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SafeLand

Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies

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Living with landslides – European and International dimensions of the project SafeLand

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SUMMARY

This report describes the rationale and European and international dimensions of the project 'SafeLand: Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies'. It provides a review of these topics, describes the project objectives and outline, along with the European and global policy context, and identifies important open issues on quantitative risk assessment and management tools and strategies for landslides at local, regional and European scales, which are to be addressed by the SafeLand project.

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1 INTRODUCTION AND PROBLEM STATEMENT

Landslides represent a major threat to human life, property and constructed facilities, infrastructure and natural environment in most mountainous and hilly regions of the world. Statistics from The Centre for Research on the Epidemiology of Disasters (CRED) show that, on average, landslide "disasters" are less common than disasters caused by other natural threats such as floods and storms (Figure 1), and that they are responsible for a small percentage of all fatalities from natural hazards worldwide. However, these and other statistics underestimate the socio-economic impact of landslides because landslides are usually not separated from other natural hazard triggers, such as extreme precipitation, earthquakes or floods. This underestimation contributes to reducing the awareness and concern of both authorities and general public about landslide risk. Brabb (1991) estimated that the global death toll from landslides has increased from 600 per year in the early 1970's through to several thousand per year by the early 1990's. A more systematic study by Petley et al. (2005) even suggested an annual average death rate of about 4000 persons for the period 1980 to 2003.

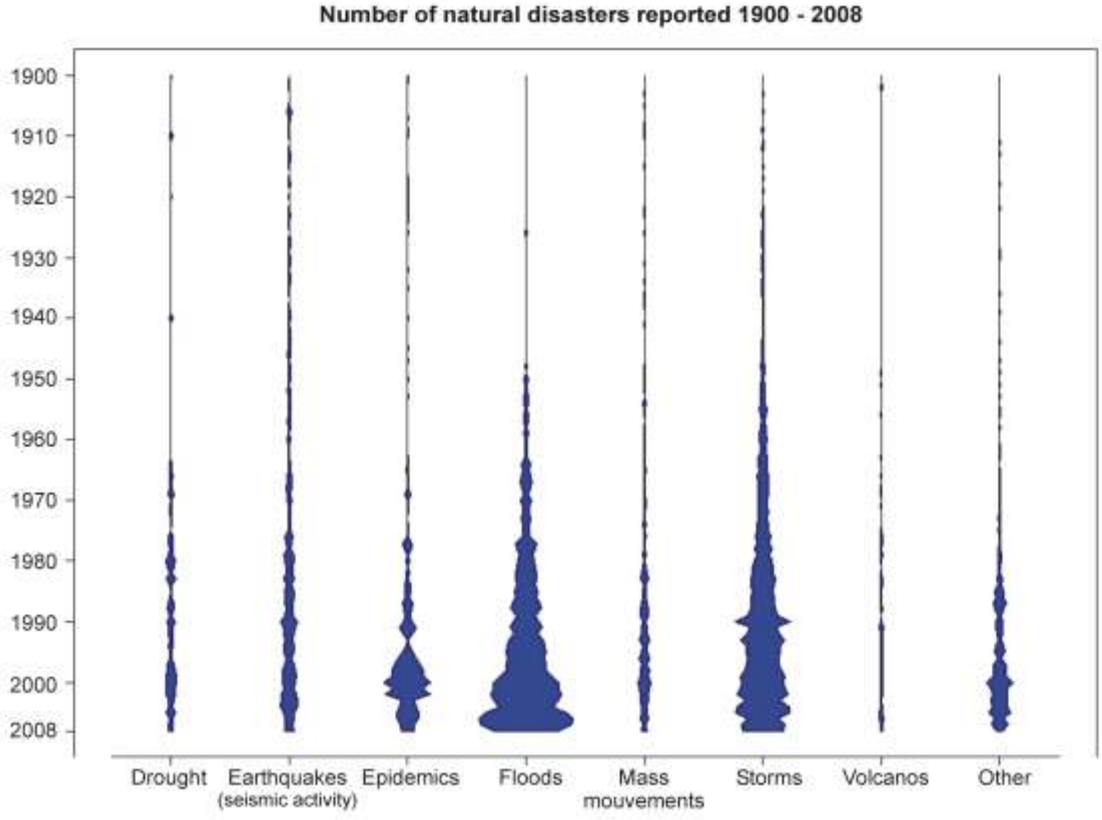

Figure 1 The number of natural disasters reported in the period 1900-2009. Source: EM-DAT – The OFDA/CRED International Disaster database. Catastrophic landslide events associated with major storms, earthquakes or floods are not usually accounted for.

According to the CRED statistics, during the period 1900-2009 Europe has experienced fewer landslide events (Fig. 2A) and fewer fatalities caused by landslides (Fig. 2B) compared to

America and Asia. However, Europe had the highest economic losses caused by landslides of all continents (Fig. 2D). According to the CRED statistics, about 16,800 persons have lost their lives because of landslides and the material losses amounted to over USD 3100 M in Europe during 1900-2009. However, as for Figure 1, the actual figures in Figure 2 are likely to be greatly underestimated, because

1) in the EM-DAT database landslide events with less than 10 persons killed are not reported, resulting in the exclusion of the majority of the events, and
2) fatalities are only reported for the trigger of the event that caused the landslide events.

Hence, casualties of landslides that are triggered by earthquakes or tropical cyclones are not included. The effects of these drawbacks are further illustrated by Petley (2008).

