# SafeLand

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

## SUMMARY REPORT

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The need to protect people and property with a changing pattern of landslide hazard and risk caused by climate change and changes in demography, and the reality for societies in Europe to live with the risk associated with natural hazards, were the motives for the project SafeLand:
"Living with landslide risk in Europe: Assessment, effects of global change, and risk management strategies."
SafeLand was a large, integrating research project under the European Commission's 7th Framework Programme (FP7).
The project started on 1 May 2009 and ended on 30 April 2012. It involved 27 partners from 12 European countries, and had international collaborators and advisers from China, India, USA, Japan and Hong Kong. SafeLand also involved 25 End-Users from 11 countries. SafeLand was coordinated by the International Centre for Geohazards (ICG) at the Norwegian Geotechnical Institute (NGI) in Norway. Further information on the SafeLand project can be found at its web site http://safeland-fp7.eu/.

## Main results achieved in SafeLand include:

- Various guidelines related to landslide triggering processes and run-out modelling.
- Development and testing of several empirical methods for predicting the characteristics of threshold rainfall events for triggering of precipitation-induced landslides, and development of an empirical model for assessing the changes in landslide frequency (hazard) as a function of changes in the demography and population density.
- Guidelines for landslide susceptibility, hazard and risk assessment and zoning.
- New methodologies for physical and societal vulnerability assessment.
- Identification of landslide hazard and risk hotspots for Europe. The results show clearly where areaswith the largest landslide risk are located in Europe and the objective approach allows a ranking of the countries by exposed area and population.
- Different regional and local climate model
- simulations over selected regions of Europe at spatial resolutions of 10x10 km and 2.8x2.8 km. These simulations were used to perform an extreme value analysis for trends in heavy precipitation events, and subsequent effects on landslide hazard and risk trends.
- Guidelines for use of remote sensing techniques, monitoring and early warning systems.
- Development of a prototype web-based "toolbox" of innovative and technically appropriate prevention and mitigation measures. The toolbox does a preliminary assessment and ranking of up to 60 structural and non-structural landslide risk mitigation options.
- Case histories and "hotspots" of European Land¬slides have been collected and documented. Data for close to fifty potential case study sites have been compiled and summarized. Most of the case study sites are located in Europe (Italy, France, Norway, Switzerland, Austria, Andorra, and Romania); but they also include one site in Canada and one in India. Almost every type of landslide and every type of movement is represented in these sites.
- Research on stakeholder workshops and participatory processes to involve the population exposed to landslide risk in the decision-making process for choosing the most appropriate risk mitigation measure(s).

# AIMS AND BACKGROUND

SafeLand was a large, integrating research project under the European Commission's 7th Framework Programme (FP7). It started on 1 May 2009 and went on for 3 years, ending on 30 April 2012. There were altogether 27 partners from 12 European countries, and the project had international collaborators and advisers from China, India, USA, Japan and Hong Kong. SafeLand also involved 25 End-Users from 11 countries. The International Centre for Geohazards (ICG) in Oslo, Norway, was the project coordinator.

The total SafeLand budget was 8.75 million Euros. SafeLand had an International Advisory Board comprised of Dr. Peter Lyttle from USGS, Professor Hideaki Marui from Niigata University in Japan and Dr. H.N. Wong, of Geotechnical Engineering Office of Hong Kong.

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 population density, protection works often cannot be built because of economic or environmental constraints, and is it not always possible to evacuate people because of societal reasons. The growing hazard and risk, the need to protect people and property, the expected climate change and the reality for society in Europe to live with hazard and risk and the need to manage risk are the reasons for the SafeLand research. The effects of global change on the evolution of landslide risk are shown schematically on Figure 1.

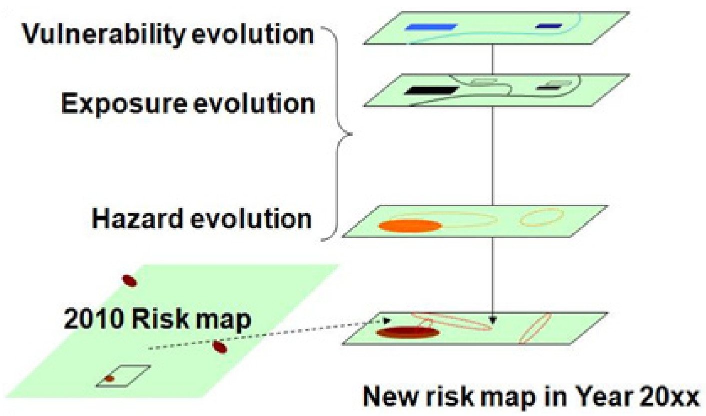



*Figure 1. Schematic diagram: Evolution of landslide risk caused by changes in vulnerability, frequency of landslides (hazard) and exposure of elements at risk.*

The SafeLand project had three main objectives:

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

To achieve these objectives, the research in SafeLand focused on:

(1) Improving the understanding of landslide triggers and run-out and the ability to estimate landslide hazards and risks.
(2) Developing a framework for quantitative risk assessment for different landslide mechanisms and different scales and intensity of sliding.
(3) Developing risk management tools and guidelines for choosing the appropriate risk mitigation strategy by involving the stakeholders.

To achieve the scientific and technical objectives, five research areas were defined, each with specific objectives:

**Area 1, Improving knowledge on landslide hazard, especially the triggering and run-out model.**

- Criteria and thresholds for climatic conditions and weather-related phenomena that would trigger landslides will be established.
- Scenarios of anthropogenic factors triggering
- different types of slides will also be prepared for countries in Europe.

**Area 2, Quantitative risk assessment (QRA).**

- Harmonise and develop improved procedures for quantifying landslide hazard (frequency) and risk at the local scale (individual slopes), the regional scale and finally the European scale.
- Identify the landslide hazard and risk "hotspots" in Europe (where hazard and/or risk are high¬est)
- Quantify the importance and effects of uncertainties on the results obtained

**Area 3, Quantifying global change scenarios (climatic and anthropogenic) and their impact on land¬slide hazard and risk in the future.**

- Quantify the impact of global environmental change (climate, forest vege¬tation, land use etc.) and human activities on exposed slopes.
- Climate change scenarios and the evaluation of landslide hazard and risk will be prepared for selected regions in Europe.
- Scenarios of future human activity and
- demography based on expected and projected prognoses, will be prepared and the evolution of landslide risk in selected "hotspots" areas in Europe quantified.

**Area 4, Development of monitoring technology, especially early warning systems and remote sensing techniques, and applications.**

- Forecast short-term weather scenarios to help predict debris flows (or "shallow landslides).
- Develop remote sensing technologies for the detection, monitoring and efficient mapping of slides.

**Area 5, Risk management, including toolbox or appropriate hazard and risk mitigation measures and stakeholder process for risk management.**

- Carry out a state-of-the-art review, propose new mitigation and prevention measures, and produce a web-based system or harmonized toolbox of technically and economically appropriate (and innovative) prevention and mitigation measures based on experience and expert judgment throughout, and outside, Europe
- Develop and test a risk-communication and stakeholder-led participatory process for choosing prevention and mitigation measures that are most appropriate from the technical, economic, environ¬mental and social perspectives.

In addition, activities related to collection of case site information, dissemination and management were identified as separate work packages.

In the following a more detailed description of the outcomes from the individual work areas are presented.

## AREA 1: LANDSLIDE TRIGGERS AND RUN-OUT

The task of Area 1, logically located as the first step in the Safeland project, was providing an updated framework about the state of the knowledge around the complex problem of the landslide hazard, with a special focus on the rupture processes related to weather and climate impact. Both landslide triggering and run-out were examined, in order to produce a comprehensive review of the problem; a special room was left to modelling of both triggering and run-out, accounting for the most advanced results of the research. The individuation of threshold values of precipitations, whose exceedance can lead to slope failure, had a special room. Finally, the role played by anthropogenic activities and earthquakes was another, even though minor, concern of the work.

The activity of Area 1 was developed through six workpackages (WPs) leading to eight comprehensive deliverables (Ds), enriched by numerous references.

The first deliverable (D1.1), developed within the WP1.1, includes a classification of the types and causes of landslides which can take place in different geomorphological contexts, especially in Europe. A description of landslide mechanisms is a special topic of the work, which in fact focuses on the processes leading to slope failure, as water infiltration, stress state changes and soil deterioration, all strictly related to weather and climate changes. A special consideration is devoted to the hydraulic and mechanical response of different soils and for the mathematical models usually adopted to simulate their behaviour.

