7. Landslide hazard and risk zoning for urban planning and development

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ABSTRACT: Disasters caused by landslides have continued to increase during the last decades notwithstanding the significant efforts of the United Nations aimed to reduce their consequences. The reason for a risk increase is essentially related to demographic pressures and territory mismanagement. Fortunately, some countries and regions have already progressed in the development of procedures for managing urban and population growth as well as for minimizing the associated risks. The procedures are based on hazard and risk zoning which, however, can imply difficulties because of technical and socio-economic contributing factors. Starting from the valuable experience gained in several countries, the present paper discusses the improvement of urban planning and development by hazard and risk zoning, albeit recognizing the efforts still required for quantifying zoning criteria and adapting them to landslides risk management necessities. Risk mitigation strategies are therefore discussed, also considering the valuable contribution that can be furnished by the skilful use of new technologies and mathematical modeling. However, improvement of both remote sensing and data treatment techniques should not detract from field work and personal judgment since the current use of landslide inventories, which are the key input parameter for hazard assessment and validation, cannot be prepared in a reliable way with automatic data capture techniques exclusively. Uncertainties and errors in landslide zoning restrict the applicability of the hazard and risk maps for practical purposes and can generate conflicts. The validation of both procedures and maps is, therefore, a necessity especially in urban areas.

1 INTRODUCTION

Previous State of the Art papers have introduced numerous landslide typologies that can involve several soil and rock types which fail through complex mechanisms strictly depending on the triggering factors, the stage of slope movements and the mechanical behaviour of the material. The previous SOA have also discussed the available landslide classifications that, starting from the 1863's (Dana 1863), have tried to place such phenomena in a general framework.

Several uses of such classifications are possible. For example, referring to the slope movement stage as introduced by Leroueil et al. (1996), landslides can be separated into two main categories: first-time failures and reactivated landslides.

First-time landslides commonly are characterised by high velocity and can produce fatal consequences. Reactivated landslides commonly cause great economic damage and, sometimes, temporary or permanent evacuation of large zones. Unfortunately, both kinds of movements and their consequences are widespread all over the world (Fig. 1) and often affect urban centres.

Interaction between landslides and many other natural hazards is also a great concern. Earthquakes,

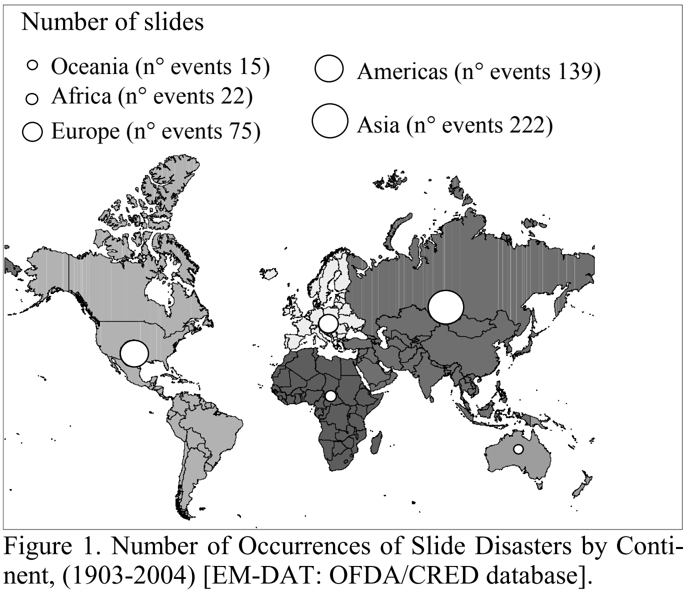


Figure 1. Number of Occurrences of Slide Disasters by Continent, (1903-2004) [EM-DAT: OFDA/CRED database].

tropical cyclones, volcanic eruptions, and tsunamis can trigger or exacerbate landslides, as well as deforestation that is indeed an anthropic hazard. Landslides, in turn, can produce and/or exacerbate floods, volcanic eruptions and tsunamis.

It is interesting to observe that, due to such interactions, landslides are considered the second most significant natural hazard among those identified by the United Nations Development Programme (UNEP 1997) which regards landslides as a type of "geological hazard", even if the term flood is commonly used to describe the consequences of rapid slope movement.

The full awareness of the effects produced by natural hazards led the United Nations, in 1989, to sponsor a resolution that declared the years 1990-2000 the "International Decade for Natural Disaster Reduction" in order "to marshal the political resolve, experience and expertise of each country to reduce loss of life, human sufferings and economic losses caused by natural hazards". Unfortunately, the praiseworthy aim of this resolution has been eclipsed by the large increase, during the end of the last century, in the occurrence of both natural disasters in general and landslides in particular (Fig. 2). The increase of damage has even been worse (Fig. 3).

There are many reasons for this increase, and it is difficult to disagree with the U.N. General Secretary when he observes (Annan 2002) that:

"*Communities will always face natural hazards, but today's disasters are often generated by, or at least exacerbated, by human activities. At the most dramatic level, human activities are changing the natural balance of the earth, interfering as never before with the atmosphere, the oceans, the polar ice caps, the forest cover and the natural pillars that make our world a liveable home. But we are also putting ourselves in harm's way in less visible ways. At no time in human history have so many people lived in cities clustered around seismically active areas. Destitution and demographic pressure have led more people than ever before to live in flood plains or in areas prone to landslides. Poor land-use planning, environmental mismanagement and a lack of regulatory mechanism both increase the risk and exacerbate the effects of disasters*".

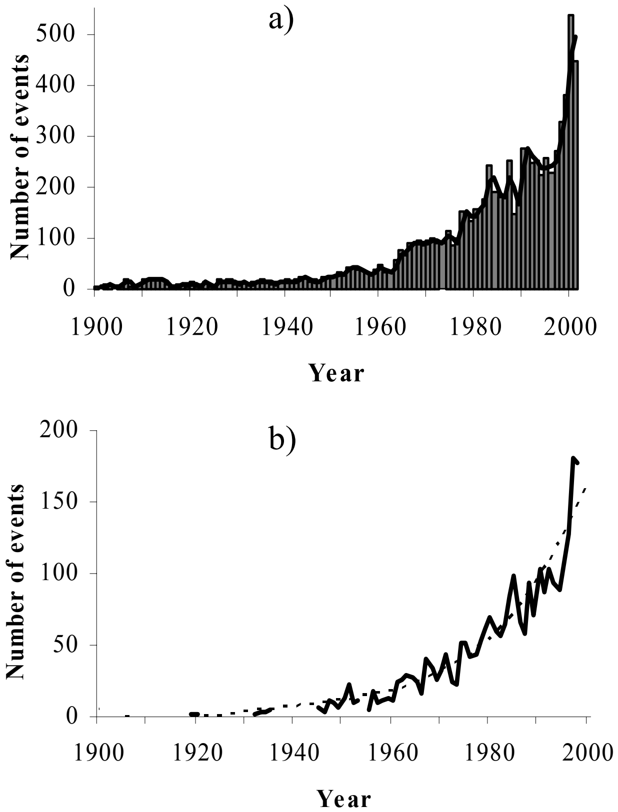


Figure 2. EM-DAT: OFDA/CRED database: a) Natural disasters; b) Landslides and Floods (Cascini 2005).

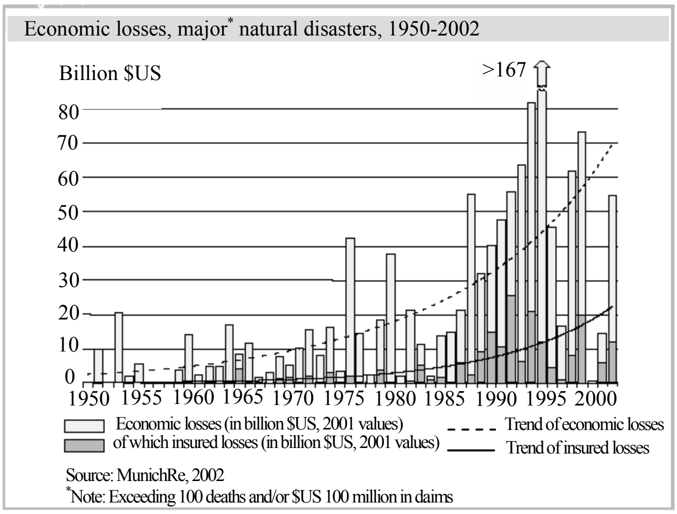


Figure 3. Economic and insured losses caused by natural disasters (MunichRe 2002).

Several examples of the negative role played by demographic pressure on the increasing number of disasters can be mentioned (Brand 1988). A reliable hazard and risk zoning for urban planning and development is, therefore, an urgent need, as is clearly stressed by the United Nations (2004). Particularly, hazard zoning should be devoted to prevent further increases of risk, which could produce both an unacceptable number of casualities and economic hardship in many countries. This is, for example, the case of several South American capital cities in which the development of marginal housing in landslide-prone areas is poorly controlled by local planning.

Hazard and risk zoning is not, however, a simple topic because of the many contributing factors: the intrinsic complexity of both landslides and their geological environment; the sector-based approach generally used in many countries, which can produce untimely and, sometimes, misleading answers to societal requests; the lack of understanding and acceptance of concepts of hazard and risk by both the politicians and populations; the absence of data regarding both the existing landslides, even more acute in built-up areas, and urban planning, including the future urban development.

Because of these difficulties, and taking the drastically different conditions in various countries into account, no single approach can be used for land-use planning to manage urban or population growth and to minimize associated risks (Programme Interreg IIC – "Falaises" 2001).

Bearing in mind the addresses of the United Nations, the present paper preliminarily discusses typical landslide hazard and risk situations in urban areas as well as the scale of the studies. After a brief review of hazard and risk frameworks, the relevant data for landslide hazard zoning, the criteria used for establishing hazard and risk classes, the validation procedures and how the existing mitigation measures can be taken into account for hazard and risk mapping are therefore examined. Later, risk mitigation strategies based on warning systems are discussed. Finally, several case histories are presented in order to show the usefulness of good policy aimed at risk mitigation.

2 STUDY AIMS AND SCALE

2.1 *Typical situations in urban areas*

Several situations may occur with respect to landslide hazard in which urban areas are concerned:

- in the case of very large dormant landslide zones, or that are generally affected by slow movements that may be permanent or occasional, old villages or new urban areas may extend onto these unstable areas, first because an active landslide zone generally presents a more gentle slope than adjacent stable zones, and thus is assessed as more favourable for settlements; then because the fast development of the suburbs of a city located in a valley may induce inhabitants to occupy unstable slopes in the vicinity of the city center, where stable areas are not available. Well-known examples of South American cities can be mentioned in this respect (Le Paz, Cuzco), but also villages in Italy or Switzerland that have developed on active landslide zones for several centuries (Noverraz et al. 1998);
- parts of towns may be exposed to rock fall hazards either if they are located at the toe of steep rock slopes, like Grenoble (FR) or St-Maurice (CH) or if they are founded at the top of a cliff formed by a rock slab capping a hill like Orvieto (IT) or Laon (FR); in this last case, the development of anthropogenic activities (e.g. mining or sewage pits) may increase the hazard level;
- cities built in debris fans (i.e. Yungay and Ranrahirca affected by the rock avalanche of Nevado Huascarán in Peru) or cities located in the paths of mudflows, lahars (i.e. Mount Rainier volcano, Washington State, USA) and lateral spreading of sensitive clays;
- instability can also be produced by non-conventional land use. Most of the urban development in the city of Manizales (Colombia), settled on an irregular relief, has been built up using a local practice of hydraulic fills: thick fills of volcanic ash are placed in the slopes using water pressure, with a scarce technical control. Several neighborhoods of this city have been affected in the rainy season by erosion, collapse and displacement of those fills;
- indirect risks for urban areas may derive from the possible damming of a river by a landslide in the valley upstream of the town, which may cause a flood when the temporary dam fails, as in Grenoble in 1219, or from a mud flow caused by the sudden melting of a snow-capped volcano, as at Armero in Colombia in 1986, or from debris flows caused by catastrophic rainfall events in the nearby mountain range, as at Carmen de Uria or Caraballeda in the northern Venezuela in 1999, or from "seiches" caused by landslides falling into lakes;
- finally, the Colombian town of Restrepo, located in the east flank of the East Andean range, is settled in the left shore of the torrential Upin River, five kilometres downstream of a large landslide. Frequently, the supply of sediments to this river has permitted that the base level of the river has increased by several meters, and now the river bed is higher than the mean level of the town, with a high risk of a flooding.

The previous examples highlight that the major risks in urban areas derive from the unplanned development during centuries as well as from the growth of marginal housing in landslide-prone areas which imply cut and fill in slopes without appropriate design, construction of leaking sewage and water pipes and a concentration of flow in creeks during rainfall events which accelerate the erosion process and destabilize the slopes along their banks. Due to the dense occupation of such poor urban areas, the risk for life related to a sudden landslide event is more critical every day.

Therefore, landslide hazard and risk studies in such exposed areas imply the assessment of various scenarios according to the type and intensity of the triggering mechanism, in which local and regional developments of landslide mechanisms must be considered, as well as their direct and indirect consequences. Then, such scenarios have to be taken into account in local and general planning, either by prevention actions (like prohibition to build in very exposed areas), mitigation actions (like construction of drainage systems) or preparedness actions (like organization of evacuation plans and installation of warning systems).

2.2 *Study area and scale*

The complexity of the landslide phenomena, and in particular the role of rainfall infiltration and run-off, often require a hazard analysis at the level of the drainage area. A very significant case is that of the valley of Rimac River in Peru, extending over an area of 3,300 km^2 and reaching the Pacific Ocean in the densely populated suburbs of Lima; although the climate at its lower end is nearly dry (2 mm/year), the intense and sudden rainfall events in its upper reaches (some 800 mm/year) cause devastating debris flows called "huaicos" which may generate damage in extensive flat areas apparently not affected by landslide hazard.

Such extensive investigations first require an analysis at a small scale (1:100,000-1:50,000) in which the hazard is generally expressed in a binomially (yes/no) without any assessment of its intensity. This document is useful for general planning purposes, in which the natural hazards only constitute one of the numerous planning constraints.

Then, in densely populated areas, investigation on landslide hazards have to be improved at an intermediate scale (1:25,000) in order to give more precise delimitations of the exposed zones and to be able to express a reliable gradation of hazard intensity with precise criteria. On the other hand, valuable hazard maps, at this scale, can be useful also in implementing monitoring systems.

Finally, when risk analyses are carried out at the level of plots of land or individual buildings, large scale mapping is required (1:5,000 or larger, depending on the available topographic documents), especially where the value of the land justifies exploiting any possibility of housing development in safe zones even if they are quite near to landslide zones.

Of course, it is important to adapt the quality of the landslide investigations to both the required scale and the pursued aims. In particular, when large scale landslide maps may severely reduce the value of a plot of land, detailed in-depth data must be gathered by in-situ investigations (boreholes, inclinometers and other techniques) as well as by mathematical modeling which, in turn, can improve the monitoring system at a site scale.

3 FRAMEWORK FOR HAZARD AND RISK ZONING

3.1 *Theoretical background*

In order to be a profitable tool for urban planning and development, landslide hazard and risk zoning must be clearly placed in a "risk management" framework which, referring to Fell et al. (2005), comprises "risk analysis" and "risk assessment".

Risk analysis is based on hazard analysis (landslide or danger characterisation and analysis of frequency) and consequence analysis (characterisation of consequence scenarios, analysis of probability and severity of consequence). Risk estimation is, therefore, obtained by a suggested formula that allows the integration of the hazard identification with the consequence analysis.

Once this process is concluded, risk evaluation calls for policy-maker decisions regarding risk acceptability or treatment and priorities to be set according to a complex and, sometimes, iterative procedure that must consider both technical and socio-economic aspects. At the end of the risk-assessment procedure, and taking the selected option into account (risk acceptance or avoidance, likelihood or consequence reduction), a treatment plan aimed at risk mitigation and control is devised as the final stage of the risk-management process.

Within the framework proposed by Fell et al. (2005), hazard zoning turns out to be a part of both risk analysis and risk assessment since the hazard distribution must be compared with the urban plan. Development can thus be authorised in terms of cost-benefit analysis and taking the available mitigation and protective measures into account. Risk zoning can be related to risk estimation and risk mitigation, highlighting the most threatened areas where remedial, protective, warning and even evacuation measures must be implemented.

With reference to the first stage of the process, identified as risk assessment by Ho et al. (2000), it must be emphasized that, frequently, hazard and risk zoning can imply problems and requires attention for several reasons, including the absence of a standardized procedure for hazard and risk mapping; the size of the study area and the need of maps at various scales; the political and economic implications; the weakness of the available data and/or, sometimes, the difficulty related to the evaluation of their reliability and so on.

Fortunately, the previous reasons are not pertinent everywhere, as some countries or regions have already progressed in the development of specific procedures that allowed the solution of practical problems. However, the current use of such procedures calls for some considerations due to several open questions, as discussed in the following section.

3.2 *Open questions*

An overview of methods and procedures for hazard and risk zoning is provided by Einstein (1988), who analyzes the landslide risk mapping framework with many examples of danger, hazard, risk and landslide-management maps.

Bonnard et al. (2004a), within the IMIRILAND

Project, analyze the consequence of risk studies on land planning procedure as well as the tendency, in the European countries, of risk management policy; moreover they give suggestions for future risk-management studies not disregarding the open questions.

Consideration of hazard and risk mapping for land-use management and development planning are also furnished by Ho et al. (2000) who outline the significant advance made all over the world. After brief comments on the meaning of some maps, they show the relevance of quantitative risk assessment (QRA), which is strongly recommended through detailed key messages.

To deepen the open questions of Bonnard et al. (2004a) and the suggestions of Ho et al. (2000), two relevant experiences are here summarized, regarding the hazard and risk zoning procedures respectively developed in France (Europe) and in Hong Kong (China).

Experiences in France and Hong Kong

France is located in Central-Western Europe on a total surface of 544,965 km^2, where 60 million people live. Its territory is systematically affected by several natural hazards among which floods are prevailing but landslides assume a relevant role from a socio-economic point of view.

To deal with these hazards, the technical and scientific communities have been engaged, since the 1970's, in producing landslide-related maps as documented by several authors and discussed by Einstein (1988) who places such maps in the landslide-risk mapping framework. The main contents of the maps are summarized below.

The first maps produced in France are those of the ZERMOS project (*Zones exposées à des risques liés aux mouvements du sol et du sous-sol),* which dates back to the 1970's (Humbert 1972, 1977, Antoine 1978). They have been produced at 1:25,000 scale and cover different terrain instabilities such as subsidence and landslides. Inside these maps three zones are identified to distinguish the absence of movements, the presence of active movements, and the potential for future activity. Lines and figurative symbols are utilized for the existing instability; scarps and run-out zones are also marked inside such maps, which can be classified indeed as " danger maps" according to the glossary definition.