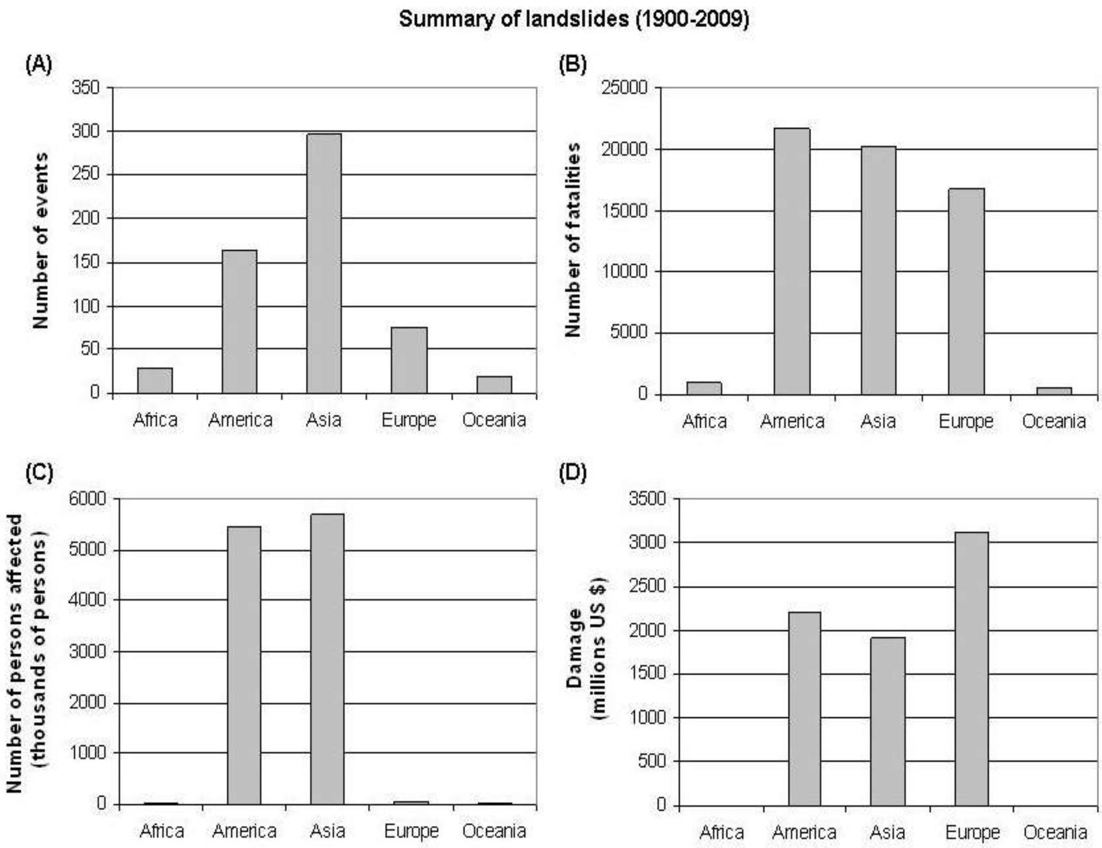

Figure 2 Important landslide statistics for the period 1900 to 2009: (A) number of landslide events (B), number of fatalities, (C) number of persons affected, and (D) cost of damage. Source: EM-DAT – The OFDA/CRED International Disaster database.

Within Europe, landslides are regularly reported in mountain areas in Italy, Spain, Greece, Switzerland, Romania, Austria, France, Norway and Sweden. Italy is the country that has suffered the greatest human and economic losses due to landslides in Europe. Also on a national scale, the number of persons affected by landslides is often much larger than reported. In Italy, for example, about 500 persons have been killed by landslides over the past

25 years, but the total number of persons impacted is 50 times that number (http://www.geotechnet.org).

Apart from mountain regions, landslides were also reported in hilly regions in Germany, United Kingdom, Belgium, Czech Republic, Slovakia, Slovenia and Bulgaria, and in coastal regions with cliffs in United Kingdom, France, Portugal and Denmark (e.g. Bromhead and Ibsen, 2006; Lageat et al., 2006; Marques, 2006). These cliffs are susceptible to failure from sea erosion (by undercutting at the toe) and their geometry (slope angle), resulting in loss of agricultural land and property. This can have a devastating effect on small communities. For instance, parts of the north-east coast cliffs of England are eroding at rates of 1m / yr.

As a consequence of climate change and increase in exposure in many parts of the world, the risk associated with landslides is growing. In areas with high demographic density, protection works often cannot be built because of economic or environmental constraints, and it is not always possible to evacuate people because of societal reasons. One needs to forecast the occurrence of landslides and the hazard and risk associated with them.

Water has a major role in triggering of landslides (Sidle et al., 1985), especially debris flows, which is one of the most frequent and destructive type of landslides. For Italy, for example, Figure 3 shows that heavy rainfall is the main trigger for landslides.

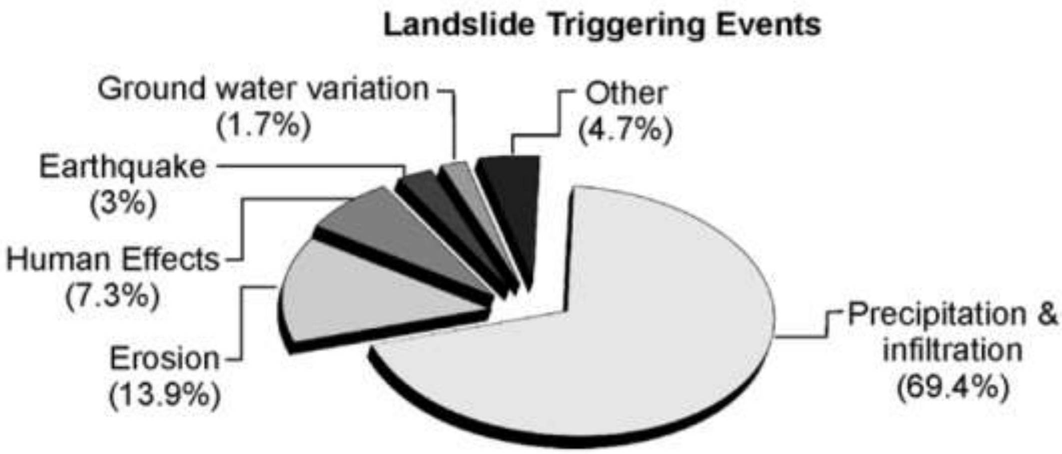

Figure 3 Landslide triggers in Italy. (Source: CNR-GNDCI AVI Database of areas affected by landslides and floods in Italy)

As a consequence of climatic changes and potential global warming, an increase of landslide activity is expected in some areas the future, due to increased rainfall (e.g. Christensen and Christensen, 2007; Fowler and Ekström, 2009), changes of hydrological cycles, more extreme weather events, concentrated rain within shorter periods of time, severe sea storms causing coastal erosion, and melting of snow and of frozen soils in the Alpine regions (e.g. Beniston, 2006).

The reality for society in Europe to live with hazard and risk and the need to manage risk were the reasons for the project consortium to propose the SafeLand Research. SafeLand will contribute to the present day knowledge on landslide hazard and risk by dedicating resources and research on technical issues (quantitative models and monitoring tools), integrating climate change and human activity scenarios into quantitative risk assessment (QRA) and developing society-oriented risk management methodologies for landslide risk prevention and mitigation.

2 THE SAFELAND PROJECT IN A POLICY CONTEXT

The SafeLand project responds to a number of international policies. For Europe in particular, SafeLand supports the EU Thematic Strategy for Soil Protection (Commission of the European Communities, 2006a) and the associated Proposal for a Soil Framework Directive (Commission of the European Communities, 2006b). The EU Thematic Strategy considers landslides as one of the main soil threats in Europe, and prompts for identification of areas at risk to landslides in EU Member States using common methodologies, as well as for risk reduction measures. On the other hand, according to the Commission's Communication entitled "A community approach on the prevention of natural and man-made disasters" (Commission of the European Communities, 2009), a better understanding of disasters such as landslides is prerequisite for developing efficient prevention measures. This requires e.g. inventories of information on disasters and developing of guidelines on hazard and risk mapping. These are important objectives of the SafeLand project. The communication further states that outcomes of the Seventh Framework Programme for Research and Technological Development should be directly implemented in European prevention approaches.

At global level, SafeLand supports the UN International Strategy for Disaster Reduction (UNISDR). UNISDR aims at building disaster resilient communities by promoting increased awareness of the importance of disaster reduction as an integral component of sustainable development, with the goal of reducing human, social, economic and environmental losses due to natural hazards and related technological and environmental disasters.

Furthermore, disaster reduction efforts are guided by "The Hyogo Framework for Action (HFA) 2005-2015: Building the resilience of Nations and Communities to Disasters", to which 168 governments agreed in Hyogo, Kobe, Japan. The plan encourages local authorities to identify landslide risk and vulnerabilities, establish hazard maps and put in place effective monitoring systems. It also recommends implementing protective engineering works, urban planning strategies, environmental management and community preparedness.

Reducing loss of life and property from natural and human-induced disasters including also landslides is also one of the objectives of GEOSS, the Global Earth Observation System of Systems (2005-2015), currently constructed by the Group on Earth Observations (GEO).