The contents of the deliverable D1.1 represent a source of information and stimulus for the following activity, developed within the WP1.2, concerning the geomechanical analysis to carry out to simulate the triggering of weather-induced landslides. The mechanical processes of slope failure examined in the deliverable D1.2 are essentially those related to precipitations and to snowmelting. To this aim, well documented paradigmatic cases are considered, highlighting factors and mechanisms of slope failure in different geomorphological contexts. A special part of the D1.2 focuses on the potential effects of incoming climatic changes, showing that the consequences of these are expected to be different from site to site because of different local climatic inputs and of the different mechanical response of various geomaterials to even similar input. An in depth analysis of the mechanisms of slope failure can be provided by ad hoc experiments or by careful monitoring of well know sites. Accordingly, results of well documented centrifuge tests, flume and field experiments on natural slopes through artificial rainfall are described in the deliverable D1.3, again in the WP1.2, discussing what lessons can be learned from them; consistently with indications reported in D1.1 and D1.2, a great variation in landslide type and behaviour, dependent on multiple factors related to soil, can be identified. The complete set of data summarised in the D1.3 represents a backbone to the work for others to draw from. Finally, guidelines for landslide modelling are presented in the D1.4 allowing the user to identify the necessary code components for a given landslide problem, select the necessary data for the model and perform the modelling steps. The geomechanical codes are evaluated with respect to the availability of components which are necessary or which allow to obtain additional expertise on different, particular landslide problems. A special room is dedicated to geomechanical modelling for early-warning systems and for the prediction of the behaviour of large landslides under different climatic scenarios, a theme that is raised, but from different viewpoints, also in previous deliverables.

The WP1.3, through the deliverable D1.5, considered the problem of the prediction of precipitation-induced landslides, already dealt with in the WP1.2, adopting a different, and largely adopted, approach, i.e. through the exploitation of statistical and empirical models which prove to be quite reliable, when based on large amount of data. The deliverable takes into account different datasets collected in the following sites: Barcelonnette, in France; La Frasse, in Switzerland; Satriano, Verzino and Sarno, in Italy; and South-Eastern and Western sides of Norway. The results show that the initial moisture conditions, essentially governed by precedent precipitations, must be accounted for the evaluation of the triggering conditions, this especially in the case of soil slides. In many cases, the contribution of snow melt can be significant. Hydraulic conductivity and thickness of soil covers can have a strong influence on the features of triggering weather events: in fact, the thresholds are affected by long-term precipitations in areas covered by deep deposits of fine-grained soils, while are controlled by short-term precipitations in areas with shallower deposits of coarse-grained soils. Concerning thresholds of landslides in rocks, freeze-thaw effects should be accurately taken into account. All these data can be useful for prediction of landslide triggering: the main advantage of empirical or statistical thresholds is avoiding the use of more complex mathematical approaches, often requiring data that are not easily available or reliable.

The role of anthropogenic activity on land stability was the main content of the activity carried out within the WP1.4 (D1.6), which looks at the wide European context. Naturally, the scale of the problem is such that local input was skipped, and only general trends were examined. The issue is approached by integrating data provided by: i) statistical analysis of historic landslides; ii) case studies of specific events; iii) expert opinion pooling. Based on such outcomes, an empirical model is suggested for assessing the changes in landslide frequency (hazard) as a function of changes in the demography and population density.

The fifth work package (WP1.5) examined run-out models, more and more adopted to assess the hazard, based on the soil surface that can be really affected by a landslide. In fact, there are slope movements whose travel distance is such to threaten thousands or more of people and buildings and infrastructure spread on the territory (urban areas), but there are also slope movements which can pose some problem only to those structures which are located just upon the landslide body. A correct evaluation of the hazard hence requires the knowledge of the soil surface that can be run by the landslide body, allowing to draw useful hazard maps that can be used by land managers. Another fundamental output of such methods is the velocity of the landslide body, a fundamental parameters for assessing the vulnerability of exposed goods (and consequent risk), and to design structural defense systems. The study (reported in the D1.7) is a comprehensive review of both analytical and empirical models, including available software, which can solve the problem. In the case of mathematical approaches, this goal is reached by: i) reporting a set of hierarchically structured mathematical models describing the basic phenomena which affect propagation phenomena; ii) providing rheological models to describe the behavior of involved soils; iii) providing numerical approaches for simulating landslide propagation; iv) providing some numerical applications.

The last deliverables (D1.8 and D1.9), set up within the WP1.6, is a summary of the available methods for analysis of triggering and run-out with indication of advantages and limits of every one. D1.8 also incorporates a short review of criteria for analysis of earthquake-induced landslides with special reference to run-out.

## AREA 2: QUANTITATIVE RISK ASSESSMENT

In Europe, there is a need for developing efficient and reliable tools on which support land use planning decisions, civil protection plans and mitigation measures to manage landslide risk. Either susceptibility maps showing the existing or potential unstable areas or hazard maps that further include the affected areas and the temporal probability of occurrence, or risk maps that additionally incorporate the severity of the consequences may be used to this end. Although the first two map types are the most common so far, latest global tendencies are shifting towards the consideration of credible risk scenarios in which the location, nature and evaluation of damages can be fully analysed. Furthermore, zoning schemes tend to use quantified susceptibility, hazard and risk assessments, meaning that qualitative descriptive rankings (i.e. low to high) are replaced by the annual probability (or frequency) of a given event of a given magnitude/intensity and its consequences in numbers (financial, population of the affected exposed elements etc.).

Despite significant improvements produced in automatic data capture, data analysis and treatment and computational advances, the landslide quantitative risk assessment (QRA) is far from a routine activity. In terms of conditional probability, the landslide risk for properties may be determined in a synthetic way as follows, accounting for all potentially affected elements at risk and all landslide types (Fell et al., 2005):

$$R(P) = P(Li) \times P(T{:}L) \times P(S{:}T) \times V(Di) \times C$$

Where R(P): expected annual loss due to land sliding (i.e. €/yr), P(Li): 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(Di): vulnerability of the exposed element in front of a landslide of magnitude "i", C: value of the element, i = 1,..k: landslide magnitudes.

In this context, the main challenge of Area 2 has been the development and harmonization of methodologies for the practical application of the risk assessment at a specific location or in a region. Given that commonly used practices present large variety between them and considering that important gaps of knowledge exist for the risk quantification, this work was organised in four main thematic tasks which are described in the following. The relevant activities were planned and organized by means of several area meetings (7-8 May 2009 in Oslo, 7-8 October 2009 in Barcelona, 29 April 2010 in Naples, 4-5 November 2010 in Barcelona, 3-4 May in Florence, 2-3 February 2012 in Oslo) and electronic contacts.

### WP2.1: Harmonisation and development of procedures for quantifying landslide hazard

With reference to the first work package (WP1), a first and necessary step towards the harmonization and development of new procedures was the review of the actual official practices at European level, as applied by geological surveys, administration offices and decision makers (hazard and risk assessment procedures, regulations and codes). The compilation of this information is useful for people managing landslide risk, practitioners interested in the currently applied procedures in their country or region, and also for researchers and scientists investigating the current state of the art. It also serves as a basis for detecting inconsistencies between methodologies and gaps of knowledge before dealing with new procedures and recommendations. The reported countries and territories are: Andorra, Austria, France, Italy (selected river basins from southern, central and northern Italy), Norway, Romania, Spain (Catalonia), Switzerland and United Kingdom. The comparison of the various methodologies indicate among others the discrepancy in terminology, the diversity of criteria for addressing the different landslide mechanisms, lack in considering the effect of hazard amplification due to the spatial superposition of different types of instabilities, as well as of the synergistic action of other natural phenomena (i.e. earthquake) wherever applicable. The poor existence of quantitative risk assessment methods for landslides, especially in comparison with hazard methods, was outlined (Deliverable D2.1).

For the harmonization of the methodologies and outputs for the susceptibility, hazard and risk, some important points are the following: the documents should be accessible to the experts and to the public. The digitalization of the maps will make them available online, allowing their reproducibility and, most importantly, the possibility of being updated. The methodologies for the assessment of the susceptibility and hazard should be transparent and reproducible. The use of step-by-step analytical or weighted factors techniques, in order to minimize the incorporated uncertainties that relate to judgmental approaches and the homogenization of hazard matrices are recommendable. So far, there is an important disparity between them, in particular on the hazard parameters, levels and thresholds used. Depending on the mapping scale and given that the quantitative information in probabilistic terms offers an objective insight to hazards and risks, when feasible, it is necessary to work on quantitative methodologies in order to minimize the uncertainties that derive from expert judgments and qualitative considerations.

To take advantage similar experiences outside Europe, a workshop was organized in the Chengdu University of Technology on April 13 and 14, 2010, with the aim to assess the state of art of landslide hazard and risk assessment in the P.R. of China. For achieving this objective, Chinese experts in landslide hazard and risk assessment were invited to give presentations and write a chapter for a report which formed one of the deliverable D2.2. The report will also be published as a book in China and it includes issues on: Landslide hazards in China: an overview; Landslide inventory mapping in China; Remote sensing applications for landslide research in China; Medium and large scale landslide hazard assessment in China; Methods for local scale hazard assessment; Landslide early warning and monitoring; Earthquake induced landslides; The case of Wenchuan earthquake.

