Grant Agreement No.: 226479

SafeLand

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

7th Framework Programme
Cooperation Theme 6 Environment (including climate change)
Sub-Activity 6.1.3 Natural Hazards

Deliverable D4.8

Guidelines for landslide monitoring and early warning systems in Europe – Design and required technology

Work Package 4.3 – Evaluation and development of reliable procedures and technologies for early warning

Deliverable/Work Package Leader: ICG/GSA   Revision: No. 1

March, 2012

Rev.	**Deliverable Responsible**	**Controlled by**	**Date**
0	ICG	CNRS	24/01/2012
1	ICG		19/03/2012
2			

SUMMARY

The document was elaborated as the last deliverable of area 4 in the SafeLand project (EC-FP7). 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. This deliverable targets end-users and aims to facilitate the decision process for stakeholders by providing guidelines. For the purpose of sharing the globally accumulated expertise, a screening study was realized amongst 14 early warning systems. As a result, the report presents a synoptic view of existing monitoring methodologies and early-warning strategies and their applicability for different landslide types, scales and risk management steps. Several comprehensive checklists and toolboxes are also included to support informed decisions. The deliverable was compiled by the ICG with contributions from landslide, monitoring, remote sensing, and social researchers from 27 European institutions. One of the main objectives of the SafeLand project is to merge experience and expert judgment and therefore to create synergies on EC-level towards guidelines for early warning and to make these results available to end-users and local stakeholders.

Note about contributors

The following organisations contributed to the work described in this deliverable:

Lead partner responsible for the deliverable:
International Centre for Geohazards (ICG)
Deliverable prepared by: *Sara Bazin*

Partner responsible for quality control:
Centre National de la Recherche Scientifique (CNRS): *Jean-Philippe Malet,*

Other contributors:
A.M.R.A. Scarl: *E. Damiano, L. Picarelli*
Ancona: *S. Cardellini*
Centro Servizi di Geoingegneria S.r.l. (CSG): *E. Garbarino, A. Gozzi, M. Lovisolo*
Geological Survey of Austria (GSA): *I. Baroň, B. Jochum, D. Ottowitz, R. Supper*
Geological Survey of Slovenia (GeoZS): *S. Kumelj*
International Centre for Geohazards - Norwegian Geotechnical Institute (ICG-NGI): *L. M. Bye, U. Eidsvig, B. Kalsnes, A. Lam, S. Lacasse, F. Nadim, M. Sparrevik, B .V. Vangelsten*
Centre National de la Recherche Scientifique (CNRS): *J.-P. Malet, A. Stumpf (previously at International Institute for Geo-information Sciences and Earth Observation - ITC)*
Joint Research Centre (JRC): *M. Van Den Eeckhaut, J. Hervás*
Risques & Développement (R&D): *E.Leroi*

Università degli Studi di Firenze (UNIFI): *E. Intrieri, V. Tofani*
Università degli Studi di Milano-Bicocca (UNIMIB): *F. Agliardi*
Universitat Politècnica de Catalunya (UPC): *J. Gili, J. Moya*
Université de Lausanne (UNIL): *C. Michoud, M.-H. Derron, M. Jaboyedoff*
Åknes /Tafjord Beredskap: *L.-H. Blikra*

We wish to thank the 14 institutions from 8 different countries that responded to the screening study: *Alberta Geological Survey* and *Université Laval* in Canada; *Geo-Tools* office and *National Park Bohemian Switzerland* in Czech Republic, *Calvados Préfecture, RTM - Service de Restauration des Terrains en Montagne,* and *Institut de Physique du Globe de Paris à la Martinique* in France, *Geotechnical Engineering* office in Hong-Kong, *Centro Monitoraggio Geologo Lombardia*, *Servizio Geologo Aosta* and *Università degli Studi di Firenze* in Italy, *Åknes/Tafjord Beredskap* and *Nebbet Monitoring Centre* in Norway, *State Geological Institute of Diunyz Stur* in Slovakia, and *Universitat Politècnica de Catalunya* in Spain.