The need for risk management strategies is further acknowledged by the Intergovernmental Panel on Climate Change (IPCC) who predicts an increase of the mean temperature as well as a change in rainfall patterns in the future, leading to potential increased instability of slopes especially in mountain and permafrost areas. In many global change scenarios, it is expected that more people will be exposed to landslide hazard. Therefore IPCC recently proposed a special report on "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" (IPCC SREX to be published 2nd half of 2011).

3 PROJECT OBJECTIVES AND STRUCTURE

The three main objectives of 'SafeLand: Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies' are:

1. to provide policy-makers, public administrators, researchers, scientists, educators and other stakeholders with improved harmonised framework and methodology for the assessment and quantification of landslide risk in Europe's regions;
2. to evaluate the changes in risk pattern caused by climate change, human activity and policy changes; and
3. to provide guidelines for choosing the most appropriate risk management strategies, including risk mitigation and prevention measures.

SafeLand will develop and implement an integrated and comprehensive approach to help guide decision-making. The methodologies developed will be tested in selected hazard and risk "hotspots" in Europe, in turn improving knowledge, methodologies and integration strategies for the management of landslide risk. The harmonised methodologies and technical developments, combined with the social, economic and environmental dimensions will play a significant role in the detection, prediction and forecasting of landslides and landslide risk posed to individuals, society and the environment.

Hazard and risk will be investigated at three different scale levels, i.e. the local, regional and European scale. A landslide is usually a localised event that affects tens to hundreds square metres of land. Also for landslide risk mitigation one often works at the local scale. SafeLand will improve and adapt existing knowledge on landslide hazard and risk to link hazards and risks at the local scale to the hazards and risks at the European scale. The largest, most detailed, scale of interest in this proposal refers to the local slope scale (less than 3 km^2) where most of the research on the triggering factors will be done. The regional studies, including the "hotspots" evaluations, form the intermediate scale: from 10 to 200 km^2, depending of the site. The smallest scale will be the "country" and European scales. This is the scale where predictions about the effects of global change have most statistical sense.

SafeLand will focus on five Research Areas. Each area deals with specific scientific and technical objectives proposed in SafeLand. The Research Areas and the interrelationships among them are illustrated in Figure 4. The scales of analysis and investigation in the five Research Areas are also shown on the figure. Each of the five Research Areas prioritises scientific advancement on the technological or the societal arena, or even both arenas.

Area 1 focuses on improving the knowledge on triggering mechanisms, processes and thresholds, including climate-related and anthropogenic triggers, and improving run-out models in landslide hazard assessment. It is fundamental work for the identification and development of appropriate landslide hazard assessment tools necessary for *Area 2*, which aims at harmonizing quantitative risk assessment methodologies for different spatial scales, looking into uncertainties, vulnerability, landslide susceptibility and landslide frequency. Area 2 will identify "hotspots" in Europe with higher landslide hazard and risk. *Area 3* integrates future climate change scenarios and changes in demography and infrastructure into this harmonised quantitative risk assessment, resulting in the evolution of hazard and risk in

Europe and the evaluation of their impact on selected "hotspots". *Area 4* addresses the technical and practical issues related to monitoring and early warning for landslides, and identifies the best technologies available in the context of both hazard assessment and design of early warning systems. *Area 5* addresses the risk management issues, integrating the developments from Area 4, as well as other methods, into a toolbox of risk mitigation measures and guidelines for choosing the most appropriate risk management strategy to reduce the risk to specific targets. All the studies will be tested and documented with the help of case studies.

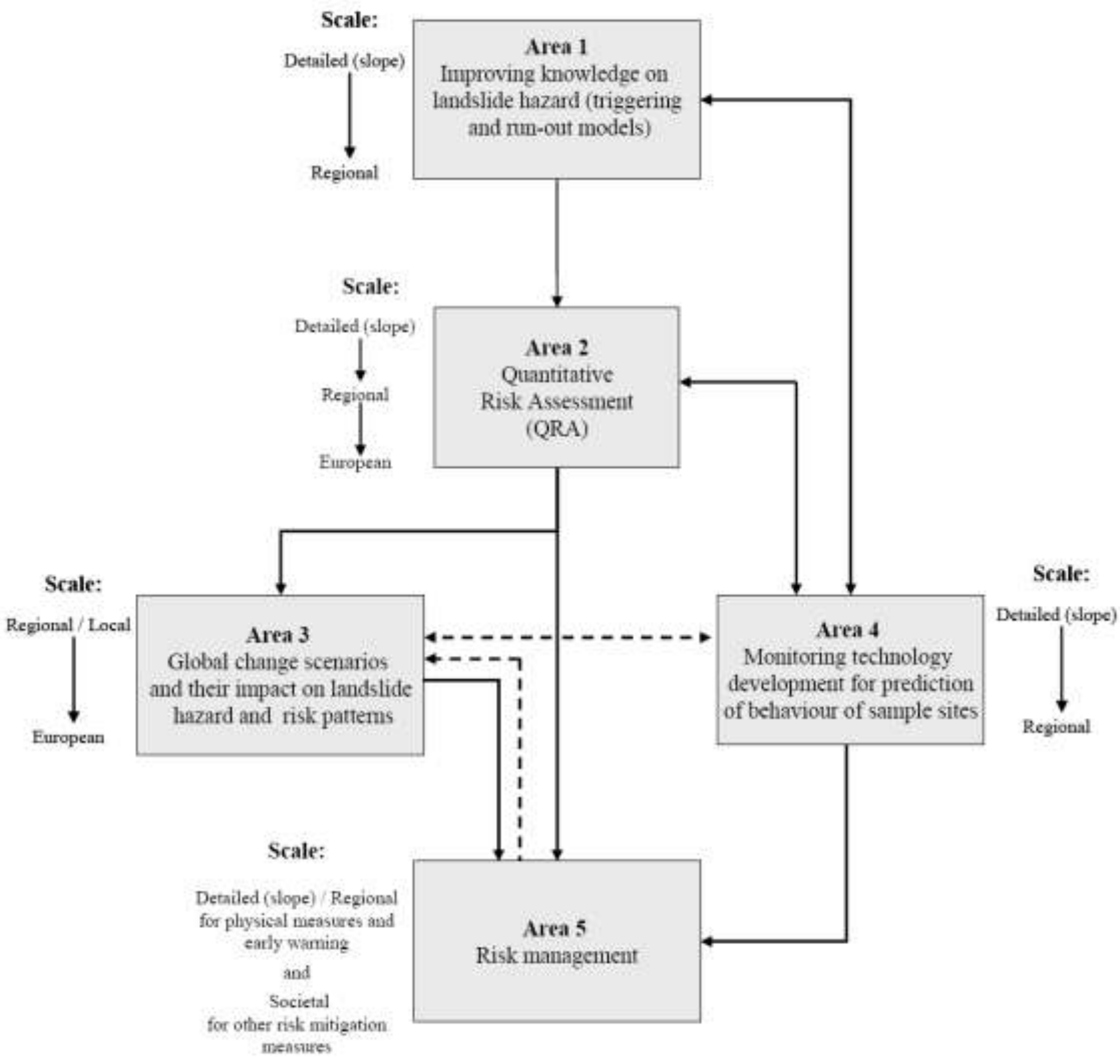

Figure 4 Relationships among activities in SafeLand Research Areas and scales of analysis considered.

SafeLand stresses the necessity of integrating the technology and social aspects to ensure that the risk assessment and management strategies are realistic and representative of the forces at play in an actual situation. Global changes, due to both climate and human activity, will provide insight in future risk patterns. The landslide risk assessment and management strategies developed in the SafeLand project will be implemented to forecast future risk.

