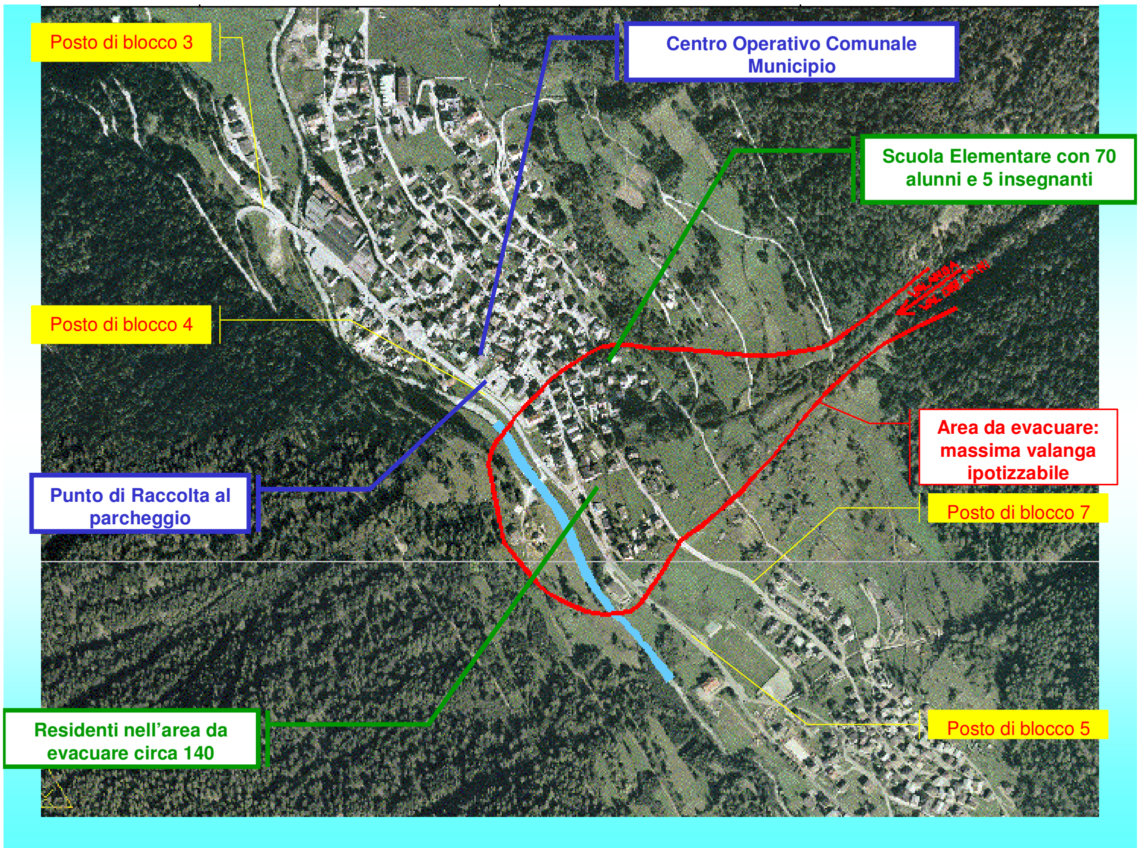


Figure 41: Evacuation plan Cogolo, Italy, showing the avalanche endangered area (red line) and the main features of the evacuation (area to be evacuated in red, school and houses to be evacuated in green, road closures in yellow, meeting point for evacuated persons and operational centre in blue) (by courtesy of Avalanche Office of Autonomous Province of Trento Italy)

Figure 42: Pictures from different phases of the evacuation drill (by courtesy of Avalanche Office of Autonomous Province of Trento Italy)

An aspect during emergencies that should not be underestimated nor in importance nor in needed time and effort is information. Correct and uniform information is of vital importance to avoid misunderstanding. Information must be included as one of the major components in the preparedness planning. Information is also of vital importance during accidents and when people have been evacuated to reduce the psychic strain and uncertainty. To ensure that significant information is disseminated to relevant people (public and media), use of common public meetings, telephone and radio/television can be suitable sources. One person should be assigned to be press representative during emergency operations. The press is always an important source to spread information, and consistent and correct information to the journalists will normally improve the quality of this information. Empirically, the importance of good information management is many times neglected.

4.4 Other Elements of non-structural Countermeasures

4.4.1 General information

Information of the population should be a regular activity and not only covered in emergencies. The benefit may be higher awareness, better education and acceptance of decisions. It is important not to panic but to inform reasonably and according to the situation and the public.

In several countries such as in France providing information is a legal requirement. The law of 1987 establishes the right of the population to be informed about foreseeable natural hazards and technological risks. The government is therefore obliged to provide information to all concerned. The law of 2003 on natural and technological risks and damage compensation has even increased the level of information which must be transmitted to the public. When a foreseeable PPR exists, the mayor is required to provide specific information every 2 years. In addition, there is also a lot of information presented in the web (www.prim.net).

Thus, from the point of view of a risk manager information should always be seen as a chance, not as an imposition. It has been clearly shown by the SWOT-analysis (chap. 2.7.3) that people in the IRASMOS countries are very open to the themes of natural hazards.

4.4.2 Specific education

Education to improve the competences related to natural hazard processes can be relevant for many people and purposes:

- Specialists performing hazard evaluation should continuously improve their capability to evaluate the hazard properly;
- Governmental employees dealing with natural hazards should know the current needs and challenges;
- Land use planners should have knowledge about natural hazards to ensure that natural hazards are properly allowed for at an early stage in the planning process.
- Technical staff in the municipalities responsible for building licenses should have adequate basic information
- Consulting engineers/companies should know about hazard elements to ensure they are included in the planning process and in the realization e.g. of buildings as well.

Based on a better knowledge, all the people living with risk can take more self-responsibility Harvey & Zweifel (2008) show the risk reducing effect of better formation but also of better equipment using data of avalanche accidents

4.4.3 Loss compensation

The psychic strain connected to disasters is high, especially if lives are lost. If economic concern comes in addition, this strain will be further worsened. Insurance companies as well as public funds and private donations play a major role in reducing this economical risk. Thus, all IRASMOS countries have systems of loss compensation.

In Norway the insurance against natural hazards is included in the standard conditions for fire insurance policies. This insurance includes full compensation for all material losses due to natural disasters. For other subjects like for example farming land, private roads and forest that can not be included in this insurance, the National Fund for Natural Disaster Assistance can compensate for part of the loss of value caused by the disaster, typically between 50 and 80%.

The French insurance system combines private funding and public decisions. Since 1992, the insurance companies receive a 9 % surtax for natural disasters. In case of floods, the warranty is effective if the national government (through the department prefect) decides to produce a natural disaster decree. This decision is the result of a negotiation between the national government and individuals or local authorities. In the case where a natural disaster decision has been taken, property damage should be covered by the natural disaster warranty which is included in every natural disaster insurance policy taken out by both individual parties and companies (FFSA, 2002). It covers any damage to houses, industrial and agricultural businesses, vehicles, etc. Since 2001, the excess price is increased in local communities where no risk prevention plans have been established in spite of many past natural disasters having occurred in the area. This has led to an increased number of local areas covered by a risk. A law passed on 13 July 1982 states that the natural disaster compensation system does not include personal damage. People wanting to be insured for those risks are obliged to take out additional contracts. Insurance companies generally only insure for low risk. The Central Tariffs Authority has been set up to ensure fairness in the system by fixing premiums. Nobody should be unable to obtain insurance even if located in an exposed area.

In Switzerland, damage due to natural hazards (not earthquakes) is covered by the compulsory building insurances. In addition, not insured losses are covered at least partly by public funds and in case of big events the private donations deliver impressive sums.

In Austria, natural hazards are not (yet) subject to compulsory insurance (Fuchs et al. 2007). Apart from the inclusion of losses resulting from hail, pressure due to snow load, rock fall and sliding processes in an optional storm damage insurance, no standardised product is currently available on the national insurance market. Moreover, the terms of business of this storm damage insurance explicitly exclude coverage of damage due to avalanches, floods and inundation, debris flows, earthquakes and similar extraordinary natural events (Schieferer 2006).

Furthermore, according to the constitution of the Republic of Austria, catastrophes resulting from natural hazards do not fall under the national jurisdiction. Thus, the responsibility for an aid to repair damage resulting from natural hazards generally rests with the federal states. As a consequence, any claim for damages is subject to a considerable insecurity, and any natural and artificial person has to take individual precautions. Thus, the society seems to be highly vulnerable to natural hazards in Austria.

However, the federal government enacted a law for financial support of the federal states in case of extraordinary losses due to natural hazards in the aftermath of the avalanche winter in 1951. The so-called 'law related to the catastrophe fund'[7] is the legal basis for the provision of national resources for

- preventive actions to construct and maintain torrent and avalanche control measures, and
- financial aids for the federal states to enable them to compensate individuals and private enterprises for losses due to natural hazards

The budget of the catastrophe fund originates from a defined percentage (since 1996: 1.1 %) of the federal share on the income taxes, capital gains taxes, and corporation taxes. The prescribed maximum reserves amount to EUR 29 million.

[7] Katastrophenfondsgesetz 1996, BGBl 201/1996

Chapter 5

Structural Countermeasures

5.1 Structural measures against snow avalanches

The development of structural countermeasures against snow avalanches started with extended settlement in the alpine areas in central Europe. In Switzerland as well as in Austria, their application was boosted by the avalanche winter 1950/51. Today, they are commonly used (Höller 2007) and their application can refer to a large body of experience and of literature but also on some administrative regulations (Margreth 2007).

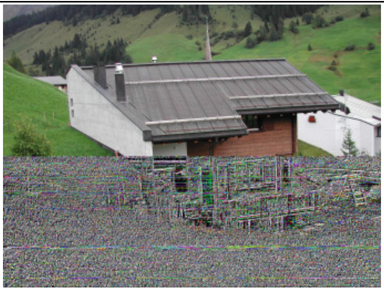
The first structural measures have been built in the release areas of known avalanche catchments. Today, the release zone is still a main area of interest for avalanche protection: the snow cover shall be prevented from gliding off and forming an avalanche. When an avalanche is at full speed, hardly any measures are possible, besides avoiding the avalanche track e.g. by galleries and tunnels. Thus, second, structural measures are applied in the lower transition area and the run-out zone, where the already decelerating snow masses can be additionally slowed down and stopped or at least deflected to less vulnerable areas. Table 13 gives an overview and a short description on the several countermeasures against snow avalanches that are in use in mountainous European countries today.

Table 13: Structural countermeasures against snow avalanches

Countermeasure	**Description**	**Example**
Snow drift regulation		
Snow fence	Snow fences are linear rows consisting of posts anchored to the ground combined with horizontal boards. The purpose of the snow fences is to collect drifting snow and thereby reduce snow heights in the starting zones, and to prevent formation of cornices. The fences are built on mountain plateaus and ridges above, and windward of the starting zones. Snow fences are usually 2-4 m high. Construction material is steel and impregnated wood mainly. The effect of the fences must be regarded as a supplement to other countermeasures, as fences alone will not eliminate avalanche hazard.	 *Visualisation of the effects of the saltation layer near a snow fence in Le Chazelet, France (photo: Cemagref)*

Jet roof	Jet roofs are inclined panels that accelerate the wind and direct it into the slope below. The purpose of jet roofs is to prevent the formation of cornices. The jet roofs are built at the edge of mountain plateaus and at ridges above, and windward of the starting zones, to direct the snow drift downhill. The effect of the ret roofs must be regarded as a supplement to other countermeasures, as jet roofs alone will not eliminate avalanche hazard. The roofs may prevent the formation of cornices, but transport drifting snow down slope where snow heights will increase and thereby lead to avalanche hazard.	 *Jet roof in Le Chazelet, France (photo: Cemagref)*
Wind baffle	A wind baffle consists of a trapezoidal board, turned upside down and fixed to one or two poles, which are anchored to the ground and facing the prevailing wind direction. The purpose of wind baffles is to create local zones of wind erosion of the snow cover. Thereby they can reduce or prevent avalanche release. Wind baffles should be located in wind exposed areas to ensure high wind speeds around the construction. Typical heights are 3 to 3.5 m; width is 1.5 m at the bottom and 3 m at the top. The use of this kind of countermeasure is limited.	 *A row of porous wind baffles with one trapezoidal panel in La Plagne, France (photo: Cemagref)*
Stabilizing constructions		
Permanent supporting structures	Permanent supporting constructions comprise two types: Rigid structures and flexible wire nets. Functionally, there are no differences between both designs. Both are erected more or less perpendicular to the slope and are well anchored in the ground. They act as barriers against creeping and gliding motions. Supporting constructions are built in the starting zone of the avalanche (release area). They are built in parallel rows, where each row is following the contour line. The distance between the rows depends mainly on the snow height, inclination of the slope and the ground conditions. The height of the structures must be dimensioned for the expected maximum snow heights for a specific return period (Margreth 2007). The structures have to bear mainly static loading, resulting from the creeping, gliding, and settling of the snow cover. Snow masses already in motion cannot be stopped by supporting structures. The constructions must be designed to withstand high forces, in the order of 10 to20 kPa, and the foundation of the constructions is therefore of great importance. Especially for the wire net constructions, the pull out forces on anchors will be high. Supporting constructions are the most commonly used countermeasure, especially in the Alpine countries, where several km of constructions are implemented each year.	 *Hill slope covered by supporting structures in Davos, Switzerland (photo: SLF)*  *Unloaded snow net. Restraints allow for deflecting the net when loaded (photo: SLF)*