Given the importance of the input data for the landslide risk assessment the attention was also drawn on landslide databases. The latter, usually including inventory maps and linked with alphanumeric information, allow quantitative landslide hazard and risk assessment on the condition that they contain information on the location of landslide phenomena, types, history, state of activity, magnitude or size, failure mechanisms, causal factors and the damage caused. So far it has not been known which national (or regional) landslide databases contain all this information, and thus allow the QRA. Therefore this study made a detailed review of existing national landslide databases in Europe together with a number of regional databases. It also proposed improvements for delineating areas at risk in agreement with the EU Soil Thematic Strategy and its associated Proposal for a Soil Framework Directive, and for achieving interoperability and harmonisation in agreement with INSPIRE Directive (as defined in INSPIRE Thematic Working Group Natural Risk Zones, 2011, version 1.9; 29/04/2011), launched by the European Union. This report was based on the analysis of replies to a detailed questionnaire sent out to the competent persons and organisations in each country, and a review of literature, websites and main European legislation on the subject. The relevant conclusions can be found in detail at deliverable D2.3 and in Van Den Eeckhaut and Hervás, 2012. As currently no harmonised landslide databases are available throughout Europe, suggestions for overcoming the variability concerning language, structure, format and accessibility are also given at the same deliverable (with mention to the INSPIRE Directive and the preliminary data specifications of Natural Risk Zones, including landslides, as well as recommendations by the European Landslide Expert Group). Thus, the performed work may serve as a platform for the construction of databases for the storage of spatial data that are made available and maintained at the most appropriate level, which are possible to be combined from different sources across the Community in a consistent way and shared between several users and applications, and further can be made available under conditions and do not have restrictions on their extensive use.

A very important part of this work package involved the editing of recommendations for landslide susceptibility, hazard and risk assessment and zoning, to be used for the quantitative assessment of the landslide hazard, vulnerability and risk, as well as for the verification and validation of the results. The recommended methodologies mainly focus on approaches for the quantitative assessment and zoning of landslide susceptibility, hazard and risk at different scales which have been summarized from recently published research work. A section discusses how shift from susceptibility to hazard, a topic that is seldom addressed. Specific methodologies developed during the SafeLand project have been incorporated, which improve previously published guidelines. They mainly consist in new procedures for calculating quantitative vulnerability, based on fragility curves and for different landslide mechanisms (Mavrouli & Corominas, 2010; Fotopoulou & Pitilakis, 2012; Smith et al. 2012). Furthermore, a selection of the best suited procedures for verification of the models and validation of the results are presented as well. The proposed procedures are categorised according to the landslide type and the working scale (site specific, local, regional and national). Particularly important and innovative aspects in this WP have been the evaluation of the probability of occurrence of different landslide types with certain characteristics, the specific consideration of the elements at risk (persons, buildings, infrastructures...) and their spatio-temporal probability in order it could be directly incorporated in the quantitative risk assessment (QRA) analysis. The respective document (Deliverable D2.4) is addressed to scientists and practitioner engineers, geologists and other landslide experts. Further publications were or are currently being prepared to include these outcomes (Corominas et al., 2012; Corominas et al., in preparation).

#### WP2.2: Vulnerability to landslides

Vulnerability assessment to landslides is a complex process that must consider multiple dimensions and aspects of vulnerability, including both physical and socio-economic factors. Physical vulnerability is a function of the intensity and magnitude of the landslide hazard as well as of the resistance levels of the exposed elements. However the vulnerability of a society and its resilience are also related to factors such as demographics, preparedness levels, memory of past events, and institutional and non-institutional abilities for handling natural hazards. Physical models are particularly useful for estimating direct impacts (physical damages, consequences) to landslides, while socio-economic models are used (and developed) for indirect and intangible losses, i.e. losses due to medium and long-term effects of the hazard event mainly of social and economic nature. Within the context of this WP, both physical and socio-economic vulnerability models related to landslides are attempted to establish.

Physical vulnerability: The present WP deals with the proposition and quantification of efficient methodologies for assessing the physical vulnerability of various elements at risk to different landslide hazards using the concept of probabilistic fragility functions or indexes, and appropriate definition of relevant damage states (Deliverable D2.5). An attempt to distinguish between different types of landslides and affected assets (buildings, persons and infrastructures) has been made. The applicability of the developed methodologies depends on few general parameters such as the landslide type, the typology and classification of the exposed elements, the analysis scale and the triggering mechanism (intense rainfall, earthquake). The main landslide movement types considered are rockfalls, debris flows and slow moving landslides. Four different analysis scales are considered: small (1:100,000), medium (1:25,000), large (1:5.000) and detailed/site specific (1:2000), requiring different criteria to identify the elements at risk. Finally, various intensity parameters are considered (e.g. permanent displacement, landslide velocity, volume of the landslide deposit, impact force, kinetic energy etc.) depending on the landslide type, the element at risk and the scale of analysis. Representative applications of the proposed physical vulnerability assessment models are provided (D2.7). A publication is also prepared including methodologies for the analytical vulnerability calculation of reinforced concrete frames (Mavrouli et al., in preparation). Additionally, the investigation of the physical vulnerability of roadways with respect to the damage caused by debris flows was also carried out. Based on a questionnaire, empirically-based fragility curves were derived, relating flow volume to damage probabilities, for three different damage states (Smith et al., 2012; Winter et al., 2012; Winter et al., in preparation).

Social and economic vulnerability: With respect to the social vulnerability, the WP is focused on the development of an indicator-based methodology to assess vulnerability levels. The indicators represent the underlying factors which influence a community's ability to deal with, and recover from the damage associated with landslides. The proposed method includes indicators which represent demographic, economic and social characteristics as well as indicators representing the degree of preparedness and recovery capacity. The purpose of the indicators is to set priorities, serve as background for action, raise awareness, analyze trends and empower risk management (Deliverable D2.6). The proposed methodology is implemented for six locations, two in Norway and one each in Greece, Andorra, France and Romania. The purpose of the case studies has been to compare vulnerability levels and to test and possibly improve the proposed approach (Deliverable D2.7B; Eidsvig et al., 2012; Eidsvig et al., in preparation).

### WP2.3: Development of procedures for QRA at regional scale and European scale

Given that for the landslide Quantitative Risk Assessment (QRA) procedures are not as well established as for earthquakes and river floods, the main objective of this work has been the improvement and development of tools for landslide zoning and the provision of a framework for quantitative risk assessment. Within this framework the main activities were realized among others with reference to (i) the integration and regionalization of the information (in particularly using modern data gathering techniques such as ground-based terrestrial laser scanner, digital photogrammetry, and remote sensing techniques such as DInSAR); (ii) the improvement and development of procedures for quantifying landslide susceptibility, frequency and intensity at different scales and (iii) the improvement and development procedures for Quantitative Risk Assessment (QRA) at different scales; (iv) validation of QRA schemes and zoning maps and (v) QRA analysis at hotspots in Europe.

The activities (i), (ii), (iii) and (v) concerning amongst others the use of modern technologies and the development of procedures for the landslide hazard and risk (with emphasis on frequency and intensity assessment) are presented in the deliverable D2.11. In the latter some examples of the quantitative risk assessment QRA for different types of landslides, at different scales and for various exposed elements (buildings and people) are presented. For every case-study, the risk is expressed using a variety of risk descriptors. Different landslide types such as deep-seated landslides, debris slides, hyper-concentrated flow, and rockfalls are studied at scales varying from site-specific to regional. The innovative aspects which are discussed involve the use of remote sensing data and the incorporation of the vulnerability in quantitative terms. Especially the latter has been rarely considered so far by other methodologies.

A second objective to enhance the landslide QRA was the improvement or development of toolboxes (set of precompiled computer routines) that can be used by stakeholders, practitioners and other interested parties for the quantitative evaluation of the key components that are involved into the landslide zoning and risk calculation (hazard, vulnerability of the exposed elements...). Three toolboxes were prepared based on deterministic or probabilistic approaches for the quantification of the risk parameters. The tools serve for (i) rockfall quantitative vulnerability of buildings (ii) rockfall quantitative risk assessment for protection galleries and (iii) rockfall quantitative risk assessment. A presentation of them is given in D2.9.