During the summer of 1982, the PER (*Plans d'Exposition au Risque*) were promulgated by law with the aim of increasing risk prevention (DRM 1990). According to these plans, maps should be developed at scales of 1:5,000 and/or 1:10,000 to be compared with urban planning documents. The final goal of the maps was risk mapping at an urban scale and the set up of regulations for land-use planning. However, such maps cannot be classified as "risk map", as they do not strictly consider all the terms (i.e. hazard and vulnerability) necessary for risk assessment.

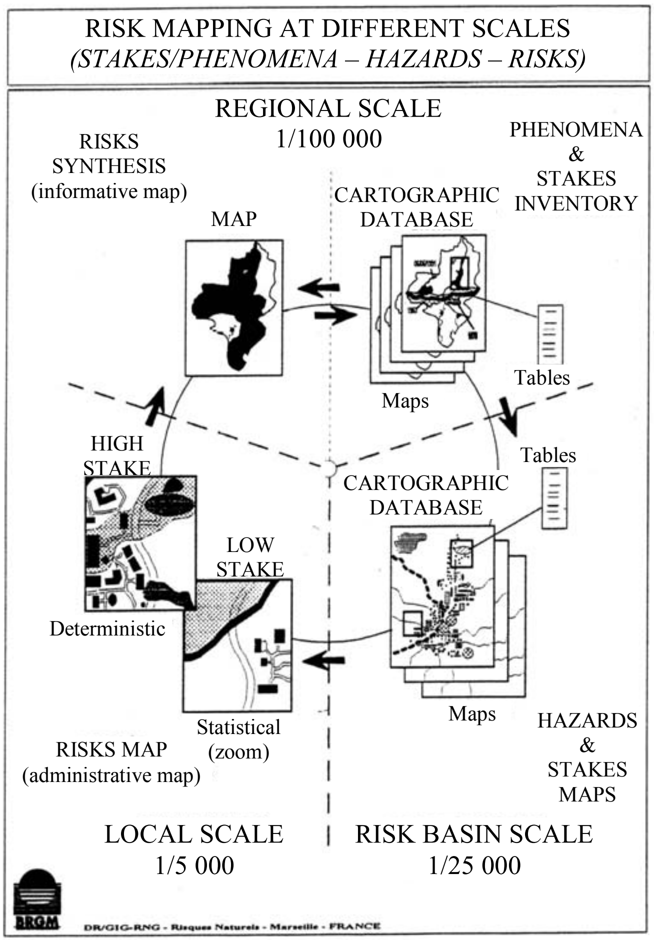


Figure 4. Risk mapping at different scales (Leroi 1997).

Due to the enormous cost of the project at a national scale, PPR (*Plans de Prévention des Risques Naturels*) were successively introduced for risk mapping at 1:25,000 scale (Besson et al. 1999, Garry & Graszk 1997, Graszk & Toulemont 1996) having a regulatory function for urban development and, at the same time, connection with urban planning. The meaning of the produced maps can be considered similar to that of the PER maps.

Interesting comments were furnished by Leroi (1996) on problems faced by the technical and scientific communities, the political and cultural choices, the financial arbitrage related to such a difficult topic. Thus, the author introduced risk mapping as a problem at different scales, with each scale having a well defined meaning and aim (Fig. 4).

Concerning Hong Kong, the territory is situated at the mouth of the Pearl river on the south coast of China; its total area is 1,050 km^2, and in 1988, its population was 5,6 million. Due to both the very hilly terrain over a large part of the area and the impressive growth of population during the previous decade, buildings and other structures were built on the midslopes and upper slopes of natural hillsides. As a consequence of the intensive land-use, and without a well-defined land-use planning, the territory experienced catastrophic landslides that resulted in fatalities and large economic costs (Vail 1984, Vail & Beattie 1985, Lumb 1975, Brand 1984, 1985, Burnett 1987).

To mitigate the landslide hazard, the Geotechnical Control Office (GCO) was established in 1977; two years later the Geotechnical Area Studies Programme (GASP) was initiated and directed towards two aspects: (a) Regional studies (at scale of 1:20,000), (b) District studies (stage 1) and District studies (stage 2) to be both carried out at a scale of 1:2,500.

Regional studies were performed subdividing the territory in eleven sub-areas, 50-100 km^2 in size, essentially on the basis of photograph investigation, site reconnaissance and existing geotechnical information. The stage 1 of District studies essentially followed the same planning, even though at a more detailed scale, whereas during stage 2 an accurate geotechnical assessment was carried out; both stages 1 and 2 were performed all over the territory within areas having a size of 2-4 km^2 each.

The results of regional studies were summarized in 7 maps [*Terrain Classification Map, Landform Map, Erosion Map, Engineering Map, Physical Constraints Map, Geotechnical Land use Map (GLUM), Generalised limitations and Engineering Appraisal Map (GLEAM)*], whereas the District studies produced 6 maps [*Terrain Classification Map, Surface Hydrology Map, Vegetation Map, Engineering Data Sheet, Engineering Geology Map, Geotechnical Land use Map (GLUM)*]. These maps are described in detail by Brand (1988) who stresses the relevance of GLUM and GLEAM maps, which can be considered as danger maps for urban planning and development.

Thanks to the high quality of the available data, a wide range of limit-equilibrium slope-stability analyses were completed. The calculated value of the safety factor, in reference to groundwater conditions produced by rainfall with a ten-year return period, was therefore associated with three risk categories respectively defined high, low and negligible concerning both the human life and the economic damage. In the paper of Brand (1988), reference is also made to the use of a probabilistic approach for both risk assessment and acceptability of failure consequence.

Starting from the impressive knowledge and data sets acquired during the time, the risk assessment has been successively developed in Hong Kong using the quantitative risk assessment (QRA) which has been applied to quantify both the global risk failure posed all over the territory by some kind of slopes and the site-specific risk at a given site. Several papers describing such studies are summarized by Ho et al. (2000), who give an overview of case studies involving the use of QRA in landslide risk assessment (Fig. 5).

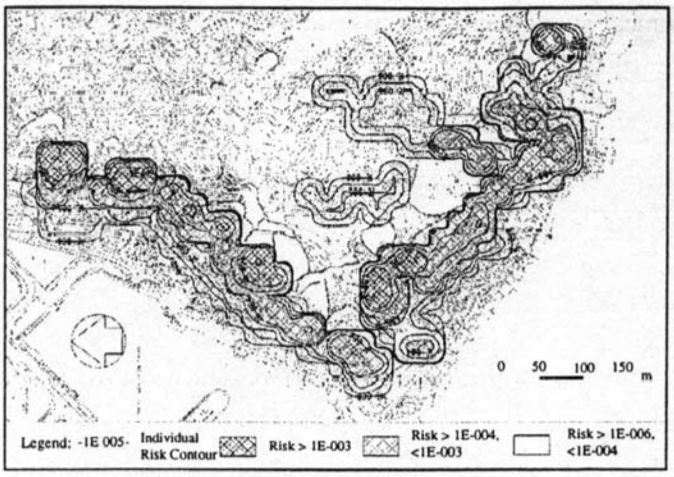


Figure 5. Example of individual risk contours obtained by QRA; Lei Yue Mun squatter villages (Atkins Haswell 1995).

General suggestions

The experience gained in France and Hong Kong, as well as the widely available literature, suggests that – due to the complexity and, sometimes, the extension of the geological context to be analyzed – hazard and risk zoning calls for theory and wide-zoning practice. Moreover, the financial support over a long period of both the Central and Local Authorities as well as the participation of the public are absolutely necessary.

From a technical point of view two different levels of zoning are almost constantly analyzed: at an intermediate scale (1:25,000 or smaller) and at a large scale (1:5,000 or larger).

Concerning the first level (1:25,000), present knowledge suggests that zoning must be produced using a qualitative approach that could be usefully applied even at the largest scales, when a lack of risk culture is clearly recognized. On the contrary, at the second level (1:5,000 or larger, as well as at a site-scale) the quantitative risk assessment (QRA) must be preferred, above all, where good and extensive knowledge is available. Moreover, independently from the utilized approach, all the maps (state of the nature, danger, hazard and risk map) must be clearly addressed and defined since, too often, confusion arises amongst danger, hazard, consequence and risk. Finally, with reference to the input elements to zoning maps, some suggestions can be furnished considering both the terms in the glossary and the available literature.

Passing over the state of the nature maps, the input elements to danger, hazard and risk zoning maps are schematically shown in Figure 6. Particularly, the danger map must include the landslide (danger) characterisation (landslide susceptible areas, landslides intensity and further data sets); the hazard map would take that information and adds frequency of

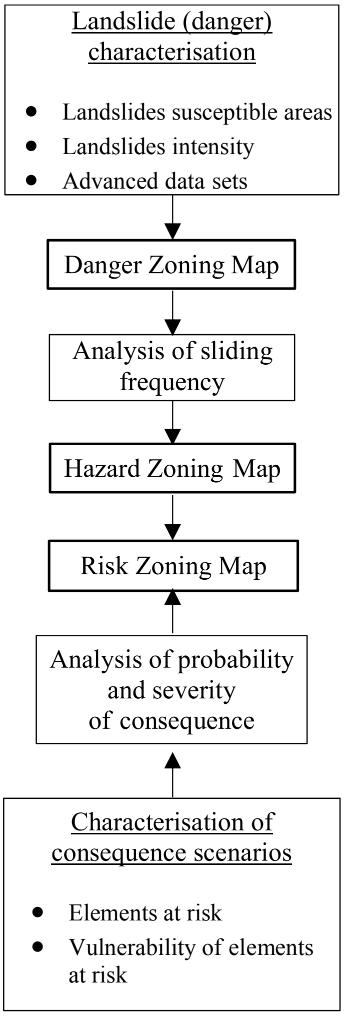


Figure 6. Input elements to zoning maps.

sliding; and the risk map adds the consequences to the elements at risk by the characterisation of consequence scenarios (elements at risk and vulnerability of elements at risk) and temporal probability analyses.

At the intermediate scale (1: 25,000), landslide susceptible areas would show as input the classification, location, areal extent and, possibly, other geometric characteristics of each landslide, creeping zone and potential sliding; the activity classes of landslides; the areas onto which the potential sliding may travel with qualitative and/or quantitative information on past events. Landslides intensity should be based on simple parameters describing the destructiveness of landslides or potential sliding as, for instance, the potential post-failure velocity. Whenever possible, other information can be useful to improve the landslides characterisation as those regarding the volume, the qualitative or the quantitative estimation of the actual rate of movement, the data set on geotechnical aspects, triggering factors and so on. Unfortunately, many of such data are difficult to collect in a systematic way at an intermediate scale; however, the danger map can be improved with time provided that the state of the nature maps have been produced according to a high quality standard.

At a large scale (1: 5,000 or larger) the above elements, even if implemented in a qualitative risk procedure, must be considerably improved with quantitative data on volumes, the actual rate of movement, more advanced parameters describing the landslides intensity; moreover, advanced geotechnical, triggering factors and further data sets are necessary. If well related such maps, even those at intermediate scale, may allow mathematical and quantitative risk assessment (QRA). Of course the choice of the most suitable model is strictly related to both the scale and the quality of the available data.

The danger map, when carefully realized, can considerably simplify the analysis of sliding frequency and the compilation of the hazard maps that must clearly indicate the likelihood of landslide magnitude (velocity and/or volume). Generally, at 1:25,000 scale, the likelihood is expressed in a qualitatively way on the basis of indicators such as, for instance, some geomorphological factors (i.e. state of activity). On the other hand, at 1:5,000 scale, the quantitative hazard estimation requires the use of advanced mathematical models such those relating, for example, the triggering factors to the landslide mobilization. However, such models need an accurate data set and an appropriate calibration inside sample areas where monitoring and other in-depth investigation are systematically completed.

With respect to consequence analysis, that is necessary to produce the risk maps, different procedures must be adopted according to the reference scale. At an intermediate scale, the analysis should be performed by appropriately selecting the reference area, the most relevant elements at risk within, and criteria for an overall qualitative estimation of the consequence. On the contrary, at a large scale, each element at risk, its vulnerability, temporal probability and criteria able to transform the individual into an areal estimation of the consequences, taking potential development programs into account, should be considered.

Finally, for risk zoning maps, risk estimation based on a well-known formula is absolutely necessary, whereas the study is carried out at either intermediate or large scale. A simple formula like that proposed by Varnes (1984) or Einstein (1988) could be better used at 1:25,000 scale, while a more complex equation (Fell 1994, Leroi 1997) should be preferred at 1:5,000 scale.

At the present, the previous described analyses have not been exhaustively developed, at both intermediate and large scale. Therefore, hazard and risk zoning can be considerably improved on condition that a wide range of research is developed with the aim of identifying, testing out and choosing reliable procedures (Bonnard et al. 2004b). These procedures must have a clear meaning from a theoretical point of view and, at the same time, the capacity to simplify the production of maps at various scales, in order to connect the regional and local requests of both risk assessment and mitigation.

Starting from the above considerations, the next chapter discusses in detail the objectives of hazard and risk zoning maps; the most relevant inputs to landslide hazard and risk zoning; the criteria for defining hazard and risk levels and subsequent zoning. Finally, the validation procedures, that are absolutely necessary in order to estimate the reliability of zoning procedures, are illustrated.

4 ZONING FOR HAZARD AND RISK MAPPING

Landslide hazard and risk maps have different objectives within the framework of landslide risk assessment and management.

Landslide risk maps provide a global view of the expected annual damage due to the potential landslide hazard by identifying the most vulnerable elements that are threatened. Based on the information supplied by such maps and cost-benefit analyses, either protective or reinforcement works can be envisioned to minimize the risk level, whereas alert systems can be established in places in order to protect the human lives. Risk maps, however, are documents that are not intended for direct use in urban planning and development because they generally reflect the current situation of potential damage but not the spatial distribution of the hazardous zones. In that respect, non-urbanized areas are often displayed as having low risk level regardless the level of existing hazard which is not quite appropriate.

The spatial distribution of hazard is shown on landslide hazard maps that are used to avoid the development of threatened areas, representing the most efficient and economic way to reduce future damage and loss of lives. On the other hand, such maps provide the appropriate elements of decision for considering the feasibility of the development with or without any stabilisation or protective countermeasures.

Zoning for both landslide hazard and risk mapping introduces the spatial dimension of the landslide hazard management. The purpose of zoning is to divide the studied area into homogeneous compartments (units) in which hazard or risk is expected to attain a similar level. To be profitably used for urban planning and development, the hazard and risk maps must be performed at an appropriate scale in order to avoid controversy in delivering building permits, expropriation and compensating measures (Leroi 1996). However, the most large scale maps (usually 1:5,000 and larger) may create difficulties due to the high level of refinement required by the necessary data (DTM, geological maps, superficial formation maps, landslide inventory, vegetation cover, groundwater regime, soil/rock properties, etc).

Notwithstanding such constraints, in the following sections the attention is essentially devoted to the largest scale, even though suggestions and comments could also be applied to the intermediate scale (1: 25,000).

4.1 Hazard zoning parameters

Ideally, a landslide hazard map should provide information concerning the spatial probabilities and frequencies of all anticipated landslide types, the expected travel trajectories and the intensities within the mapped area (Hartlén & Viberg 1988).

A significant amount of effort has been made during the last decades in developing procedures for hazard mapping which, however, have to face some important challenges.

Landslides are gravitational processes that display a variety of motion mechanisms and propagate at different velocities, with travel distances strictly dependent on the landslide mechanism, the mobilised volume and the characteristics of the path which cannot always be predicted beforehand. Moreover, the spatial assessment of the magnitude-frequency relationships is not easy to obtain. Finally, the definition of landslide hazard levels and subsequent zoning – no matter whether they are expressed in qualitative or quantitative way – should have a correspondence with the damaging capability of the phenomena as well as the feasibility of implementing countermeasures.

Despite such constraints, quite often classes of the different landslide hazard components are defined arbitrarily rather than on landslide risk management considerations.

Defining landslide susceptible areas

As previously stated, landslides characterisation calls for zoning susceptible areas that can be pursued by many approaches. Early attempts were based on qualitative overlaying of geological and morphological slope-attributes (Nilsen et al. 1979), and soon evolved to more sophisticated assessments involving data treatment and multivariate analyses (Neuland 1976, Carrara 1983). The reader will find comprehensive summaries in Carrara et al. (1995), Van Westen (1994, 2004).

Anyway, to be exhaustive, the zoning of landslide susceptible areas have to include both the potentially unstable slopes (Brabb 1984) and the area affected by the arrival of landslide debris (propagation area). Not considering this area will lead to an underestimation of the risk over the exposed elements (Leroi 1996).

Notwithstanding the availability of several methods for estimating the distances travelled by landslides – respectively based on empirical, deterministic or mathematical models (Sassa 1988, Sassa et al.

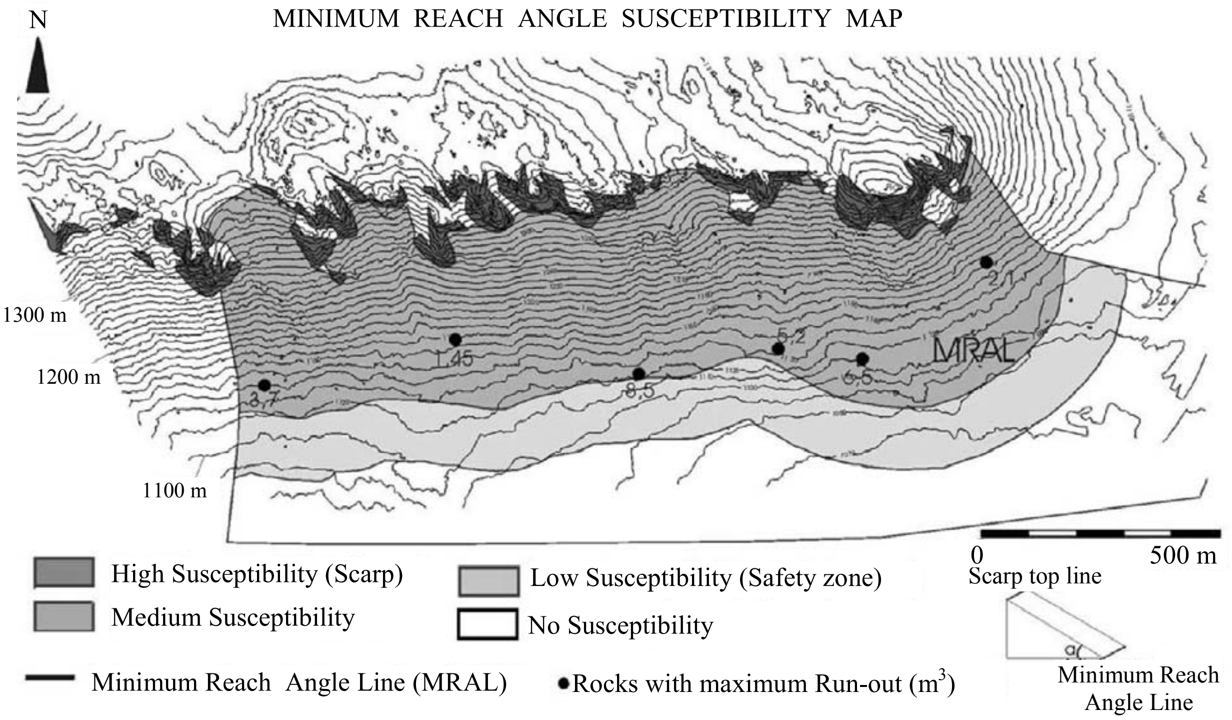


Figure 7. Rockfall susceptibility map of the La Cabrera Sierra (Ayala et al. 2003). Boundary of the susceptible area (MRAL) has been traced using the minimum reach angle for the expected rockfall volume.