Temporary supporting structures	Temporary supporting structures have the same function as permanent supporting structures. They are used in areas of reforestation, as the regenerating forest will provide the protection, when trees are high enough. Temporary supporting structures are usually designed for a lifetime of roughly 50 years. The usual types are timber rakes and tripods. While timber rakes are connectively built in a row, tripods are spaced at uniform distances. The success of temporary supporting structures depends on the success of reforestation, which is impacted by other factors such as ungulate browsing, choice of plants, vegetation period, snow height and light conditions. (Leuenberger 2003)	 *Combined timber rakes and tripods (photo: WSL/SLF)*
Afforestation	In general, protection forest is one of the most cost-effective mitigation measures against snow avalanches in alpine countries. Thus, afforestations may provide a reliable and sustainable protection against snow avalanches. However, natural conditions in potential avalanche release zones may be rather unfavourable for the growth of trees. Moreover, it may need up to some decades till the trees are high and strong enough to withstand the snow creeping. Thus, afforestations have to be carefully adapted to the habitat, may need additional help by temporary supporting structures and, finally, need some time to become effective.	 *Vertical structuring of cluster afforestation after 80-120 years (photo: WSL/SLF)*
Breaking constructions		
Avalanche breaker	Breaking mounds are structures built in a dice pattern to slow down the speed of the avalanche. The structures are placed in the run-out zone where avalanche speeds are relatively low. Braking mounds are usually built of earth materials, but concrete, reinforced earth structures and other materials are used as well. They are most effective against wet snow avalanches. Fluidized dry snow avalanche will usually not be stopped by braking mounds. New dimensioning criteria for catching and deflection dams, plus breaking mounds are recently developed in the EU-Satsie project, but further studies, both practical and theoretical, are needed to validate the dimensioning criteria (Jóhannesson 2006).	 *Avalanche breakers in Iceland (photo: WSL/SLF)*
Deflecting and catching constructions		
Catching dam	Catching dams are built transversally to the flow direction of an avalanche. They are intended to stop avalanches completely before they can reach objects at risk. The design of dam height depends on the velocity and flowing height of the design avalanche. Large avalanches flowing at high speed can hardly be stopped by catching dams and there are many examples of avalanches overtopping such dams. The effectiveness of catching dams is therefore dependent upon a location near the end of the run-out zone of the avalanches. In addition, there must be sufficient space above a catching dam to store the volume of snow corresponding to the tongue of the design avalanche successfully stopped by the dam.	 *Avalanche and debris flow catching dam. The smaller dams in the front view are intended to slow down the flow (photo: SLF)*

Deflecting and catching dam	Deflecting dams are designed to deflect flowing snow out of an endangered area. The structures are inclined to the flow direction by a certain deflection angle. Deflecting dams may be used to divert avalanches away from objects at risk. Deflecting dams are often a cost-effective solution and several examples of successful deflections of medium sized avalanches have been documented. The dimension (height) of the dam is very essential for its effectiveness. Several avalanches in one path can fill up a dam which can cause overtopping by subsequent avalanches.	 *Deflection dam protecting a settlement (photo: NGI))*
Gallery	Avalanche sheds or galleries are designed to protect roads and railroads by allowing avalanches to pass over the object. A typical shed is a concrete structure with a thick inner wall and roof, and either with columns or a solid outer wall. There are different guidelines in Europe for calculation of design loads and use of load cases and load factors (e.g. ASTRA & SBB 2007 for Switzerland). Norwegian guidelines require design for four different load cases. Sheds are widely used for protection of roads and railroads, and are regarded to give near 100 % protection when properly designed. However, they are expensive so careful cost analyses are required for their need, benefits and alternatives.	 *Avalanche shed used for highway protection*
Tunnel	Similar to galleries this measure is used to protect roads. Because tunnels are very expensive, they are only used when other measures are not feasible because of topographic conditions, or when there are a great number of avalanches crossing the road.	 *Tunnel in loose deposit used to protect a highway in Norway (photo: NGI)*
Reinforcements		
Local protection	Especially buildings can be structurally reinforced to withstand the impact forces of an avalanche. Typically these reinforcements are encouraged by building codes in settled hazard zones with lower to medium impact forces.	 Residential building with a reinforced wall on the hillside (photo: SLF)

5.2 Structural measures against debris flows

Structural measures against torrents have been applied in Alpine torrents already for centuries (Vischer 2003). Not only silvicultural management but also constructional works such as check-dams or deflection dams were important to protect early settlements (Luzian 2002). However, due to the complexity of processes in torrential catchments (e.g. the interaction of slope and channel processes) and the limited knowledge about it, hazardous processes tended to be underestimated and disasters regularly occurred (Aulitzky et al. 1994). In addition, some measures had unwanted side-effects such as the deficit of sediments in the lower channel sections as well as in the main rivers leading to erosional problems. Thus, new concepts had to be created. The underlying concept was to attribute different functions to different structures since the experience had shown that individual structures might not be able to fulfil multiple functions. As a result, functional classifications were developed (Üblagger 1973).

In recent years, the implementation of different adapted functional structures is state of the art. Due to the variety of processes related to debris flows, there exist several measures that are in use in mountainous European countries to reduce debris flow risks (VanDine 1996, Hübl & Fiebiger 2005). Generally, countermeasures in torrents (Table 14) can be applied to:

- Increase the stability of the slopes and decrease erosional processes in the catchment area;
- Consolidate and stabilize the channel bed (prevent erosion);
- Transform debris flows in water and solid discharge with less energy;
- Slow down or retain the solid discharge at or near the fan apex;
- ensure the flow from the fan apex to the main river without flooding on the fan.

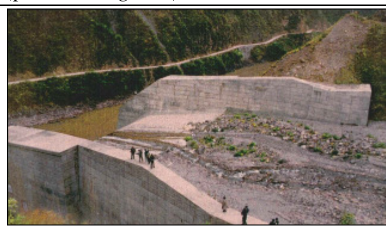
Table 14: Structural countermeasures against debris flows

Countermeasure	**Description**	**Example**
Increase slope stability		
Drainage	The ecosystem of wet or unstable areas can be stabilized by drainage systems which drain the water out of unstable ground layers. In such a way, high pore water pressure along potential shear surfaces can be avoided and consequently reduce the danger of occurrence of sliding layers.	 *Drainage system (Florineth 2004)*
Soil bio engineering	Soil bioengineering uses dead and alive plant material to cope with erosion. These measures can initiate or accelerate phyto-sociological successions and processes, reduce surface erosion, improve soil water conditions and control shallow land sliding. The combination of soil bioengineering applications protecting the surface (seeding) and stabilizing structures made of wood is very successful in practice. Up to the time when the seeding or the live plants reach their full efficiency, the wooden technical constructions will stabilize the soil. The success of soil bioengineering measures depends on the stabilizing effect	 *Brush layer (Florineth 2004)*

	of the previously installed technical structures (Hübl & Fiebiger, 2005).	
Afforestation	Mass movements at steep slopes are frequent phenomena in mountain areas. They can be reduced by stabilizing the masses with afforestation by bushes and trees, whose roots consolidate the ground. However, the effect is limited. Therefore, this measure is an additional action in the frame work of technical or other biological countermeasures in order to develop a healthy forest and provide optimal natural hazard safety for alpine regions.	 *Cluster afforestation after 40-80 years (photo: WSL/SLF)*
Consolidation / Stabilization		
Sill	Due to the high energy of discharge in steep torrential channels, lateral and vertical erosion can occur. This erosion causes a lowering of the channel bed and further instable embankments and slopes. According to the natural slope and bed material, the stream bed can be stabilized by several sills, installed in series with a mostly constant distance. The height-difference from one field to another should not exceed 1 m; the bed slope should not exceed 5 %. A series of sills is able to reduce the flow velocity by permanent alteration of the hydraulic conditions from supercritical (Fr>1) to sub critical (Fr<1) flow. Thus, fields in between the sills tend to scouring. Therefore, the design of sills concentrates on keeping local scours as shallow as possible, so that the scours will not destabilise the banks and the sills themselves.	 *Series of sills out of stone masonry (photo: IAN-BOKU)*
Ramp	The bed of channels which are endangered by vertical erosion can be stabilized by local structures such as block-ramps. Block-ramps are hydraulic structures with a coarse surface and a relatively low gradient. In terms of nature-like and ecological structures, ramps should be preferred whenever possible. Block-ramps – like most of the other hydraulic structures – are installed for dissipating energy of the water. In the case of block-ramps, the energy-transformation occurs by the turbulence of the discharge, which is caused by the high roughness of block-ramps. The resistance of the ramp body against the mechanical forces of the discharge is the determining factor for stability. (Whittaker & Jäggi 1986, ÖWAV, 2003)	 *Bedded block-ramp (photo: IAN-BOKU)*
Closed check dam	A closed check dam is a structure placed transversally to the torrent, from one bank to the other and permanently backfilled. Mostly, closed check dams are designed as gravity dams or single standing structures, but there exists a wide variety of other structural designs. Usually, series of check dams are built and spaced regularly along the channel. The slope gentling due to the check dam induces a flow velocity reduction. As a consequence the erosional capacity of the flow is reduced and the sedimentation is forced. Furthermore, bank erosion is limited as check dams tend to reduce the shifting of the torrent. In other cases, check dams can stabilize the banks, the backfill acting as an abutment for potential landslides. (Deymier et al. 1995) The long-time performance of flexible debris flow	 *Series of gravity check dams (photo: Cemagref)*

	barriers (see also paragraph about temporary debris deposition) as a substitute for rigid check dams was investigated inside the framework of a research project (Wendeler 2008). These barriers remain backfilled in the river bed in order to have the same function as rigid check dams with the advantage of an easy and fast installation time.	 Series of flexible ring net barriers as check dams (photo: WSL)
Transformation of process		
Debris flow breaker	A debris flow breaker will be the first upstream measure of a series of structures. Its function is to decrease the energy level of the debris flow. Moreover, the debris flow masses can be deposited at an intended location in a more or less controlled way (Kettl, 1984). Downstream, the debris flow breaker is followed by several structures controlling the sediment management. In special cases, debris flow breakers can operate as an avalanche breaker. (Armanini et al. 2004)	 *Debris flow breaker (photo: IAN-BOKU)*
Drop structure	Debris flows loose most of their dynamic forces if they fall down over a certain height and crash on to a horizontal surface. This effect is utilised by drop structures. Drop structures are especially qualified for steep fans and should be built in series. Even on steep fans several thousand cubic meters of solids can be deposited. The small grain sizes and the fines will be cleared away, so there is less danger of erosion in the downstream channel. There is no unwanted water retention possible. Even woody debris cannot interfere with this.	 *Series of drop structures in combination with a deflection wall (Jenni & Reiterer, 2002)*
Organic debris filtration		
Open check dam (rake)	As the woody debris tends to block the functional openings of open check dams, it has to be filtered out in a way that allows undisturbed transport of water and mineral sediments. Woody debris rakes are always realized in combination with other sediment management measures. They can be constructed as independent structures or integrated into a structure for filtering or dosing sediments.	 *V-shaped woody debris rake (photo: IAN-BOKU)*
Permanent debris deposition		
Retention basin	A terminal barrier dam aims at controlling the solid discharge. The transported particles are stopped progressively due to the reduced flow velocity in the retention basin and the limited size of openings in the terminal dam. The backfill increases progressively up to the top of the dam by alluvial accumulation. The area upstream of the debris barrier can be excavated to reduce the gradient and to increase storage capacity. Depending on the site, an inlet structure	 *overview from upstream of a retention*

	may be constructed upstream of the storage basin to minimize erosion of the streambed. After a debris flow has occurred, the coarse-grained debris trapped behind the debris barrier must be removed. This form of debris flow control is generally considered to be the most sophisticated and generally the most costly. Properly located, designed, and constructed, it may be the most positive form of debris flow control. To avoid erosion of the channel downstream of the retention basin, it is interesting to facilitate self-cleaning. However, mostly an additional stabilization of the channel downstream e.g. by sills is necessary. (Zollinger 1985)	*basin (photo: IAN-BOKU)*
Temporary debris deposition		
Open check dam	Apparent problems with debris retention dams and the problems caused by bedload deficit downstream of these structures (erosion) initiated attempts to manage the bedload transport with temporary sediment deposition. The idea behind is to let the smaller grain sizes pass through and retain the larger ones to cut the peaks of discharge. Open check dams have an opening in their central part, often provided with grids or bars, with the function of regulating the solid discharge In modern debris flow mitigation, debris check dams are located downstream of debris flow breakers, followed by an array of check dams for stabilizing the channel. This concept can be described as a "functional chain" or a "torrential training system". The requirements to these structures can be summarized as follows: ▪ Hazardous discharge and sediment peaks should be retained as well as woody debris ▪ Regular sediment transport should be possible ▪ The retention volume of the basin should continuously be available for flood and debris flow events, but solids should be retained during an event and removed again by the mean discharge. These requirements were introduced by Üblagger (1973) as "sorting" and "dosing". ▪ Maintenance access is necessary for artificial clearing ▪ Migration of aquatic fauna should not be prevented Flexible ring net barriers can also be used for debris and driftwood retention (Wendeler 2008). These barriers allow the normal sediment transport due to a basal opening and will be only activated in a debris flow event case. Then, the larger grain sizes and the driftwood are retained whereas the water with sediment can pass through. Flexible debris flow barriers consist of high-tensile steel wire ring nets which are fixed with shackles between support ropes anchored in the slopes. Due to lightweight components, the installation is fast and easy, even in hard accessible mountainous areas. The ring nets blend into the landscape and are, compared to massive constructions, hardly visible from a distance.	 *A 12 meters high open check dam, just after construction (photo: Cemagref)*  A flexible barrier as temporary debris retention structure (photo: WSL)
Protection / Deflection		