We also wish to thank the experts who evaluated the monitoring techniques for subchapter 3.1.2.2: *F. Zott* from Inst. of Mountain Risk Engineering, BOKU - University of Nat. Resources & Life Sciences, Vienna, Austria, *J. Klimes* from Inst. of Rock Structure & Mechanics, Czech Academy of Sciences, Prague, Czech Republic, *P. Wagner* and *P. Ondrejka* from State Geological Inst. of Dionyz Stur, Bratislava, Slovak Republic, and *V. Vybiral* from Sensor, Ltd., Pezinok, Slovak Republic.

Disclaimer

CONTENTS

Acronyms used in document

ALARP	As Low As Reasonably Practicable
CAP	Common Alerting Protocol
CPT	Cone Penetration Tests
CPU	Central Processing Unit
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DInSAR	Differential Interferometry Synthetic Aperture Radar
DSGSD	Deep-Seated Gravitational Slope Deformations
EaR	Elements at Risk
EMF	Environmental Monitoring Program
EWS	Early Warning System
GB	Ground-Based
GIS	Geographic Information System
GML	Geography Markup Language
GNSS	Global Navigation Satellite System
HRA	Hazard and Risk Assessment
LCC	Life Cycle Cost
LiDAR	Light Detection And Ranging
LiSA	Linear SAR
PDF	Probability Density Function
RSS	Really Simple Syndication
SAR	Synthetic Aperture Radar
SLML	SafeLand Mark-up Language
SMS	Short Message Service
SRTM	Shuttle Radar Topography Mission
TDR	Time-Domain Reflectometer
UML	Unified Modelling Language
W3C	World Wide Web Consortium
XML	Extensible Mark-up Language
XSD	XML schema Definition

1 INTRODUCTION

Within the general framework of the interrelated work packages and deliverables produced for the SafeLand Project, the objectives of Work Package 4.3 is to evaluate and develop reliable procedures and technologies for early warning on landslides. In particular, deliverable D4.8 is intended to provide guidelines on design and required technology and to produce an Early Warning System (EWS) toolbox. A screening study realized amongst 14 existing landslide EWSs around the word is also presented (Chapter 2 and Appendix A) and two stakeholder example studies in Europe (Norway and Slovenia) are examined in Appendix B.

All the other deliverables of the Area 4 are deeply linked to D4.8. In particular in order to avoid a strong content overlapping we make reference for an in-depth examination to the following other deliverables:

- D4.1 "*Review of monitoring and remote sensing methodologies for landslide detection, fast characterisation, rapid mapping and long-term monitoring*". It provides the technical description of all the available monitoring methodologies for landslides, among which some are usable in EWS.
- D4.2 "*Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technologies and validation at selected test sites*". Its goal is to develop a set of connected numerical simulations able to realize an early warning procedure for the prevention of landslides due to meteorological events.
- D4.3 "*Creation and updating of landslide inventory maps, landslide deformation maps and hazard maps as input for QRA using remote sensing technology*". It provides the methodology for setting up and updating landslide inventories and for feeding and maintaining adaptive hazard maps. These products are necessary for the design of EWS.
- D4.4 "*Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides*". It contains an overview of more than 30 different remote sensing techniques and information about their applicability with respect to different landslide types, displacement rates, and observational scales. It is structured in a set of comprehensive tables and provides the guidelines for selecting suitable remote sensing techniques for the stakeholders.
- D4.5 "*Evaluation report on innovative monitoring and remote sensing methods and future technology*". It covers all kinds of technologies, ranging from the application of traditional monitoring methods to the improvement of new and advanced technologies. It also reports a survey to collect information about the usefulness of remote sensing for landslide study and to evaluate its applicability for landslide detection, mapping, monitoring and early warning.
- D4.6 "*Report on geo-indicator evaluation*". It provides a more specific description of the monitored parameters (also called geo-indicators) and an advanced knowledge on the correlation between different indicators, their role as early warning parameters and quantification of thresholds.
- D4.7 "*Report on the development of software for early-warning based on real-time data*". Its goal is to design an appropriate multi-parameter monitoring platform for specific classes of landslides.