With respect to the activity (iv), standards for validation of both hazard and risk assessment models have been proposed for the quantification of the reliability of the assessment (accounting for data vagueness and uncertainties, "limited" knowledge on the physics of the processes and taking into account the issue of the "mapping unit", independently of the scale), as well as the quantification of the validity of the assessment (considering validation/evaluation of the maps, robustness and accuracy of the predicting systems and output types). The compilation of the proposed methodologies is presented in deliverable D2.8. Developments carried out during the SAFELAND project have been included in the document (Baeza et al. 2010)

### WP2.4: European risk hotspots

The public and media focus on landslide hazard and risk in Europe is greatly increased in the immediate aftermath of catastrophes such as the widespread flooding and landsliding in Switzerland and Austria in summer 2005, Messina (Italy) in autumn 2009, or the events in Madeira in January 2010 and southern Italy in February 2010, despite the fact that numerous landslides occur all over Europe every year. Experts know to a certain degree which parts of the

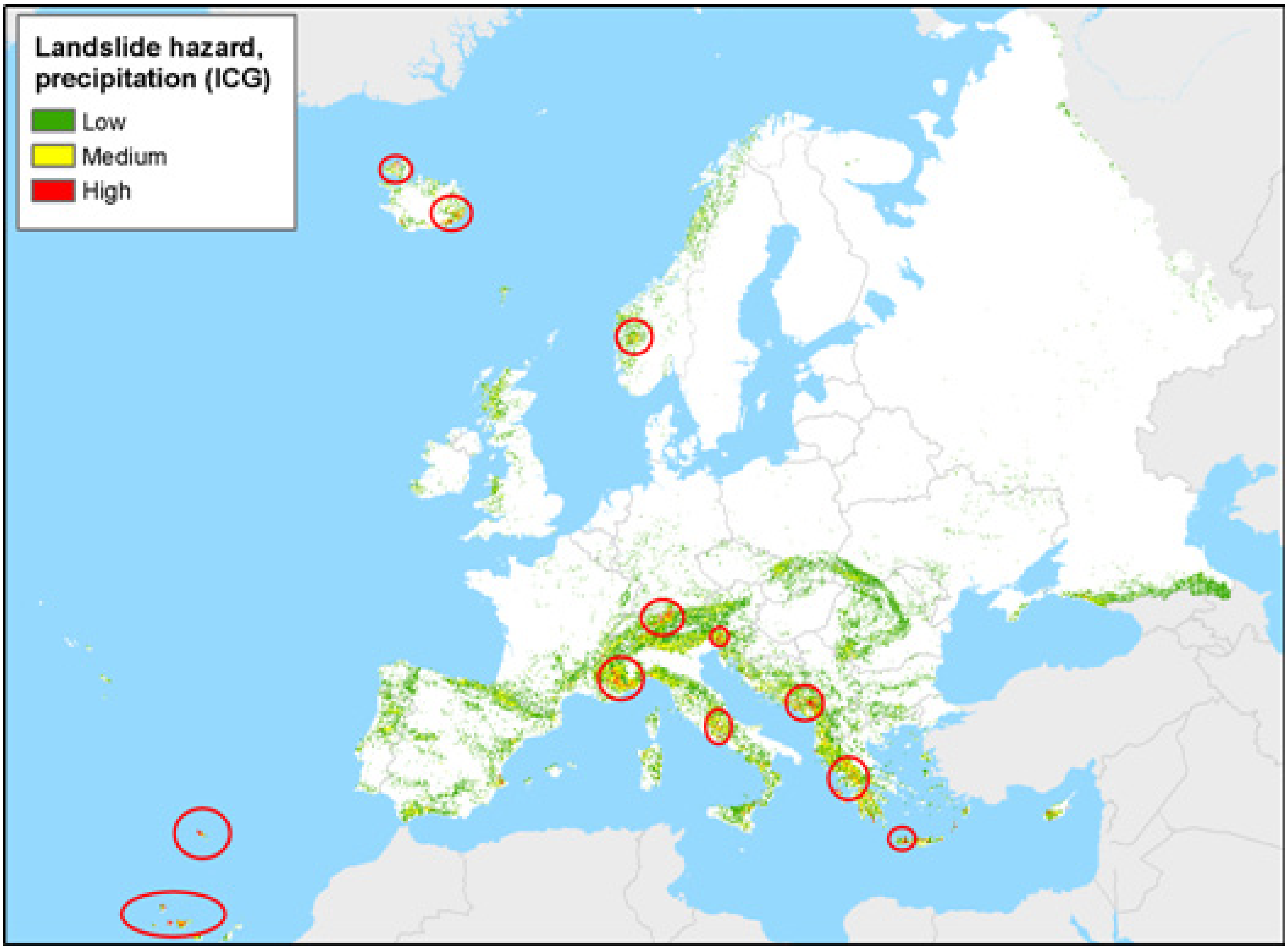



*Figure Area 2: Landslide hazard caused by precipitation (results from the ICG model). Red circles show possible hotspots*

continent are most exposed to landslide hazard. Nevertheless, neither the geographical location of previous landslide events nor knowledge of locations with high landslide hazard necessarily point out the areas with highest landslide risk. In addition landslides often occur unexpectedly and the decisions on where investments should be made to manage and mitigate future events are based on the need to demonstrate action and political will. The goal of this study was to undertake a uniform and objective analysis of landslide hazard and risk for Europe.

Two independent models, an expert-based or heuristic and a statistical model (logistic regression), were developed to assess the landslide hazard. Both models are based on applying an appropriate combination of the parameters representing susceptibility factors (slope, lithology, soil moisture, vegetation cover, etc.) and triggering factors (extreme precipitation and seismicity). The weights of different susceptibility and triggering factors are calibrated to the information available in landslide inventories and physical processes. The analysis is based on uniform gridded data for Europe with a pixel resolution of roughly 30 m x 30 m. A validation of the two hazard models by partner organizations in Scotland, Italy and Romania showed good agreement for shallow landslides and rockfalls, but the hazard models fail to cover areas with slow moving landslides. In general, the results from the two models agree well pointing out the same countries with the highest total and relative area exposed to landslides. Landslide risk was quantified by counting the number of exposed people and exposed kilometres of roads and railways in each country. This process was repeated for both models.
The results show the highest relative exposure to landslides in small alpine countries such as Lichtenstein. In terms of total values on national level, Italy scores highest in both the extent of exposed area

and number of exposed population. Again results agree between the two models, but differences between the models are higher for the risk than for the hazard results. The analysis gives a good overview of the landslide hazard and risk hotspots in Europe and allows a simple ranking of areas where mitigation measures might be most effective. These outcomes are described in detail at the deliverable D2.10.

## AREA 3: GLOBAL CHANGE SCENARIOS

Area 3 includes 3 Work Packages:

1. WP3.1 Climate change scenarios for selected regions in Europe
2. WP3.2 Human activity and demography scenarios
3. WP3.3 Landslide risk evolution in selected "hotspots" areas

A short summary of the activities in this period is given below.

**European scale:**
Regional climate model simulations from EU FP6 ENSEMBLES project (25 x 25 km$^2$ resolution over Europe) have been used to perform an extreme value analysis for trends in heavy precipitation events (D3.1). Summer and winter have been examined separately to identify seasonal characteristics in the patterns of changes on the 1961-2099 time period.
The large-scale pattern of heavy precipitation changes appears to be consistent across the simulations (8 regional models). In winter the simulations agree in particular well on the positive changes in heavy precipitation over the northern and central European land masses. Inconsistencies are mainly found in regions where regional features play a large role. This is in particular the case in the mountainous regions or at the foothills of the mountains. In summer most model agree on the positive trends in heavy precipitation over Scandinavia and on the negative trends over southern Europe. Largest inconsistencies are found in the transition zone across central Europe which separates areas with positive trends in the North and areas with negative trends in the South.

IIn parallel to the this analysis of extreme precipitation events patterns, "Expected changes in climate-driven landslide activity (magnitude, frequency) in Europe in the next 100 years" have been studied (D3.7). The European-scale analysis of present and future landslide hazard and risk has required many simplifications. The main difficulty was to find homogenous datasets that cover all of Europe with the same accuracy. This problem is even increased when the datasets have to cover future predictions. The climate model results used in this study are based on a physical climate model and have a reasonable level of uncertainties in the future predictions. On the other hand, land cover and population datasets are secondary products based on climate simulations and economical modelling, which naturally include more errors in the process and are far more uncertain. In this context, the predicted changes in landslide hazard and risk in Europe, although certainly indicative, have to be investigated and used with care. The main changes in landslide risk at European scale are mainly due to changes in population pattern in Europe.

Nevertheless, the results from this study are useful for a prognosis of the landslide hazard and risk in next 80 years in Europe. In total, the change affects about 0.7% of the total European population. This increase has to be seen in comparison to other climate change imposed challenges for the next 80 years (e.g. flooding, drought). Ten countries can still expect some significant changes of more than 2% increase in exposed population. Most of these countries have significant challenges to cope with the landslide risk already today.
Landslide hazard threatens today about 3.8% of the European citizens. The mitigation of these problems is a significant challenge already today and should be continued with all available efforts. The slight increase expected for the next 80 years will not change this situation significantly. If all mitigation efforts against landslides that are necessary today are implemented, Europe will be very well prepared for the expected future changes in landslide hazard and risk.