SafeLand's research programme is organised in 21 Work Packages, 18 of which are grouped under the five Research Areas (see Figure 5).

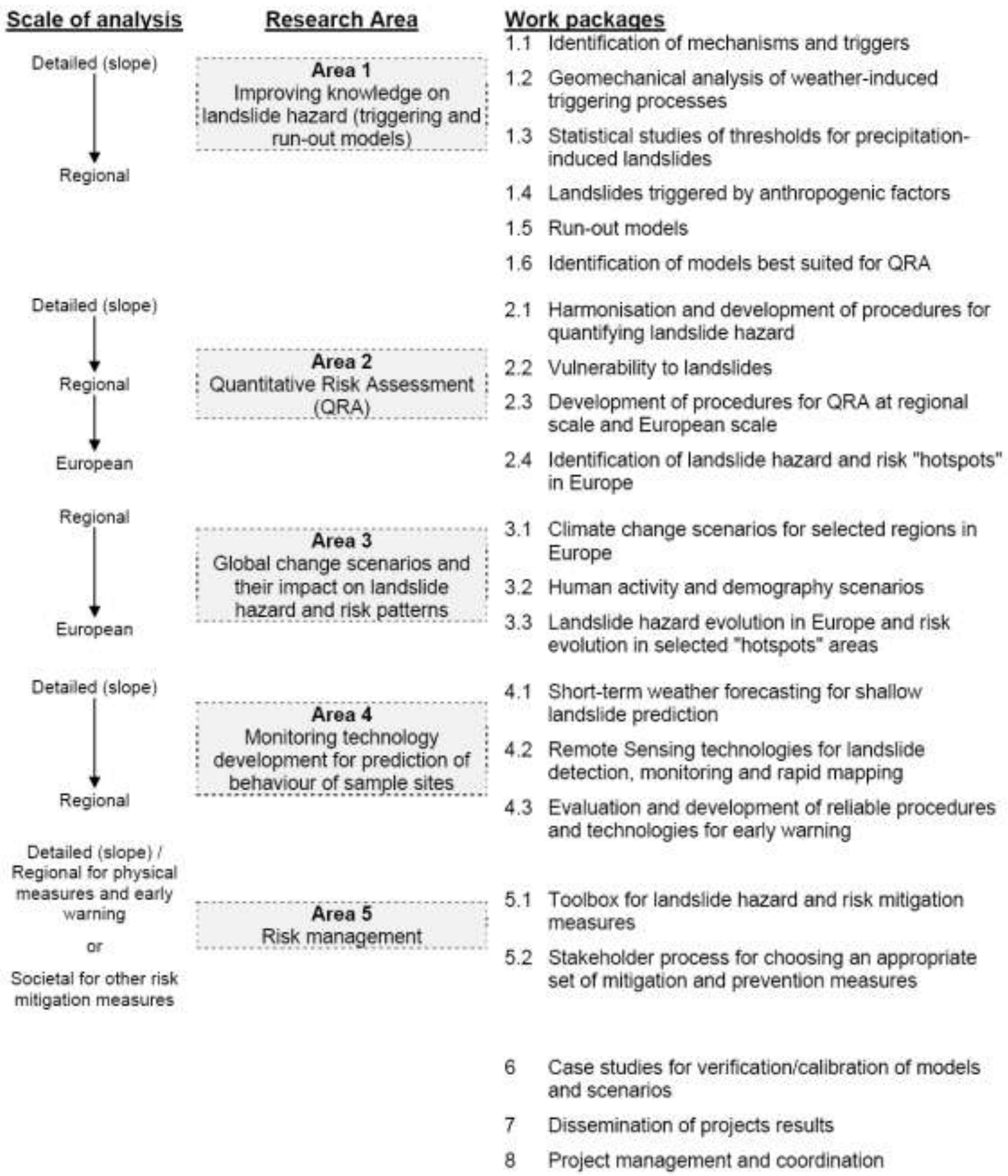

Figure 5 Work packages in SafeLand.

4 PROGRESS BEYOND THE STATE-OF-THE-ART

4.1 IMPROVING KNOWLEDGE ON LANDSLIDE HAZARD: TRIGGERING AND RUN-OUT MODELS

The ability to predict landslide occurrence, thus to assess the hazard, is a fundamental prerequisite for effective risk mitigation. In fine-grained soils, slope failure is usually a long-term process and the analysis of precursors (rainfall and hydrological cycles) and geo-indicators (observed movements) is essential for successful prediction (Saito, 1965). For landslides in rocks and in granular soils, the challenge is the very short time between initiation of the failure process and slope collapse (Picarelli et al., 2007; Eberhardt, 2008). This requires new and original criteria for in-time prediction and alerting (Picarelli, 2000; Imre and Springman, 2006).

Significant progress has been made on the understanding of triggers and processes of slope failure (Springman et al., 2003). In particular, a number of numerical codes have been developed to predict: a) the long-term preparatory factors of slope deformation and failure; b) the short-term conditions that can lead to a catastrophic failure; and c) the spatial and temporal distribution of landslides triggered by precipitation, and the landslide features affecting the risk (Baum et al., 2005a). The stability of active layers in mountain permafrost within a global warming scenario has also been investigated numerically (Arenson et al., 2006).

Monitoring of instrumented sites and some experiments on large to full-scale physical models (Ochiai et al., 2004; Moriwaki et al., 2005; Olivares and Picarelli, 2006; Friedel et al., 2006; Chikatamarla et al., 2006; Bowman et al., 2006, 2007) have provided useful data for the improvement of both understanding and the codes available. On the other hand, statistical methods have been developed to define thresholds to be used within early-warning systems (Glade et al., 2000; Sirangelo and Braca, 2002; Guzzetti et al., 2008; Frattini et al., 2009). Finally, numerical codes for the assessment of the size, runout and velocity of landslides (Hungr, 1995; Pastor et al., 2003; Hungr and McDougall, 2009) enable a rational evaluation of the hazard and the risk at the local, individual slope scale, provided that the vulnerability of the elements at risk is known.

However, in spite of the high quality work which has been done in many parts of the world, there is still a large potential for improving reliable landslide prediction models. Calibration and validation of triggering and runout models requires reliable data, but this is currently rarely available, because of the high cost of real-scale experiments and monitoring. In the SafeLand project, data will be collected through monitoring of a relatively high number of test sites and through controlled laboratory tests. This data will allow to check and improve the performance of existing numerical and statistical models, and, if necessary, to develop new models.

SafeLand will progress the state-of-the art through an integrated review and implementation of all the recent research on triggers, landslide mechanisms, and landslide runout. The methodologies and models will be compared and assessed in terms of their usefulness in quantitative risk analysis (QRA), and new approaches will be recommended. Prediction of landslides over both spatial and temporal scales will be carried out, considering climatic triggers such as precipitation, snow and permafrost melting and anthropogenic triggers. This advancement will require further development of knowledge in the area of landslide triggers and run-out distance, and application and testing of the methodologies in laboratory experiments and in field cases. Through such investigations, the validity domain of the models, their versatility with respect to other environmental conditions and their ability to simulate global change scenarios will be investigated. Since actual landslide instability (in-situ, full scale instability) is much more complex than laboratory experiments, uncertainty in the model predictions must be carefully addressed and quantified.

4.2 QUANTITATIVE RISK ASSESSMENT (QRA)

In many European countries, there is extensive use of landslide susceptibility and hazard zoning (Malet and Maquaire, 2009), and to a lesser extent landslide risk zoning. Many of the zoning schemes are qualitative in nature. For appropriate landslide risk management, one needs to quantify the hazard by assigning an annual probability (frequency) to the potential landslide, and the risk.