2004, Corominas 1996, Pastor et al. 2003) – only a few experiences have been published in which the travel distance of landslide debris has been taken into account in defining susceptible areas (Corominas et al. 2003b, Michael-Leiba et al. 2003).

Ayala et al. (2003) have combined the concept of reach (travel distance) angle with a numerical model for delineating the area affected by rockfalls. The method is based on the intersection of the line of sight dipping according to the angle of reach, from the potential rockfall source, with the ground surface. The line defined by linking all the intersections is the minimum reach angle line (MRAL); the procedure has been implemented in a GIS environment (Fig. 7). Zoning criteria have distinguished between a high susceptibility area (the scarp or rockfall source), a medium susceptibility area (the run-out zone) and a low susceptibility area (a stripe of land of 100 m wide, defined for safety purposes). The zoning criteria can be refined by using boundary lines of expected travel distances determined by using trajectographic analyses (Copons et al. 2004).

Zoning Landslide Intensity

Once the susceptible areas have been defined, intensity (magnitude or severity) of the landslide phenomena is a key parameter in landslide (danger) characterisation, which lack a standardised accepted definition and scale. Nevertheless, it is widely accepted that landslide intensity is the capability to produce damage. Concerning the reactivated landslides, the damage can be related to the slope movement stage, as in the case analysed by Bonnard and Noverraz (1984), who use rate of displacements of the landslide units (>10 cm/yr, 5-10 cm/yr, 1-5 cm/yr and presently stable zone) to select sectors that must be evacuated or continuously monitored. Instead, first time-failures and subsequent rapid movements of large masses generally have catastrophic consequences.

Hungr (1997) defined landslide intensity as a set of spatially distributed parameters describing the destructiveness of the landslide. These parameters are varied, being the maximum movement velocity the most accepted one although total displacement, differential displacement, depth of moving mass, depth of deposited mass, depth of erosion are alternative parameters. Nevertheless, by keeping in mind the design of protective structures, other derived parameters like peak discharge per unit width, kinetic energy per unit area, maximum thrust or impact pressure may be also considered. However, no direct correlation can be established between intensity and both the landslide mechanism and size because intensity is also given by the relative location of the threatened elements with respect to the landslide source, transit or deposition area, as in the case of many rockfall events (Fig. 8).

In conclusion, the establishment of a landslide intensity scale for danger zoning requires first the discussion on how it will affect the definition of hazard levels. In terms of landslide hazard management, intensity could be defined referring to the resistance (resilience) of the exposed elements, or the possibility of occurring fatalities, but thinking on cost-benefit bases it should consider the capability of ei-

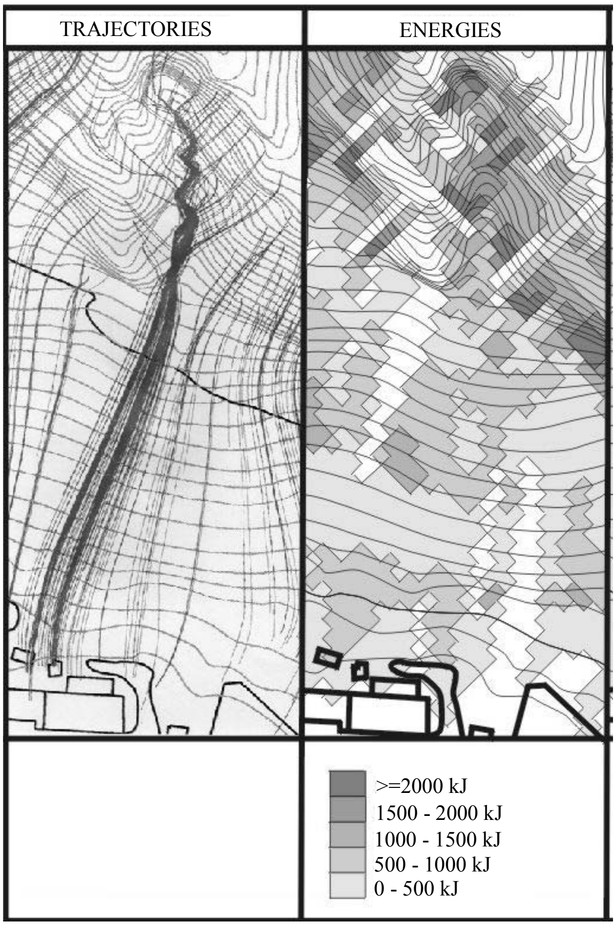


Figure 8. Rockfall trajectories (left) and spatial distribution of the kinetic energy in KJoules (right) for simulated rockfall events in Andorra (Copons et al. 2004).

ther stabilization or protective works. These different approaches can be observed, for instance, in the intensity levels defined for Swiss hazard maps which were based on the expected damage on both persons and buildings (Lateltin 1997), while in the case of the Andorra Principality hazard mapping, intensity was defined taking the resistance of the protective structures, particularly for rock falls, and the feasibility of stabilization works into account (Corominas et al. 2003b).

Frequency Classes

It is recommended that frequency will be expressed as probability of occurrence or by a return period (Lateltin 1997) based on hazard acceptability criteria.

Frequency of landsliding can be determined from historical data, relation to triggering event frequencies (e.g. rainfall, earthquake) with known annual exceedance probabilities, or relating pore water pressures to rainfall or snowmelt exceedance probabilities, which will produce insatibility conditions. However, care should be taken in the establishment of landslide frequencies, based on either historical or prehistorical (silent witnesses, landslide dated series) because the conditions responsible for a given landslide frequency in the past may no longer exist (Lateltin 1997). Similarly, land-use changes like forest logging or forest spreading may change significantly the magnitude (intensity) – frequency relationships.

Several methods have been proposed for defining landslide frequency classes, based on landslide inventories and qualitatively describing landslide activity by a geomorphological assessment. Suggested activity classes (WP/WLI 1993, Cruden and Varnes 1996) include: active, suspended, dormant, relict and stabilized landslides.

Activity classes have also been used to produce landslide hazard maps (Carrara et al. 1991), although these classes require some additional judgement to be translated in recurrence periods or probability of occurrence before the resultant maps could be considered as real hazard maps.

Ideally, landslide hazard maps should also provide some insight on when first-time failures might occur, although this is an unsolved challenge. Frequency and return period are valid concepts for repetitive events but not for unique ones. This issue may be approached by using predictive models. For instance, maps showing safety factor values of the slopes for different rainfall and/or groundwater scenarios are already available in some regions (i.e. Savage et al. 2004). In such cases it is possible to determine the groundwater conditions that may lead a given slope to fail for the first time and the probability of occurrence (which is obtained from annual exceedance probability of the triggering factor). However, other factors such us stress release mechanisms or weathering processes can introduce a great degree of uncertainty in the obtained figures.

Zoning landslide hazard levels

Landslide hazard is the result of the interplay of different factors, some of which can be obtained and mapped easily and some not. As previously stated, zoning must include both landslide detachment zones and the deposition areas.

Referring to the detachment zone, it must be considered that changes produced by urban development may induce changes in the behaviour of the slopes. For instance, overloading of the slopes by new constructions or leaks from the sewage system can aggravate the previous stability conditions.

As it concerns the deposition zone, it must be taken into account that progression of the destabilised mass can be impeded by the presence of buildings, producing the stoppage of the movement, the diversion of the moving mass or the thickening, although the case of Las Colinas in Salvador in 2002 proved that the progression of a fast landslide mass could not be limited by small houses.

A particular challenge for landslide hazard maps is predicting the evolution of ongoing instability situations such as the rate and extent of a receding cliff in both coastal and riverain areas which are subjected to erosion and undermining action of streams, or that of landslide head scarps developed in weak and unstable materials, that in the case of sensitive clays can reach several hundreds of meters and even kilometres. Successive landslides and removal of the material by erosion generate new slope geometries that have different stability conditions. It has been observed that development boundaries established for safety beyond the unstable crest may become obsolete in a matter of few decades (Fekner 2002). In such cases it is necessary to integrate the cliff receding rates in the maps, which are often based on the observation of series of aerial photographs or on results of numerical models (Walkden et al. 2002). Similarly, the consequences of future climate change or land-use changes are seldom considered and this fact introduces a degree of uncertainty that must be quantified.

A source of uncertainty can also come from cascading effects such as the temporary blockage of debris flow material by bridges and subsequent breakage. Finally, in some areas protective and stabilization works have been carried out. The affected slopes must be considered in terms of hazard (residual hazard). According to the type of works, a straightforward consideration of a reduction in hazard level cannot be justified.

4.2 Risk zoning parameters

Vulnerability of the elements at risk

The characterisation of consequence scenarios is based on elements at risk and vulnerability of elements at risk.

The classifications of elements at risk for landslides are very preliminary compared to other hazards. They range from generic classifications based on the main land uses, namely urban, industrial, infrastructures, or agricultural (Calcaterra et al. 2003; Remondo et al. 2003) to detailed structural analyses of the buildings (Spence et al. 2004) which require specialized expertise. A different approach considers that main damage to the exposed elements is structural, corporal and operational (Leone et al. 1996).

Vulnerability is the degree of loss of an element within the landslide affected area (Fell, 1994). Procedures for assessing the resistance and vulnerability to earthquakes and floods are relatively well established and accepted. On the contrary, the assessment of vulnerability of the elements at risk (e.g. buildings, persons) to landslides still requires significant efforts in terms of definition and grading.

First, the main loads that landslides can exert on exposed elements depend on displacements and associated deformation, in particular: tilting; pressure, either lateral or resulting from impact; accumulation due to transport; and ablation or undercutting due to the erosion (Leone et al. 1996).

Moreover, within a large landslide, there exist sensitive areas where damage will be more likely (or higher), no matter the total landslide displacement or the released energy will be. This occurs, for instance, in the landslide boundaries, such as the head, or in local scarps where tensile stresses are developed with the result of tension cracks, surface ground depletion and local rotation. Similarly, large differential deformations are expected in the landslide foot where thrusting and bulging of the ground surface might take place.

Finally, the resistance of a building might be enough to resist the impact of a falling block but it can be insufficient to avoid the development of tension cracks due to differential displacements produced by a translational slide. On the other hand, the vulnerability of lives and properties may be different and, for instance, a house may have a similar high vulnerability to both slow-moving and rapid landslide, while a person living in it may have a low vulnerability in the first case (Fell 1994, Fell and Hartford 1997).

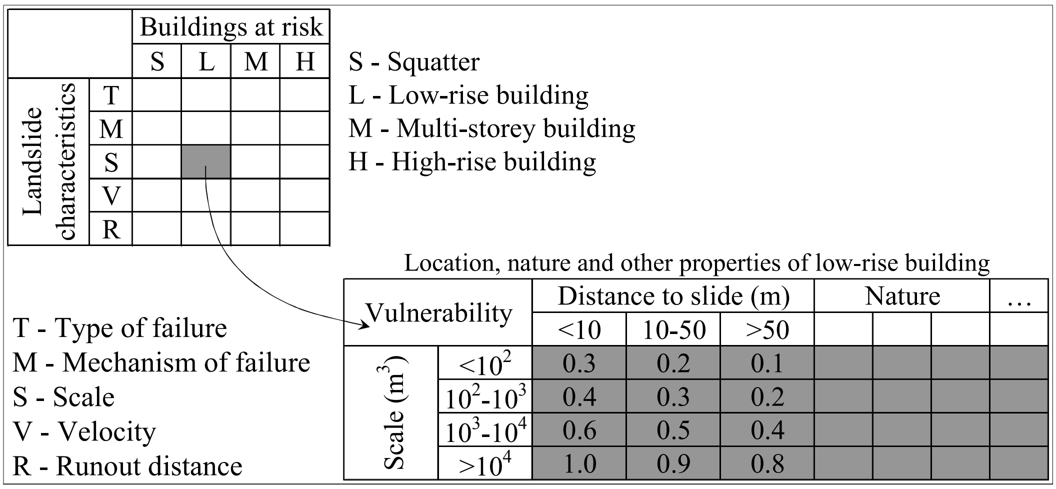
For the above considerations, some specificities must be taken into account in the assessment of the vulnerability to landslides. For a similar structure or building, the expected damage will depend on three factors: (i) the type of landslide mechanism (rockfall, debris flow, slide, etc); (ii) the intensity (velocity, volume); and (iii) the relative location of the vulnerable element in relation to the landslide trajectory (Table 1) or to the position inside the landslide affected area.

In order to include these relationships, the different landslide types and intensities are faced against the vulnerable elements in Figure 9. In any case, vulnerability assessment with such accuracy can be usually performed, at a very detailed scale, where well-documented landslides are available. This is the case of La Frasse in Switzerland where, after detailed reconnaissance study and systematic monitoring, a map showing different landslide units, moving at different displacement rates could be prepared (DUTI 1983; Noverraz and Bonnard, 1990).

In order to obtain reliable results, the performance of structures during past landslide events is also a suggested criterion, taking also the quality of main-

Table 1. Vulnerability to destruction of people, buildings and roads by debris flow events in Cairns, Australia (Michael-Leiba, 2003).

Unit	People	Buildings	Roads
Hill slopes	0.05	0.25	0.3
Proximal debris fan	0.5	1.0	1.0
Distal debris fan	0.05	0.1	0.3



		Buildings at risk			
		S	L	M	H
Landslide characteristics	T				
	M				
	S		▨		
	V				
	R				

S - Squatter
L - Low-rise building
M - Multi-storey building
H - High-rise building

Location, nature and other properties of low-rise building

Vulnerability		Distance to slide (m)			Nature				…
		<10	10-50	>50					
Scale (m^3)	$<10^2$	0.3	0.2	0.1					
	10^2-10^3	0.4	0.3	0.2					
	10^3-10^4	0.6	0.5	0.4					
	$>10^4$	1.0	0.9	0.8					

T - Type of failure
M - Mechanism of failure
S - Scale
V - Velocity
R - Runout distance

Figure 9. Example of structural vulnerability matrix (Dai et al. 2002).

tenance works into account. In that respect, the preparation of inventories of the damage caused by past events and back-analyses of impact velocities and performance of the structural elements (Faella & Nigro 2003) are really indispensable.

Risk zoning

Risk cannot always be readily determined because of the difficulty in assessing the elements at risk (in a forward planning situations) and vulnerability of the elements at risk. There is also a need to make some assumption about the temporal probability of the elements at risk. For buildings is not an issue (it is 1.0), but for persons it will be less than 1.0 in most of the cases. In practice for zoning it is common to assume persons are in the area affected by the landsliding 100% of the time. This is conservative but has precedents in other industries.

Risk classes must also take the risk culture into account which is different from one society to another, particularly when comparing non-developed and developed countries. As a consequence, in what concerns landslide risk, there is almost no indication of what is an acceptable, tolerable and unacceptable risk. Therefore, we must first distinguish between risk to life and risk to properties.

Risk to persons is evaluated by the loss of lives. According to the IUGS (1997), the incremental risk from a hazard should not be significant compared to other risks to which a person is exposed in the everyday life. The probability of the individual risk is, therefore, compared with the probability of natural death. A normally accepted order of magnitude of a hazard of death related to a particular activity is around 10^{-4} per annum (Archetti & Lamberti 2003). The Australian Geomechanics Society (AGS 2000) considers as tolerable a value of 10^{-4} per annum for the person most at risk in existing constructed slopes, and 10^{-5} per annum in newly constructed slopes while acceptable risk is considered to be an order of magnitude smaller than the mentioned figures. This criterion is similar to that adopted by Hong Kong for new and existing developments (ERM 1998; Ho et al. 2000). A graphical view of the risk acceptability criteria is given by F-N curves (Fig. 10). These curves represent the relationship between the annual probability of an event causing N or more fatalities and the number of fatalities. The boundaries between acceptable, tolerable (or As Low As Reasonably Practicable), and unacceptable may be used as a criteria for risk zoning. A review of criteria used for establishing acceptable and tolerable risk in the industry and several administration offices is found in Fell and Hartford (1997).

The vulnerability matrix method proposed by Leone et al. (1996) gives an example of allowing the consideration of a wide range of situations and reducing the subjectivity in the assessment of landslide risk. It is transparent because it is possible to calculate indexes of economic (direct and indirect), functional and human losses. When multiplying these indexes by the annual probability of occurrence of the

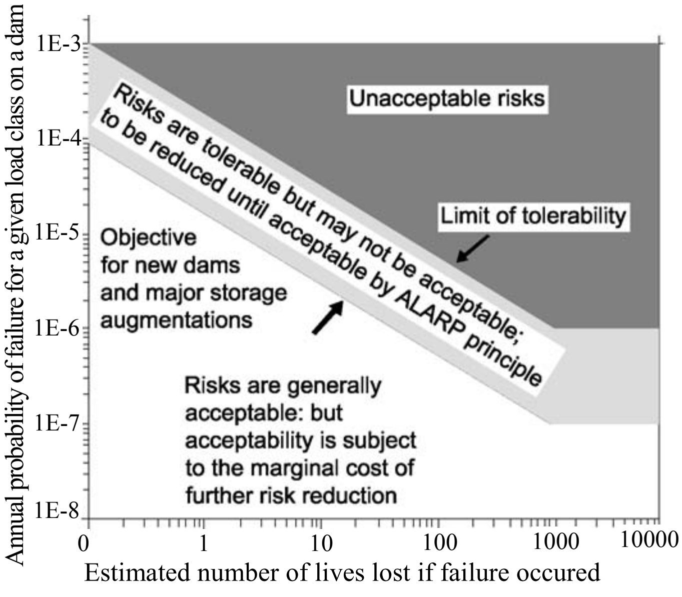


Figure 10. ANCOLD criteria for societal risk (ANCOLD 1998).

landslide and the number of exposed elements, it will provide a quantitative estimation of the risk (Fell et al. 2005).