Deflection structures	Deflection structures are installed to redirect debris flows away from high endangered areas towards areas with low vulnerability. Deflection walls are similar to lateral berms in the way that they are usually built immediately down slope from the apex of the debris fan, and parallel to the desired path of the debris flow whose lateral movement they are used to constrain. They differ from lateral walls or berms in that they deflect the flow path and prevent it from going straight. They can be used to protect a structure, deflect the flow to another area of the fan, or increase the length of the flow path, thereby decreasing the overall gradient and encouraging deposition. Walls are usually constructed of reinforced concrete; berms are usually constructed from local materials, but can be a composite.	 *Deflection dam (IAN-BOKU, 2003)*
Local protection	Especially buildings can be structurally (e.g. stronger walls) or functionally reinforced (e.g. optimized placement of openings such as doors and windows) to withstand the impact forces of a debris flow and reduce flood damage. Typically these reinforcements are encouraged by building codes in settled hazard zones with lower to medium impact forces.	
Discharge control		
Transport channel	Transport channels are generally installed on the alluvial fans of torrents. Their main purpose is to ensure the flow of a given discharge without flooding or flow diversion into the surrounding zones. Thus, a crucial point is the size of their cross section which will determine their hydraulic capacity. A secondary purpose is to avoid excessive erosion in that calibrated reach, especially in the case that the transport channel is built downstream of a sediment trap that will catch the main part of the sediment load and deliver "clear" erosive water.	 *Transport channel made of masonry (photo: tur gmbh)*
Overpass and road tunnels	If the places to protect by debris flow are crossed by important way of communications like streets and railways, an overpass or a road channels can be built to guarantee a good protection for the infrastructure.	 *Shoot over tunnel to protect the railway Baoji-Chengdu (China) against debris flows*

5.3 Structural measures against rock avalanches

There exist only few countermeasures against rock avalanches. The frequency of this hazard is just to low and therefore the planning of mitigation measures has not been prioritized. Moreover, the triggering mechanisms have not yet been fully understood making it difficult to know how countermeasures best could be implemented. The large volume and great forces involved in rock avalanches makes it rather impossible to implement traditional physical measures used for smaller rock falls, e.g. anchors, rock bolts, nets and concrete ribs. Thus, experiences on countermeasures for rock avalanches are mainly based on monitoring systems including early warning and evacuation of endangered zones. Only two possible physical measures might be relevant for rock avalanches:

- Blasting: There exist only few examples of rock avalanches that were initiated by explosives. On the territory of the former Soviet Union rock avalanches were triggered artificially to form dams for hydropower generation and debris flow protection. However, there exist no examples where explosives have been used with primary objective to reduce risk of rock avalanches. Because the consequences of the blasting operation are hardly predictable and the involved rock volumes are huge, blasting seems not be a recommendable measure for rock avalanches in European mountain.
- Drainage systems (underground water drainage, diversion of surface water): Many of the rock avalanches are presumably triggered by building up of cleft water pressure. Measures reducing the possibilities of water to be stored in the unstable rock mass will in such cases improve the stability and reduce the rock avalanche hazard. Such measures are widely used for the smaller rock slides where joint geometry affecting the water flow is better known. However, for big rock avalanches such measures have only been exceptionally used.

Unlike snow avalanches and debris flows, structural measures are not feasible to manage rock avalanches. The risks have to be handled mainly by non-structural measures.

5.4 Effectiveness of countermeasures

The effectiveness of countermeasures plays an important role when it comes to decide on their implementation. The effectiveness determines whether the required level of safety can be achieved and allows for further investigations such as cost-benefit analyses. Moreover, the concept of effectiveness enhances the planning of countermeasures because it encourages constant optimisation and it helps to search for risk-oriented measures and not only for hazard-oriented solutions, which has been the traditional approach.

In general, the effectiveness can be assessed by estimating the influence of the countermeasure on the risk formula (chap. 3.1) and its parameters (Table 15). The effectiveness of a countermeasure is then calculated as the difference between the initial risk without the countermeasure and the residual risk with the countermeasure.

Table 15: Effects of countermeasures on the parameters of the risk formula

	Effect on …			
	p_j probability (frequency) of scenario j	**$P_{i,j}$ probability that an object i is present, while scenario j is occurring**	**A_i value of object i**	**$v_{i,j}$ vulnerability of object I due to scenario j**
non-structural measures: land-use planning	no influence	possible reduction in a long-term perspective	possible reduction in a very long-term perspective	indirect reduction e.g. by building codes
non-structural measures: special case relocation of	no influence	strong reduction / elimination of the risk	strong reduction / elimination of the risk	no influence

buildings based on land-use planning				
non-structural measures: temporary measures, emergency management	possible e.g. by artificial release	possible e.g. by road closures or evacuations	no influence	possible e.g. by mobile protection measures / temporary reinforcements
structural measures	to reduce probability is a main objective of structural countermeasures	in exceptional cases, e.g. shelters or galleries	no influence	lower vulnerability as a result of reduced impacts by hazard processes and of reinforcement of buildings

However, due to scientific gaps as well as due to the peculiarities of each situation, effectiveness is not always clearly quantifiable and uncertainties may be remarkable. As a consequence, decisions on countermeasures may differ considerably from one situation to another. These differences also influence the land-use in the protected area and therefore may have important economic and socio-political effects.

To improve this situation, in Switzerland a general procedure as well as instructions for selected countermeasures (including protection forests) against snow avalanches, rockfall, landslides, debris flows and floods are currently under development (Romang et al. 2008c). This procedure might be of interest also for a broader international application and is presented in the following chapters. However, the procedure is limited to structural measures, which are often preferred to protect settled areas and thus are of great importance. In near future, the procedure should mainly contribute to comprehensive and comparable technical evaluations of the hazard reduction effect of structural countermeasures. The integration of non-structural measures is basically possible but not done yet. To strengthen the integral approach also in the planning and evaluation of countermeasures this implementation should be a next step.

5.4.1 Basic principles

Countermeasures that are considered in hazard maps should be in accordance to some basic principles (Table 16). These principles make sure that a minimal level of quality, safety and sustainability is fulfilled. Because the presented Swiss approach focuses on settlements, these basic principles are rather strict. They would be less restrictive e.g. for the protection of traffic lines with temporary measures. However, also in situations with a probably lower level of protection or reliability, some minimal standard based on the following list should be defined.

Table 16: Basic principles for the consideration of countermeasures hazard maps

no.	principle	Rule
1.	Quantification of hazard reduction	The effectiveness of countermeasures is estimated by the effect on the risk parameters, e.g. the intensity and probability of hazardous processes. Thus this effect has to be quantifiable.
2.	Effect exceeds uncertainties	The effect of the countermeasures has to be bigger than the uncertainties relied to the hazard and risk management are.
3.	Assessment of scenarios	The effect of the countermeasures has to be analysed for different scenarios such as the relevant scenarios for hazard maps (e.g. in Switzerland with a theoretic return period of 30, 100 and 300 years) as well as for exceedance scenarios representing a remarkable overload of the countermeasures.
4.	Delineation of	The countermeasures have to be assessed focusing on the single element / structure as

	the system	well as with respect the whole system (e.g. a catchment area with several interacting elements).
5.	Permanent availability	Countermeasures considered in hazard maps have to be realised at the time of the assessment and have to be permanently available over the next 50 years, at least.
6.	Inspection and maintenance	Inspection, maintenance and, if necessary, renovation and renewal work have to be guaranteed for every countermeasure.
7.	Temporary countermeasures	Temporary countermeasures such as artificial release of snow avalanches or mobile flood protection generally are not considered in hazard maps.
8.	New countermeasures	When planning new countermeasures their effect can be assessed the same way as for existing countermeasures. However, the consideration in land-use planning and similar products implies their realisation first.
9.	Time effects	Countermeasures as well as processes are changing over time. Thus, the consideration of countermeasures implies on the one hand maintenance of the countermeasures and of the whole system and on the other hand a periodic verification of the risk situation.

These basic principles may substantially improve the assessment and the management of existing as well as of new countermeasures because of three main reasons:

- First, the principles 1, 3, 4 and 8 define the basic conditions for the assessment including the methods and the data.
- Second, the principles 2, 5 and 7 lead to a remarkably pre-selection of countermeasures. But it has to be remembered that these principles are valid only for settlement protection. In other cases they probably will not be handled so strict.
- Third, the principles 6 and 9 highlight the long-term aspects of risk management and reveal the responsibility of human beings to continuously monitor and maintain the reliability and functionality of the countermeasures.

5.4.2 General approach

When the basic principles are fulfilled the effectiveness of the countermeasures can be analyzed in more detail. The need for such a study may arise either with regard to already existing measures that have to be assessed e.g. for possible effects on hazard zones or when new countermeasures are planned and their effectiveness has to be assessed in advance. Although there may be some differences e.g. concerning the available data or the design criteria of the countermeasures, the same general approach can be used for both tasks (Figure 43). This approach is subdivided in three main steps called general assessment, assessment of countermeasures and assessment of effectiveness. These three steps are followed by the pre-discussion of the implementation e.g. in land-use. Because this step is covered not only by hazard and risk specialists it is treated separately.

Step 1: general assessment

The main goal of the first step is to decide whether the effect of the countermeasures may be relevant for the hazard assessment or not. To answer this question, basic information on the processes as well as on the countermeasures is needed. The level of detail varies with respect to the situation, the hazard and the measures. However, with regard to the following steps it is generally recommended to go further into detail than minimally required for step 1. Based on the information on processes and measures the situation is evaluated generally: are the measures arranged with respect to the whole system (e.g. avalanche dam below multi-release zones respecting the different avalanche paths) and does a hazard reduction seem probable (e.g. is the type of measure adapted to the hazard)? If yes, a relevant reduction effect is assumed. If not, the countermeasures will still be analysed in detail when negative effects (e.g. higher intensity of hazard processes) might occur. Else the procedure is finished here and the hazard assessment is done without any respect to the countermeasures.

Step 2: assessment of countermeasures

In the second step the countermeasures are evaluated technically by determining their reliability. This step goes much more into detail than the first one. Thus, the information on processes as well as on countermeasures has to be enhanced. The hazard should be described by different hazard scenarios and by their impact in the structure. Already existing structures should be assessed in the field, focussing e.g. on the documentation and the evaluation of the current state of the construction. Then the reliability is defined by analysing structural safety, serviceability and durability of the countermeasures. These concepts from engineering practice (Eurocode 2002) are well suited to characterise countermeasures against natural hazards, too. Generally, structural safety guarantees the stability of the structure, serviceability ensures its functionality and, finally, durability provides for a long lasting quality of the structure. As shown by the diagram structural safety always has to be fulfilled. Else the structure is not reliable. Because not all countermeasures depend on stability (e.g. drainage systems) structural safety can also be bypassed. For serviceability the diagram additionally asks whether the structure might fail functionally or not. For example if the cross-section of a check dam in a torrent is blocked by debris its serviceability is not fulfilled anymore. Depending on the load, the type of structure and the banks this deficiency not necessarily leads to a failure but it might so. Finally, durability is less weighted than the other to factors. This is mainly due to the fact that deficits are not immediately critical and can be solved in the near future. However, this assumption implies for a well organised and regular maintenance service. In situations where different structures interact (e.g. series of check dams) not only the single structure but also the whole system of countermeasures has to be assessed similarly. Finally, the reliability is defined according to the flow chart (Figure 43) distinguishing high, limited and low reliability. If the reliability is low and no additional negative effects have to be expected, the procedure will finish here.

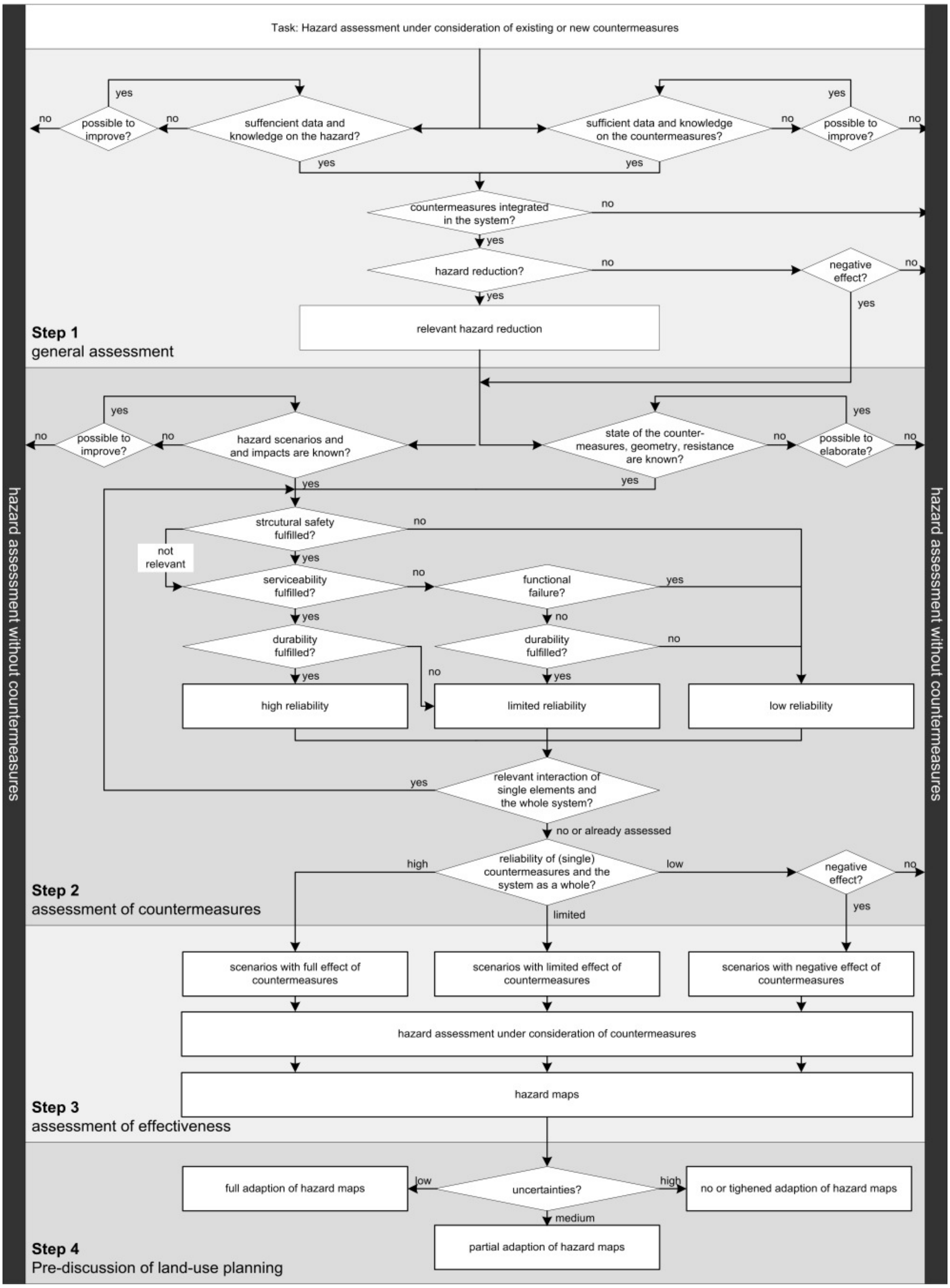


Figure 43: Procedure for the assessment of the effect of countermeasures on hazard processes