**Local sites:**
Climate simulations have been downscaled to a 3.8 x 3.8 km$^2$ resolution on 4 selected sites in Europe (Nedre Romerike, Southern Norway; Pizzo d'Alvano, Campania, Italy; Barcelonnette, French Alps; Telega, Romania) for the time period 1951-2050, employing the A1B emission scenario (D3.3). The usage of the model output data for simulations on an even more refined grid is expected to improve the ability to

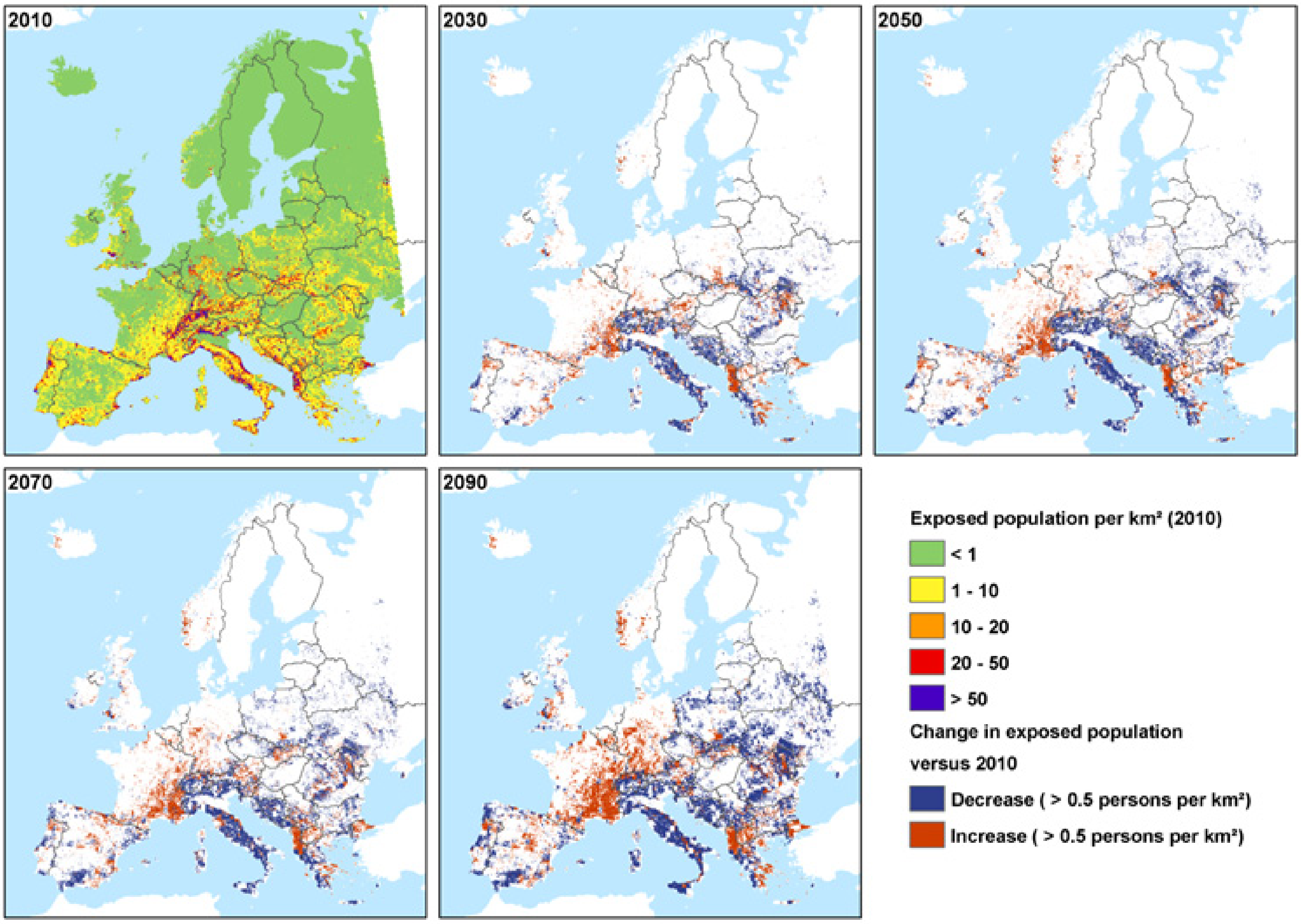



*Figure Area 3: Exposed population in 2010 and the positive or negative change until 2090. Changes are mostly due to changes in the population pattern in Europe.*

simulate even localized heavy precipitation events in regions where rain-induced landslides occur on a regular basis.

- In the area of Nedre Romerike strong increases of temperature are projected especially in winter, while a general increase of precipitation is expected in winter, with a general increase of extreme events which is most pronounced in the western part of the domain.
- In the area of Pizzo d'Alvano, a growth of temperature is also projected, even if less evident than the previous case. In winter, strong increases of precipitation (with strong extreme events) are expected in the area of Pizzo d'Alvano, In summer slight reductions are expected for the average monthly precipitation over the whole domain, which is in contrast to a projected increase in daily precipitation extremes in the Pizzo d'Alvano region and along the western coast line.
- In the area of Barcelonnette significant increases of temperature are expected in the future, up to 3o C, in both seasons, but especially in winter. An increase of precipitations is expected in small sub domains in both seasons, with slight changes of extreme events on the whole domain.
- In the area of Telega, a general increase of temperature of about 1.5o C is expected over the whole domain, for both summer and winter. In winter an increase of precipitation is expected, while a general significant reduction is expected in summer; an increase of extreme events is expected in winter and summer in the north of the domain with the magnitude of the changes being higher in winter.

The impact of climate change on landslide hazard has been assessed on the three focused areas: Pizzo d'Alvano for Southern Italy, Barcelonnette for the Alps and Nedre Romerike for Southern Norway (D3.8). Even if these sites present different contexts in view of landslides causes (climates, size of landslides), the analyses show that climate change is likely to induce similar trends in landslide activities. Based on the IPCC A1B scenario and on the resulting climate change scenarios at local scale, the different models predict an increase in landslide activities. This change would materialize either as an increase in the frequencies of landslides or as an increase in surface area of the potentially unstable areas.

The results differ from the predictions provided by larger scale models. These differences might be explained by the finer calibration processes used for local scale analysis and also to the finer climate model used, which, for example, take into account the influence of topography on climate (mostly on precipitation). So, if large scale models are useful to determine where landslide activities will vary relatively to the other regions, the different kinds of local scale models are necessary for urban planners and all local authorities to estimate what would be the future risks in their communes or valley, with for some of the models, spatial information. However, these models require precise data, not only for calibration but also for prediction, and so climate models should be adapted to such resolutions, like in this study.

In parallel to the climate scenarios, human activity and demography scenarios have been developed on the Norwegian and the French sites (D3.5 and D3.6). When they exist, prospective data were used. Unfortunately, data are sparse, rarely spatialized and not always adapted to the local context. However, this lack of information can be partially compensated by the analysis of past and present trends. Satisfactory data have been collected for the Barcelonnette site and have allowed the elaboration of demography scenarios at local level by 2030. The land use change scenario by 2100 has been studied. Acknowledging significant uncertainties, the demographic forecasts can be extended from 2030 to 2100. Demographic scenarios have been partially developed for the Nedre Romerike site (Norway). Three studies of landslide risk assessment have been performed on French, Norwegian and Scottish sites (D3.9). The results seem to show a similar trend: an increase of landslide risk which is more or less significant depending on the considered sites. Due to a high level of uncertainties on population and traffic evolution scenarios, precautions need to be taken when interpreting and using the results.

## AREA 4: MONITORING TECHNOLOGY

Area 4 addresses the technical and practical issues related to monitoring and early warning of landslides, and identifies the best technologies available both in the context of hazard assessment and in the context of design of early warning systems. Area 4 is subdivided into 3 Work Packages (WPs).

### WP 4.1 Short-term weather forecasting for shallow landslide prediction (D 4.2)

The main outcome of WP 4.1 has been the setting up of a prototypal Early Warning System (EWS) specifically conceived for the prediction of shallow landslides, which are the most dangerous landslide typology because they are usually associated to very high velocities (and thus to a high destructive power), long runout distances and absence of premonitory signals before the triggering. The work of WP 4.1 is presented in detail in the Deliverable D4.2 "Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technology and validation at selected test sites". In deliverable D4.2 the proposed EWS works like a complex chain, in which rainfall forecasts are used by hydrological and geotechnical models to forecast, with a sufficient lead time (18 to 48 hours), where and when shallow landslides will occur. The EWS has a multi-scale approach, using different forecasting models specifically engineered for high-detail analysis at the slope scale and for regional scale applications. The EWS was tested on several test cases with very different meteorological and geological settings. In general, in case of rainfall induced shallow landslides, a quite good agreement was found between the prediction and the observed ground truth.

### WP 4.2 Remote sensing technologies for landslide detection, monitoring and rapid mapping (D4.1-D4.3-D4.4-D4.5)

In WP4.2 a detailed analysis on the use of remote sensing techniques for landslide studies is carried out. Both well established and experimental techniques were compared and discussed with the objective to: i) Define and validate methodologies for detection, rapid mapping, rapid creation/updating of inventories/hazard maps, characterization, monitoring of landslides at regional and catchment scales using advanced remote sensing techniques; ii) Assist end-users and stakeholders in the selection of the most appropriate remote sensing techniques to be incorporated within integrated risk management processes and best practices.

D4.1 - Since during the last decade several and very different remote sensing techniques have undergone rapid development, one of the main outputs of Area 4 is the Deliverable D4.1 "Review of Techniques for Landslide Detection, Fast Characterization, Rapid Mapping and Long-Term Monitoring".
D4.1 provides a comprehensive overview (and technical analysis) of the different ground-based and remote sensing techniques currently available for the detection, fast characterization, rapid mapping and long-term monitoring of landslides. In addition, this deliverable provides helpful and extensive support not only for researchers, but also for technicians and stakeholders, through the critical analysis of practical applications of these techniques to seventeen case studies.