This type of calculation can easily be carried out for zoning studies based on subareas defined by GIS. However, to the authors' knowledge, there exist no standardised costs that can help in defining risk classes.

Finally, residual risk, that is to say, the risk remaining after mitigation or protective measures have been undertaken, has to be considered in urban areas. At this end, risk maps must be documents easily updatable and any change, either in hazard assessment (i.e. by implementing countermeasures) or in the elements at risk, have to be incorporated (Copons et al. 2004). However, it should be kept in mind that residual risk has different meanings. For instance, in Switzerland (Lateltin 1997), areas with residual risk are those affected by a hazard of high intensity but with very low probability of occurrence.

4.3 Validation of zoning

Despite the large amount of work carried out and the availability of landslide hazard assessment methods, they seldom have been validated. Nevertheless, there is a need of checking the predictive capability of future landslides, in both space and time, which strictly depends on the quality of the input data used and, among them, the landslide inventory. Particularly, the latter plays a fundamental role as either dependent variable in statistical analyses or for validation purposes.

An exercise of independent landslide inventory mapping performed by three groups of geomorphologists in the Italian Apennines (Ardizzone et al. 2002) has shown that discrepancies among maps were very high (in the range of 55-65%). When all the maps were overlain, the spatial mismatch of the landslide deposits polygons was over 80%. These authors also analysed how such errors might affect areas with villages and infrastructures, considering a buffer of 100 m width from roads and urban areas. Comparison of the landslide inventory maps (Fig. 11) showed that the disagreement was 58.9% of the mapped landslide area. The mismatch can be strongly reduced up to 20-25% by working with morphologically-meaningful-terrain units and by training the members of the group mapping the area. Similar results were obtained in another hazard mapping exercise by three different teams in Alpago Basin, Italy (Van Westen et al. 1999); the area mapped equally by all three teams is only 35% and landslides inventoried differ in almost an order of magnitude. These results show that we are still far from having reproducible results for landslide hazard assessment.

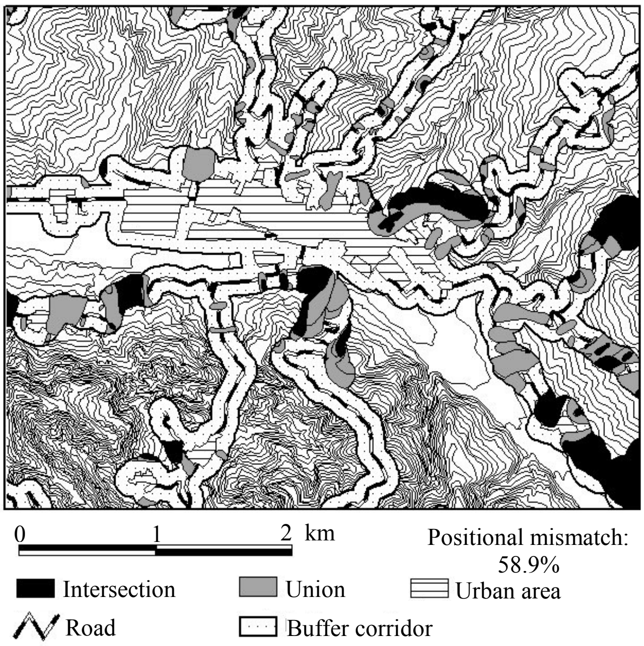


Figure 11. Comparison of the landslide inventory maps prepared by two groups of geomorphologists of Milano and Perugia in an urban area of the Staffora basin, Italy (Ardizzone et al. 2002). Landslide coincidence (intersection) and disagreement (union) is indicated. The position mismatch is 58.9% (Ardizzone et al. 2002).

The IUGS Working Group on Landslides understood that the variety of approaches used in assessing the different components of landslide risk can result in significant differences in outcome if the same problem is considered separately by different practitioners (IUGS 1997). However, the objectivity in the assessment of landslide hazard does not necessarily result in an accurate hazard map. For example, if a very simple but verifiable model is used or if only few parameters are taken into account, the procedure may be highly objective but will produce an inaccurate map (Soeters & Van Westen 1996). In such a situation, a key issue is finding a reliable procedure for validating the susceptibility and hazard maps prepared by one or more teams. Validating process is not trivial. A common method for validating is to consider a landslide population independent from that used to assess landslide hazard and calculate the percentage of landslides within each susceptibility or hazard class.

Several strategies have been developed to obtain the landslide control set. The strategies differ basically in the method for obtaining the landslide set (Remondo et al. 2003): (a) the landslide inventory of the study area is split in two groups, one for estimating hazard and another for validation (i.e. Carrara et al. 1991); (b) the hazard assessment analysis is carried out in a part of the study area and the map (model) is tested in another part, obviously with different landslides; and (c) the hazard assessment is carried out using landslides occurring in a certain period and validation is performed with landslides occurring in a different period. The latter is the most adequate to test the validity of the prediction made; it has been performed after the occurrence of extreme events in zones where previous susceptibility or hazard mapping were available (Irigaray et al. 1999).

The results of the exercises performed with different groups of landslide specialists mentioned above and the analysis validity procedures confirm that discrepancies are mostly due to the quality of the input data used in landslide hazard and risk assessment rather than on the methodologies used. In particular, the landslide inventory (type, activity, number and extent of landslides) is the basis for hazard assessment and its validation.

The most frequent technique used for producing landslide inventories is aerial photo-interpretation. Several studies have shown that differences between the interpretations carried out by different observers can be very large (Carrara et al. 1992, Dunoyer & Van Westen 1994).

Powerful computer programs and GIS technology have given the opportunity to solve complex problems requiring large amount of data and computational capabilities. However, it is not always true that computer-generated maps could be more objective, accurate and credible than hand made maps (Carrara et al. 1999). We still have to rely on field work performed by skilled and experienced professionals for obtaining some key parameters. In any, case, when data available are insufficient for analytical evaluation of failure (or reactivation) probability and its intensity, error bars in deriving magnitude-frequency relationships can be more than two orders of magnitude, and errors in risk may be larger (Michael-Leiba et al. 2003).

5 RISK MITIGATION STRATEGIES

5.1 *Urban planning and emergency plans*

At the end of risk-estimation procedure, acceptance or avoiding of both hazard and risk must be selected and priorities have to be individuated (Fell et al. 2005). Of course, such relevant decisions can be made easier by hazard and risk zoning which can direct the urban planning and development, the emergency plans and the countermeasure planning.

Concerning the first aspect, it can be observed that many cities and towns in developed and developing countries, that are affected by landslide-prone areas, have been applying legal rules for their development for several decades, which are specified in the local planning documents and regularly updated. The most common practice includes the delimitation of zones in which building is either prohibited or restricted to some types of constructions with a low occupation level. Sometimes prescriptions can be imposed with respect to preliminary geotechnical studies or simply information is given to the owners regarding the existence of a low intensity hazard level due to landslides.

The main problem is, however, not the elaboration of local plans or rules for the use of landslide-prone areas, but the long-term applicability of such plans. For instance, in the capital of Honduras, Tegucigalpa, the planning documents elaborated in the seventies excluded any construction on the zone of Berrinche landslide on the left bank of Comayagua River; but after several decades of non-respect of these prescriptions, hundreds of houses built at its toe were destroyed by the sudden reactivation of the slide following Hurricane Mitch.

Another situation in developing countries may occur when marginal housing is suddenly expanding outside of the planned building areas, even despite of the existence of strict limitations or regulations, and implies a high risk situation due to uncontrolled debris flow hazard, as it is the case in the outskirts of Pichincha volcano, west of Quito, the capital city of Ecuador. It is even more difficult to evacuate these zones as the municipal services themselves are supplying electricity and water to these new housing developments.

Due to the previous considerations, emergency plans and remedial measures must be strongly implemented, within the short time, to limit the consequence of landslides. In the present section a significant example of both emergency plan and subsequent risk mitigation is discussed, whereas the second part of the Chapter is devoted to monitoring systems aimed at the improvement of emergency plans.

The case of Falli Hölli village management

The Canton of Freiburg, in the Western part of Switzerland, presents a high percentage of landslide-prone areas, i.e. more than 10 % of the whole cantonal area, especially in the Prealps, where Flysch formations are abundant. This canton had been one of the first ones, in 1976, to prepare a preliminary map of landslides at a scale 1:25,000 that included a distinction between active slide zones, probable or substabilized slide zones and stable zones.

In a mountainous area of the Commune of Plasselb, called Falli Hölli (i.e. literally “fall in to hell!”), in which the forest cover had been removed in the XIXth century, it was planned to build a small tourist village and the first building permits were already delivered in 1969. When a more extensive local management plan was developed and submitted to the approval of the cantonal authorities, several cantonal administrative offices that were required to give their advice opposed the plan, arguing the presence of an active slide that was clearly delimitated in the preliminary map of landslides, but also the difficulties of access (the road leading to the area was very narrow) and the lack of connections with other tourist areas.

However, these denials were objected by the communal authorities as an unjustified obstacle to economic development. Therefore, the State Council of the Canton of Freiburg, after listening the opinion of an expert who had not seen any signs of active movements at the site of the planned village (which indeed was correct, but did not consider the global slide phenomenon called Chlöwena), finally accepted the project for political reasons in 1977. Most of the 36 chalets were thus built between 1980 and 1990 (Fig. 12).

In 1992, in order to improve the due consideration of natural hazards in the Canton of Freiburg, a special "Natural Danger Committee" was set up by the Government, including representatives of the political authorities, of the planning and forest services, of the cantonal insurance office and of the juridical service. This committee proposed to launch a landslide mapping program at a scale 1:10,000 that was carried out between 1993 and 1999 over an area of 400 km^2 (the plain areas were not mapped).

In March 1994, one of the houses of the village of Falli Hölli began to be seriously affected by movements and was dismantled, after some attempts to divert the sliding mass with 7 m long wooden piles, which later proved to be inefficient as the slip surface was much deeper. The progressive reactivation of the sliding zones from the top to the bottom of the slope was observed and monitored from May 1998 on and it clearly appeared to the panel of experts that a major and uncontrollable phenomenon was developing. Therefore, several preparedness actions were set up step by step, between April and June 1994, without any phase of panic:

- prohibition to sleep in the houses of the village;
- prohibition to stay in the houses;
- evacuation of the furniture of all houses;
- auction sale of the furniture and goods of the hotel;
- emptying of gas tanks for domestic heating;
- prohibition to penetrate in the landslide zone.

Between the middle and the end of July 1994, the movement in the zone of the village seriously accelerated from 0.20 m/day to 6.0 m/day, causing indeed few structural damage to the chalets, but major tilting, as the slip surface was some 36 m deep; the building area was somehow compressed, the access roads crushed and sheared, and finally the restaurant located in the lower part of the village was totally destroyed (Fig. 13). At the end of September the crisis was over, with a total displacement of 200 to 250 m, and since then, only residual movements of a few millimeters to 2 cm per year are recorded at Chlöwena landslide (Vulliet & Bonnard 1996).

The owners of the buildings were compensated for their loss by the Cantonal Building Insurance Company at a very short notice (17 million SFr, i.e. 15 million USD), even though the structures were no destroyed; but they could not be repaired. However no compensation is possible for the loss of value of the land (about 99% of loss), which caused the opening of a judicial action; but later the complaint by a group of owners was withdrawn.

Despite of the nearly complete stabilization of the 1,5 km^2 slide, it was decided to destroy the ruins of the chalets, to clear the site and give it back to nature. Only one corner of a basement was left, as a memorial of the "disaster".

This local event induced the cantonal State Council to provisionally suspend all building projects in active landslide areas, to require a technical review of all existing building zones in conflict with active landslide areas in 13 communes of the Prealps and finally to state specific planning and building prescriptions for the landslide areas. They were classified in three categories: liable to build, liable to build under determined conditions, not liable to build. It is clear in this case that even though a full risk analysis was not carried out, a detailed qualification of the risk level was produced, allowing the

Figure 12. View of the village of Falli Hölli at the beginning of the crisis. These houses moved over more than 200m. Some drainage ditches are seen in the back of the village.

Figure 13. The restaurant was destroyed at the end of July, 1994, due to a shear movement.

short term management of the landslide areas on which building zones had been legally planned for many years.

The second consequence of Falli Hölli disaster was the elaboration of comprehensive hazard maps for landslides, floods, snow avalanches and debris flows, taking into account the relative intensity and probability of the phenomena, as well as the resulting threats. The mapping of all the zone of the Prealps is now carried out. On the basis of such documents, the local management plans are progressively revised and in specific situations protection works are undertaken.

The third consequence of Falli Hölli disaster was to induce the Swiss federal authorities to publish recommendations for the consideration of landslide hazards in land planning, in 1997, which could contribute to homogenize the elaboration of hazard maps between the 26 cantons of Switzerland that are independently responsible of such a task (see SOA6). This document is presently revised to produce constraining guidelines. Thanks to the risk conscience that developed after Falli Hölli case, most cantons have produced or are producing comparable hazard maps that are coupled with practical building limitations, so that an efficient protection is provided despite of the fact that no thorough quantified risk analysis is carried out.

5.2 *Monitoring systems*

Before analysing the possibilities furnished, at small and large scale, by both the present technology and the mathematical modelling, few considerations are necessary as it concerns: the problem to be faced; the best approach to be used; the test to be systematically carried out in order to improve the confidence on systems devoted to the population safeguard.

As it concerns the first aspect, monitoring systems are directed to the check-in of several elements which can be essentially included among the triggering factors (rainfall, earthquake, anthropogenic factors, etc.), the indicators or revealing factors of slope stability conditions (water content, groundwater and/or pore pressure regime, opening of superficial cracks, etc.) and the effect caused by the triggering factors (soil and/or element at risk displacements). Such elements can be qualitatively and/or quantitatively measured and can be or not related to other elements included in the same or other classes. The selected option strictly depends on the size of the study area, the landslide typology and the available instrumentation.

With reference to the second question, the multidisciplinary approach seems to be the most profitable one, due to the complexity of problems to be faced, above all when wide area must be considered. From this point of view large efforts need to be done as all the scientific communities are, sometimes, reluctant to furnish their contribution not having the control over the whole process.

Finally, all procedures, especially those based on an advanced technology and/or modelling, must be systematically tested in sample areas as, too many times, enthusiasms and initial beliefs are not confirmed by the obtained results.

Notwithstanding the absence of studies that simultaneously respect all these points, summarizing the research able to furnish a significant contribution in the monitoring field is not easy. As a consequence, in the following the attention will be essentially focused on some examples, highlighting the relevant contribution that, in the next future, will be furnished by monitoring systems at both regional and urban scales.

Regional scale

The scientific literature does not define techniques, methods of use and aims of monitoring systems over large areas. However, the available proposals indicate that the most promising techniques can be essentially based on remote sensing in order to confine, inside a large area, zones where an emergency will probably occur. To this end and referring to the intermediate – small scale (1:25,000 and smaller), in the following examples or considerations will be furnished stressing, when possible, the role played by hazard and risk maps in order to obtain useful results.

The first example refers to a back-analysis devoted to test the meteorological and hydrological maps as possible indicators of imminent instability phenomena inside a portion of the Campania Region (Southern Italy) whose total extension is 13,595 km^2. The study area (of about 3,000 km^2 in size) is covered by pyroclastic soils of volcanic origin which, during the centuries, have been systematically involved in fast slope movements causing victims and huge economic damages (Cascini & Ferlisi 2003).

As discussed in Cascini (2005), the instability phenomena are triggered inside well defined geomorphological units which are accurately indicated in the hazard and risk maps available, since 1999, at 1:25,000 scale all over the region territory and at 1:5,000 scale as it concerns some urban territories. The first stage movements involve soil covers of the geomorphological units according to complex mechanisms generally characterised by slip surfaces not deeper than 1÷2 m. The whole area simultaneously affected by these phenomena can range from some hectares up to 100 km^2 as in the case of the events dated 1954 and 1998 (Cascini & Ferlisi 2003). Consequently, the total destabilized volume can range from few thousands to some million cubic meters which rapidly move downslope where high urbanised areas are located. Finally, rainfall triggers such phenomena although different intensity and du-

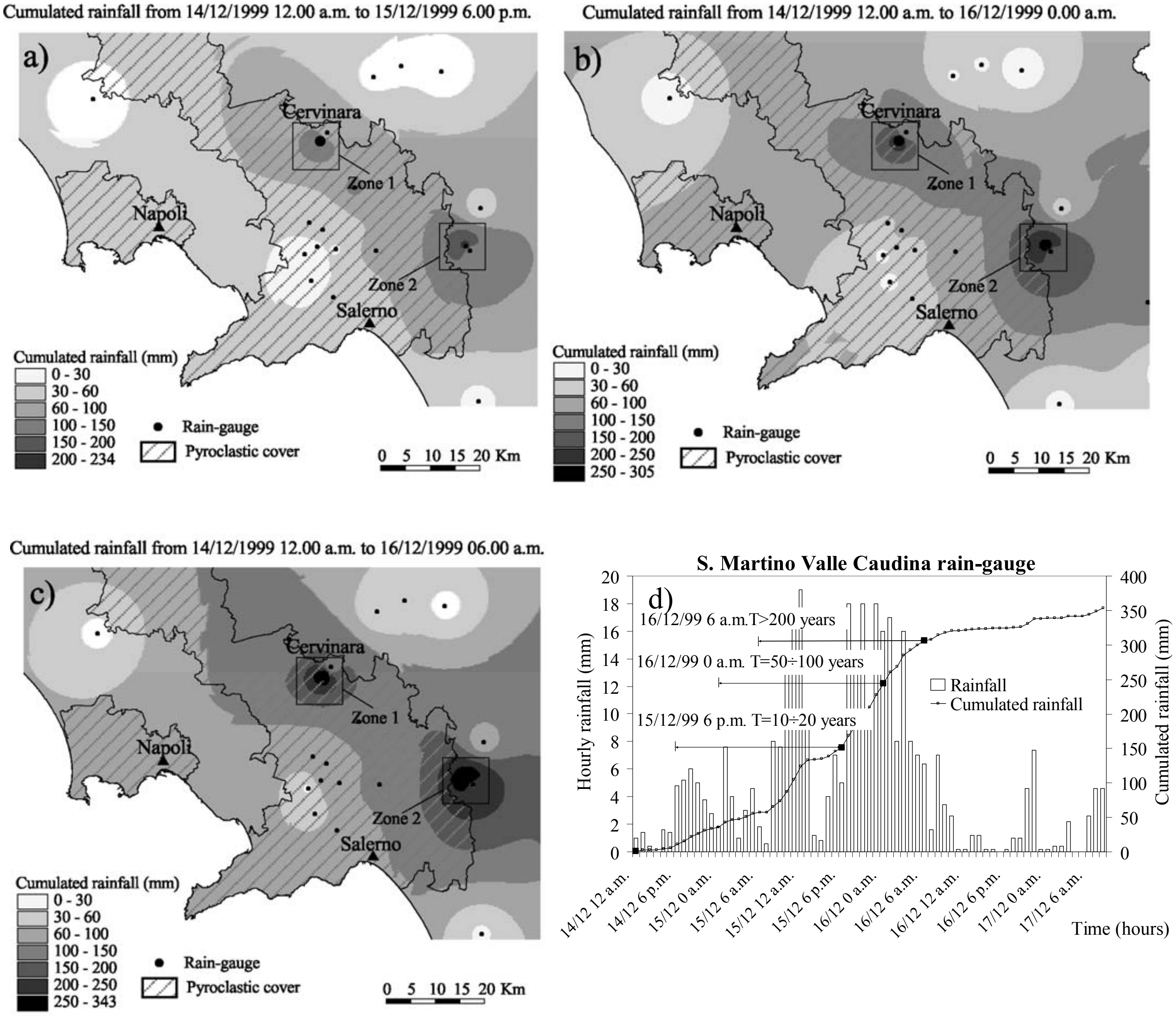


Figure 14. Rainfall event of 15-16 December 1999 in Campania Region (Southern Italy). Areal distribution of cumulated rainfall at different time (a, b, c). Cumulated and hourly rainfall recorded at a rain-gauge inside zone 1, and return period (T) of the backwards cumulated rainfall over 24 h period (d).

ration are necessary passing from autumn to spring; anyway a minimum duration of many hours is necessary to trigger instability phenomena of a significant magnitude.