Step 3: assessment of effectiveness

The third step contains the hazard assessment under consideration of the countermeasures with respect to their reliability. In scenarios with full effect the countermeasures are considered to work as good as possible. The hazard will be reduced depending on the impact (e.g. flow velocity) and geometric conditions (e.g. dam height) of the structure. In scenarios with limited effect the countermeasures will be partly effective. These scenarios result from problems with serviceability or durability. For example a partially backfill of an avalanche dam reduces its serviceability and thus the effective dam height is reduced. The dam still may have an effect but less than in perfect condition. Admittedly, in such situations the limits to functional failure are not that strict. Scenarios with negative effect mostly lead to more severe hazards (e.g. increased debris load due to dam failure). The hazard assessment is then concluded by hazard maps for each scenario (depending on return period of the process and reliability of the countermeasures).

Step 4: Pre-discussion of land-use planning

In the final step recommendations are prepared for the implementation of the hazard map in land use planning. Especially the uncertainties in the whole assessment should be evaluated from a general view. Based on this information the adaptation of already existing hazard zones but also the appropriate use of protected areas in the reach of new countermeasures can be discussed. It should always be kept in mind that natural hazards are only one relevant point for land-use planning and that the people who are in charge of it are not hazard and risk specialists. Hence the information provided by the hazard assessment should be simple and clear.

5.5 Concluding Remarks and Outlook

Today, risk managers have several possibilities at their disposal to reduce risks. First, land-use planning based on hazard maps should be the leading strategy. If there exists locations for settlements with less restrictions and lower costs for development than in the reach of natural hazards, it is mostly reasonable to select these alternatives. Second, structural as well as non-structural measures can be used to reduce and to control risks in preventive, interventive and recovery phases. Generally risk managers should take advantage of all these different alternatives and seek for optimal combinations.

However, the crucial point in this respect is effectiveness. Countermeasures can only be compared and optimally selected when their effectiveness is known. For structural measures the knowledge is continuously improving. In recent years, several studies focused on the interaction of hazard processes and countermeasures (Johannesson 2006). The results help to estimate more accurately the effect of countermeasures in a specific situation. Other authors aimed at developing a general framework for the assessment of effectiveness (Romang & Margreth 2006), which was also illustrated in the previous chapters. In contrast, the situation with regard to non-structural measures is worse. Only little information is available (e.g. empirical values for the artificial release of snow avalanches) although their effectiveness in general seems to be out of question. As a consequence real integral planning is yet difficult. But if its basic idea is respected on the conceptual level, there might result solutions which head for a more integrated risk management than it used to be.

To further develop integral planning and evaluation of countermeasures, scientific work should concentrate on several aspects: first, the knowledge on the effectiveness should be further improved for structural as well as for non-structural measures. Second, case studies of integral approaches should be elaborated to illustrate and to promote the idea of integral risk management. Third, costs and benefits related to natural hazards risk management should be further analysed, especially focussing on indirect economic effects. And fourth, the long-term perspective of risk management should be emphasised more e.g. by proving decision helps for an optimal land management.

Chapter 6

Economic Aspects

6.1 Why economic Evaluation?

Preventive action against natural hazards requires high investments in infrastructure and organization as well as political assertiveness, while it provides an increase in public safety – a non-exclusive and non-rivalling good. The public good character of risk mitigation induces well known inefficiency issues that have been discussed in detail by Public Choice theory (Frey & Kirchgässner 2002). As public goods imply market failure, risk mitigation projects are foremost planned and implemented by the responsible public authorities. In most European countries public authorities hold a constitutional mandate to protect their citizen from natural hazards. In this chapter, we therefore refer to the protection against natural hazards as a public good. However, this is not to say that the importance of private mitigating actions should be neglected as they can significantly reduce the consequences of natural hazards.

Within an integrated approach to natural hazard management, the economic evaluation of countermeasures deals with the question of how much money society would optimally spend to reduce the risk resulting from a specific hazard source. The main task of evaluation is thus to determine society's willingness to pay (WTP) for reductions in risk and society's willingness to accept a specific level of residual risk, respectively. By this understanding, economic risk evaluation aims at providing a decision basis on competing risk mitigation projects or policies. The shift from a hazard-based toward a risk-based management of gravitational and other natural hazards heightens the importance of the economic evaluation of risk mitigation projects and policies. Therefore, we will address the challenges associated with the evaluation of countermeasures against natural hazards, providing a condensed overview on the theoretical basis of risk evaluation approaches and the main practical issues evolving with natural hazard mitigation projects and policies.

6.2 Theoretic Background of economic Evaluation

Three main conceptual approaches have developed in recent years to evaluate mitigation projects and policies. The common approach in environmental economics is cost-benefit analysis (CBA), which estimates societal WTP for changes in the risks to human life and property in monetary terms. By contrast, the common approach often used by government agencies and in health economics is cost-effectiveness analysis (CEA), which evaluates alternative mitigation projects by either maximizing risk reduction from a given budget or by minimizing costs to reach a default safety standard. In many evaluations of environmental goods and services, monetizing the utility of certain action is not feasible or insufficiently reflects people's preferences for such action. In these domains, analysts often draw on multi-criteria analysis (MCA), which is a structured decision-making process that integrates multiple criteria in a formal way (Eisenführ & Weber 2003; Keeney & Raiffa 1993). In Table 17, we summarize the cornerstones and domains of application of both approaches.

Table 17: Summary of the concepts and the domains of application of CBA and CEA

Method	**CBA**	**CEA**	**MCA**
Decision Rule	„Maximize net benefit"	„Minimize risk from a given budget"	„Maximize (ordinal) utility"
Theoretic Background	Neoclassical Welfare Economics	Decision science / Extra-welfarism	Decision science
Aims at	Maximizing societal benefit from risk reduction	Maximizing public safety from risk reduction	Maximizing (ordinal) utility from risk reduction
Applied mainly to	Environmental Risks: Costs theoretically unlimited Low baseline risk ($R < 10^{-4}$) Population based view Long-term perspective	Health Risks: Costs constrained High baseline risk ($R \sim 10^{-2}$) Affected based view Short-term perspective	All areas of decision-making: Costs are but one criterion Baseline risk is not decisive, but changes in risk are Views of affected and not affected can be integrated and weighted

In order to understand common grounds and differences of these concepts, it is necessary to identify and analyze the impacts of natural hazard mitigation over time. Mitigation measures aim at avoiding or at least reducing risks to life and limb as well as to property. Consequently, benefits of mitigation consist of the prevented losses, the averted affection of local economies, and the gain in perceived security obtained by the endangered people. The implied costs include resources directly invested in the implementation, operation, and maintenance of mitigation measures as well as indirect costs caused e.g., by reductions in property values due to changes in zoning or by business interruptions due to preventive evacuations. A third type of costs commonly neglected in natural hazard management is externalities imposed to third parties and associated with specific mitigation measures (e.g., negative impacts on the beauty of scenery). Summarizing, mitigation of natural hazards can be seen as an investment in future safety and eventually affects future consumption possibilities (Ganderton 2005).

Decisions upon mitigation measures are particularly thorny, as they require difficult tradeoffs between the money to be spent preventatively on mitigating action and the damages to be expected by natural hazards. Both, the impact of mitigation and the expected damages involve uncertainties, mainly because hazard incidences are hardly predictable in magnitude and impact. Additionally, the exposure of values at risk is likely to change over time—as does the perception of risk, which is more strongly related to exposure than to magnitude (Renn et al. 1992). Furthermore, the perception of natural risks is different from technical risks insofar as natural risks are often seen as recurring, non-influenceable "acts of god" (Slovic 2000). All of the described characteristics are inherent companions of natural hazards and influence the evaluation of risks from natural hazards. However, CBA, CEA and MCA deal with them in different manners. In order to better understand the three conceptual approaches to risk evaluation, we will briefly review their rationales in the following sections.

6.3 Rationales of Cost-Benefit Analysis (CBA)

The concept of CBA acts on the fundamental goal of welfare economics that society seeks to maximize social welfare by allocating its resources in such a way that any reallocation would make it worse off. Referring to natural hazards, society operates at its safety optimum, if and only if the average expected costs due to natural hazards and the mitigation measures already employed could not be lowered by a de- or increase in risk mitigation. Constrained by scarce public resources and competing public interests, these safety optima are not static but reflect actual societal values and preferences (Keeney 1995).

CBA bears on the assumption that the utility brought about by a good or service – in this case increased safety against a natural hazard – decreases marginally with increasing amounts of safety, while the cost to reduce risk, i.e. the costs of risk mitigation measures increases marginally with an increasing level of safety (Figure 44). Decreasing marginal utilities of mitigation ($\partial^2 U(Q)/\partial Q^2 < 0$) state that dependent on how much of the initial risk is already reduced, any further unit of risk reduction becomes less and less useful. Increasing marginal costs ($\partial^2 C(Q)/\partial Q^2 > 0$) are due to the employment of redundant and less cost-effective measures, which have to be adopted to eventually further reduce already small levels of risk. By this formulation it becomes clear, that the optimal amount of risk reduction to be provided by mitigation measures requires simultaneously maximizing the utility of mitigation and minimizing the respective costs. Technically spoken, optimality is derived by maximizing the net benefits of mitigation (max E[U(Q)] = max {U(Q) – C(Q)}) implying that marginal benefits are equal to marginal costs (Tietenberg 2006: 56).

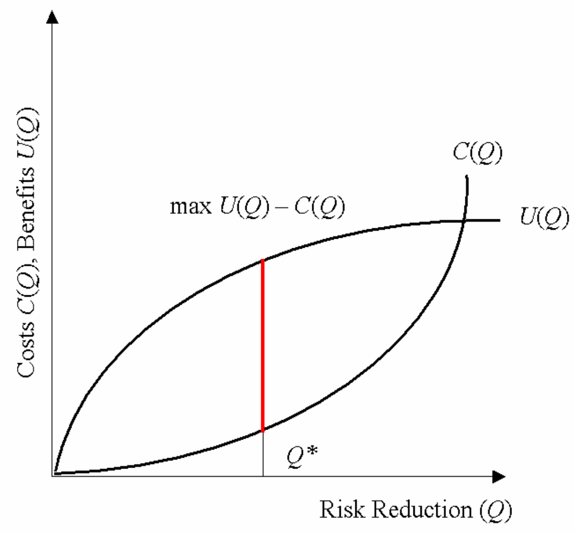


Figure 44: Graphical representation of cost-benefit analysis and the resulting optimal level of risk reduction

6.4 Rationales of Cost-Effectiveness Analysis (CEA)

Using the expected net benefit as decision criterion among different mitigation scenarios requires monetizing all socially relevant costs and benefits associated with a project. However, the benefits derived by a project may not be monetizable in a sufficiently reliable way. According to Boardman et al. (2005), the CEA approach might be indicated when (1) the most important impact cannot or should not be monetized, (2) only a part of the benefits can be quantified while others are uncertain, or (3) the benefits of a project are valued not for themselves, but with regard to their contribution to a superior goal.

CEA focuses on cost-efficiency in mitigation by seeking to achieve either a target level of residual risk by minimal costs or to maximize the risk reduction measured e.g. in human lives saved from a given budget. However, CEA does in general not yield optimal resource allocation in the economic sense, as it neglects the diminishing marginal utility of public safety and the decreasing public demand for mitigation measures. In contrast to CBA, the concept of CEA is based on the assumption that the utility of a good or service such as safety against natural hazards is constant among the range of its application ($\partial^2 U(Q)/\partial Q^2 = 0$), while the cost to produce safety increases marginally with increasing amounts of the good ($\partial^2 C(Q)/\partial Q^2 > 0$). The cost-efficient amount of risk reduction results, when the marginal cost equals the slope of a predefined budget constraint I expressing the marginal costs that society is assumed willing to pay to avert one fatality (min C(Q) under the constraint I = P(Q) × Q where P(Q) denotes the price for the Qth mitigation unit) (Figure 45). In practice, budget constrains and decision rules upon the selection and adoption of a project are selected either based on the league table approach or on the threshold approach. The league table approach adopts projects and policies based on their relative value of cost-efficiency until all available resources are spent. By contrast, the threshold approach most often used in technical and natural hazard management compares the absolute value of cost-efficiency with a normatively determined threshold value, which then functions as the budget constraint.