D4.3 – "Creation and updating of landslide inventory maps, landslide deformation maps and hazard maps as input for QRA using remote sensing technology".
This deliverable represents a linkage between the recent technological developments in remote sensing and quantitative risk assessment (QRA) methods. It can be regarded as a useful document for end-user and stakeholders, since it provides: i) A comprehensive view on the latest developments of remote-sensing technologies as applied for the creation and updating of landslide inventories and deformation maps; ii) An overview of input datasets for hazard and risk assessment that can be obtained through remote sensing; iii) Definitions and discussion of suitable updating strategies.

D4.4 – "Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides".
End users and stakeholders may use these guidelines for selecting the remote sensing technologies which are most suitable to detect/characterize/map/monitor the landslide process at hand. Combining the technological features of each remote sensing method, the possible geomorphological features of the landslides (e.g. typology, displacement velocities and observational scales) and risk management strategies, the guidelines can be used to initially constrain the choice of methods to a few techniques that seem most feasible for the landslide process at hand. Before final decisions on the methods to be used are taken, further information and expertise will typically be required, and D.4.4 makes reference to useful sources of information, in the Annexes and through links to other SafeLand deliverables.

D4.5 – "Evaluation report on innovative monitoring and remote sensing methods and future technology"
The aim of this deliverable is making an evaluation of the most innovative landslide monitoring and remote sensing technologies used at present, as well as suggesting needs for research and technical developments of the existing methodologies. The evaluation was based on the information gathered from a review of the latest improvements of the most promising ground based and remote sensing techniques, two questionnaires on their actual use within Europe and a discussion of the technical and scientific improvements obtained through several operational applications within SafeLand case studies.

### WP 4.3: Evaluation and development of reliable procedures and technologies for early warning (D4.5-D4.6-D4.7-D4.8)

WP 4.3 has focused on three main tasks: analysis of current state-of-art in monitoring and early warning technology; identification of useful "geo-indicators" (parameters to be measured and used as indicators in early warning systems for the landslide-related processes); evaluation and implementation of guidelines for monitoring and early warning. The outcome of the work has been reported in 4 deliverables (of which D4.5 is a joint deliverable with WP4.2).

D4.6 – "Report on Evaluation of Mass Movement Indicators".
Several physical parameters that can be correlated with the triggering of landslides were reviewed and evaluated. D4.6 could be used to assist the decision of which "indicator" can be more effectively used for real-time measurements in a specific monitoring or early warning system. This evaluation was mostly based on analysis and evaluation of monitoring field data of unstable slopes at 14 SafeLand test sites. An additional goal was to define the possible critical values of the indicators to define alert thresholds for the triggering of mass movements.

D4.7 – "Report on the development of software for early-warning based on real-time data".
This deliverable describes a centralized interface for early warning centres to integrate and manage data from different monitoring stations. New software was specifically developed to support technical staff in data analysis and in the decisional process. D4.7 gives a brief description of the application structure and all necessary steps to start up a system.

D4.8 – "Guidelines for monitoring and early warning systems in Europe - Design and required technology". D4.8 summarizes how landslide early-warning systems should be designed and operated and presents a screening study of existing EWS systems worldwide, discussing their applicability to different landslide types, scales and risk management steps. Several comprehensive checklists and toolboxes are also included as guidelines to support the decision process for stakeholders.

## AREA 5: RISK MANAGEMENT

SafeLand Area 5 research has provided information and tools that can inform and facilitate efficient and fair policies for managing the risks of landslides, including:

- A compendium of tested and innovative mitigation measures for different landslide types;
- A user-friendly web-based "toolbox" that can help users identify appropriate landslide risk mitigation technologies;
- Information on the institutional arrangements across European and other countries that provide opportunities and challenges for landslide risk management;
- The first-time design and testing of a participatory process for collective decisions on landslide risk management than build on the methodologies mentioned above, and include elicitation of stakeholder views; and,
- The development and application of methodologies for assessing landslide risk mitigation measures, including Spatial Multi Criteria Evaluation and probabilistic benefit-cost analysis.

The results of this research will be useful to researchers, experts, policy makers and all persons with an interest and stake in landslide risk management. In more detail, the main results include:

SafeLand researchers provided a **compendium** of tested and innovative structural and non-structural (including insurance) mitigation measures for different landslide types (D5.1). This compendium is the basis of a user-friendly web-based **toolbox** that can help experts and other users identify appropriate technologies for protecting people and property against landslides (D5.2). The compendium and toolbox are based on a classification of measures depending on whether they reduce the hazard (for example, a retaining wall), reduce vulnerability (for example, strengthening structures) or reduce exposure (for example, relocating homes). Each measure includes a "fact sheet" that describes the measure, gives guidance on its design, schematic details, practical examples and references. The fact sheets also include a subjective rating of the applicability of the specific mitigation measure in relation to the descriptors used for classifying landslides. The web-based toolbox includes the following features: data management, user forum, help function, report generation function and the ranking of the mitigation measures as they apply to a particular landslide context.

While the toolbox can be useful for uncontested decisions on mitigating landslide risk, landslide risk management is moving increasingly into public arenas. Yet, there is little information on how different political, scientific and cultural contexts influence the character and application of risk mitigation policies. SafeLand research partly fills this gap with case studies in Italy, France, Romania, Norway and India, each based on a literature survey and interviews with legislators, scientists, planners and other risk managers in order to investigate and understand **the role of legislation and science in the policy processes** (D5.5). Often it is asserted that it "takes a disaster to get a policy response", and the case studies show a relationship between the incidence of disasters, and progress and shifts in landslide risk management. Disasters can catalyze moments of change in risk management aims, policy and practice, but these are embedded in ongoing trajectories and socio-technological and political positions and relationships. Variations in the role of science and scientists, governance structures and interest groups, legislation, availability of economic and political instruments, social learning, facilitation of communication and trust, media intervention, access to information, and external pressures and shocks were some of the issues identified by this report that impact the cognition and management of risk practice in a society.

Increasingly public interventions to reduce the risk of landslides and other hazards are moving from "expert" decisions to include the public and other stakeholders in the decision process. Indeed, EU legislation, most notably the Water Framework Directive, is requiring public officials to consult stakeholders in the allocation of public funds for risk mitigation. The SafeLand project developed and tested **a public communication and participatory process** for mitigating the risks of landslide in the highly at-risk community of Nocera Inferiore in southern Italy (D5.7). The pilot study demonstrated the potential and challenges of public participation in decisions characterized by high personal stakes and intricate technical, economic and social considerations. It should prove useful in informing similar processes, as stakeholders in Europe increasingly demand a voice in choosing landslide mitigation measures.

The research for the design and testing of a participatory process was structured in four parts: 1) a case study analysis with a literature review and semi-structured interviews, 2) a public questionnaire , 3) six meetings with selected residents, and 4) communication activities, including a website, videos, an online discussion group, press releases and contacts with local media. In the end, the selected resident group agreed on fundamental priorities, i.e. the improvement of the warning system, the implementation of an integrated system of monitoring and active (usually non-structural) risk mitigation measures. Much more debate was devoted to the relocation of residents from the most endangered areas and/or the need to build passive structural works, especially on private properties. The results show that it is feasible to organize an expert-informed participatory process that respects and builds on conflicting citizen perspectives and interests, and demonstrates spheres of policy consensus as well as policy dissent.

As stakeholders participating in the Nocera Inferiore became acutely aware, the costs of preventing or reducing the risk of landslides with structural and other measures can be high, and these expenses compete with other public and private investments. Resources are often constrained as was demonstrated in Nocera Inferiore, where the national government had allocated 11 million Euros to the municipality for prevention measures. The experts had estimated that at least 10 times this amount might be needed for protection measures. It is clear that difficult choices have to be made on how to invest these funds. **Benefit-cost analysis** (BCA) is a methodology for assessing the social benefits of public investments and comparing them with the social costs (D5.3). It is a standard methodology for investments where the benefits and costs can be easily specified without large uncertainties. However, it is far from certain if or when a landslide will occur in a specified region, and even more uncertain for a specified slope. For this reason, standard BCA is not applicable. Confronting this challenge, SafeLand researchers developed and demonstrated a BCA approach based on probabilistic risk assessment for landslide risk, with applications in Nocera Inferiore, Italy, and Barcelonnette, France. The research demonstrates the advantages of this approach, and also the challenges in specifying the hazard probabilities, exposure and vulnerability of the at-risk assets and people. It also confronts the issue of how to include benefits of reducing the risk of life loss from landslides.