Taking the characteristics of the analysed phenomena into account, meteorological and hydrological maps have been drawn with reference to the event occurred during the night between the 15th and 16th December 1999, as a consequence of rainfall started about 40 hours before. The instability phenomena, of medium magnitude, threatened the town of Cervinara where 5 casualties were recorded. It is interesting to observe that fast movements were originated inside a geomorphologic unit defined as at high attention level (see Sect. 6.3) by the hazard maps available at 1:25,000 scale.

On the basis of the meteorological maps and by an interpolation of rainfall data, Rossi et al. (2004) reconstructed hydrological maps within an interval of 6 hours. Some of these hydrological maps are furnished in the Figure 14 which highlights two different zones affected by heavy cumulated rainfall: one inside the pyroclastic cover (zone 1) and the second one outside (zone 2). It is interesting to note that, inside zone 1, the cumulated rainfall over 24 hours – computed backwards from the 6.0 p.m. of the 15/12/1999 (i.e. more than 6 hours before the event) – reached values having a return period of 10-20 years; on the other hand, the return period rapidly increased in the following hours (Fig. 14d). Referring to the hazard map and the rainfall threshold value, at the present in force in some other parts of the Campania Region (Rossi et al. 1998), it can be concluded that the availability of the meteorological and hydrological maps should have activated the emergency plan, some hours before the event occurrence, only with reference to the few little towns located inside the zone 1 (Fig. 14).

Of course this is just a back-analysis, so no definitive conclusion can be drawn; anyway the obtained results strongly encourage a real time experimentation with the aim of further improving the warning systems in force.

The second example deals with the soil moisture detection over large areas using remote sensing (LANSAT-7-ETM) and a digital elevation model. Particularly, Urciuoli (2004) analyzes, at a small scale, the instability phenomena inside a river basin, about 63 km^2 large, of Southern Apennine where landslides involving clayey soils are widespread all over the investigated territory. The author furnishes, first of all, accurate “state of the nature maps” where landslide phenomena are inventoried according to a geomorphological scheme which identifies four different stages of slope movements (Guida & Iaccarino 1991). Each of these stages is, therefore, characterised by velocities ranging from 0.3 m/day to 0.06 mm/year on the basis of data collected in sample areas by inclinometers and topographical survey. Using statistical techniques, MIRI and NDVI indexes are obtained by the remote sensing observations and overlapped to the instability phenomena classified as previously described (Fig. 15a). Observing that different values of MIRI index correspond to the four defined stages of slope movements, the author individuates different hazard levels inside well defined zones of the whole investigated territory (Fig. 15b).

Referring to (Reginato et al. 1976, Quattrochi & Luvall 1999, Scipal et al. 2002, Moeremans & Dautrebande 2000) as it concerns the soil moisture detection by remote sensing, it is evident that this kind of experimentation must be strongly encouraged and, where it is possible, coupled with meteorological and hydrological maps in order to link triggering factors, indicators (revealing factors) of slope instability phenomena and effects produced by the triggering factors.

At this regard, growing attention is worthy to be put on the use of SAR (Curlander & McDonough 1991) interferometry to measure the superficial displacements (Massonet et al. 1994), using two interferograms at different time periods (DInSAR) (Van Westen 2004). However, at the present, the application of DInSAR is restricted to the monitoring of a single landslide phenomenon, notwithstanding the world-wide coverage by single images on area of 10,000 km^2, available since 1992.

Some interesting attempts to overcome the limitations of the DiffSAR are represented by both the new algorithm SBAS (Small Baseline Subset) (Berardino et al. 2002), implemented at I.R.E.A. and based on a particular post-processing of a set of interferograms, and the PS technique (Ferretti et al. 1999a, 1999b), developed at POLIMI and patented worldwide (Colesanti & Wasowski 2004). However, up to now, such techniques have been utilised to measure ground displacements characterised by a prevailing vertical component (e.g. subsidence phenomena) as discussed in Allievi et al. 2003, Van der Kooij et al. 1995, Carnec et al. 1995, Worawattanamateekul et al 2003, Kircher et al. 2003, Galloway et al. 2000, Wegmuller et al. 2000.

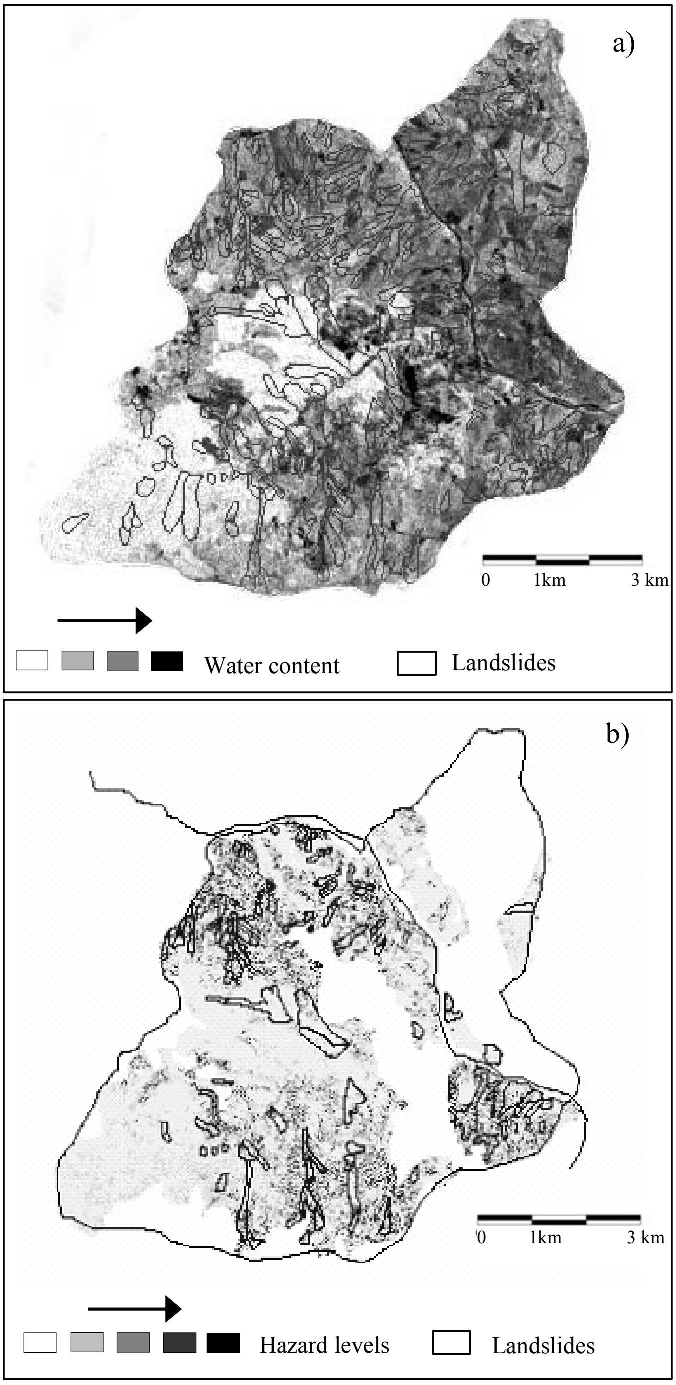


Figure 15. Landslides and Miri index (a);landslides and hazard levels (b) (Urciuoli 2004).

At the present, reliable data can be furnished by remote sensing to update the urbanised areas as it is discussed by van Westen (2004). Such information, easily obtained with reference to the elements at risk (Stilla et al. 2003, Priestnall et al. 2000, Fraser et al. 2002), are particularly useful for the Central and Local Authorities to improve the emergency plans and/or to impose sanctions in the case of buildings located, without permission, inside inhibited areas.

In conclusion, remote sensing seems to be able in furnishing, in the next future, a significant contribution for landslide risk mitigation, at small - intermediate scales, on condition that multidisciplinary studies will be systematically carried out and the obtained results will be rigorously tested in sample areas on the basis of ground monitoring validation and reliable hazard and risk maps.

Urban scale

At large scale (1:5,000 or higher), monitoring systems can be based on instruments, techniques and interpretative procedures that can notably improve the landslide risk mitigation. Above all, remote sensing based on satellite techniques begins to furnish significant features with reference to the displacements of a single landslide phenomenon (Fruneau et al. 1996, Squarzoni et al. 2002, Berardino et al. 2003, Colesanti & Wasowski 2004, Gili et al. 1999, Malet et al. 2001). On the other hand, the reduction in area extent allows measurements of physical quantities, at local and site scale, as well as the use of well-known and powerful engineering models to correlate the experimental data. Such models can be used to define alert threshold which can be based, for a certain landslide typology, on displacement rate, groundwater change, rainfall characteristic and so on. Referring to instability phenomena triggered by rainfall, some examples are furnished in the following.

The first case study refers to an area of about 60 km^2, located in Southern Italy where, in May 1998, fast landslides, originated in pyroclastic deposits covering a dolomitic bedrock, caused 160 victims and large economic damage in 5 small towns (Cascini 2004). Thanks to the real time monitoring of the rainfall intensities over small time intervals (5-10 minutes) measured at 5 rain-gauge stations, Rossi et al. (1998) set up rainfall thresholds (Fig. 16) with the aid of hydrologic models, which were used as an alarm system to safeguard the people living inside the risk area. These hydrologic models use empirical based probabilistic methods capable to furnish relationships between historic records of rainfall and landslide occurrence; the obtained relationships are then utilised to predict the probability of future landslides on the basis of actual rainfall intensities. Hydrologic models, like the previous one or similar, are quite diffuse in the scientific literature and they have furnished significant results in many geo-environmental contexts (i.e. Caine 1980; Crozier & Eyles 1980; Cascini & Versace 1988; Wilson & Wieczorek 1995; Sandersen et al. 1996; Wilson 1997).

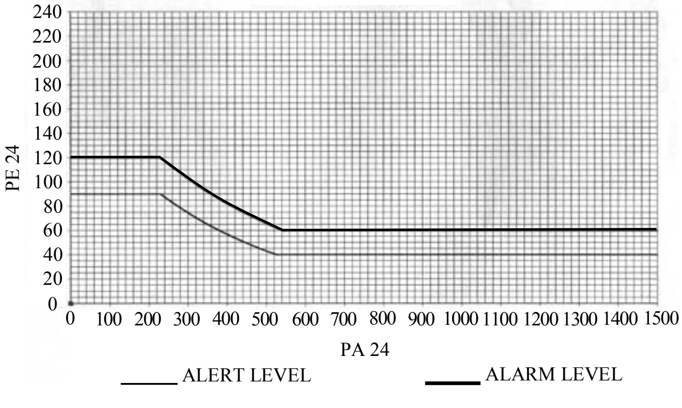


Figure 16. Alert and alarm rainfall thresholds over a 24h period. PE24: mean value of the cumulated rainfall over 24h period before the time t; PA24: mean value of the cumulated rainfall from the beginning of the hydrologic year up to 24 hours before the time t (Rossi et al.1998).

The results obtained by these models can be, however, notably improved with the aid of further instruments oriented at the monitoring of physical quantities related to the indicators of slope stability conditions.

For example, considering the superficial in situ water content, a promising procedure has been experienced in a number of sites inside some hydrologic basins of the Australian territory (Woods et al. 2001) by TDR sensors and neutron probes installed in the first 0.6 m of depth and whose data are acquired via remote locations. The above data have been then utilised to link rainfall to the distribution of superficial water content (Western & Grayson 1998). Notwithstanding this procedure has been used for a proper validation of a deterministic model rainfall-runoff, it could be suitable employed in the field of mass movements, in order to individuate, during and before a rainfall event, those areas where considerable aggravating conditions for slope stability could develop. In addition, the availability of these data could notably improve an appropriate calibration of physically-based analytical methods – e.g., SHALSTAB (Pack et al 1998), SINMAP (Montgomery & Dietrich 1994), DSLAM (Wu & Sidle 1995), TRIGRS (Savage et al. 2003) and other recent methods (Savage et al. 2004) – aimed to estimate potential relative instability of slopes in a GIS setting.

Besides the superficial water content, other indicators can be measured such as the pore water pressure both in saturated (positive pore water pressures) or in unsaturated (negative pore water pressures or suction) conditions.

An example of suction measurements over large areas is furnished by the tensiometers data acquired over the above cited area located in Southern Italy, where unsaturated pyroclastic deposits are susceptible of fast landslides. In this area, investigated sites were mostly situated at medium-high slope levels, nearby and/or inside the triggering areas of 1998 landslides (Fig. 17). The analyses performed by Cascini & Sorbino (2003), on more than 3000 suction data acquired at the investigated sites, have shown that monthly average suction values differ only with respect to depth, but they attain the same values independently of the investigated sites. These findings seem to reveal that the pore pressure in the pyroclastic deposits is affected by analogous time trend all

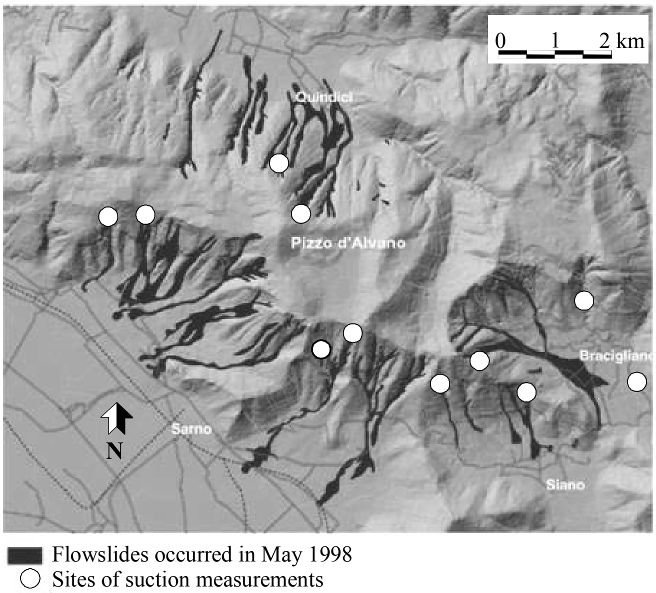


Figure 17. Map of May 1998 flowslides and sites of suction measurements (Cascini et al. 2003).

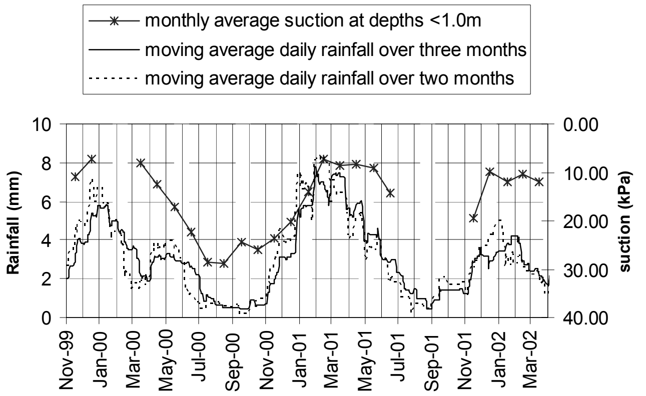


Fig. 18. Comparison among monthly average suction values at depths lower than 1.0 m and the moving average daily rainfall over two-month and three-month period (Cascini & Sorbino 2003).

over the area and, consequently, they evidence the possibility to correlate soil suction values to rainfall data. At this respect, Figure 18 compares the average suction values at depths of less than 1 m, that is the depth generally involved in the flowslide triggering areas, to the daily moving average rainfall values, the latter being calculated over two- and three-months periods. As can be seen, the average suction values are in clear agreement with the moving averages of the rainfall data. These results highlight encouraging perspectives towards an improvement of the alarm system – which, as previously stated, is currently based on rainfall data only – by taking the suction values into account. Further improvements can also derive by the application of geomechanical models inside specific and representative sites (see Sect. 6.3).

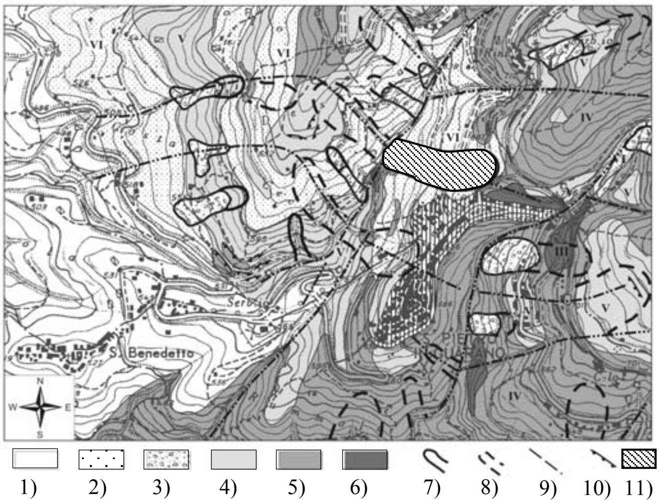


Figure 19. Part of the weathering grade and landslides map of the Western Sila study area (Calabria-Southern Italy): 1) sedimentary soils; 2) colluvial and residual soils (class VI); 3) landslide debris; 4) completely weathered gneiss (class V); 5) highly weathered gneiss (class IV); 6) moderately weathered gneiss (class III); 7) recent landslide scarp; 8) old landslide scarp; 9) fault; 10) rock landslide scarp; 11) analysed landslide (Cascini et al. 1994).