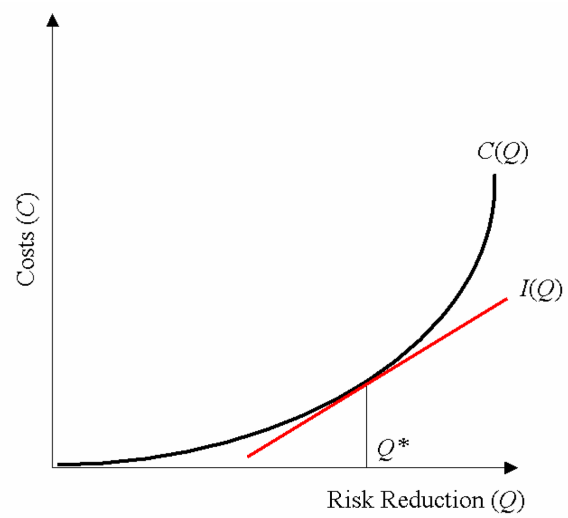


Figure 45: Graphical representation of cost-effectiveness analysis and the resulting cost-efficient level of risk reduction

6.5 Rationales of multi-Criteria Analysis (MCA)

Unlike the above described approaches, MCA has evolved over the last years as a new means to evaluated complex risk mitigation projects that involve many stakeholders, conflicting goals and hardly quantifiable attributes (Brouwer & van Ek 2004; Gamper et al. 2006). Being qualitative or semi-qualitative, these methods can be used to yield an ordinal utility ranking of different mitigation scenarios at less costs and complexity as the cardinal utility order provided by CBA. However, up to now these methods have hardly been applied in natural hazard management. Here, we resign from introducing the myriad of methods subsumed under the terms multi-criteria analysis or multi-criteria decision analysis, but instead refer the interested reader to reference works such as Keeney and Raiffa (1993) or Eisenführ and Weber (2003).

6.6 Practical problems within the evaluation process

Some practical problems in evaluating risk and risk mitigation projects are common to all of the described approaches. Here, we address the most important problems and give some recommendations how to evaluate natural hazard mitigation projects. As most problems arise within specific steps in the evaluation process, they may be attributed to one of the standardized procedures of the evaluation task (Boardman et al. 2005: 7-17), which we use to structure the practical problems and issues of consideration.

1. Specify the set of alternative risk reduction projects or policies

The technical risk analysis and the assessment of risk reduction measures generally provide more than one feasible way of reducing a risk. In order to limit the evaluation process, the analyst may specify a set of alternative mitigation projects or policies, which fulfil minimum criteria such as the feasibility, bankability and acceptability of the selected alternatives.

2. Monetize all the project impacts

CBA attaches monetary values to all impacts caused by a mitigation project, CEA at least to the cost relevant impacts. In economic terms, the crucial task of monetizing is to measure benefits and costs at their utility maximizing use (Boardman et al. 2005; Ganderton 2005). In case of market goods, the impacts of mitigation can be approximated by related changes in social surplus assuming that the benefit to society derived from the consumption of a market good would have been lost without adequate mitigation measures to protect this good from damage or loss. Under market conditions, demand for and supply of the concerned good in relation to its market price can be used to calculate the forgone utility (social surplus) and to eventually assess the value of mitigation. However, in non-competitive markets prices are biased. While some of the impacts of mitigation can be approximated by market prices, others cannot. Particularly when monetizing the risks to life and limb, alternative economic evaluation concepts have to be applied to determine the preferences for a reduction in risk. The standard economic approach to evaluate life saving interventions is the concept of the value of statistical life (VSL) that has advanced over the past 20 years (see technical report, chapter 6.3 for a detailed derivation of the VSL and the different methods to empirically estimate it). Most studies on the VSL estimate values between €2-5 million per statistical life saved (Viscusi & Aldy 2003).

Moreover, it is likely that large natural hazard events entail indirect costs due to secondary effects such as productivity losses, depreciated real estate values in the vicinity of damage and in areas threatened by future hazards, costs incurred through the obligation of the public sector to obtain title to property that has recurring hazards, loss of tax revenue on devalued property or in the mandatory conversion of private property to public property, loss of tourism revenues, expenses for emergency services and public health workers, impacts on water quality and ecosystems (Okuyama & Chang 2004). The estimation of these costs is very difficult and best guesses by the analyst have to be made on most of the relevant impacts.

3. Discount benefits and costs to obtain present values

Costs and benefits of risk mitigation projects occur at different points in time (Figure 46). Usually, mitigation projects necessitate investments in planning, construction, and organization before they provide any benefit. Furthermore, as natural hazards are stochastic phenomena, it is not clear when (and if) they provide a benefit. It might even be that no hazard event occurs within the lifetime of the mitigation measure. At the other extreme, a constructive mitigation measure can be damaged soon after implementation requiring unforeseen costs of repair.

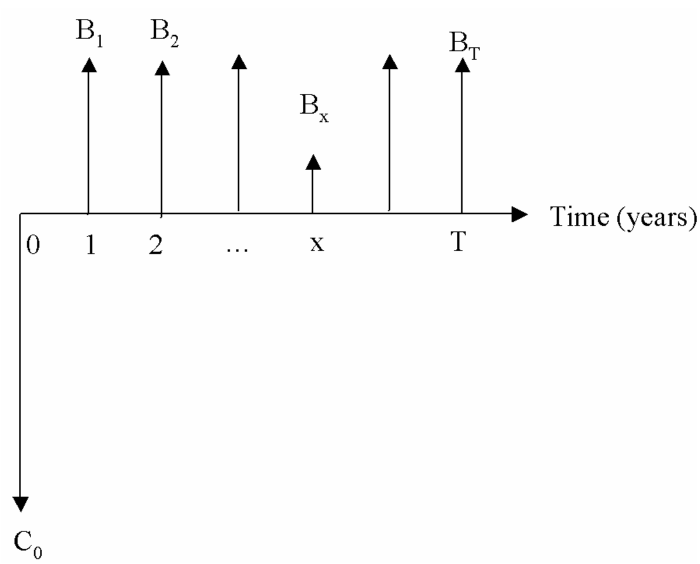


Figure 46: Graphical example of the discounted benefits and costs over a risk mitigation project's lifetime T, in year x, we observe a hazard events that decreases the benefit Bx e.g. by causing repair costs

In order to account for asynchronies, any cost or benefit including the value of human live – when occurring in the future – should be discounted to its present value. Most economists agree upon those investments into risk mitigation projects have to be discounted as any other investment in order to be consistent with the goals of welfare economics. The rate of social discounting, however, is a highly controversial issue and no recommendations can be given as to which discount rate is most appropriately. In many environmental risk projects discount rates between r = 2-7% are used depending on the time horizon of mitigation.

This discount rate r is used to determine the present value of annual project costs Ct summarized over the project i's lifetime T:

$$PVC(i) = \sum_{t=0}^{T} \frac{C_t(i)}{(1+r)^t}, \qquad (6.1)$$

and the present value of project i's annual benefits Bt summarized the project i's lifetime T:

$$PVB(i) = \sum_{t=0}^{T} \frac{B_t(i)}{(1+r)^t}, \qquad (6.2)$$

in order to have a common ground for evaluation. Otherwise, the decision maker would be equal between a benefit or cost occurring now and a benefit or cost occurring in 20 years, denying the possibility of alternative investment and inflation of prices.

4. Compute the net present value of each alternative

The net present value (NPV) of each alternative i is then obtained by summing up the discounted annual benefits Bt and costs Ct over project's lifetime T:

$$NPV(i) = \sum_{t=0}^{T} \frac{B_t(i) - C_t(i)}{(1+r)^t}, \qquad (6.3)$$

where t denotes a specific year during T and r is the discount rate.

5. Compare the alternatives with regard to their net present values or their benefit-cost ratios

Subsequently, the alternatives are ranked based on their NPV: the alternative that yields the highest NPV is consequently the most preferred alternative, while the one with the lowest NVP is the least preferred alternative. Alternatively, the benefit-cost ratio (B/C) might be used to decide, which alternative should be selected. To obtain the benefit-cost ratio (B/C), we divide the present value of benefits (Eq. 6.2) by the present value of costs (Eq. 6.1). If B/C > 1, a projects pays off, if B/C < 0 a projects does not pay off. Generally, a project i is preferred over a project j, if it holds that B/C (i) > B/C (j).

6. Perform sensitivity analysis

A key feature of any sound evaluation is the sensitivity analysis of the results. How does the preference ranking of the alternatives looks like, if the annual risk has been under- or overestimated by 10%, if the costs have been under- or overestimated by 10%, the discount rate is 1% higher or lower than in the initial evaluation? The results of this analysis point out to what input parameters the ranking of alternatives is particularly sensitive. Efforts should thus be made to improve knowledge about the most sensitive parameters, while robust parameters can be estimated with less effort.

7. Make a recommendation to policy makers

The capability of economic risk evaluation of natural hazards and respective mitigation measures lays in establishing a framework within which alternatives are valued and compared as objective as possible. Done in an open, transparent, and participative process, risk evaluation can thus be said to be more solution-oriented than the mere expert assessments traditionally conducted in natural hazard management. The decision making itself, however, is not done within risk evaluation but rather more between the involved decision makers. In that sense, the evaluation tools described above are a working horse, allowing to provide the decision makers with sound recommendations.

6.7 Conclusions

In this chapter we have outlined some economic aspects, which should be included into the evaluation of countermeasures against natural hazards. We have described the rationales of the most important valuation methods and have thereby defined optimality criteria that are useful to valuate and compare different projects and policies with each other. While not being a panacea, the application of these methods allows basing decisions on sound and comparable principles. Eventually, this leads to transparent and comprehensible decisions, which enable the decision makers to justify their decisions about promoting or abandoning a specific risk mitigation project. Moreover, the use of the cost-benefit concept provides the basis for an optimal allocation of resources. Consequently, public budgets are used for the implementation of projects that provide the largest benefit to society.

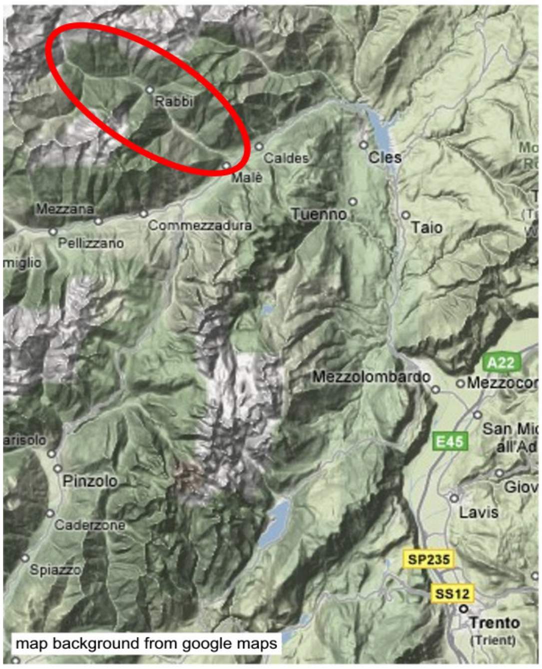
However, it is obvious that economic aspects are all but one criterion in safety-relevant decisions. When deciding upon natural hazard projects, practitioners do well to pay attention to the remaining aspects such as the availability of transport facilities, environmental sustainability and values, the beauty of scenery and the acceptance of the local population. While these aspects could in principle be monetized and integrated into CBA (Pommerehne 1987), this is commonly not done. Therefore, their recognition in early phases of natural hazard projects is a must. Methods such as the MCA seem to be appropriate to better integrate these aspects into the decision-making approach. Future research will thus be directed toward a better recognition of these economically intangible aspects.

Chapter 7

Case Studies

7.1 Risk assessment and Planning of Countermeasures – Case Study Snow Avalanches "Nigolaia"

The Nigolaia avalanche site is located in the Italian Alps, within the Autonomous Province of Trento (Figure 47). Cappabianca et al. (2008) used this site to perform a comprehensible risk assessment and a cost-benefit analysis for two alternatives of defence structures. The responsible municipality finally decided to realise one of the alternatives. The case study is therefore a well-suited example to illustrate best practices in the risk management of snow avalanches. The following results are mainly taken from the mentioned publication.



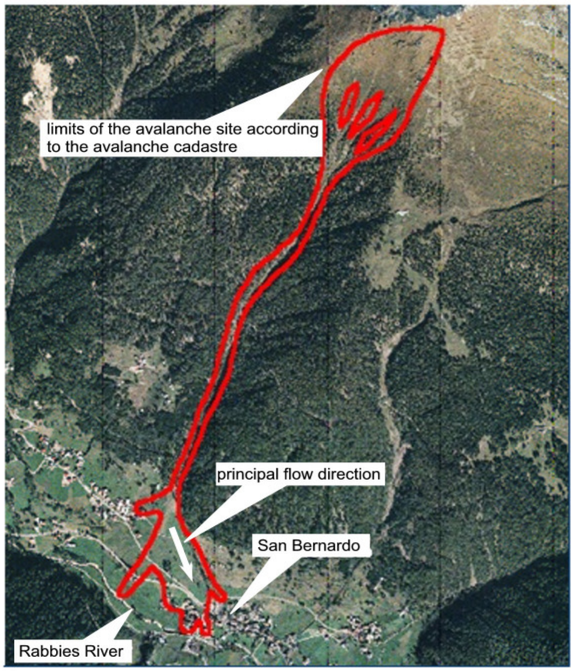


Figure 47: Geographic setting of the Rabbi Valley in the north-eastern part of Italy (on the left) and aerial view of the avalanche site "Val Nigolaia" (on the right)

7.1.1 Hazard Assessment

The release area, with an aspect S-SW, is approximately situated between 2550 and 2200 m a.s.l. and covers an area of about 9.5 ha with inclination ranging between 35° and 45°. The avalanche path is partly channelled and covers a vertical drop of about 1500 m; its length is about 3 km.