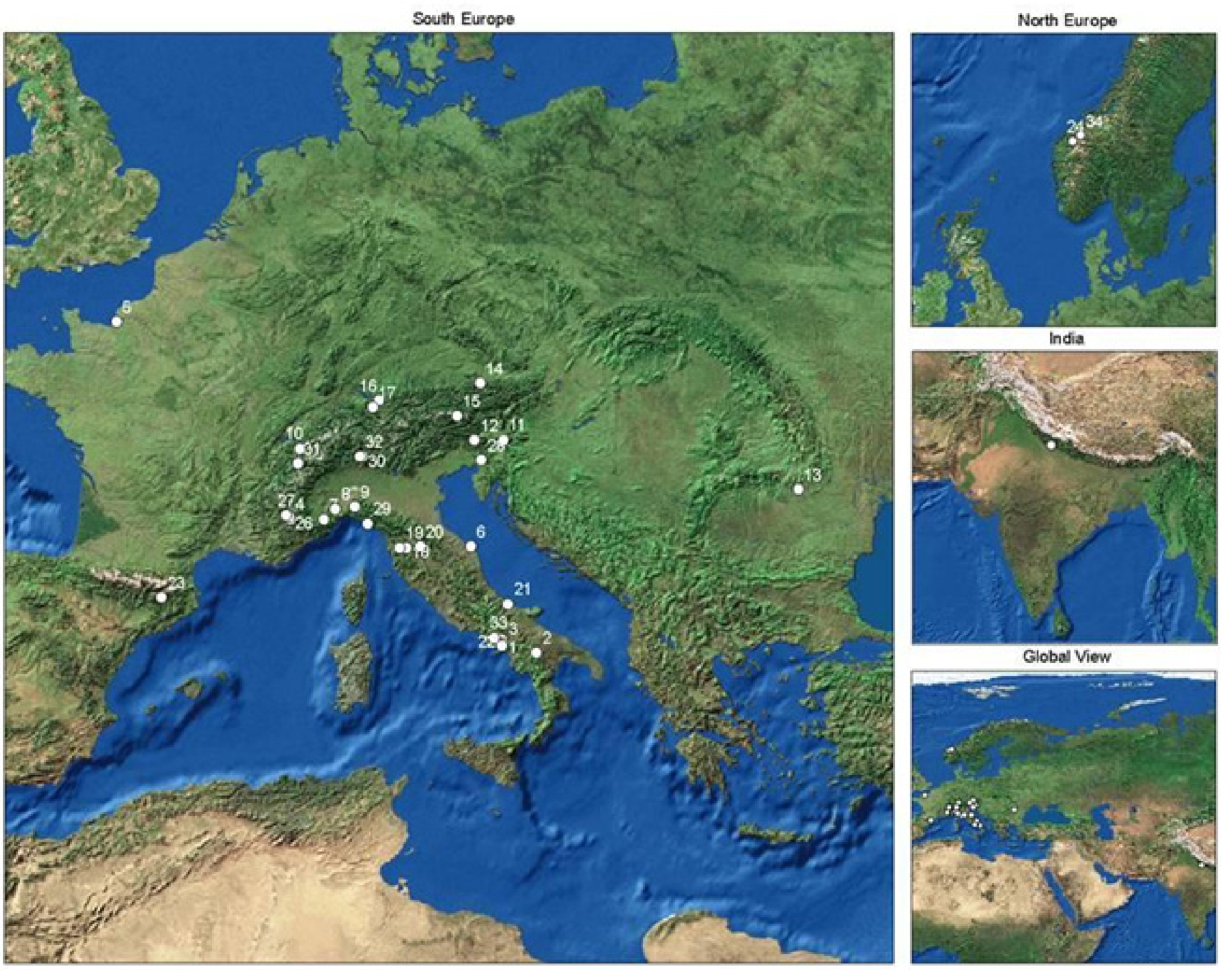
As the applications of BCA indicate, it is often difficult to quantify all the social benefits and costs of landslide risk mitigation measures. For example, how does one account for the emotional and financial traumas of moving long-time residents away from high-risk areas, or how can the analyst account for the aesthetic aspects of structural protection measures versus "green" alternatives? To confront these difficulties, and provide analyses that support stakeholder participation, SafeLand researchers demonstrated the applicability of **Spatial Multi Criteria Evaluation** (SMCE) for the *qualitative* assessment of the landslide hazard, vulnerability and risk (D5.6). The methodology can support decision makers who are faced with making evaluations of projects or policies based on criteria that cannot all be expressed with a common numeraire, for example, money, and for which stakeholders evaluate the criteria differently. Since stakeholders evaluate the various hazard and vulnerability criteria differently, SMCE supports multi-stakeholder decision processes in identifying a generic set of relevant criteria and techniques for weighting these criteria.

Finally, to carry out a probabilistic risk assessment it is important to clearly specify the uncertainties, which is an essential part of any risk assessment process (D5.4). Uncertainties can either be aleatory (for example, the frequency and intensity of rain fall is inherently and irreducibly uncertain) or epistemic as an inherent part of the models and statistical methods. SafeLand researchers have provided an application of a **methodology for the quantification of uncertainties** existent in the risk assessment and risk management processes. The specific focus is on uncertainties in the characterization of parameters in landslide models. The researchers advocate a Bayesian approach for the representation, handling and management of uncertainties in the context of decision making with a specific application to rockfall hazards.

## WP 6: DEMONSTRATION SITES AND CASE STUDIES FOR VERIFICATION/CALIBRATION OF MODELS AND SCENARIOS

The main objective of WP6 is to document case histories and "hotspots" of European Land-slides (including potentially unstable slopes), and to provide the technical data for the case studies to be used in other work packages in SafeLand, in particular:

- **WP1.1 Identification of mechanisms and triggers**
- **WP1.2 Geomechanical analysis of weather-induced triggering processes**
- **WP1.3 Statistical analysis of thresholds for precipitation-induced slides**
- **WP1.5 Verification and calibration of run-out models**
- **WP2.2 Calibration of models for vulnerability to landslides**




| ID | SITE |
|---|---|
| 1 | Cervinara |
| 2 | Masseria Marino |
| 3 | Montaforte Irpino |
| 4 | Super Sauze |
| 5 | Villerville - Cricqueboeuf |
| 6 | Ancona |
| 7 | Bagnaschino |
| 8 | Casella 1 |
| 9 | Casella 2 |
| 10 | La Frasse |
| 11 | Macesnik |
| 12 | Stože/Log pod Mangrtom |
| 13 | La Butoi |
| 14 | Gschliefgraben |
| 15 | Sonnblick |
| 16 | Sibratsgfäll/Rindberg |
| 17 | Laterns/Schnepfau |
| 18 | Pesa - Elsa |
| 19 | Val d'Era |
| 20 | Valdarno Superiore |
| 21 | Petacciato |
| 22 | Pizzo d'Alvano |
| 23 | Vallcebre |
| 24 | Åknes |
| 25 | Nainital |
| 26 | La Valette |
| 27 | Barcelonnette |
| 28 | Slano Blato |
| 29 | Castagnola |
| 30 | Bindo |
| 31 | Courmayeur |
| 32 | Fiumelatte - Varenna |
| 33 | Liri - Garigliano - Volturno |
| 34 | Mannen |

*Figure 2. Locations of some of the case study sites in SafeLand.*

- **WP4.2 Remote sensing technologies for landslide detection**
- **WP4.3 Technologies for early warning**
- **WP5.1 Toolbox for landslide hazard and risk mitigation measures**
- **WP5.2 Stakeholder processes for choosing appropriate mitigation strategy**

More than 40 potential case study sites were compiled and summarized in deliverable D6.1. These comprise 39 sites in Europe located in Italy, France, Norway, Switzerland, Austria, Andorra, and Romania; as well as one site in Canada and one in India. Almost every type of landslide and every type of movement is represented in these sites. Figure 2 shows the locations of 34 of these sites.

## WP 7: DISSEMINATION OF PROJECT RESULTS

The dissemination of SafeLand Project outcomes was aimed to allow the scientific community and stakeholders to be aware of the activities carried out within the Project in order to catch their interest in the achieved results as well as to equip these groups/audiences with the right skills, knowledge and understanding of all the fulfilled objectives. To this aim, the WP7 was totally devoted to share the results coming from Project activities as widely as possible.

To this aim, the dissemination and exploitation of the results as well as the management of intellectual property were developed in two different ways: first, the internal exchange amongst the Project partners (internal dissemination) and, second, the distribution of final results to end-users (external dissemination). Particularly, in the WP7, three different tasks were developed:

1. **Dissemination activities through the web portal of the Project;**
2. **Educational activities;**
3. **Dissemination to decision-makers, professionals and scientists.**

The SafeLand web site (www.safeland-fp7.eu) was set up in the first phase of the Project together with an Extranet page for internal use. The web site provides information about the Project, the research carried out and its objectives and presents the consortium Partners. Moreover, by the end of the Project, all the obtained results collected in Deliverables have been made available on the web page.

As it concerns Task 2, collaboration and know-how exchange were carried out via key educational activities such as "LAndslide Risk Assessment and Mitigation" (LARAM) International School and Mountain Risk Project.

As for LARAM School, organized by the University of Salerno (Italy) which has been one of the partners in SafeLand Project, it is held yearly and is aimed at 40 PhD students selected every year from those working in the field of Civil Engineering, Environmental Engineering, Engineering Geology or with a similar Engineering background. The main objectives of LARAM are: to develop high educational interdisciplinary programs for assessing, forecasting and mitigating landslide risk over large areas; promote the creation of "on the job" vocational training programs aimed at solving real landslide risk problems using the most advanced theories and methodologies in the fields of geotechnical engineering, geomechanics, geology, mathematical modelling, monitoring, GIS techniques, etc. During the three years of SafeLand Project there was a close cooperation between LARAM School and the Project since many members of the School teaching team were participants to the SafeLand Project.
In 2011 a new LARAM initiative (1st LARAM-Asia Course), also supported by the SafeLand Project, started with the aim to: establish an annual 2 weeks high-level course for PhD students from Asian countries; improve research collaboration between Asian researchers within international initiatives. The Course was organized by: the State Key Laboratory of Geohazard Prevention and Geoenvironment Protection of the Chengdu University of Technology (CDUT-SKLGP) from Chengdu, China; the University of Salerno (Italy); the United Nations University – ITC School for Disaster Geoinformation Management of the University of Twente, the Netherlands; the International Centre for Geohazards (ICG, NGI, Norway) and the Asian Disaster Preparedness Center (ADPC, Bangkok, Thailand).