As for positive pore pressures, the monitoring performed over an area of about 7.5 km^2 is briefly synthesised. The area is located on the western slopes of the Sila Grande massif (Southern Italy), where gneissic lithotypes, generally deeply weathered, crop out (Fig. 19). In the area, the most common forms of instability involve covers (of depths ranging from 10-20 m) composed of colluvial, residual, and saprolitic soils (Cascini et al. 1994), that are characterized by several decades of total quiescence, followed by sudden reactivations in correspondence of particularly wet seasons.

Measurements of pore pressure regime – performed in correspondence of representative landslide phenomena – have systematically revealed (Gullà & Niceforo 2003) the presence of two aquifers with distinct groundwater tables: the first one located in the bedrock and having a quite steady-state character; the second one inside the unstable cover showing a strongly transient character, strictly related to seasonal rainfall events. Notwithstanding the monitoring of groundwater regime – in some sites taken over a long period of time (up to twenty years) – the absence of effects during many decades in all the sites did not allow the individuation of pore pressure values responsible for remobilisation of the landslides (Gullà 2004). For this reason, it was considered worthwhile to analyse in detail a representative landslide phenomenon (of about 20,000 m^2 in size) whose reactivations, in 1931 and 1981, caused severe damage to many public and private buildings.

The analyses, carried out by three different models, were aimed to predict both the critical rainfall events and the pore pressure able to mobilise the cover. On the basis of the rainfall data, available since 1923, the first hydrologic model highlighted that a five-months cumulated rainfall (900 mm), having a return period of 50 years, is capable to produce the cover reactivation (Cascini & Versace 1988). On the other hand, a statistical analysis of

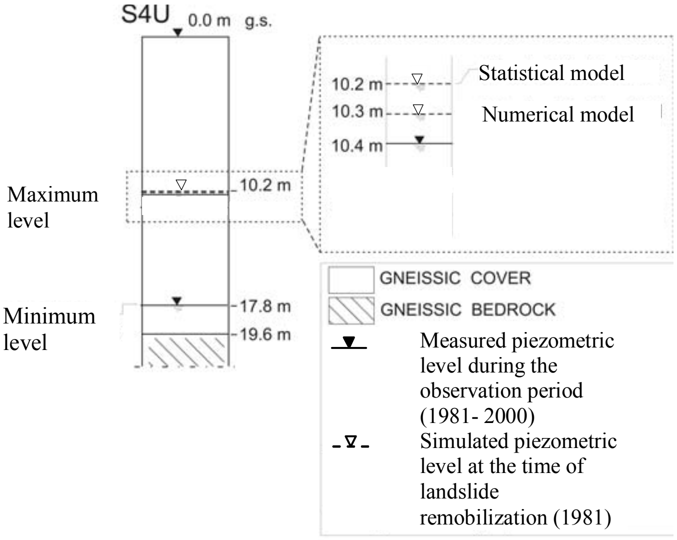


Figure 20. Measures and estimates of the piezometric levels inside the analyzed landslide.

piezometer measurements (Cascini E. et al. 1992) taken over twenty years, allowed the estimation of the local groundwater table presumably attained during the recent cover mobilisations (1931, 1981). Finally, through the seepage analyses of the saturated-unsaturated regime (Sorbino 1994, Cascini et al. 1995), the third model furnished the pore pressure corresponding to the mobilisation of the whole cover.

The obtained results (Fig. 20), together with other in-situ measurements, were therefore utilised to define the indicators of the landslides reactivation at both site and local scale, notwithstanding the total absence of movement, during the investigation period, for all the instability phenomena inventoried inside the sample area.

6 CASE HISTORIES

Notwithstanding the absence of a standardized procedure for hazard and risk zoning, several hazard and risk maps have been developed to solve practical problems at small, intermediate and large scales. An overview of the aims pursued, the adopted methods and the obtained results are furnished in Ahmad & McCalpin (1999), Atkins Haswell (1995), Brabb et al. (1999a, 1999b), Corominas et al. (2003a), Dai et al. (2002), Einstein (1997), Hayne et al. (2002), Michael-Leiba et al. (1999, 2002), Turrini & Visintainer (1998).

In the following, five case studies show the way to overcome the difficulties generally faced with hazard and risk zoning, essentially related to reference scale, weakness of the available data and procedures; moreover, they allow to realise the usefulness of the produced maps as it concerns the risk mitigation to be pursued by regional and urban planning, warning systems and stabilisation works.

Particularly, the first example (Colombian cases) shows the usefulness of the small and large scale analysis in function of both the aim pursued and the size of the study area. The second case (Southern California) highlights, at an intermediate scale, the usefulness of back analyses based on reliable input data concerning the triggering factors, in absence of detailed in-situ investigations. The third case (Southern Italian Apennine) discusses the method for hazard and risk assessment, at an intermediate scale and over large areas, which was developed – in absence of either a suggested procedure or risk education – to confront the urgent need requested by the Central Authorities. Finally, the last two cases (Andorra Principality and Icelandic lowlands) highlight the feasibility of both accurate investigations and studies, at large scale, when some conditions are satisfied (risk management process started some years before; availability of advanced data sets; small extension of the analysed area).

6.1 *Some Colombian cases*

The geographic location of Colombia, both in the circumpacific region and in the inter-tropical area, the population concentration and the development of main economic activities in the Andean mountainous area, favor the occurrence of landslides and other instability processes, with great detriment for the development of the country. In the last 25 years many investigations had been carried out related with the distribution and effects of mass movements that affect mainly infrastructure works and urban areas.

One of these studies was a landslide inventory along the road country network that was carried out by the Ministry of Public Works and the National University of Colombia (1989).

For hazard assessment, the direct or heuristic method was used (Soeters & van Westen 1996) by combination of geomorphologic criteria with thematic maps on geology, morfo-structural units, climate, seismicity and land-use (Montero & Cortés 1989). On this basis, the whole country was classified into 15 relative hazard provinces, each one distinguished by a particular landslide-related behavior and numbered in descending order of susceptibility to slides, flows and other types of movements. Later, these 15 provinces were regrouped into 5 hazard categories, according to the distribution of the processes in the territory, with density, frequency and recurrence of the movements (INGEOMINAS 2002). This information is presented in Figure 21, with the following conclusions:

- 30% of mass movements are of great magnitude (greater than one million cubic meters and/or causing catastrophic effects).
- 90% of the mass movements are located in geological fault areas being triggered mainly by rainfall (more than 4000 mm/year and intensi-

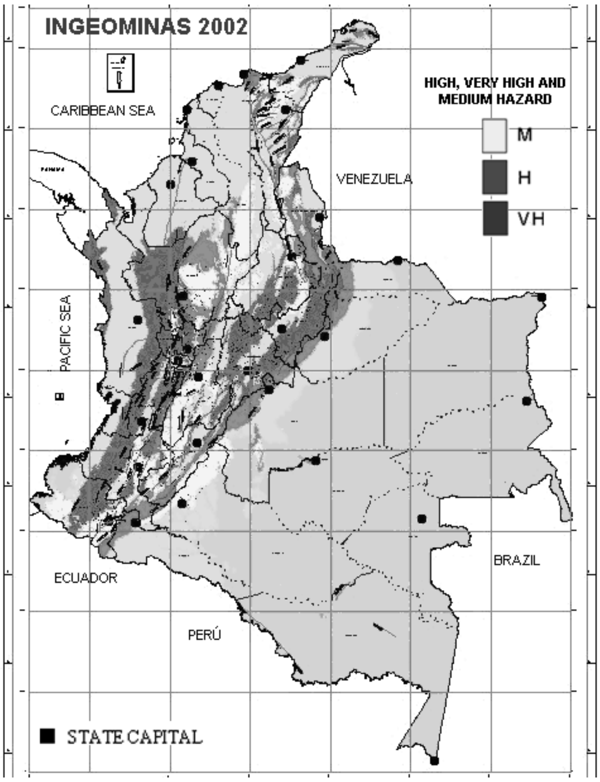


Figure 21. Relative Lanslide Hazard Map for Colombia (INGEOMINAS 2002).

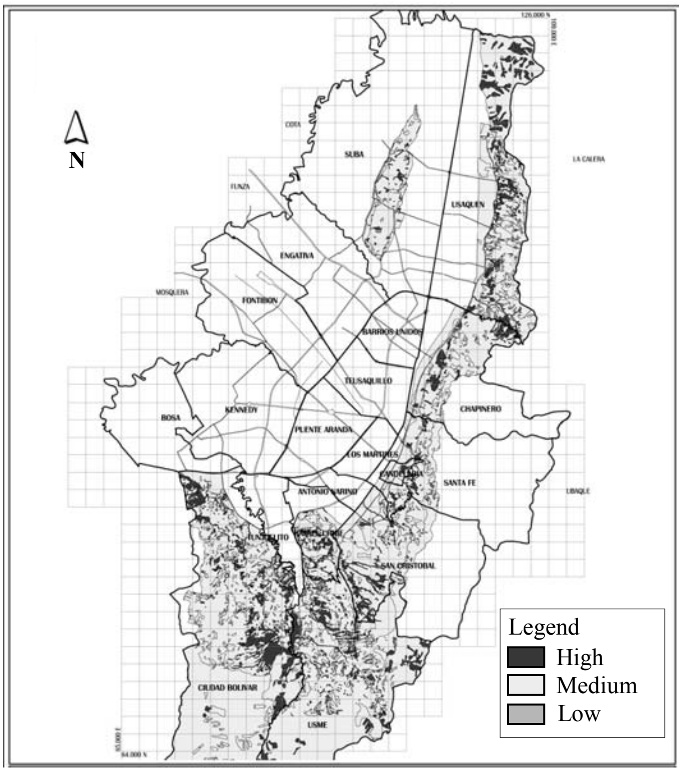


Figure 22. Landslide Hazard Map for Bogotá, Colombia [Dirección de Prevención y Atención de Emergencias (DPAE)]

Table 2.

Landslide Hazard	**Relative 10yr - Fs**	**Relative 10yr - Pf**	**Area (km²)**	**Area (%)**
High- H	Fs < 1.1	Pf > 44.3%	19.97	11.0
Med.- M	1.1< Fs < 1.9	12.1% < Pf < 44.3%	111.10	61.3
Low- L	Fs > 1.9	Pf < 12.1%	50.13	27.7
		TOTAL	**181.20**	**100.0**

ties frequently ranging from 20 to 30 mm/hour).

- 55% to 60% of the movements are concentrated in provinces I and II (Very High Hazard zones).
- 20% to 25% of movements fall in provinces III and IV of High Hazard.
- 28% of the cities and town are affected by landslides especially the ones located in the Very High and High Hazard zones that correspond to the more developed areas of the country.

It is worth noting that 69% of the large landslides are still active or dormant; most of them are triggered by human activities related with highways construction, deforestation, improper land-use and population settlements in sub-urban areas of the cities and towns (Montero 2003).

In the late 90s, Bogotá, the Colombian Capital city, carried out several studies to identify and quantify the main natural hazards that could affect or affects the urban zone. Studies were done, and three hazard maps were obtained: seismic hazard map, flooding hazard map and landslide hazard map.

The landslide hazard map (Fig. 22) was done in 1998 for a 10-year exposure period and it was obtained by means of three concurrent methods: Semi-quantitative Landslide Hazard Index (SCLHI), Natural Slope Methodology (NSM) and Landslide Inventory (LNDI). The first method (SCLHI), developed by Ramirez & Gonzàlez (1989), uses weighted indexes for 4 intrinsic factors (surface materials, relief, drainage density and vegetation) and 4 triggering factors (rainfall, earthquake, erosion and anthropogenic effects). The second method (NSM), by means of surface morphology deconvolution of topographic and geological data (Shuk 1990), allows to find relative factors of safety (Fs) and relative failure probabilities (Pf), including rainfall and earthquake effects, for several exposure periods. Finally, the landslide inventory (LNDI), allowed the calibration of the other two methods and five maps at 1:10,000 scale were produced. Excluding the southern Usme District, studied by other methodologies, 181.2 square kilometers of hillslopes were evaluated with the result listed in Table 2.

6.2 *Southern California*

The 1994 Northridge, California, earthquake (**M** 6.7) triggered more than 11,000 landslides over an area of about 10,000 km^2 (Harp & Jibson 1995, 1996). This is the first earthquake for which all of the data sets needed to conduct a rigorous, detailed regional analysis of factors related to seismically triggered landsliding are available. The data sets include (1) a comprehensive inventory of triggered landslides (Harp & Jibson 1995, 1996), (2) about 200 strong-motion records of the main shock recorded throughout the region of landsliding, (3) detailed (1:24,000-scale) geologic mapping of the region, (4) extensive data on engineering properties of geologic units, and (5) high-resolution digital elevation models of the topography. All of these data sets were digitized and rasterized at 10-m grid spacing using ARC/INFO geographic information system (GIS) software. Then these data sets were combined in a dynamic model based on Newmark's (1965) permanent-deformation (sliding-block) analysis, which yields estimates of coseismic landslide displacement in each grid cell from the Northridge earthquake (Jibson et al. 1998, 2000). The modeled displacements were then compared with the digital inventory of landslides triggered by the Northridge earthquake to construct a probability curve relating predicted displacement to probability of failure. Once calibrated with Northridge data, the probability function can be applied to predict the spatial variability of failure probability in any ground-shaking scenario of interest in the southern California region. Because the resulting hazard maps are digital, they can be updated and revised with additional data that become available, and custom maps that model any ground-shaking conditions of interest can be produced when needed.

Figure 23 is a flowchart showing the sequential steps involved in the hazard-mapping procedure. Data layers consist of 10-m grids. The sequence is relatively straightforward:

- estimation of the static factor of safety against slope failure (ratio of resisting to driving forces) in each grid cell. To this aim shear-strength data were compiled from local geotechnical engineering firms, and a representative shear strength was associated to each unit on the geologic map, which yields friction (ϕ') and cohesion (c') grids. A digital elevation model (DEM) was analyzed to produce a slope map;
- estimation of the critical acceleration (threshold seismic acceleration needed to initiate slope movement) by combining the factor-of-safety grid with the slope grid to yield the critical acceleration grid, which represents seismic landslide susceptibility (Newmark 1965);
- estimation of Newmark landslide displacements using an empirical regression equation (Jibson et al. 1998, 2000) that requires knowing the critical acceleration of the slopes and the distribution of shaking intensities from the Northridge earthquake. Critical accelerations were estimated as described in step 2. Arias (1970) shaking intensities were contoured throughout the region, as measured by about 200 strong-motion recordings of the mainshock;
- construction of a curve to estimate probability of slope failure as a function of Newmark displacement. The map of landslides triggered by the Northridge earthquake was compared to the Newmark-displacement grid. For sequential intervals of Newmark displacement, the proportion of cells containing landslides was computed and the proportion of failed slopes in each interval as a function of Newmark displacement was plotted. A regression curve based on a Weibull distribution was fit to the data.
- use of the calibrated regression equation to generate maps showing probability of seismic slope failure in any shaking scenario of interest. This is done simply by estimating Newmark displacements by combining a ground-shaking grid of interest with the critical acceleration grid, as in step 3 and then estimating probabilities of failure using the calibrated regression curve from step 4.

Figure 24 shows a sample area from southern California of a seismic landslide hazard map using this procedure. Maps made in southern California using

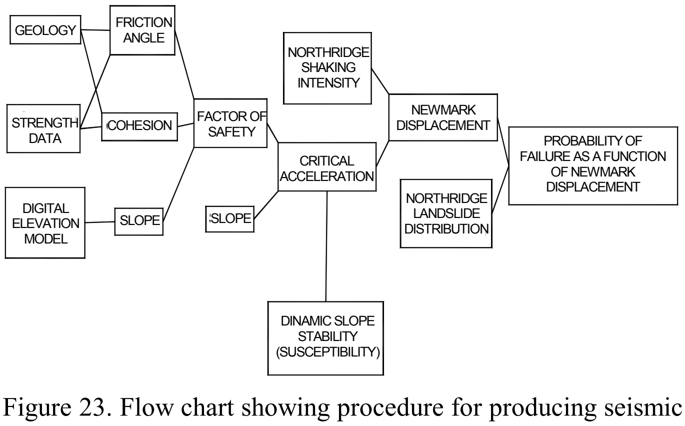


Figure 23. Flow chart showing procedure for producing seismic landslide hazard maps (from Jibson et al., 2000).

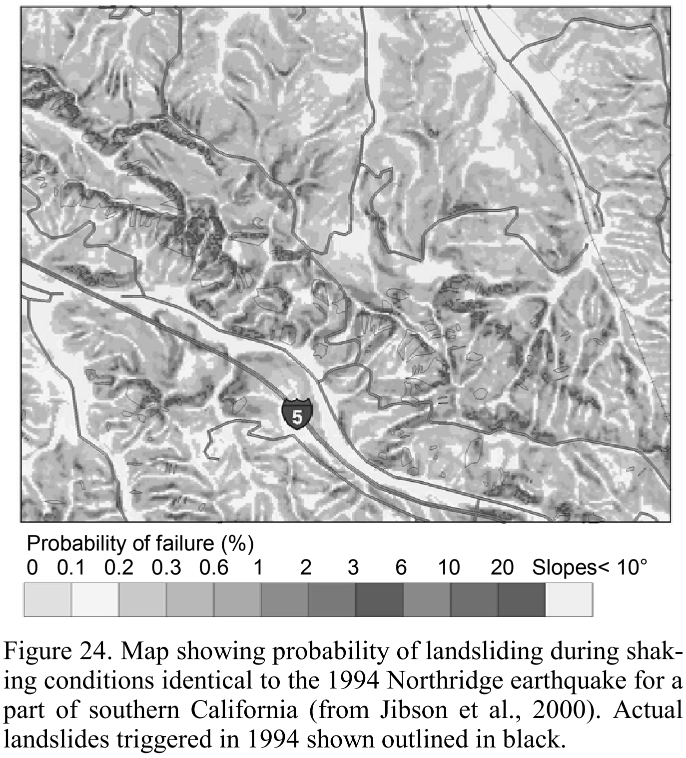


Figure 24. Map showing probability of landsliding during shaking conditions identical to the 1994 Northridge earthquake for a part of southern California (from Jibson et al., 2000). Actual landslides triggered in 1994 shown outlined in black.

this method are experimental and currently are being used as research tools. A much simplified version of this methodology does, however, form the basis of regulatory maps (scale 1:24,000) produced in 2004 by the State of California. These maps simply define zones of potential seismic landslide hazards; a site is either in a potential hazard zone or not. Any development planned within the hazard zone must then comply with various public policies aimed at insuring that seismic landslide hazards are identified and mitigated as part of the project. Each local municipality (city, county, etc.) is responsible to prescribe its own procedures to be followed for development within a potential hazard zone. Thus, the maps trigger a public-policy process that is tailored to each local government's need.