At first, a probability density function of the release depth was derived from 8 meteorological gauging stations in the region. Then snow avalanches were modelled using VARA1D (Nettuno 1996). In the run-out zone the calculations were made separately for eight different avalanche profiles. The definition of these profiles was supported by the study of historical data and the analysis of the run-out zone morphology. Model runs were performed for a total of 60 different release depths from 0.05 m to 3 m with an increment of 0.05 m. This way the maximum impact pressures at each point of the computational grid along each profile were recorded. Finally, the results along the profiles were interpolated in order to produce a 2D map.

The simulations showed a linear relation between release depth and avalanche impact pressure. Consequently, the probability density function of the impact pressure in the run-out zone is of the same type as the one of the release depth. Hence, the probability density function and therefore the probability of a certain impact (which is needed for the risk calculation) can be derived from the distribution of the release depth.

7.1.2 Risk assessment

The risks were calculated based on the probability of impact (derived from the release depth probability) and on the vulnerability of the threatened object. As the study focused on buildings and people inside them, two different vulnerability functions were used: the vulnerability curve of Wilhelm (1998) referring to concrete buildings and the corresponding relation suggested by Cappabianca (2006) for people inside buildings. The specific values at risk, calculated at the points of the computational grid along each simulation profile, were interpolated using then TIN command in ArcGIS® in order to create specific risk maps (Figure 48).

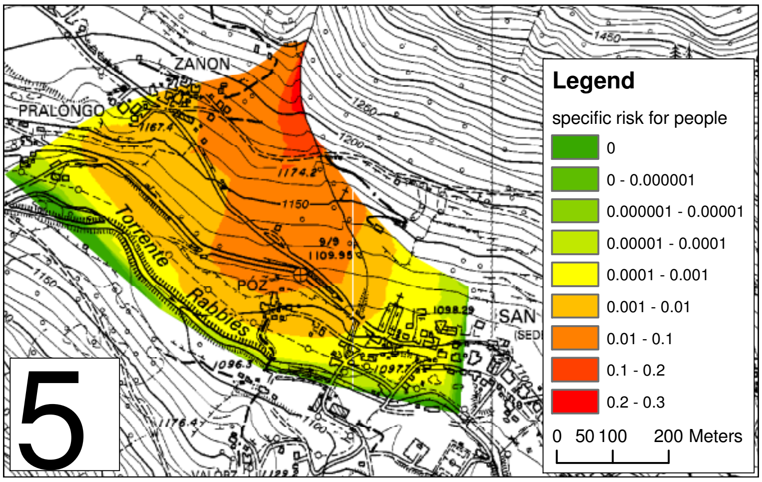


Figure 48: Risk map for people in buildings (unit: annual expected number of victims)

The risks were evaluated referring to the Icelandic regulations (Arnalds et al. 2004). These regulations consider individual risk in residential areas acceptable if it is less than 0.3×10^{-4} annually. The risk map shows that in all the inhabited area individual risk exceeds this acceptable risk level for residential areas. In order to reduce individual risk countermeasures were analyzed in terms of risk reduction.

7.1.3 Planning and evaluation of countermeasures

Two different alternatives of snow fences were hypothesized:

- snow fences in the release area between 2550 m a.s.l. and 2400 m a.s.l., where the terrain slope is more than 45° would reduce the potential release area to altitudes of 2400-2200 m a.s.l.;
- snow fences between 2550 m a.s.l. and 2350 m a.s.l. would exclude rocky outcrops from the release area.

In the simulations with the dynamic model it was assumed that the snow fences are 100% effective. They would eliminate all avalanche releases in the area where fences are located. The remaining release area (in the non-controlled area) will be significantly smaller.

The risk calculation procedure described above was adapted to these two protection scenarios and specific risk maps were obtained (Figure 49).

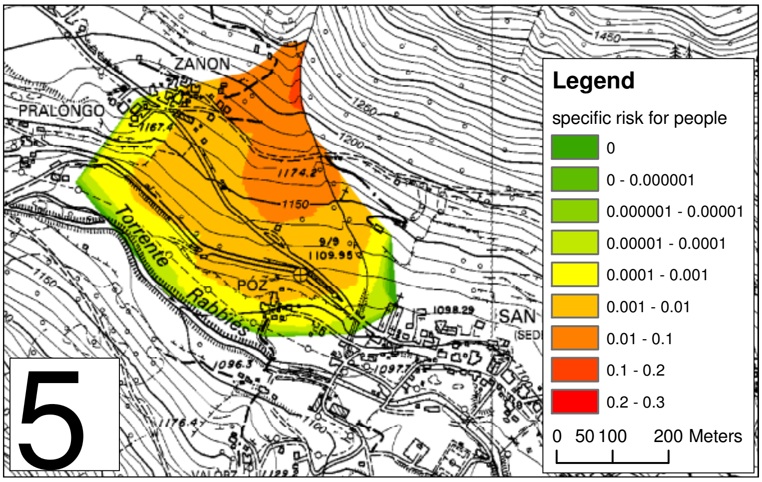


Figure 49: Risk map for people in buildings for countermeasures-scenario 1 (unit: annual expected number of victims)

Although the reduction of release volumes reduces the specific risk in the valley bottom (proposal 1 reduces the total specific risk for people to 40% and proposal 2 to about 20% of the baseline risk), these protective works would still not provide sufficient risk reduction to the village of Zanon to reach the acceptable individual risk for residential buildings according to the Icelandic standards.

In a successive step a cost benefit analysis was performed. The annual costs included construction costs as well as maintenance and repair costs of the snow fences. Construction costs were assumed to be 0.6 million Euro per hectare and annual maintenance and repair costs to be 0.5% of the investment costs (Margreth 2004). Annual benefits were estimated as the difference in annual expected damage (Euro) between the baseline risk and the scenarios with countermeasures. Human life was valuated using the WTP-concept (willingness to pay). Since no Italian values are available, the case study refers to Swiss suggestions and a value of about 10 million Euro was used (PLANAT 2004). The cost-benefit analysis (see Chapter 6.3) showed that both scenarios would be efficient and that the second scenario is more advantageous than the first one (NPV1 = 5.6 Mio€; NPV2 = 7.1Mio€).

Finally, the municipality decided to mitigate the risk level in the valley bottom by means of supporting structures in the release zone of the avalanche. The construction works will lead to set up about 3.5 km of snow nets protecting a relevant amount of the potential release area (altitude range between 2300 and 2550 m a.s.l., similar to scenario 2). The overall cost of the intervention is estimated at 4.5 million Euros, with a significant risk reduction for people inhabiting the valley.

Figure 50: Construction works in the release zone of the Nigolaia avalanche site (by courtesy of the Avalanche Office of Autonomous Province of Trento Italy)

7.2 Sound Hazard Assessment and sophisticated Warning System – Case study Rock Avalanches "Åkneset"

Rock falls and rockslides are serious natural hazards, mainly because of their tsunamigenic potential. In 1934 a 3 million m^3 rockslide near Tafjord in Storfjorden triggered a tsunami and 40 people were killed. The Åknes rock slope is also located in Storfjorden, Norway. For rock avalanches the Åkneset experimental site gives valuable information about what kind of investigations and instrumentation that is necessary on the one hand to assess the hazard and the risk of the slide as well as of the tsunami and on the other hand to operate early warning systems. The experience from this site will be used as guideline to other dangerous locations in Norway.

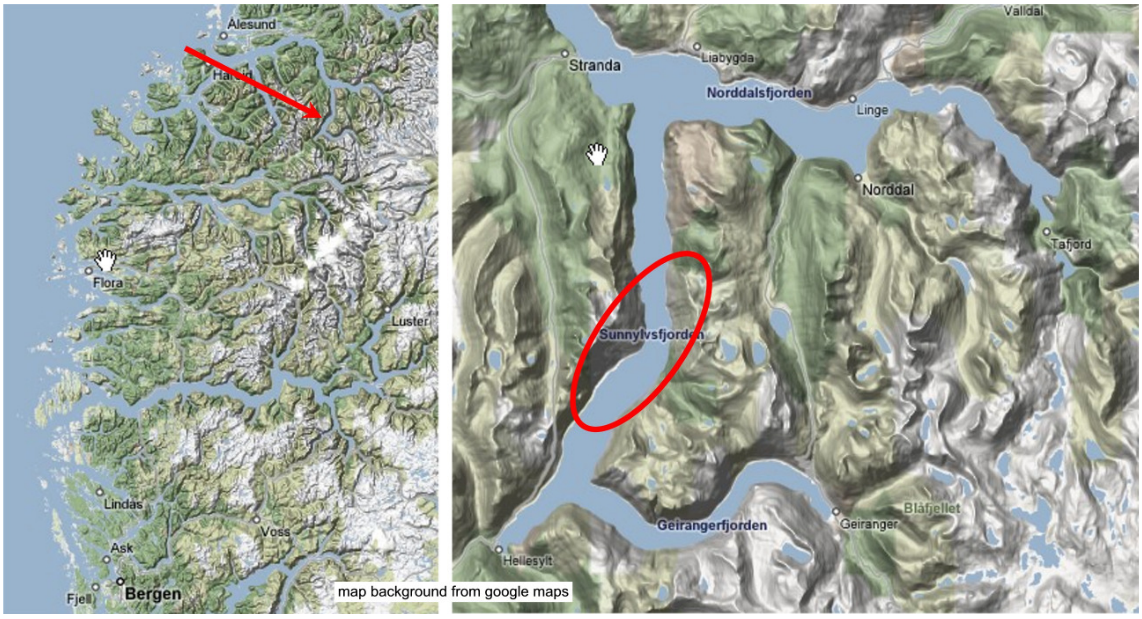


Figure 51: The Åkneset experimental site is located at the west coast of Norway

7.2.1 Hazard Assessment

The rockslide poses a relatively minor threat, but could still impact on traffic frequenting the fjord below the source slope. The big threat from Åknes is its tsunamigenic potential.

This means that the hazard is comprised of two parts:

- The probability of a rockslide at Åknes.
- Estimation of tsunami run-up height caused by a rockslide from Åknes into the fjord.

The probability of rockslides can be estimated based on a probability-magnitude relationship which is derived from historical data (Hungr et al. 1999). Blikra et al. (2005) evaluated the rockslide hazard in Storfjorden by investigating the spatial and temporal pattern of previous rockslide events. Based on this data representing the last 10,000 years a rock volume probability function was calculated with power regression and, finally, the sliding probability for any interval of sliding volumes was calculated. According to Blikra et al. (2006) these should be considered as a lower bound of the rock slide probability, due to imminent geological evidence found at the Åknes site. Consequently, risk estimates for the Storfjorden based on historic data will be assumed as a lower bound.

Table 18: Annual failure frequency for sliding volume intervals in Storfjorden

Volume intervals (mill. m^3)	**Annual failure probability**
[0.5, 2]	0.0036
(2, 4]	0.00074
(4, 7]	0.00035
(7, 12]	0.00022
(12, 20]	0.00013
(20, 35]	0.00009
> 35	0.00016

The slide mechanism has been studied in detail on the one hand to estimate probable slide volumes for different scenarios and on the other hand to have best possible basics for the early warning system. Recent studies by Kveldsvik et al. (2008) estimate that about 650,000 m^3 of the Åknes rockslide is potentially unstable (Figure 52). Further analysis of on site geological mechanisms derived in Ganererød et al. (2008) and displacements measured at the slope surface using discontinuous deformation analysis (Shi and Goodman 1985, Shi 1988) generated a block segmentation as illustrated in Figure 53.

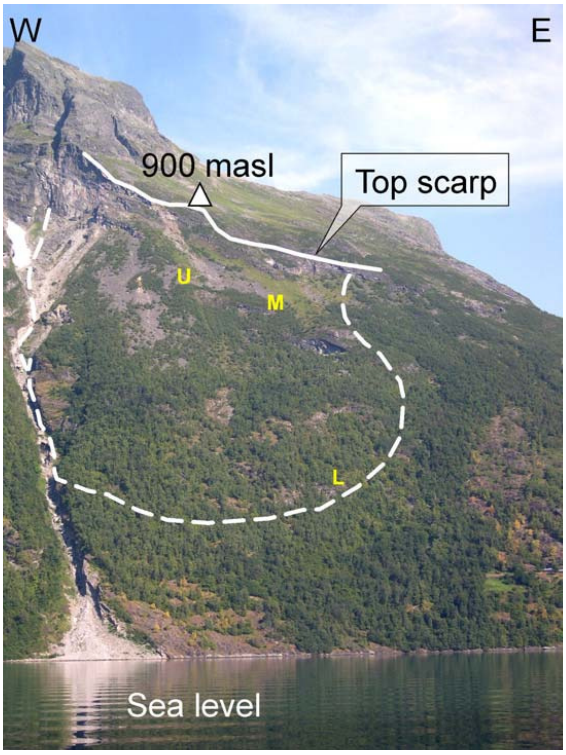


Figure 52. Overview of the Åknes rock slope. The white lines indicate the contour of the unstable area as derived through various investigations (slightly modified after Derron et al. 2005)

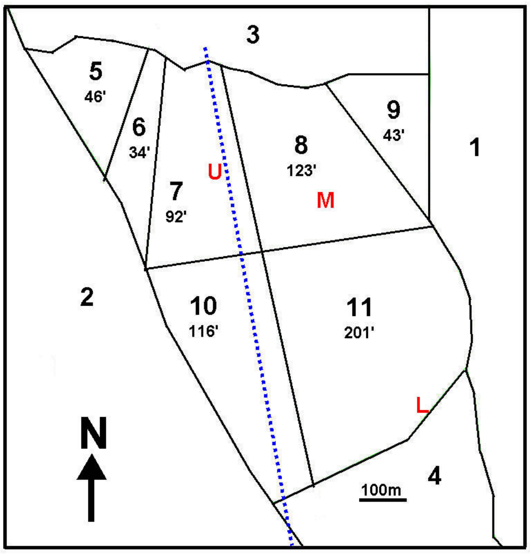


Figure 53: Block model of the Åknes rock slope. Black numbers: Block numbers and areas in $1000m^2$ for each assumed unstable block. Red letters: location of the upper, middle and lower boreholes. Blue broken line: profile for numerical modelling (modified after Kveldsvik et al. 2008)

In the upper half of the assumed unstable part of the slope the highest displacement rates have been measured in Block 5 – 7; a horizontal component of about 7cm/year since 1983, and about 13cm/year from 1961 to 1983. Somewhat larger displacement rates are indicated in Block 5 and 6 compared to Block 7 by the more limited data exist for these two blocks. Block 8 has been shown to move at a smaller rate than Block 7. Block 9 appears to move little or not at all. In the lower half, most of Block 11 has moved insignificantly from 2004 to 2006, and measuring points in the photogrammetric data sets are too few for drawing any conclusions for the period before 2004. Measurements do not exist for Block 10. Rock slides occurred on the western flank of Block 10 in 1940 and 1960 or 1961 which may indicate that movements take place in this part of the slope. A rock slide is also known to have occurred on the upper western flank between 1850 and 1900 (Kveldsvik et al. 2007).