The first landslide hazard maps were prepared in the 1970s (i.e. Kienholz, 1978). Landslide hazard maps show the areas that are stable and the areas that may be affected by existing or future landslides, including those where landslides may travel onto them. The landslide hazard maps should also provide information of the probability of occurrence of landslides and their magnitudes (Varnes, 1984). None of the early landslide maps had the capability of predicting the temporal probability of occurrence.

In the literature, useful reviews of landslide hazard assessment and mapping may be found (i.e. Varnes, 1984; Van Westen, 1993; Soeters and Van Westen, 1996; Aleotti and Chowdhury, 1999; Guzzetti et al., 1999; Dai et al., 2002; Cascini et al., 2005; Chacón et al., 2006; Hervás and Bobrowsky, 2009). Methods used for landslide hazard assessment include: (i) geomorphological mapping of landslide hazard, where investigators directly estimate actual and potential slope failures; (ii) heuristic methods, where also the expert's opinion is used to assess the hazard by ranking and weighting of instability factors according to their assumed or expected importance in causing landslides; (iii) knowledge based analysis or 'data mining' where patterns in landslide hazard are automatically extracted through computer models such as clustering, decision trees and support vector machines (Quinlan, 1993); (iv) statistical or probabilistic methods, based on the observed relationships between each factor and the past distribution of landslides [discriminant analysis (Carrara et al., 1995; Guzzetti et al., 1999), logistic regression (Dai and Lee, 2001; Ayalew and Yamagishi, 2005; Van Den Eeckhaut et al., 2006), Bayesian methods and neural networks (Gómez and Kavzoglu, 2005; Lee et al. 2006)]; and (v) deterministic methods applying classical slope stability principles such as infinite slope, limit equilibrium and finite element techniques, and some with GIS integration (Zhou et al., 2003; Montgomery et al.; 1998; Crosta, 1998; Frattini et al., 2004; Savage et al., 2004; Baum et al., 2005b). Recently, some studies focussed on the comparison and combination of different methods (e.g. Carrara et al., 2008; Van Den Eeckhaut et al., 2009), but the conclusions of the different studies are not always in perfect agreement.

Qualitative methods can be successfully applied to evaluate landslide risk in some areas (Cardinali et al., 2002). However, a quantitative assessment allows more objective risk evaluation. In addition, Corominas et al. (2005) and Fell et al. (2008) suggest the use of quantitative methods for risk assessment in response to an increasing need for quantitative risk management principles. The most direct way of computing QRA is by quantifying each of the components of the hazard equation (Hungr et al., 2005). In terms of conditional probability, the landslide risk for properties may be determined as follows, accounting for all potentially affected elements at risk and all landslide types (Fell et al., 2005):

$$R(P) = \sum_{i=1}^{k} [P(L_i) \times P(T:L) \times P(S:T) \times V(D_i)] \times C \qquad \text{(Eq. 1)}$$

where:

R(P): expected annual loss due to landsliding (i.e. €/yr)
$P(L_i)$: annual probability of occurrence of a landslide with a magnitude "i"
P(T:L): probability of a landslide with a magnitude "i" reaching the element at risk
P(S:T): temporal spatial probability of the element at risk
$V(D_i)$: vulnerability of the exposed element in front of a landslide of magnitude "i"
C: value of the element
i = 1,..k: landslide magnitudes

Practical application to zoning at a specific location or region is a challenge, because despite significant improvements produced in automatic data capture, data analysis and processing, model validation and computational advances, QRA is far from a routine activity. Key components such as magnitude (intensity)-frequency relationships and vulnerability of the exposed elements require significant research. Upscaling of Eq. 1 to a map requires first the analysis of the spatial and temporal probabilities of specific groups of elements at risk in the map to be hit by mass movements of different magnitudes (Van Westen et al., 2005), and secondly the estimation of the degree of loss to these elements at risk.

SafeLand will harmonise and develop new generic procedures for quantitative landslide hazard assessment. Some of the available methods for assessing the probability of landsliding have been reviewed by Mostyn and Fell (1997), Baynes and Lee (1998), and Picarelli et al. (2005a, b). SafeLand will specifically address:

1. The calculation of the spatial and temporal probability of landslide occurrence. Spatial probability (or susceptibility) is meant as the likelihood of the occurrence of landslides in a given location or terrain unit (i.e. Chung and Fabbri, 1999; Gorsevski et al., 2006). The spatial probability represents the failure potential of a terrain unit characterized by a set of parameters (slope angle, soil strength, etc). The temporal landslide probability will also be estimated. Existing methods are readily usable for hazard and risk zoning because the landslide magnitude (intensity) – frequency is a spatially distributed relation (Hungr, 1997).

2. The estimation of landslide vulnerability. The vulnerability of exposed elements to landslides has different components (Birkmann, 2006). It represents the systems or the

community's physical (structural), economic, social and environmental susceptibility to damage. Some approaches exist for single elements (Leone et al. 1996; Faella and Nigro, 2003; Roberds 2005; Galli and Guzzetti, 2007). For landslide risk zoning, it is necessary to develop specific vulnerability indicators for every element at risk, using the concept of probabilistic fragility functions and appropriate definition of relevant damage states (Pitilakis, 2006). SafeLand will propose fragility functions and damage states for every element at risk, including sources of uncertainties related to the temporal probability and the probability of spatial impact. The fragility functions proposed in SafeLand will consider most uncertainties (natural or aleatory, epistemic, site characterization, mathematical or model and others) quantified through probability distribution functions.

SafeLand will implement the methods developed to identify landslide hazard and risk "hotspots" in Europe. The analyses will also quantify the importance and effects of uncertainties on the results obtained. The outcome of QRA will serve as reference risk maps, using integrated GIS-based models. Area 2 has dual dimensions not only treating technological development on landslide hazard (frequency) and harmonising quantification procedures, but also including the sociological aspects such as societal vulnerability, and the elements at risk.

To identify the landslide hazard and risk "hotspots" at European scale, a simplified first-pass analysis method, similar to the approach adopted by Nadim et al. (2006) in the Global Hotspots study, will be employed. These authors estimated landslide hazard by an appropriate combination of the triggering factors (mainly extreme precipitation, human activity and seismicity) and susceptibility factors (slope, lithology, soil moisture, vegetation cover, etc.). The scale of the analysis will be a grid of roughly 1 km $\times$ 1 km pixels. The intersection of the obtained landslide hazard "hotspots" with population density and infrastructure density maps, and an appropriate set of socio-economic indicators (GDP, Human Development Index, etc.) provides a first-pass estimate of landslide risk "hotspots". Although the main focus of the this proposal is on landslides triggered by climate factors and human activities, also earthquake-induced landslides must be considered to get an overview on the overall landslide hazard in Europe. The methods developed by Nadim et al. (2006), or more recently by ICG in the FP6 project SAFER (Seismic eArly warning For EuRope) can be used for this.

4.3 QUANTIFYING GLOBAL CHANGE SCENARIOS AND THEIR IMPACT ON LANDSLIDE HAZARD AND RISK IN THE FUTURE

The landslide risk pattern in Europe is dynamic and its evolution is mainly due to two major factors: climate change and changes in demography (anthropogenic influences). Climate influences the magnitude and frequency of landslides via the non-linear soil-water system. The number, frequency and magnitude of landslides are likely to change (mainly increase) in landslide prone areas because of climate change (Beniston, 2006; Bocheva et al., 2009; Harris et al., 2009). The role of water content, and hence precipitation, in triggering landslide activity is universally accepted. The effect of temperature variation resulting in a change of water content or even the ground fabric, for instance creation of fissures and cracks, in combination with precipitation may also have a dramatic effect on landslide susceptibility.