Some of SafeLand Partners (CNRS, ITC, UPC) organized the Mountain Risks Conference (November 2010) in Florence devoting a specific SafeLand session to the Project results via the keynote lecture given by the SafeLand coordinator Prof. Farrokh Nadim as well as several papers and presentations. Moreover, an education/training activity was carried out during an Intensive Course (June 2010), within the Mountain Risks Project in Barcelonnette (one of the super-site study area of SafeLand), with the aim of teaching how to carry out risk assessment for landslide and flood hazards, and how the risk information can be used in disaster risk mitigation. The computer exercises were completed by talks and seminars given by experts on management options used in France, and field visits of landslide and flood prone areas in the Barcelonnette Basin and in the Trièves Plateau.

Moreover, within the SafeLand Project a GIS-based training package on landslide risk assessment containing 12 case studies from 4 different countries and using different scales of analysis was developed. The target group for this training package on GIS for landslide risk assessment consists of University students, PhD researchers and practitioners on landslide hazard and risk assessment.
Finally, a software for handling of monitoring data was designed to support technical staff in data analysis and decision processes. The software is a separate and independent tool for real-time geo-scientific quantitative risk analysis, including threshold evaluation, thus helping the user (i.e. technicians working in the Early Warning Centre) to increase the quality of the geo-scientific evaluation.

With reference to Task 3, due to the high scientific level of the research activity developed by all the participants to the Project, SafeLand research findings were presented in several peer reviewed articles and in a 3-page presentation edition of International Innovation (December 2011), an international magazine disseminating science, research and technology. Moreover, some special issues on International Journals are under development to present the results of each Work Area of the Project.

During SafeLand Project many meetings, open workshops and conferences were also organized such as:

- the open workshop on "Landslide Monitoring Technologies & Early Warning Systems – Current Research and Perspectives for the Future" held in Vienna in February 2010;
- the SafeLand workshop on Remote sensing and monitoring held in Florence in May 2011;
- the 2nd Conference on Slope Tectonics held in Vienna in September 2011 (http://www.geologie.ac.at/slope_tecto_2011/) with the support of the SafeLand Project;
- the 6th LARAM Workshop "SafeLand (EU FP7 Project) - Living with landslide risk in Europe", held in Salerno (Italy) in September 2011 and attended by PhD students, researchers, technicians, decision makers and authorities in charge of the territory governance in Italy and Europe (http://www.laram.unisa.it/workshop/index).

A series of SafeLand related papers were also presented at the Second World Landslide Forum (WLF, Rome October 2011), aimed at gathering scientists, stakeholders, policy makers and industry members dealing with the management of landslide risk, including a special session dedicated to the Project. At the end of the Project, a special session on "Effects of global change on spatial and temporal patterns of landslide risk"was organized during the EGU General Assembly 2012 (22-27 April 2012, Vienna, Austria), to present the results of SafeLand project.

With reference to the dissemination to decision-makers and professionals, a toolbox for mitigation measures was implemented to assist and to guide the user in the choice of the most appropriate mitigation measures for potential landslides situations.

Finally, a risk-communication strategy and a participatory process was carried out for the case study of Nocera Inferiore (Campania region, southern Italy). The activities (leaded by IIASA) dealt with: semi-structured interviews (the interviewees included officers of various agencies in charge of risk management at provincial and regional level); a participatory process (1 public open meeting, 5 meetings with 15 selected residents, evaluation and feedback via questionnaire, informal meetings with local activities, parallel working groups); a questionnaire survey; communication and education activities (setting up of a web site - http://safeland.iiasa.ac.at/index.php/Main_Page, online discussion group, press releases and contacts with local media, simulation exercise with students at the LARAM School 2011 organized by UNISA).

## SOCIAL IMPACT

The final results of the SafeLand project are expected to have impact on the protection and safety of population and material property in Europe at several levels: technology will be improved, new more reliable maps will be made available and public awareness will be put on the agenda in a systematic manner. Dialogue and understanding among scientists and experts will be made more natural and early warning systems will be ready for implementation. Stakeholders and authorities will have improved access to a risk management system for increased safety and cost-effectiveness. The project deliverables are expected to help provide the basis for future European directives in relation to natural hazards.

The project brings together leading European research centres and technologically advanced SMEs with highly developed experience in their specialized fields, such as GIS, remote sensing, modelling, risk assessment and management and decision-support, to allow a leap forward in pre-disaster planning and mitigation in Europe and worldwide. The list of the European organizations involved in SafeLand is provided in the table below.

The SafeLand project, in co-ordination with the JRC-chaired European Landslide Working Group ("the Landslide Group") will provide Member States with a common methodology for the first identification of areas at risk to landslide threat.

| Partner Number | Partner name | Partner Shortname | Country |
|---|---|---|---|
| 1 (Coordinator) | International Centre for Geohazards | ICG | Norway |
| 2 | Universitat Politecnica de Catalunya | UPC | Spain |
| 3 | A.M.R.A. s.c.a.r.l. | AMRA | Italy |
| 4 | Bureau de recherches géologiques et minières | BRGM | France |
| 5 | Università degli Studi di Firenze | UNIFI | Italy |
| 6 | International Institute for Applied Systems Analysis | IIASA | Austria |
| 7 | Joint Research Centre | JRC | Italy |
| 8 | Fundación Agustín de Betancourt | FUNAB | Spain |
| 9 | Aristotle University of Thessaloniki | AUTh | Greece |
| 10 | Universita' degli Studi di Milano - Bicocca | UNIMIB | Italy |
| 11 | Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. | MPG | Germany |
| 12 | Centro Euro-Mediterraneo per i Cambiamenti Climatici s.c.a.r.l. | CMCC | Italy |
| 13 | Studio Geotecnico Italiano S.r.l. | SGI-MI | Italy |
| 14 | University of Salerno | UNISA | Italy |
| 15 | University of Twente – International Institute for Geo-information Science and Earth Observation ( United Nations University) | ITC | Nertherlands |
| 16 | Eidgenössische Technische Hochschule Zurich | ETHZ | Switzerland |
| 17 | Université de Lausanne | UNIL | Switzerland |
| 18 | C.S.G. S.r.l. Centro Servizi di Geoingegneria | CSG | Italy |
| 19 | Centre National de la Recherche Scientifique | CNRS | France |
| 20 | King's College London | KCL | United Kingdom |
| 21 | Geologische Bundesanstalt (Geological Survey of Austria) | GSA | Austria |
| 22 | Ecole Polytechnique Fédérale de Lausanne | EPFL | Switzerland |
| 23 | TRL Limited | TRL | UK |
| 24 | Geological Institute of Romanian | GIR | Romania |
| 25 | Geological Survey of Slovenia | GeoZS | Slovenia |
| 26 | Risques & Développement | R&D | France |
| 27 | Central Recherche S.A. | CRSA | France |
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**Examples of specific impacts of SafeLand are:**

- The inventory (synthesis) of landslide "hotspots" in Europe will be a significant contribution to a proposal for a Soil Framework Directive that asks Member States to identify areas at risk to landslides on the basis of a common methodology. Identifying sensitive areas and/or contexts in Europe where changes in landslide frequency may be expected will constitute a roadmap for actions required and level of urgency for improving safety and reducing risk associated with landslides.
- The guidelines for landslide susceptibility, hazard and risk assessment will contribute not only to the development of the common risk assessment methodology but also to systematic quantification of landslide risk. QRA outputs will provide guidance to stakeholders in where to direct research and development efforts and to allocate resources where uncertainties need to be reduced or where cost-effectiveness can be increased.
- The methodology for landslide risk assessment due to global change, both climate change and anthropogenic changes, at the European level will help policy-setters and decision-makers to optimize the urban development and infrastructure planning.

SafeLand has already started to have some impact through its dissemination activities. The achievements of the project were presented to PhD candidates working on landslide-related issues at the LARAM School in 2009 and 2010, and special sessions at the LARAM Workshop in Salerno in September 2010 and at the Mountain Risks Conference in Florence in November 2010 were dedicated to SafeLand. Some of the SafeLand End-Users attended the first annual meeting of the project in Naples and the project workshop on quantitative risk assessment (QRA) in Barcelona. The methodology developed in SafeLand for large-scale landslide hazard and risk mapping is used in the upcoming Global Assessment Report of UNISDR to estimate the number of people affected by landslides world-wide.

Further information on the SafeLand project can be found at its web site http://safeland-fp7.eu/

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