Based on the block model combined with estimates of depth to the basal sliding surface, some slide volume scenarios have been derived (Table 19). Maximum depth of 120m was assumed in Block 7 and 10, smaller in the Block 5 and 6.

Table 19: Volume estimates of some slide scenarios with assumed probabilities of occurrence

Sliding of block numbers	Estimated volume in million m^3	Probability of occurrence
Block 5 and 6	2.5	Most likely
Block 5, 6 and 7	9	Least likely
Block 5, 6, 7 and 10	19	Intermediate

Finally, the scenarios for the tsunami modelling were defined. Besides the volume, also the run-out length and the impact velocities had to be estimated. The considered volumes ranged from 2 to 35 million m^3 with run-out from 800 to 1250 m and velocities between 40 (for the biggest scenario because it starts closest to the fjord) and 65 m/s. The tsunami generation and propagation was modelled with a LSW model (Harbitz & Pedersen 1992). The results are shown in Figure 54 and Table 20.

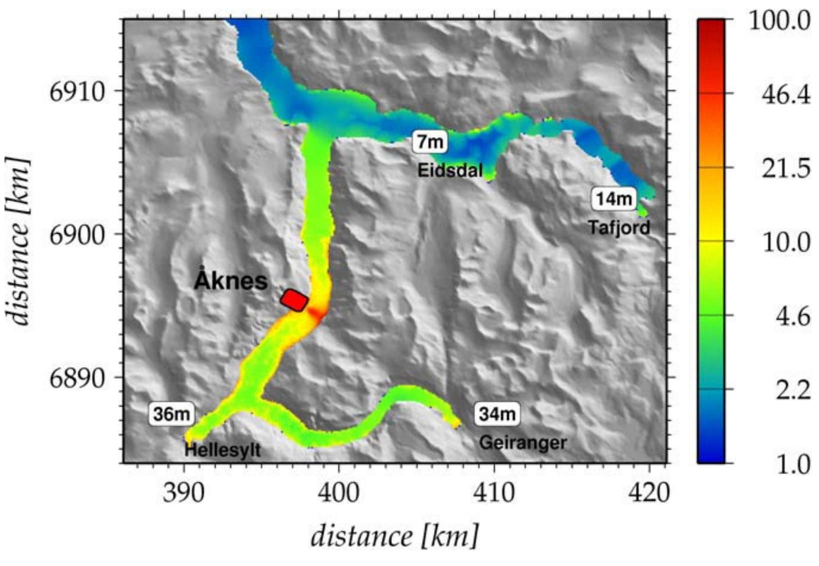


Figure 54: Maximal surface elevation for the 35 Mm^3 scenario given in meters (logarithmic scale). The estimated run-up at Hellesylt, Geiranger, Eidsdal, and Tafjord is given in the white boxes. The results correspond to a probability of 80 %

Table 20: Estimated run-up at selected locations. The run-up is given in meters and is assumed to be within a probability of 80 %

Location	**2 Mm^3**	**4 Mm^3**	**6 Mm^3**	**8 Mm^3**	**12 Mm^3**	**23 Mm^3**	**35 Mm^3**
Hellesylt	3.5	6	9	13	13	36	36
Geiranger	2.5	4.5	8	11	11	32	34
Eidsdal	0.4	0.8	1.6	2	2	7	7
Tafjord	1	2	3	4	4	13	14

7.2.2 Risk assessment

Vulnerability

The vulnerability described herein is scenario-based, i.e. it is related to specific tsunami threats. This vulnerability is both related to the intensity of the tsunami and the susceptibility of the vulnerable elements, here the people living in the exposed areas. The vulnerability is the fraction of people in the affected areas loosing their lives in case of a tsunami. The quantitative model for vulnerability (Figure 55) is based on historic data from previous tsunami in Norway as well as world-wide (Furseth 2006, Rosetto et al. 2007, EEFIT 2006, Reese et al. 2007).

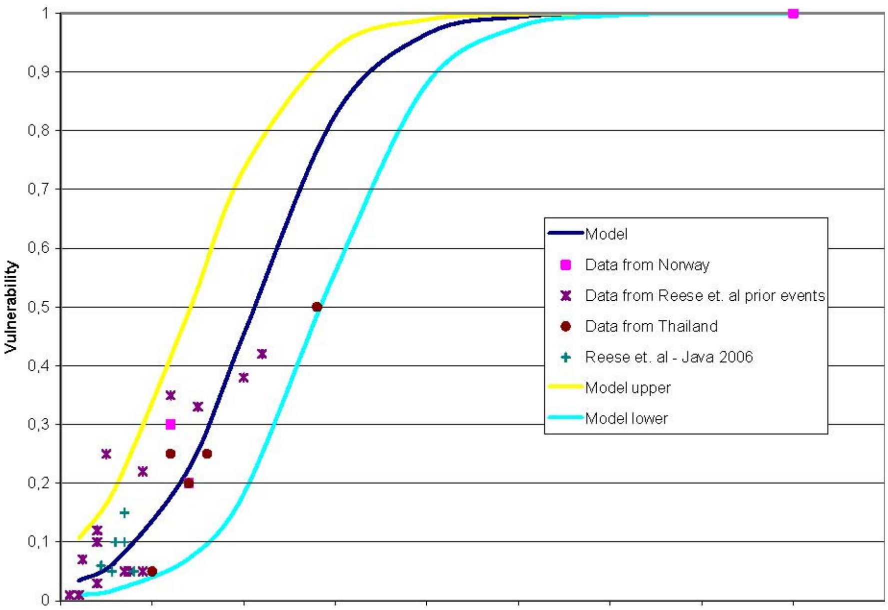


Figure 55: Empirical quantification of vulnerability as function of inundation height

Since the vulnerability is a function of inundation height, the vulnerability varies through the village. Therefore the resulting vulnerability for one village was weighted according to the percentage distribution of the elements at risk at different elevation levels and the related inundation depth, Example: inundation height 11 m, 20% of the people are located at 0 m, 30% at 5 m, 50% at 10m, S is the vulnerability function: resulting vulnerability = 0.2 x S(11) + 0.3 x S(6) + 0.5 x S(1).

Table 21 shows the weighted vulnerability for the 4 locations in study.

Table 21: Weighted vulnerability for the different scenarios

Location	Hellesylt		Geiranger		Tafjord		Eidsdal	
Volume (mill. m^3)	Low	High	Low	High	Low	High	Low	High
[0.5,2]	0	0,072	0	0,028	0	0,007	0	0,001
(2,4]	0,008	0,10	0,004	0,052	0	0,010	0	0,010
(4,7]	0,010	0,29	0,005	0,24	0,002	0,013	0	0,021
(7,12]	0,032	0,49	0,015	0,36	0,002	0,22	0,004	0,029
(12,20]	0,38	0,97	0,091	0,94	0,007	0,48	0,005	0,085
(20,35]	0,69	0,99	0,38	0,99	0,018	0,54	0,008	0,11
>35	0,78	1	0,63	1	0,047	>0,54	0,011	>0,11

Elements at risk

Table 11 shows number of people living/staying in the exposed areas. The exposed area is defined as the area within the inundation limit of the largest sliding scenario.

Table 22: Number of people at risk

Communities	**Tourists number (maximum in high season)**	**Population**	**Assumed average through the year and through day/night for the exposed areas of the communities***
Hellesylt	5000	300	250
Geiranger	15000	100	360
Tafjord	600	50	100
Eidsdal	1500	160	270

**It is assumed the inhabitants and tourists are present 50% percent of the time in the exposed area of Hellesylt. The tourist season is assumed to last two month with one fourth the maximum tourist number present in the exposed area. The numbers are averaged through the year and through day and night.*

Risk assessment

Two approaches were proposed for quantifying risk at the prescribed locations in the Stafjorden. An 'explicit approach', based on the principle that the expected risk value equals the product of the expected value of hazard, vulnerability and losses, with a further relaxation to account for, and the Bayesian network approach, which relates the causal dependencies between key events . Only the first is presented here.

For one sliding volume interval Vol_1, the contribution to the total risk is given by

$R(Vol_1) = H\ (Vol_1) \text{ x } V\ (Vol_1) \text{ x } L$

where R, H, V and L refer to "risk", "hazard", "vulnerability" and "elements at risk", respectively.

The value of risk for the whole range of volume intervals is found by summing the risk over all volume intervals

$R = \Sigma\ R(Vol) = \Sigma\ \text{H}(Vol) \text{ x } V\ (Vol) \text{ x } E(L)$

The results for the 4 locations in study are listed in Table 23.

Table 23: Contribution to risk from each volume interval and the aggregated risk for all volumes

Location	**Hellesylt**		**Geiranger**		**Tafjord**		**Eidsdal**	
Risk (fatalities per year) for each volume interval (in mill. m^3)	Low	High	Low	High	Low	High	Low	High
R([0.5,2])	0	0,065	0	0,036	0	0,0025	0	0,001
R((2,4])	0,0015	0,019	0,0011	0,013	0	0,0007	0	0,002
R((4,7])	0,0009	0,025	0,0063	0,030	0,00007	0,0005	0	0,002
R((7,12])	0,0018	0,027	0,0012	0,029	0,00004	0,0048	0,00024	0,002
R((12,20])	0,012	0,032	0,0043	0,044	0,00009	0,0062	0,00018	0,003
R((20,35])	0,016	0,022	0,012	0,032	0,00016	0,0049	0,00019	0,003
R(>35)	0,031	0,040	0,036	0,058	0,00075	0,0096	0,00048	0,005
R(All volumes)	0,063	0,23	0,056	0,24	0,0011	0,029	0,0011	0,03

7.2.3 Early warning system

The design of monitoring systems is largely controlled by the slide scenarios and the deformation pattern at the specific sites. The possibility to do a forecast during an event is largely dependent on a good understanding of the 3D deformation pattern. This requires a series of different monitoring types that can detect both surface and subsurface deformation. Åkneset is presumable the most extensive instrumented rock mass in Europe and includes more or less all possible instruments available today to monitor rock avalanche initiation.

Table 24: Instrumentation of Åkneset

Surface monitoring	Crack meters/extensometers	
	Tilt meters	“
	Single laser	Primary sensor: Reliable and robust
	Total station	2:
	Global positioning systems (GPS)	
	Lidar scanning	2
	Ground-based radar	2
	Seismic network	2
Subsurface monitoring	Borehole inclinometer	Primary sensor: Reliable and robust
	Borehole extensometer	Primary sensor: Reliable and robust
	Piezometer	3
Supplementary monitoring	Meteorological station	3

Reliability:
1 = Primary sensor: reliable and robust
2 = Secondary sensor: not yet reliable for full operational monitoring
3 = Tertiary sensor: support/information sensors

A fully operational early-warning systems needs to include the following important aspects:

- Reliable monitoring network, including stable power supply and data transfer
- Full operational monitoring (technical and geoscientific)
- Warning procedures, including evacuation routes and implemented warning systems

In Åknes the early warning is based on the rate of movements (Figure 56). Five alert levels are used (Table 25).