During the Little Ice Age all over Europe, an increase in landslide activity was observed due to increased rainfall combined with lowered temperatures (Dapples et al., 2003; Bertolini et al., 2004). It is therefore important to assess the combined effect of precipitation and temperature variation. One 'empirical' observation for the French Alps is that wetter winters and drier summers are becoming more common, i.e. more or less the type of climate actually experienced by Italy or the Spanish Pyrenees. These empirical observations, however, do not allow quantitative statements about location or magnitude and frequency of future landslide events because of the diversity of landslide types, environmental predisposing factors (susceptibility), and climate parameters in mountain areas (orography, vertical gradients, etc.).

Several experiments using downscaled climate change time series in hydrological and slope stability models have been proposed to quantify the impact of climate change on landslide activity in the Italian and French Alps, in Southeast Spain, in Norway and in South England (Dikau et al., 1996; Grandjean et al., 2006, Malet et al., 2006, Durand et al., 2006, Jaedicke et al., 2008).

Improvement of landslide risk assessment also requires further investigation of other climate and human related factors. At a local scale, a number of attempts have been made to propose methodologies for landslide risk assessment with focus on some of the specific features listed below:

- the influence of land-use change on soil moisture availability. During the last century, for example, population migration from mountains to valleys and the abandonment of traditional agricultural practices has resulted in forest expansion in the Alps;
- the loss of precipitation by interception and the removal of soil moisture by transpiration due to changes in vegetation species or vegetation cover (human-induced or climate-induced);
- the effect on slope stability through time from changes in the root characteristics. There is no agreement whether these changes will enhance or reduce slope stability by modifying the soil characteristics (loading, strength parameters, hydrological parameters).
- the influence of human activity like deforestation or timber harvesting on the hydrological regime of slopes and on sediment yield.
- the impact of new developments and facilities (roads, railroads, buildings) on slope geometry or hydrology, and hence on slope stability.
- the possible increase of risk due to increased concentration of people, land development, infrastructure and goods in environmentally privileged but hazardous regions.

The work packages in Area 3 of SafeLand will contribute to adjust the QRA methodology and tools developed in Area 2 in order to take into account the impact of global environmental change (climate, forest vegetation, land use, etc.) and human activities on exposed slopes at regional and European scale. Not only the influence of climate change on rainfall induced landslides, but also the impact of changes in freeze-thaw cycles on rock falls and the impact of sea level rise on coastal landslides will be considered. Climate change scenarios will be calculated for some hotspot areas (Fig. 6). Downscaling techniques will be used to increase scenario resolution from 25 km × 25 km down to 2.8 km × 2.8 km. Based on existing or hypothetical prognoses, human activity and demography scenarios for 2030, 2050, 2070, 2100 will be established on a regional (i.e. selected hotspot areas) and European-scale. Integration of the scenarios in adjusted QRA methodology (implemented in GIS-based model) will finally allow preparation of the landslide hazard and risk evolution maps. Particular attention will be given to the uncertainties on risk evolution due to global change. It is important that the procedures developed in SafeLand to carry out scenario studies of climate change and human activity can be applied long after the project has been completed. The methodology developed in SafeLand will be generic and could be adapted to other regions.

At European scale, SafeLand will focus on developing a global simplified methodology to describe the expected changes in the climate-driven landslide activity in the next 100 years. Evolution trends of landslide risk in Europe will be assessed from the analysis at regional scale.

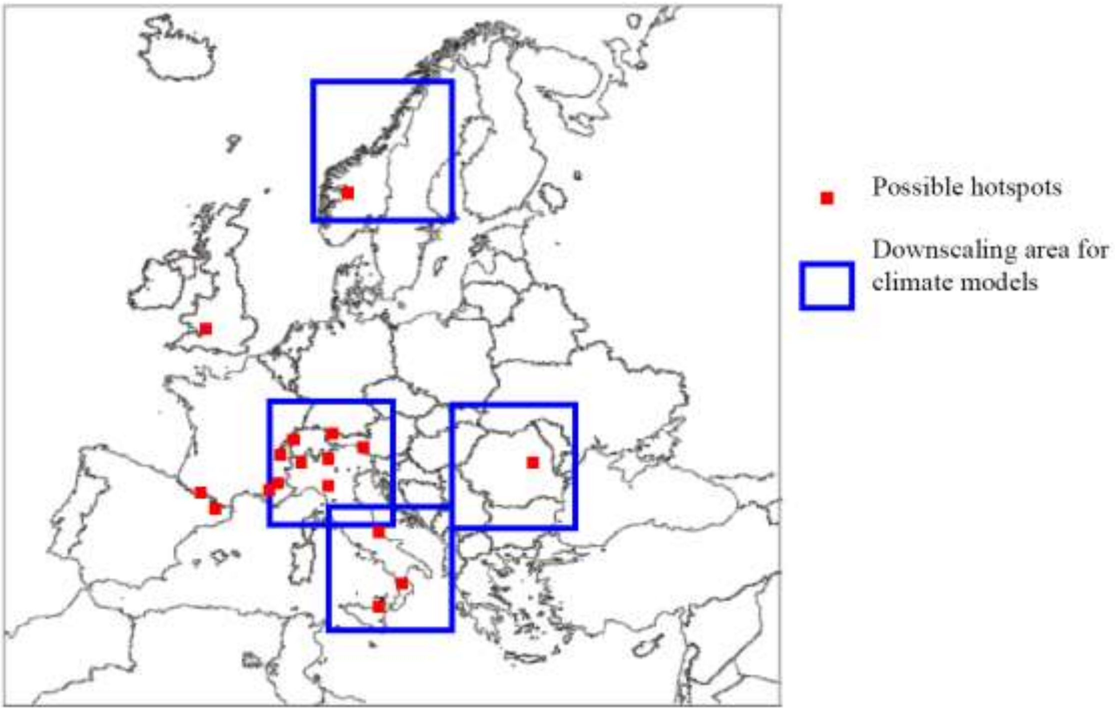

Figure 6   Areas suggested in the project proposal to evaluate climate scenarios.

4.4 DEVELOPMENT OF MONITORING TECHNOLOGIES: EARLY WARNING SYSTEMS AND REMOTE SENSING TECHNIQUES

Instrumentation systems to monitor landslide behaviour are employed in many locations with different geological settings and landscapes and with different landslide types throughout Europe. Often such systems are used in conjunction with surface mapping and sub-surface investigations to determine where protective measures are necessary in order to reduce landslide risk.

Scientists are today increasingly relying on satellite data to produce landslide inventories and risk assessment maps over wide areas; remote sensing data from optical and microwave sensors (Synthetic Aperture Radar, SAR) are applicable to landslide mapping and monitoring due to their multispectral and textural information, high repetition cycles and global coverage. The integration of SAR and optical imagery, along with SAR interferometric techniques, are currently used for characterising landslides (Hilley et al., 2004; Metternicht et al., 2005; Vilardo et al., 2009).