6.3 *Southern Italian Apennine*

Two landslide disasters, in 1997 and 1998, caused 166 fatalities and huge economic losses in several towns of the Campania Region of Southern Italy (Cascini 2005). As a result of these disasters, the Central Government passed a law requiring the River Basin Authorities to zone the landslide risk using simple and rapid procedures.

Notwithstanding the total absence of hazard and risk maps at the time the Law was passed, risk zoning was obtained at a 1:25,000 scale all over the Italian territory (301,401 km^2) in the following two years. Particularly, the risk zoning was calibrated according to the four risk levels defined by the Central/Government as follows:

- Very high (R4): human life loss and destruction of buildings, infrastructure and environmental as well as interruption of economic activities are expected;
- High (R3): victims, functional damage to buildings and infrastructure, as well as partial interruption of economic activities are possible;
- Medium (R2): limited damage to buildings, infrastructure and environmental may occur;
- Low (R1): social, economic and environmental damage are of marginal relevance.

To assess the risk levels, general instructions were furnished, but no specific technical advice and procedures were suggested. In the present section, the results obtained for the territory of the National Authority of Liri - Garigliano and Volturno river basins (Central-Southern Italy) are summarized (Cascini 2005). Inside this territory (of about 12,000 km^2 in size), undeveloped areas affected by dormant, active or potential landslides were also mapped and classified, although it was not required by the Law. Particularly, referring to the risk levels so far defined and the Cruden & Varnes (1996) suggestions, these areas were considered worthy of different attention levels classified as follows:

- Very high (A4), if the area was inside the source, transport or depositional zone of extremely rapid, very rapid or rapid landslides;
- High (A3), if it was inside a moderate or slow landslide, both active or dormant, potentially triggered by an earthquake;
- Medium (A2), if moderate or slow landslide was inside an aseismic area;
- Low (A1), if the area was involved in a very slow or extremely slow landslide.

To zone the risk and attention areas, detailed and territory-wide state-of-nature maps (geology, geomorphology and soil cover) were preliminarily compiled. Subsequently, with the aid of such maps as well as of aerial photo interpretation and available information, 30,000 landslides together with their surrounding areas, and zones potentially affected by fast slope movements were mapped using Varnes classification (1978), creep evidence, a simplified version of the slope movement stage defined by Leroueil et al. (1996), state of activity, and other simple criteria described in Cascini (2005).

Starting from these elements, susceptibility maps (danger maps in the sense of the present paper) were then obtained by adopting velocity estimates of the dormant or active landslides, as well as of the source and propagation areas potentially affected by first stage movements, using a simplified version of the Cruden and Varnes criterion (1996). Particularly, a maximum movement velocity was associated with each of the mapped landslide according to the nominal scale shown in Figure 25; an example of so obtained danger map is furnished in Figure 26. Finally, on the basis of landslides activity, simplified hazard maps were produced by using the nominal scale of Figure 27.

Inside the analyzed territory, simplified vulnerability maps for all the towns (450) were also produced. These maps also contain the expansion areas in the urban-planning scheme, the essential facilities (hospitals, barracks, schools etc.) and the damaged buildings, scheduled according to the nominal scheme of Figure 28.

Referring to the Varnes' formula, the risk levels (Fig. 29) were obtained by overlapping hazard and vulnerability maps. An example of map containing the attention and risk levels previously defined, is shown in Figure 30. Considering the small extent of risk areas (about 4.6% out of the whole territory) compared to the extent of the attention areas (about 15% out of the whole territory), it can be concluded that an improvement of land-use planning is an urgent need. This is confirmed by an historical analysis (O.U. 2.38 1998) that highlights the increase, in Southern Italy, of victims and damages after the second World War despite the same frequency through time of the most dangerous phenomena.

I ≡ the highest expected velocity	
I	**Landslide type**
High	Flowslides, Debris flow, First Failure in brittle materials
Medium	Occasional reactivation and Active landslides
Low	Deep-Seated Gravitational (Slope) Deformation, Lateral spreads

Figure 25. Intensity classes of the landslides (Cascini 2005).

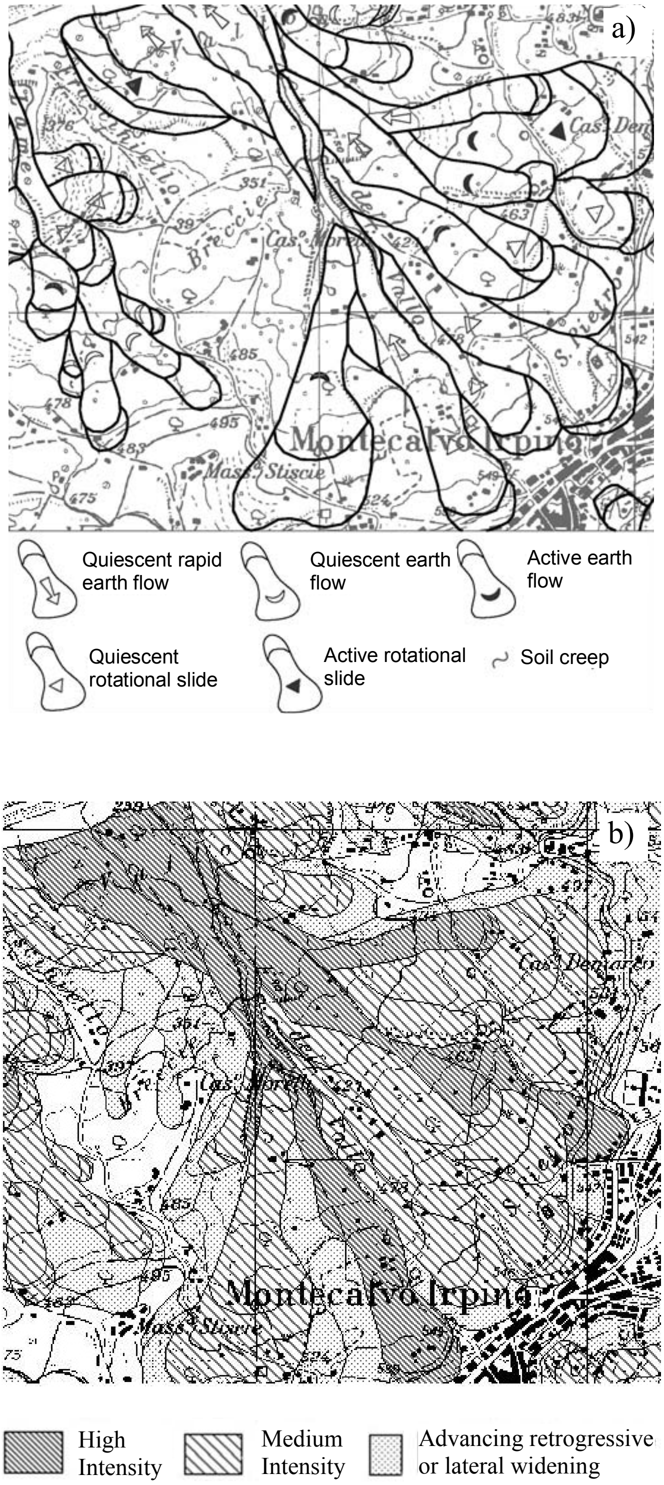


Figure 26. Example of landslide inventory and danger map, not considering earthquake effects (Cascini 2005).

INTENSITY	HAZARD	Landslide activity
HIGH	HIGH	active
		quiescent
MEDIUM	HIGH	active
	MEDIUM	quiescent
LOW	HIGH	active
	MEDIUM	quiescent

Figure 27. Hazard nominal scale (Cascini 2005).

I	Building tipology	Observed Damages	VULNERABILITY
HIGH	All	Not considered	HIGH
MEDIUM	Strategical building	Not considered	HIGH
	Common building	YES	
	Common building	NOT	MEDIUM
LOW	Strategical building	Not considered	MODERATE
	Common building	YES	
	Common building	NOT	LOW

Figure 28. Nominal scale for vulnerability (Cascini 2005).

	I	HIGH	MEDIUM		LOW	
	HAZARD	H	H	M	H	M
Vulnerability	**high**	Hh	Hh	Mh		
	medium		Hm	Mm		
	modest				Hm	Mm
	low				Hl	Ml

R4	R3	R2	R1
█	▓	▒	░

Figure 29. Nominal scale for risk level evaluation (Cascini 2005).

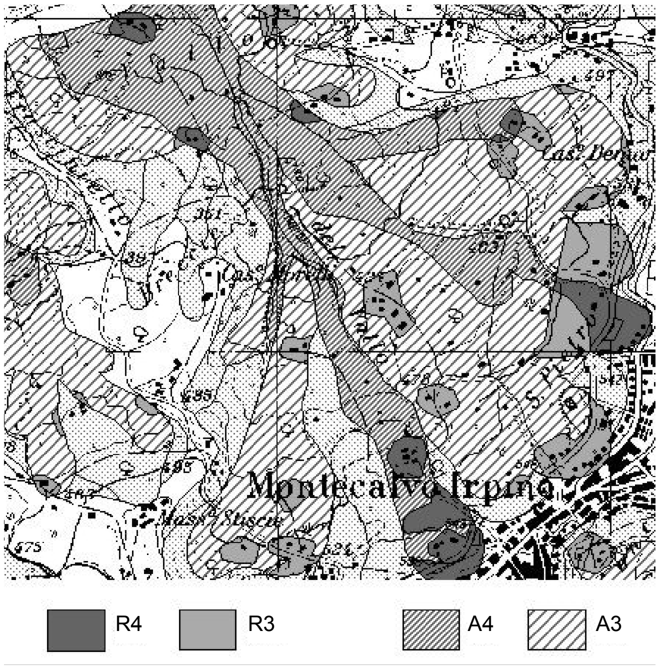


Figure 30. Example of map containing attention and risk zones (Cascini 2005).

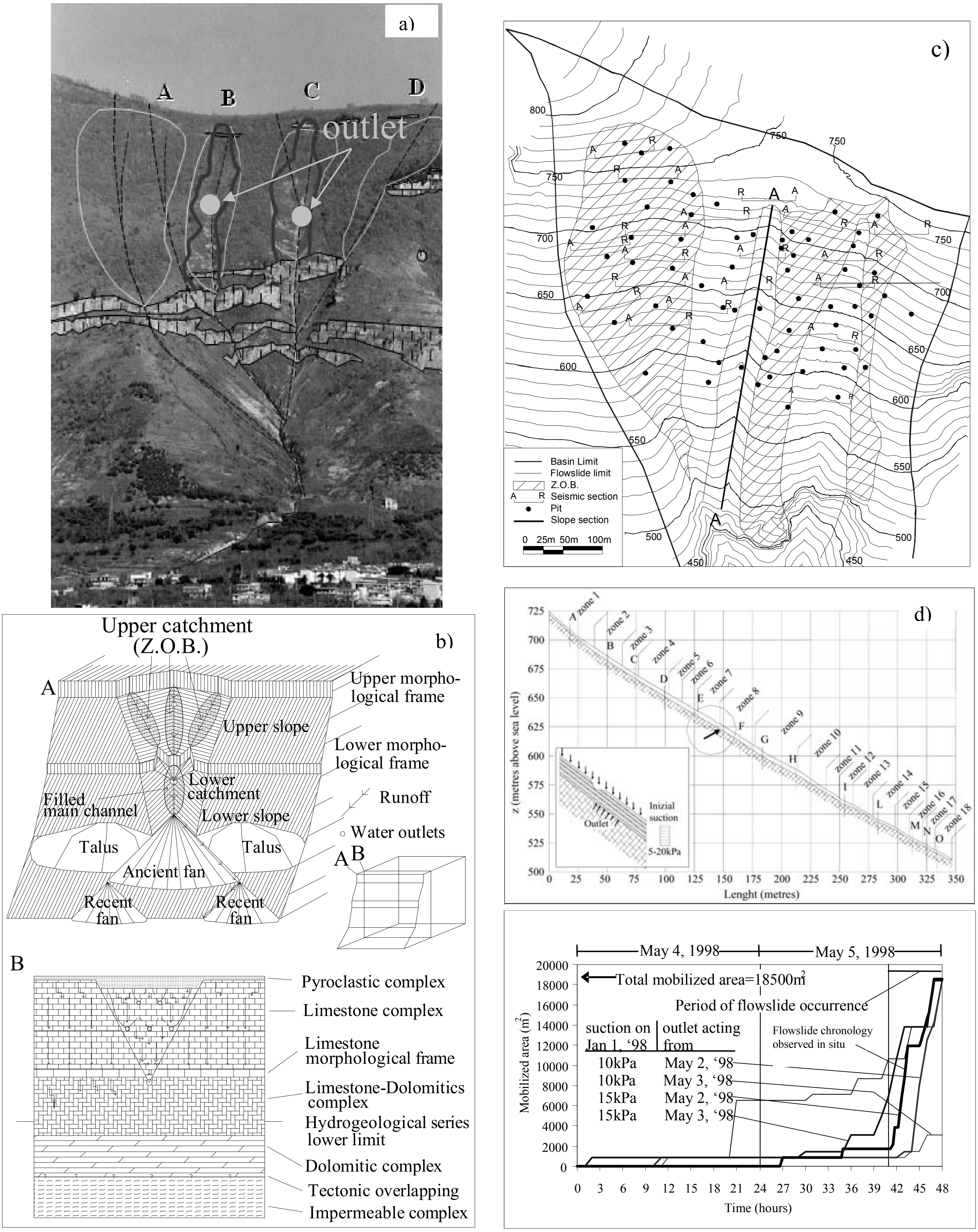


Figure 31. Sample area and Zero Order Basins (Z.O.B.) covered by pyroclastic covers (a); outlets are identified by the hydrogeomorphological model (b) only in correspondence of the Z.O.B. where instability phenomena occurred (B-C). In-situ detailed investigations (c); geomechanical analysis of groundwater regime and slope stabilty condition, along section A-A, based on recorded rainfall, different unsatured initial condition and considering the outlet presence according to the hydrogeomorphological model (d). (Cascini et al. 2003, modified).

An improvement of land-use planning calls for in-depth investigation and analysis to be carried out at more detailed scales (1:5,000, 1:2,000) and to be implemented into the quantitative risk assessment (QRA) procedure. As a matter of fact, the current deepening at 1:5,000 scale, by using the previously described procedure, systematically confirms the obtained results at 1:25,000 scale, not allowing the reduction of both the hazard and risk zone, as it is reclaimed by Local Authorities. A further confirmation of the reliability of the official documents is furnished by the fast slope movements triggered after their presentation, which all developed inside the mapped hazard and risk zones.

Investigations and studies at more detailed scale (1:5,000, 1:2,000) are in progress inside an area (3,000 km^2) characterised by widespread high attention (A4) and risk zones (R4) for the presence of pyroclastic covers, potentially threatened by fast slope movements.

Such deepening is strongly based on geotechnical and geomechanical models that are systematically tested by back-analyses of phenomena triggered during the events occurred in 1998's. Such analyses are developed using topographic surveys, detailed in-situ investigations, pore-water-pressure measurements and soil properties estimated both in saturated and unsaturated conditions, since pyroclastic covers are commonly characterized by partial saturation during the triggering stage.

An example is furnished in Figure 31 which refers to a sample basin (of about 40,000 m^2 in size) where covers B and C were destabilized during the events dated 1998. As discussed in Cascini (2004), the geomechanical modelling agrees with a hydrogeomorphological model set up at massif scale (1:25,000) extending over an area of about 60 km^2. Similar results, at both basin and massif scale are not obtained using other physically based models that neglect some local conditions (stratigraphy, presence or absence of outlets in the triggering zone, and so on) playing a relevant role in the triggering stage.

Considering the encouraging results furnished by the geomechanical models as well as by the vulnerability analyses carried out in the same area by Faella & Nigro (2003), it can be concluded that a quantitative risk assessment seems to be possible even if improvement of hazard and risk zoning maps requires both time and adequate financial support. Moreover, alarm system and countermeasures design should significantly be improved when investigations and studies at more detailed scale will be completely developed.

However, up to now, in the areas where the disasters occurred, the available maps have allowed the implementation of an alarm system for population safeguard, based on rainfall threshold values, and the countermeasure identification in order to assess the necessary financial cost.

6.4 *Andorra Principality*

The Principality of Andorra is a small country located in the Pyrenees, between France and Spain. In recent times the country has been hit by large floods and several landslide events. The most intense events occurred in October 1937 and November 1982, producing widespread shallow sliding, debris flow activity, and flooding of the Valira river. In October 1987, rains lasting for several days triggered a rock slide, killing three people, blocking a primary road and isolating for some weeks one of the main valleys. On the other hand, frequent rock falls produce damages and great concern in the highly urbanised areas of Andorra la Vella, the capital of the country, and Santa Coloma (Corominas et al. 2003a).

Actions for landslide risk management started in 1989 after some scattered initiatives. In 1989 the Andorran administration promoted the completion of a landslide and flooding hazard map at 1:25,000 scale for most of the territory (Corominas et al. 1990). The map was prepared based on both geomorphological reconnaissance and expert criteria. The landslide susceptibility was assessed taking into account the presence of instability features, a landslide inventory and the critical slope angles for different landslide types (Corominas et al. 1990). The probability of occurrence was established only in a qualitative way by considering the presence of field instability features (open scars, tilted trees, cracks, etc) in large landslides and the degree of preservation or dismantling of existing dormant movements. Frequency of shallow landslides was assumed that of the triggering factors, in this case, heavy rains. Four hazard categories were defined and mapped with different colours: green (no hazardous phenomena have been detected), yellow (presence of either local or small magnitude phenomena), orange (either generalized small magnitude phenomena or dormant large landslides) and red (active large landslides). The map was used by the administration to directly deliver building permits and for the design of protective works. However, for practical landslide management, the map showed important restrictions due to the scale of the map, which was too small for urban planning, and to the simplicity of the method used for the landslide hazard assessment that defined imprecise hazard boundaries.

A great step forward in the control of landslide hazard was given by the Urban and Land-Use Planning Law approved in 1998. This law demands that those zones exposed to natural hazards can not be urbanized and that Urban Plans of the municipalities must take the presence of zones exposed to natural hazards into account. Following this law, the Andorran administration promoted several studies and maps, among them, the landslide hazard map of Andorra at 1:5,000 scale (Corominas et al. 2003a).