Table 25: Alert levels at Åknes

Alert level	**Rate of movement**	**Activity**
Green	Small variations in movement	Situation can be handled by staff at the emergency control centre Technical maintenance
Blue	Seasonal differences Threshold-value 1	Higher frequency of recordings Geological expert group is informed
Yellow	General increased movement Threshold-value 2	24 hours continuous observations Geological expert group is involved Police and municipalities are informed
Orange	Acceleration in movement Threshold-value 3	Emergency control centre continuously manned All relevant personnel in emergency management are involved
Red	Increased acceleration in movement Threshold-value 4	Evacuation is initiated

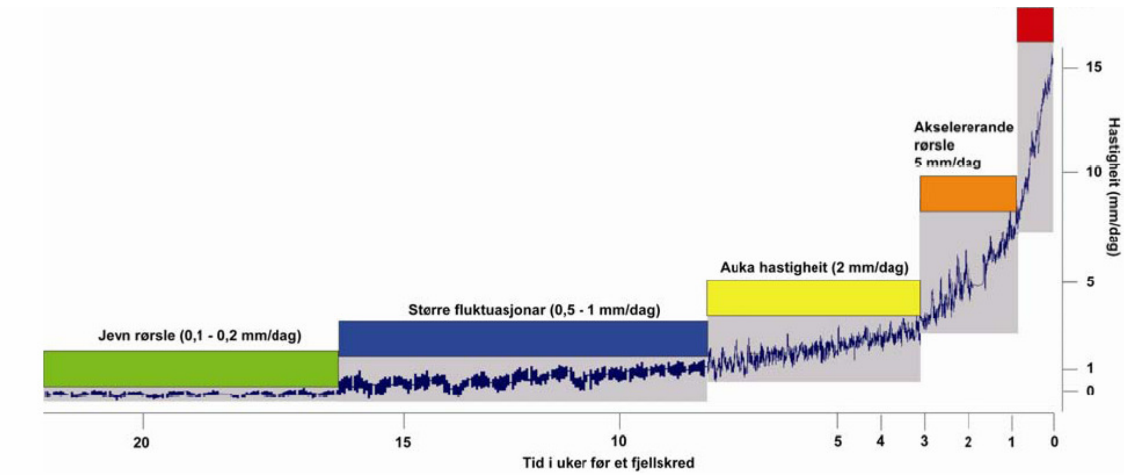


Figure 56: The alert levels depend on the rate of movement. Y-axis: Velocity of movement (mm/day). X-axis: Time (indicated by weeks before a possible rock avalanche)

Chapter 8

Recommendations

Austria, France, Italy, Norway and Switzerland are already well able to deal with natural hazards. Hence, these countries as well as the European community in general are ready to take the next steps. Further progress will be built on a solid foundation, moving toward a more integral and more risk-oriented approach. Moreover, the general conditions for advancing integral risk management of natural hazards are favourable today. Political as well as public awareness is high and the need for safety and risk reduction is likely to increase by various reasons. First, the increasing need for living, industry and traffic infrastructure generates increasing numbers of elements at risk. Second, the increasingly scarce public financial resources call for systematic procedures to prioritise protection projects. Third, the future climate change makes it necessary to rethink presently accepted hazard scenarios and risk mitigation procedures. Based on the present report as well as on the findings of the other outputs of IRASMOS[8], a series of recommendations for the implementation as well as for further enhancements of integral risk management of snow avalanches, debris flows and rock avalanches can be given here.

In addition, we recommend proceeding in the process of SWOT. A detailed analysis of the results (chapter 2) needs to be done for each country individually, including combinations of SO, WO, ST and WT., in order to improve integral risk management in the future

Apply the concept and the methods of Integral Risk Management

The present report as well as the findings of IRASMOS in general provide the foundation and the methods to put integral risk management into practice. Thus attention should turn to the following points:

- A sound assessment of the hazard and the risk is fundamental for all of the following working steps. The application of up-to-date methods by experienced professionals as well as the allocation of funds by the responsible authorities is a must.
- The planning and the evaluation of the countermeasures should be based on an integral and open-minded approach. Although reasonable solutions to reduce risks in a specific situation are usually limited, there may result additional alternatives when preventive, interventional and recovery measures are considered equivalent and combined optimally, questioning the traditional overweight of preventive measures Countermeasures

[8] see appendix

not only have to be implemented, the results have to be evaluated and in particular further development has to be monitored to allow for further correction to be made at an early stage. If not, risk management may miss its target in the short-term and moreover in the long-term.

- Risk management is not only a question of sophisticated methods and effective practical processes, it is also a question of management and of leadership. Leadership is responsible for sound strategies, good decisions and last but not least, for the review of the whole process and the application of enhancements.
- Finally, risk management of natural hazards is not done for its own sake. Various interactions, for example with different stakeholders, should be considered and taken into account.

In the end, the application of the concepts shown and methods to real cases is highly desirable because this experience will give valuable feedback on practicability and will provide an important input to further methodical improvements.

Boost information and communication

During the SWOT-workshops, many of the discussed strategies for enhancement included communication. In addition, there is a need for risk managers to improve public understanding. Thus there is a need for a concrete risk communication strategy in natural hazard management, finding the right quality and quantity of information for different groups of recipients. However the topic of risk communication is extremely diverse because it encompasses all communication processes related to the management of risks as well as the necessary prerequisites and processes which involve individuals, groups and institutions (Zwick et al. 1997). Initially here are some simple information and communication strategies that could be helpful:

– After disastrous events public awareness is extremely high, but only for a few days. Information can be transferred very effectively during that time, but has to be prepared in advance. For this reason it would be advisable for all agencies that provide information in case of natural disasters to prepare for this moment and to have their tools and products ready for communication.

- Risk communication should not be limited to the communication of expert findings to the general public – many members of the public refuse to be 'educated'. Risk communication should instead include all the stakeholders in a comprehensive risk dialogue (IRGC 2005). Until now, this has not been implemented sufficiently nor anchored in practice. This should be done more. It might be particularly helpful in more complex situations, e.g. when the risk comes from very rare but disastrous events and large scale countermeasures would be necessary, possibly hindering daily life.

After all, the statement of Wanczura (2006: 180) may give further insight in the role of communication. "Public awareness is one key factor for a successful risk management process. Information and training belong to complementary actions within a risk management process that are an important part of supporting society's preparedness for disasters. Information, its provision and exchange belong - as an element of risk governance - to the risk communication process that has to fulfil three main objectives:

- to ensure that all receivers of a risk message are able and capable to understand its meaning,

- to persuade receivers of such message to change attitudes towards the risk and the behaviour and
- to provide the basis of a two-way communication process that helps to solve risk conflicts (also enhance public participation in the emergency decision-making process).

The aim of providing people with information is to broaden their view of/for hazards and risks, because only those hazards and risks that are known can be mitigated. This should finally lead to a change in the people's behaviour into a direction where they can actively respond to risks. Training goes further still, as it provides citizens and experts with the knowledge of how to adequately react in case of hazardous events."

Encourage collaboration

The segregation of responsible governmental agencies is a main problem in the practical application of risk management. Even though some administrative reorganisation is ongoing in different countries, some handicaps will remain because an optimal organisation for all tasks does not yet exist. Nonetheless collaboration can be improved as shown by the following examples:

- PLANAT was created in 1997 by the Swiss Federal Council as an extra-parliamentary commission. It consists of twenty specialists coming from all regions of Switzerland and representing the Confederation, the cantons, research, professional associations, business and insurance companies. The commission wants to avoid a duplication of effort in the area of protection against natural hazards and to make better use of existing synergies. It mainly posits a necessary paradigm change from the protection against hazards to a new risk culture.
- The main challenge in Norway has been to clarify the distribution of responsibilities at different federal levels. Until now ten different ministries have been involved with natural hazard challenges, and it has been unclear which ministry should generate the long-term strategies to meet new challenges in the best way. A new agency responsible for coordination of natural hazards (the Norwegian Water Resources and Energy Directorate) will start work in 2009 and hopefully strengthen risk management in Norway in the coming years.

International collaboration continuously grows in importance. The SWOT-analysis clearly showed that the different countries involved could profit from a more intense exchange. The national institution as well as the EU should benefit from this process of "learning from each other". The research initiatives funded by the EU Commission provide excellent opportunities for it to grow.

Risk management of natural hazards is not a battle to fight alone. Collaboration including interdisciplinary approaches is a must in science but also in practice. It should be actively encouraged as shown by a Norwegian initiative: the Research Council of Norway (NFR) funded the establishment and the management (2000-2010) of the International Centre of Geohazards (ICG) hosted by NGI and consisting of several institutes in Norway with expert knowledge of natural hazards (University of Oslo, Norwegian Technical University in Trondheim, Norwegian Geological Survey and NORSAR, research centre for seismology in Norway). The centre performs world-class advanced research on all kinds of geohazards, among them debris flows and rock avalanches.

Include and strengthen local competences

European countries are able to deal with natural hazards on the national and for the most part also on the regional level. On the local level, knowledge is often limited because this entity is just too small to have specialists to cover all areas, however this level is crucial in risk management. The local authorities are responsible for the safety of the population. They play an important role in emergencies and they also strongly influence prevention, e.g. through their major role in land-use planning. Thus, they should be at the centre of additional education, and they should also be included actively in risk management process, e.g. by participatory procedures. A quite promising strategy is to also include local representatives directly in the risk management processes, e.g. by assigning them tasks related to forecasting and warning. This strategy is pursued successfully in the snow avalanche domain in the Alps.

Deal with uncertainties

Dealing with risks means dealing with uncertainties. These uncertainties may result from the lack of data or model inaccuracies but also from difficulties in the decision-making process and during implementation. Based on a discussion of these uncertainties during an expert workshop in 2007 (see IRASMOS deliverable D3.2), a group of specialists made some suggestions to deal with this challenge:

- Continue research
  - Research work and products should be evaluated carefully before being transferred to practice; a high quality of research work must be maintained.
  - There is competition between the different institutes: This may limit the time for validation, but the competitive situation may also be stimulating.
- Standardisation
  - It is important to harmonize methods, to define standards, to develop (legal) regulation procedures, etc.
  - Nevertheless, the uncertainties of methods should be communicated to the experts (not necessarily to public) so that they can use the methods and interpret the results appropriately.
- Integrate stakeholders
  - include science practitioners, decision makers and other people in the decision process
  - take local information into account (e.g. when historic information in events)
  - take decision acceptability into account
  - find the right local people
- Trust building
  - responsible should stay in their (geographic and/or organisational) environment for some time in order to guarantee continuity and generate credibility
  - public information (participating debates)

Tackle further scientific needs

<u>Risk analysis</u>

- Hazard analysis is for many rapid mass movement processes already on a high level; emphasis must be on reducing the uncertainty of hazard estimations on the one hand and on understanding the future influence of climate change on the processes but also on the whole risk management process on the other hand.
- The determination of damage potentials has so far neglected the inclusion of changes over time. Fuchs et al. (2005) have started to outline approaches taking these shifts into consideration. However, these analyses have been made looking backward in time. In order to look forward in time, more attention will have to be paid to appropriate discounting schemes.
- Damage susceptibility is an area of increasing interest and one of the remaining weak points in risk analysis; upcoming research will be based on larger samples of damaged objects and individuals at risk.
- Calculation of risk in the fields of natural hazards has so far mostly been based on expectation values and has been done in discrete risk frameworks. In future, there has to be an inclusion of second and third moments of probability distributions calling for the use of continuous risk frameworks.

<u>Risk evaluation</u>

- Worst-case scenarios are a way to consider extreme events and a risk aversion toward such catastrophes. The use of these scenarios is also an appropriate way of implementing the precautionary principle into risk evaluations. However, it has not been clarified, which weight these scenarios should be given. This weighting issue might be of minor importance as long as sufficient resources are available. In the case of competing projects and scarce budgets prioritising based on worst-case scenarios seems however unjustifiable (see discussion about the inclusion of aversion functions).
- The individual risk is today evaluated by comparing actual risks to safety goals. These goals are set normatively and are therefore subject to controversial discussions. The definition of these safety goals is not a scientific but a political, ethical, and legal task. Further research on this issue might therefore be unrewarding. But a systematic way to compare risks and benefits between different domains of daily life (medicine, natural hazards, traffic, etc.) might at least provide a more sound basis for these political and ethic discussions.
- The collective or societal risk has been emerged as one key topic to risk evaluation. Based on the concept of willingness-to-pay, many different approaches to estimate societal preferences for risk reduction have been developed. In this research area, progress will continue and with regard to risk specific studies, improving research methods by the use of results from risk perception research will be made.

<u>Risk mitigation</u>

- Effectiveness of mitigation measures/strategies or policies is the key to improve our ability to cope with natural hazards. Here, the understanding of the interactions between the hazard, the mitigation measure and the human action (maintenance, repair and control) will have to be improved. Research on mitigation measures (e.g. with simulation studies) and their application (e.g. organisational conditions for decisions on emergency management) will help to develop a better understanding of their effectiveness and appropriateness under varying environmental conditions.

- The evaluation of mitigation performance is closely related to the collective or societal risk evaluation. In the end, it is the risk reduction that counts as the benefit of a specific mitigation measure/strategy, represents the good for which people are asked to pay. Here, there will be an increasing research need on intangible effects that come with risk mitigation measures such as their impact on ecology, on scenery, or on general living quality. It will be challenging to integrate these issues into standard evaluation methods.
- Process understanding and forecasting procedures should be made more precise spatially and temporally in order to improve the potential of organisational measures and to further improve the acceptance of decisions by the public.
- Current hazard maps should be developed further towards risk maps, with the long-term goal of producing dynamic risk maps reflecting short-term changes in the hazard and exposition during a critical incident.

It is anticipated that the recommendations towards establishing a common standard and best practice in IRM on Extremely Rapid Mass Movements made by IRASMOS will have positive impacts on research-based policy at both the national and European level. We envision an easily achievable transfer of IRM objectives and strategies to extremely rapid mass movements as well as other potentially hazardous natural processes or a combination thereof.

On the local level, building codes and hazard zoning may be improved, revised or appropriately reformulated on the basis of IRM principles. The importance of risk sensitivity and risk evolution over time may warrant the implementation of scheduled mandatory quality reviews or audits to check whether hazard and risk maps are still up to date, or whether the local vulnerability to extremely rapid mass movements have changed substantially. The assessment of the design lifetime of various risk-related products will be an important asset for decision support in this matter.

On the European level, results of the IRASMOS project may provide an impetus to divide research focal points into sub-priorities in FP7 and following programs. Moreover, with the gradual dissemination and acceptance of such best practices, future calls in EU Framework Programs may consider and specifically focus on risk-related issues in natural hazards research and mitigation, especially where their cost-efficient implementation is necessary. This may also be of importance with regard to knowledge transfer and exchange in cooperation activities with Third World and developing countries, e.g. in EU INCO initiatives. IRM principles can be applied to other risk-related issues and allow an ideal platform for comprehensively addressing natural, technological, and other unexpected hazards and risks. Several multidisciplinary issues may be developed with regard to various environmental safety regulations, and international cooperation in natural hazards and disaster risk management at the European level.

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