A pre-condition for precise hazard mapping and subsequent risk assessment and mitigation measure implementation is the availability of up-to-date and accurate topographic information (maps or digital elevation models, DEM). Since such data are not available in many areas, especially in developing countries, air- and space-borne optical imagery (e.g. Corona, Landsat, SPOT, Aster, Ikonos, QuickBird) and microwave data (e.g. ERS, Radarsat, Envisat) can be used instead to derive DEM. Such data can be used to inventory and classify areas prone to landslides and terrain types relevant to landslide hazard assessment (e.g. Hervás et al., 2003, Nichol et al., 2006; Domakinis et al., 2008, Casagli et al., 2009). Remotely sensed data can also be used for DEM related GIS modelling (e.g. Tstutsui et al., 2007). Even terrain displacements can be measured with high accuracy from repeated remote sensing data coverage. Using these methods, terrain cover, geometry and dynamics of an area can be investigated without direct access.

High- and very high resolution (HR/VHR) optical data (such Aster, Spot-5, Ikonos, Quickbird, WorldView, Komposat, Formosat, OrbView) can be used to inventory and classify areas prone to landslides and terrain types relevant to landslide hazard assessment (e.g. Hervás et al., 2003; Nichol et al., 2006; Domakinis et al., 2008; Casagli et al., 2009). Such data is also very useful for change detection purposes (Mantovani et al., 1996; Delacourt et al., 2007; Frauenfelder et al., 2009) and canfor DEM related GIS modelling (e.g. Tstutsui et al., 2007). Even terrain displacements can be measured with high accuracy from repeated remote sensing data coverage (e.g., Kääb, 2002; Canuti et al., 2004; Delacourt et al., 2004; Deballa-Gila and Kääb, 2010). Using these methods, terrain cover, geometry and dynamics of an area can be investigated without direct access.

New techniques such as Differential SAR Interferometry (DInSAR), Permanent or Persistent Scatterers Interferometry (termed PSInSAR, PSI, PS or IPTA) and high resolution optical image processing are increasingly exploited for risk assessment studies. DInSAR and PSInSAR are powerful techniques to measure centimetric displacements from satellite data and has been successfully applied to detect landslides (Ferretti et al., 2001; Colesanti and Wasowski, 2006; Wasowski et al., 2006), subsidence, post-earthquake ground surface displacement pattern (e.g. Massonnet et al., 1993; Atzori et al., 2008) and volcanic activity (e.g. Massonnet et al., 1994, Puglisi et al., 2008). Ground-based interferometric radar (GB-SAR) such as LISA (Linear SAR) is capable of assessing the deformation field of an unstable slope in the areas characterised by high radar reflectivity (Antonello et al., 2004). Merging results from different technologies, e.g. merging of very high spatial resolution (VHR) optical data with DInSAR or PSInSAR results, opens up a wide range of new applications within landslide hazard mapping and risk assessment.

Another method increasingly used for landslide characterisation is the exploitation of Light Detection and Ranging (LIDAR). LIDAR is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. From LIDAR point clouds extremely high-resolution DEMs (sub-meter spacing) can be generated allowing for general landslide characterisation as well as for the identification of the orientation of geological structures, down to the individual fracture (e.g., Bitelli et al., 2004; Dewitte et al., 2008; Oppikofer et al., 2008; Fischer et al., 2010).

Near-surface geophysical investigation methodologies (seismic, gravimetric, magnetic, electric and electromagnetic) are often applied to monitor hydrogeological phenomena. New electric and electromagnetic survey techniques have been applied to areas with complex geology (seismic, geothermal, volcanic and landslide areas, etc.; e.g. Godio and Bottino, 2001; Sass et al., 2008; Pfaffhuber et al., 2010). The results of these geophysical investigations are used as input data for slope stability analysis in order to achieve a better understanding of the landslide behaviour.

The fast technological improvement in the field of landslide monitoring has led to a large number of sparse applications on single case studies. However, these individual studies lack harmonization and standardization.

In many landslide-prone areas, it may be too costly or physically impossible to stabilise a potentially unstable slope. Mitigation work may be too intrusive in sites of cultural and/or natural heritage, or for other reasons. Early warning systems allow the adoption of strategies for the mitigation of landslide risk not involving the construction of expensive and environmentally damaging protective measures. The understanding of critical factors in landslide behaviour and the manifestation of critical processes within the set of monitoring parameters (geo-indicators) represent an important basis for early warning systems.

On an operational basis, thematic layers (hazard / susceptibility maps, movement identification and monitoring) need to be coupled with real time continuous measurement and with observations on possible triggering events. The output should call for action at different levels, involving local, regional, national and even international authorities.

In SafeLand, Area 4 focuses on landslides that are most affected by climatic triggers. Short-term (i.e. 0 to 3 days) weather scenarios will be forecasted to help predict debris flows (or shallow landslides). The research will develop remote sensing technologies for the detection, monitoring and efficient mapping of landslides. The work will involve an evaluation of existing technology and development of new technology, including procedures and techniques, hardware and software, for early warning of sliding movements. The technologies will be applicable to both the local scale for individual slopes, and the regional scale.

A common methodology for detection, rapid mapping, characterisation and monitoring of landslides at regional scale using advanced remote sensing techniques will be adopted, as well as a common methodology for the rapid creation and updating of landslide inventories and consequently hazard and risk maps at regional scale. Three classes of technologies (i.e. spaceborne radars, airborne and VHR spaceborne optical sensors, and airborne geophysics) will be exploited and integrated. The main expected outcome is the integration of these advanced remote sensing techniques within a QRA framework for a global integrated risk management process.

User-oriented guidelines for incorporation of advanced remote sensing technologies within integrated risk management processes and best practices will be developed. The toolbox of remote sensing applications and early warning will be proposed as part of an integrated risk management process including procedures for data acquisition and updating, recommended processing methods, and guidelines for data integration in QRA and risk mitigation measures.

The improvements offered through new and advanced technologies, including geo-electrical, selfpotential monitoring, acoustic noise measurements, Differential Monitoring of Stability (DMS), optical fibres, and acoustic emissions, will allow the extension of the investigated area at a very high execution speed. This will result in improved understanding of the landslide phenomena through the assessment of the internal structure and 3D deformation pattern, designing of appropriate multi-parameter monitoring platforms for specific types of landslides, definition of thresholds and detecting behaviour changes, and advances in the methodology for warning and pre-warning.

4.5 RISK MANAGEMENT: TOOLBOX OF HAZARD AND RISK MITIGATION MEASURES, AND STAKEHOLDER PROCESS FOR RISK MANAGEMENT

Risk management integrates the recognition and assessment of risk with the development of appropriate strategies for its mitigation. Landslide risk management typically (but not solely) involves decisions at the local level (Fell et al,, 2008), and a lack of information about landslide risk and how this risk is changing on account of climate, land-use and other factors appears to be a major constraint to providing improved mitigation in many areas. Beyond risk communication and awareness, pro-active mitigation and prevention options can broadly be categorised as (1) structural slope-stabilization measures to reduce the frequency and severity of the hazard, (2) non-structural measures, such as land-use planning and early warning systems, to reduce the hazard consequences, and measures to pool and transfer the risks (Popescu, 2002). Within SafeLand, a major focus of the research on landslide risk management will be on developing a harmonised toolbox of "tried-and-tested" as well as innovative pro-active mitigation measures based on experience and expert judgment across Europe, and to some extent outside Europe. The toolbox will facilitate the selection of measures reducing the probability of occurrence of the undesirable events and/or reducing the consequences of the events, also in view of expected global changes (both climate change and societal change). The generic toolbox will provide user-friendly guidance for local and regional processes.