The methodology for establishing the hazard categories and zones included the susceptibility assessment, runout distance, expected intensity and the probability of occurrence (Corominas et al. 2003b). All existing large landslides were considered susceptible for reactivation. For small first-time failures (shallow landslides, debris flows, rockfalls), the lithological map was combined with the critical slope angles for each landslide type to define landslide susceptibility. Compared with the previous map of 1989, the availability of a detailed DTM along with a brand new layer of superficial formations has allowed a much precise identification of potential landslide sources. The susceptibility assessment was completed with the definition of the expected travel distances which were delineated based on the extent of the landslide deposits, the empirical relationships between landslide volume and the angle of reach (Corominas 1996) and checked with Eurobloc, a 3-D numerical model (Lopez et al. 1997; Copons et al. 2001). The treatment of these information layers was carried out by means of a GIS (Arc-Info).

In the landslide hazard map of Andorra, intensity classes were defined taking the resistance of the protective structures into account (especially for rock falls) rather than the vulnerability of the threatened elements. In particular, three intensity (energy) classes were considered: low (0 to 2,000 KJ), medium (2,000 to 10,000 KJ) and high (more than 10,000 KJ). Boundaries between classes were established based on the performance of the commercial rock fall fences and earth embankments. Impact energies over 10,000 KJ were considered as non-manageable while existing large landslides were all supposed of high intensity because, even though they often display small displacement rates, remedial works use to be both inefficient and economically unaffordable and catastrophic surges can not be always disregarded. Hazard categories for zoning and planning purposes were based on these intensity classes. Those places where impact energy of rock falls is high, and where either active or dormant large landslides may experience sudden reactivation, have been considered of high hazard, except for those events with low probability of occurrence (Corominas et al. 2003b). When landslide threat can be handled with the appropriate countermeasures, hazard was considered of a moderate (mid) level.

The landslide hazard zoning has been incorporated in the administrative procedure for delivering building permits. The map has been first subjected to public audience. All the land classified as high hazard can not be developed with only a few exceptions (i.e. roads without alternative corridors). In case of moderate hazard, the owner or developer must fill a form of acknowledgement of the type of threat that may affect the property which must be signed by the engineer or architect in charge of the project. Furthermore, they must provide a technical report including explicitly the countermeasures that will be undertaken to avoid or mitigate the potential landslide hazard along with an estimation of the residual risk. In the moderate hazard category sensitive buildings such as schools or hospitals are not allowed. Hazard category of a particular area can be reconsidered in the future if more detailed studies demonstrate that hazard level is lower than previously estimated or new remedial or protective works are feasible. It is thus implicitly accepted, that improvement of engineering protection practices may alter the hazard category of an area (Corominas et al. 2003b).

Parallel to the landslide hazard map, special attention was paid to the rock fall hazard in Andorra la Vella and Santa Coloma (Copons et al. 2004). Frequent rockfall, ranging from about 1 m^3 to few hundred cubic meters, occur on the steep slopes of the glacial-shaped Valira river valley, made of granodiorite. Fallen block accumulate at the slope foot generating coalescent talus slopes which have been developed during last decades. In December 1983, January 1994, and January 1997, several buildings were hit. In June of 1998, the Andorran Ministry of Public Works started a Rock Fall Master Plan (RFMP) with the purpose of reducing the risk in the area.

The main achievement of the RFMP was the establishment of a boundary line (Fig. 32) above which hazard is considered very high and building is forbidden. The line was defined by taking the impact energy of the falling blocks into account. The boundary line was published in the Official Journal of the Principality in 1998, and since then it has been used by the Andorra Government for authorization of new developments. Rockfall fences were built above the mentioned line to protect building. Nevertheless, when the boundary line was defined, some

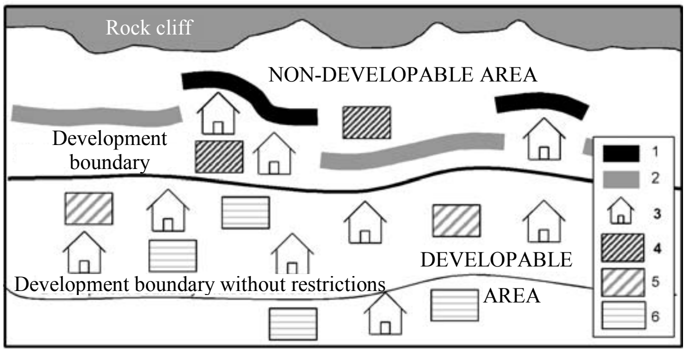


Figure 32. Development zoning at the Andorra la Vella-Santa Coloma based on rockfall hazard. The upper boundary for development is given by the thick continuous line. Above it rockfall protective fences and embankments (1 and 2) are design to protect the existing buildings and the developable area below. There, new buildings (3) are prohibited in the available plots of land (4). Below this boundary, land plots (5) can be developed provided that protective structures exist. A lower development boundary is defined by a thin continuous line. Below it development of plots of land (6) can be made without restrictions (Copons et al. 2004).

buildings were already within the exclusion area. For all the cases, the RFMP also considered the design of additional rockfall defences (Copons et al. 2000).

The establishment of this line required many trajectographic analyses with a 3-D numerical code (Copons et al. 2001) and the assessment of rockfall frequencies from tree damages (Moya & Corominas 2004). A rockfall flow (events per unit length) was obtained as well (Copons et al. 2004). Results of the numerical simulation of rock fall trajectories were the kinetic energy, height of bounce and rock fall trajectory which were used for the design of the protection fences and to calculate the residual hazard. At any given location, the numerical modelling yielded the percentage of intercepted blocks by the projected fences. The product of the percentage of passing rocks with the rock fall flow, defined above, gives a first estimation of the residual hazard (expressed as a number of events per unit length in a given period of time) existing in the area after protective works were completed. In the RFMP the residual hazard obtained for new development areas below the development boundary is always lower than 10^{-5} to 10^{-6} events per metre and year. By assuming the presence of a person 100% of the time in this one metre wide path with a vulnerability of 1.0, which is a conservative value, this rate is considered in the scientific literature as an acceptable risk (Fell & Hartford 1997).

The administrative procedure for building authorisation has been conceived not as an additional constraint to the developers but as guidance. By means of the GIS and its data base, they may know the type and nature of the hazard, if any, they are confronting with. Furthermore, they know in advance a first estimate of magnitude and frequency of the event, thus allowing a preliminary cost-benefit analysis of the intended development. On the other hand, with this map and the administrative procedure, local authorities are expected to have better tools for land use planning and hazard management.

6.5 *Icelandic lowlands*

Since the coastline of Iceland is highly incised by fjords having steep slopes, villages developed on the few available lowlands below the mountains. Due to location, climate and still active geological processes, the villages are frequently damaged by several typologies of slope movements, snow avalanches and floods.

Following two catastrophic avalanches occurred on 1995, when 34 casualties were recorded inside zone marked “safe” on the official hazard maps, regulations for avalanches and landslides (including debris flows) were completely revised. At the present, hazard and risk zoning must be developed at large scale (1:5,000), on the basis of the quantitative risk assessment (QRA) and by observing a number of constraints among which: preparation and structure of hazard zoning; data collection; risk assessment; acceptable risk; explanation accompanying the hazard maps.

Due to the complexity of the phenomena, observance of regulations requires efforts from operative, technical and scientific points of view, as it is highlighted by the IMO (Iceland Meteorological Office) website that offers documents, data, reports and papers on the subject. An overview of both the natural phenomena occurring in Iceland and the approach used for hazard and risk zoning is furnished by Jensen and Sönser (2002), Arnalds et al. (2002), Jónasson et al. (1999).

After a brief introduction about general settings, topographic characteristics and land-use in Iceland, Jensen and Sönser discuss the process oriented to landslide hazard assessment for Eskifjörður (Fig. 33), furnishing data on sites, human settlements, climate and extreme rainfall, geology and bedrock of rivers watershed (about 2 - 4 km^2 in size) falling through the village, and the loose soils (Andosols) covering the bedrock. Then, the authors analyse flood and geomorphic processes of mass movements (creep slope, slide, rockfall and debris flow) observing that debris flows generally initiate at zone > 25°, travel along the channel (> 10°) where erosive phenomena can occur, and stop at flat areas < 10°. Floods and debris flows are mainly triggered by intensive rainstorms and/or rapid snow melting, bursting of a dam created by snow or debris blocking the channel.

The hazard assessment for mass movement is, therefore, analysed on the basis of site investigation, literature review and some elements (historical events and frequency map) required by legislation (The Ministry of Environment 2000). Moreover, water runoff in the channels is determined for different return periods of rainfall intensity. Hydrographs for the catchment area are then developed, and the dominating channel process is estimated by using the van Dine’s (1985) model, that allows to distinguish among stable condition; bedload transport; debris torrent; infinite slope failure and bedrock sliding. Fi-

Figure 33. Eskifjörður and the names of main landmarks. (Photo: Esther H. Jensen).

nally, referring to some phenomena (floods and debris flows) and critical rainfall with different return periods, the authors furnish for some selected sites the waterload, debris volume (erosional processes) and debris volume including slides from the banks.

Further details on hazard assessment and zoning of mass movements can be obtained by Arnalds et al. (2002), who also analyse the avalanche hazard for Eskifjörður. With reference to avalanches, the authors describe the snow depth measurements in starting area together with track and runout zones. Estimation of runout is, therefore, furnished for selected sites with the aid of a method that is not explained in detail. However, the basic concepts of this and similar methods can be obtained by Jónasson et al. (1999), who describe a quantitative procedure for estimation of snow avalanche risk in residential areas, measured as annual probability of being killed.

The procedure is developed on the basis of a data set including 196 Icelandic avalanches, fallen from 81 different paths in 50 different hillsides, threatening 8 towns and villages. The observation history of each path (name, date, stopping position, width, profile, etc.) ranges from 80 to 100 years.

Considering that frequency estimation must regard avalanches expected to fall every 100, 300, 1,000 and 3,000 years (The Ministry of Environment 2000), the authors recognise the impossibility of frequency estimation of long avalanches if limited to local history. Therefore, they suggest to combine the avalanches history of all the paths in data set, so lengthening the observation time. To this aim, they assume an avalanche standard path, that is representative of the Icelandic avalanche paths; it is parabola shaped, 700 m high and reaches level ground 1,600 m from the starting point (Fig. 34).

In order to calculate the runout of avalanches along the standard path, a physical transfer method for avalanche flow, based on the Coulomb resistance parameter μ and the mass-to-drag parameter M/D, is used as an alternative to the topographical α/β model developed by Jóhannesson (1998a, 1998b). On the basis of the standard path, the physical transfer method and all the data collected in data set, the authors obtain the "runout indices", measured in hectometres (Fig. 35), and estimate, via statistical analysis, the exceedance probability that an avalanche reaches a "runout index (*r*)" larger than $r = 13$, that is assumed as reference value for the Icelandic avalanches. Therefore, the exceedance probability is used to estimate, on the basis of the local history, the frequency of a single path avalanche at a general runout index.

As it concerns the elements at risk, the authors estimate the probability of surviving an avalanche striking a house on the basis of: the element exposure; the avalanche speed profile obtained by the physical transfer method; recorded data by previous case histories, etc.. Finally, a formula is furnished to calculate the risk of living or working in a building under an avalanche hillside; the formula takes into account the speed and shape (tongue effect) of the avalanche, the frequency of avalanches pasting the building, the probability of death. An example of risk estimation is furnished in Figure 36, where dashed and unbroken lines respectively represent the estimated level of risk and the runout indexes. It is interesting to observe that, in correspondence of the acceptable risk fixed by regulations ($R = 0.3\times10^{-4}$ for living house), the calculated return period is approximately T = 5,700 years, while T = 800 years corresponds to $R= 3\times10^{-4}$.

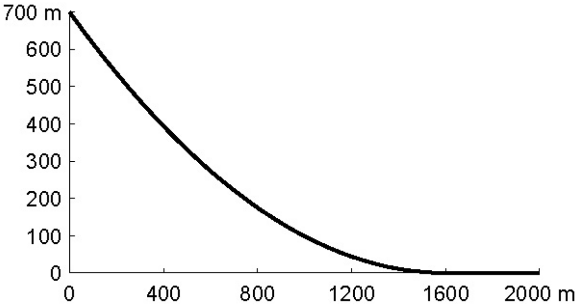


Figure 34. The standard path (Jónasson et al. 1999).

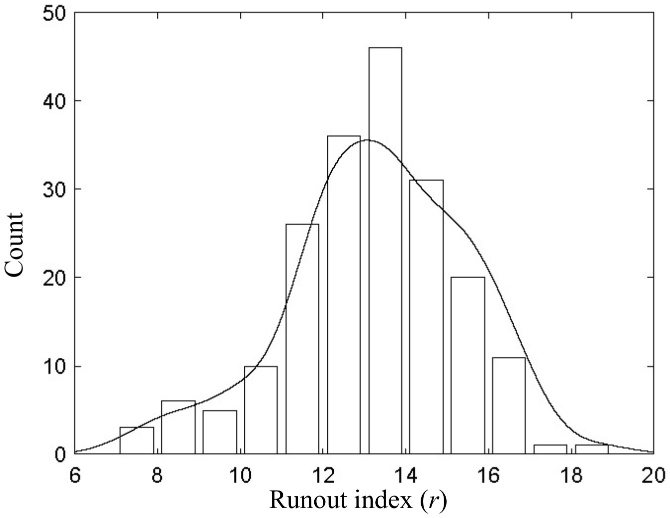


Figure 35. Runout indices of 196 Icelandic avalanches together with kernel estimated data density function (Jónasson et al. 1999).

Referring to Jónasson et al. (1999) for more details, it must be stressed that the authors suggest the way to further improve the proposed method that, however, is considered not helpful in identifying starting zones of avalanches and not suitable with reference to: other natural hazards (for instance slush or mudflow); areas where countermeasures have been realised; hillsides where information on avalanche history is not available in data set. In this case, however, the method could be used to evaluate an upper limit of the risk under the hillsides.

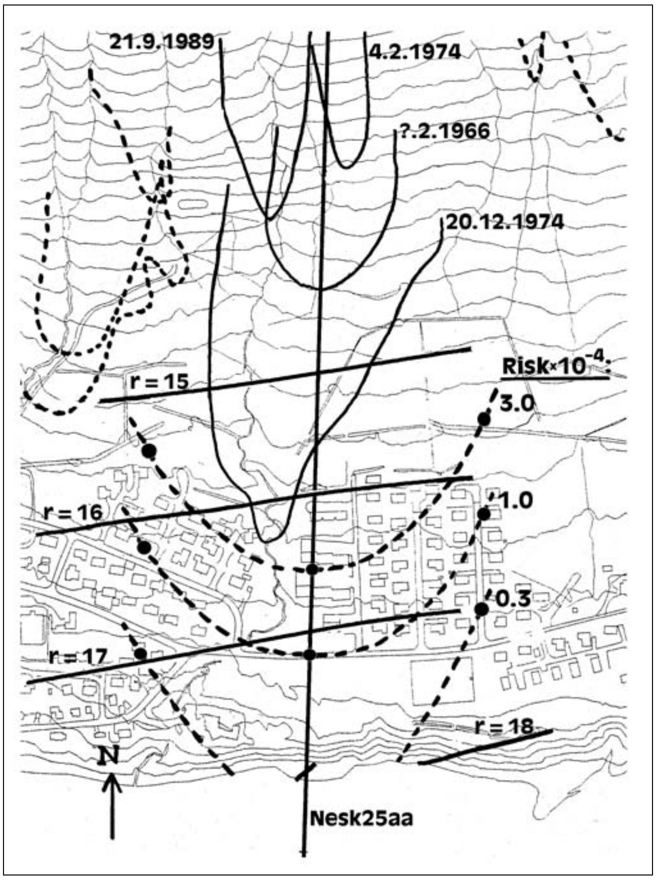


Figure 36. Risk estimation due to avalanches from Bakkagil, Neskaupstaður. Scale 1:7,500 (Jónasson et al. 1999).

7 CONCLUDING REMARKS

During the last decades several strategies for landslides risk management have been developed to fight against the consequence of such phenomena which threaten all the continents, although with different intensity and recurrence. The strategies include hazard and risk zoning methods, as well as non-structural measures.

As it concerns the first point, the experience gained and the results obtained in several countries encourage the use of hazard and risk zoning to improve the urban planning and development as well as to minimize the associated risk. However, some remarks derive from the scientific literature.

There is a need for standardized and reproducible methods for assessing hazard and risk components, and particularly in what respects to the definition of classes.

Frequency and risk should be quantitatively assessed, as they can improve the reliability of hazard and risk zoning, that is the way forward to getting uniformity in planning.

Development in automatic data capture techniques should not put aside field work and personal judgement. Exercises of comparing hazard maps performed by different teams show important discrepancies in the results. The main differences are due to the quality of the input data and, particularly, in the completion of the landslide inventories. Despite of the impressive improvement of the remote sensing techniques, the identification and interpretation of landslide features is not evident and the appropriate completion of the landslide inventories still rely on the skill of the specialists.

Both hazard and risk maps must be checked and validated with reliable procedures. Working with large scale maps requires a great deal of accuracy in defining boundaries of the hazardous zones and of the magnitude-frequency of the events. The lack of both complete and reliable data sets in many landslide threatened urban areas is a constraint for the achievement of a minimum level of quality in the documents. This might be a source of future arguments and conflicts.

With reference to the non-structural measures, they include the prohibition or restriction of building in hazardous areas, the establishment of warning systems in location where the hazard cannot be avoided but risk can be minimized by early warning and evacuation plans, and legal measures and economic subsides in case of catastrophe.

Prohibition and restriction to development, if possible, is probably the most efficient way to minimize both hazard and risk. This can be put into practice if landslide hazard maps and hazard zoning are available in a particular area, the last to be integrated in urban planning and regional development analysis. However, the long-term applicability of local plans or rules for the use of landslide-prone area still represents a main problem in several countries.

Evacuation plans and warning systems can represent a valuable safeguard measure for population living inside risk zones, providing that a good educational programme including training has been developed, as in the case of Hong Kong, and an efficient monitoring system has been implemented.

Monitoring systems are generally based on the check-in of selected factors among the triggering ones, the indicators of slope stability conditions and the effects caused by the triggering factors. To be efficiently implemented in warning systems, the experimental observations must be systematically tested in sample areas and elaborated by an advanced mathematical modeling aimed to individuate reliable threshold values of rainfall, displacement, etc.. Moreover, the efficiency can be improved by coordinating national, regional and urban systems, working at different scales, and by systematically testing out of the new technologies, not disregarding difficulties and misleading results.

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