Figure 7 illustrates in a "bow-tie" diagram the two components of hazard and risk mitigation. Risk is the measure of the probability and severity of an adverse effect to life, health, property, or the environment. Mitigation and reduction of hazard and risk can be done by reducing (1) the frequency (probability) of an adverse event/threat occurring and/or (2) the vulnerability and/or exposure of the elements at risk.

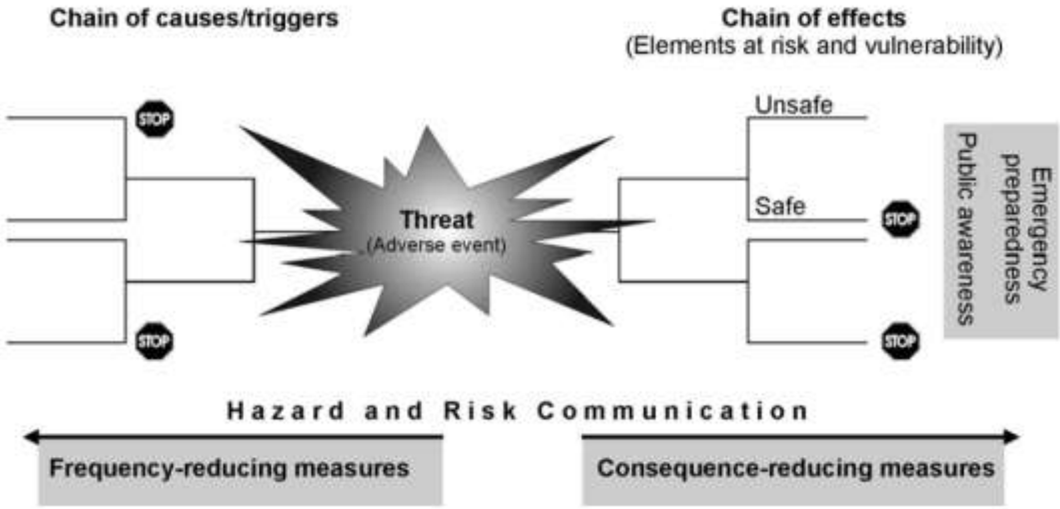

Figure 7 "Bow-tie" diagram of hazard and consequence reducing measures.

The selection of appropriate mitigation strategies should be based on a future-oriented quantitative probabilistic risk assessment, coupled with useful knowledge on the technical feasibility, as well as costs and benefits, of risk-reduction measures. European policy processes rarely consider probabilistic information on the risks, costs and benefits, and this research will provide them with a tested methodology for this purpose. Climate and land-use changes will be modelled and case studies will be prepared.

Experts acting alone cannot choose the "appropriate" set of mitigation and prevention measures in many risk contexts. The complexities and technical details of managing landslide risk can easily conceal that any strategy is embedded in a social/political system and entails value judgments about who bears the risks and benefits, and who decides. Policy makers and affected parties engaged in solving environmental risk problems are thus increasingly recognizing that traditional expert-based decision-making processes are insufficient, especially in controversial risk contexts (Renn et al., 1995). Often heavily shaped by scientific analysis and judgment (e.g., acceptable risk), traditional policy approaches are vulnerable to two major critiques. First, because they de-emphasise the consideration of affected interests in favour of "objective" analyses, they suffer from a lack of popular acceptance. Second, because they rely almost exclusively on systematic observation, they often slight the local and anecdotal knowledge of the people most familiar with the problem, and they risk producing outcomes that are incompetent, irrelevant or simply unworkable. Conflicting values and interests, as well as often conflicting and uncertain expert evidence, characterise many landslide risk decision processes. These characteristics become more complex with long time horizons and uncertain information on climate and other global changes.

Risk communication and stakeholder involvement has been widely acknowledged for supporting decisions on uncertain and controversial environmental risks, with the added bonus that participation enables the addition of local and anecdotal knowledge of the people most familiar with the problem (Covello, 1998). Which citizens, authorities, NGOs, industry groups, etc., should be involved, and in which way, however, has been the subject of a tremendous amount of experimentation and theorising. The decision is ultimately made by political representatives, but stakeholder involvement, combined with good risk-communication strategies, can often bring new options to light and delineate the terrain for agreement.

The research and applications of Area 5 have great potential for advancing landslide risk management practices in Europe. For the first time, a toolbox of mitigation methodologies and strategies (with harmonized descriptions) will be available to inform local decision processes. European policy makers have seldom utilized probabilistic risk information, and the communication and participatory processes will demonstrate how this type of information can be effective in stakeholder-led decisions. The European publics are increasingly demanding more transparency in their risk-management institutions, and the design of stakeholder processes will add to the credibility of institutions dealing with landslide risks.

The current state of the art (baseline) of landslide risk management can be characterized as lacking or not taking full advantage of:

- knowledge on the risks and uncertainties in most localities;
- knowledge of the performance and effectiveness of the wide range of structural and non-structural mitigation measures;
- understanding of the role of scientists and uncertain scientific information in complex political risk management processes characterized by multiple institutions, legal/historical frameworks and contending stakeholder views;
- effective communication of landslide risks and mitigation options to the relevant publics and stakeholders;
- use of GIS and other technologies for informing political decision processes; and
- effective participatory processes for informing political decisions on landslide mitigation.

Ultimately, the success of Area 5 can be assessed by asking the relevant authorities and stakeholders in the selected case study region(s) whether in their view the decision process and anticipated outcomes have been improved by the toolbox, institutional analysis, communication strategy, GIS-assisted methodologies and participatory process. A follow up feedback session and questionnaire will be designed and administered to assess views on these and other relevant indicator questions. A report based on this feedback will be prepared for documenting the advances of this research against the current baseline.

A second indicator of success will be the applicability of the original research methodologies and data generated by this research to other landslide risk areas throughout Europe and globally. Much of the theoretical and methodological innovation will contribute to progress in the analysis and understanding of environmental risk perception, communication and policy analysis beyond landslide risk.

5 CONCLUSIONS

In this report the overall objectives of the project ‘SafeLand: Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies’ were presented and framed in an international and European context. Important objectives of SafeLand are (1) to improve the ability to forecast landslide hazard and to detect hazard and risk zones, and (2) to develop generic quantitative risk assessment and management tools and strategies for landslides at the local, regional and European scales.

SafeLand will contribute to fill important gaps in the knowledge on landslide risk, and will therefore respond to European and global risk management policies including, among others, the EU Thematic Strategy for Soil Protection and its associated Proposal for a Soil Framework Directive, and UNISDR and IPCC recommendations. A review of recent landslide research has allowed identification of important research questions on landslide risk assessment and management, to be dealt with in the project. The proposed research is not without risk and possibility of failure, but the team of partners, with their recognised expertise and wide network, are in a good position to master the challenge to be met during the three years of research.

At the outcome of the SafeLand research project, at local scale, scientists, authorities and stakeholders will be able to quantify triggers, their mechanisms, conditions and thresholds, model and quantify the landslide run-out. On some selected regions, forecasted landslide hazard and risk zones considering also global change (both anthropogenic and climate) will be mapped. Uncertainties will have been quantified and will provide one of the necessary inputs for realistic hazard and risk calculations. At European scale, current and future landslide hazard and risk “hotspots” will be identified. A framework for the quantitative assessment of the risk associated with landslides will have been developed and procedures will have been tested to ensure that the implementation of risk management is effective, with a toolbox for the selection of the most appropriate set of mitigation and prevention measures and proven process of risk communication.

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