SafeLand Area 5 is also linked to this deliverable. Work Package 5.1 "*Toolbox for landslide hazard and risk mitigation measures*" aims at identifying cost-effective structural and non-structural landslide mitigation options and at producing a web-based "toolbox" of innovative and technically appropriate prevention and mitigation measures. We make reference to the following deliverables of Work Package 5.1:

- D5.3 "*Quantitative risk-cost-benefit analysis of selected mitigation options for two case studies*". It covers different decision making strategies.
- D5.4 "*Quantification of uncertainties in the risk assessment and management process*". It focuses on the uncertainties of these decision making strategies.

Work Package 5.2 "*Stakeholder process for choosing an appropriate set of mitigation and prevention measures*" focuses on four "hotspot" case studies in Europe and one case in a developing country. We make reference to one deliverable of Work Package 5.2 which concentrates on policy risk management through risk-communication and participatory stakeholder-led processes:

- D5.5 "*Five scoping studies of the policy issues, political culture and stakeholder views in the selected case study sites – Description of methodology and comparative synthesis report*".

1.1 DEFINITION OF EWS INCLUDING EXPLANATION OF TERMS

1.1.1 Glossary of terms

The terminology used in this deliverable is that suggested in D1.1, D2.1, D2.4, D4.6 with several additions (early warning system, forecast, lead time, mitigation measures, monitoring, preparedness, public awareness, response, threshold), based on the following references:

Evangelista, E., Pellegrino, A., Urcioli, G. (2008). Mitigazione del rischio di frana. In: Strategie di intervento per la mitigazione del rischio di frana, L. Picarelli editor, Progetto di ricerca P.R.I.N. 2001 – 2003, Ministero dell'Istruzione, dell'Università e della Ricerca Scientifica (M.I.U.R.).

Sassa, K., Picarelli, L.,Yueping, Y. (2009). Monitoring, Prediction and Early Warning. K. Sassa, P. Canuti (eds.), Landslides Disaster Risk Reduction, Springer-Verlag Berlin Heidelberg.

UN-ISDR (2009). Terminology on disaster risk reduction United Nations International Strategy for Disaster Reduction, UN-ISDR-20-2009, Geneva, Switzerland.

Definitions of the main terms are:

- **Consequence:** The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.
- **Danger:** The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a rock fall). The characterization of a danger does not include any forecasting.

- **Early warning system (EWS):** The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.
- **Early warning parameter of landslides:** A mass-movement indicator allowing detection of an impending critical activation or acceleration of the landslide(s).
- **Elements at risk:** The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.
- **Exposure:** The temporal-spatial probability of the elements at risk within the landslide path.
- **Forecast:** Definite statement or statistical estimate of the likely occurrence of a future event or conditions for a specific area. In meteorology a forecast refers to a future condition, whereas a warning refers to a potentially dangerous future condition.
- **Frequency:** A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.
- **Hazard:** A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.
- **Individual risk to life:** The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.
- **Landslide:** A wide variety of processes that result in the gravitational movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. Among landslides, different typologies are recognized mainly by the kind of material involved and by the movement mechanism.
- **Landslide activity:** The stage of development of a landslide; pre-failure when the slope is strained throughout but is essentially intact; failure characterized by the formation of a continuous surface of rupture; post-failure which includes movement from just after failure to when it essentially stops; and reactivation when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (e.g. seasonal) or continuous (in which case the slide is “active”).
- **Landslide hazard map:** The subdivision of the terrain in zones that are characterized by the temporal probability of occurrence of landslides of a particular size and volume, within a given period of time. Landslide hazard maps should indicate both the zones where landslides may occur as well as the runout zones. A complete quantitative landslide hazard assessment includes:
  - Spatial probability: the probability that a given area is hit by a landslide;
  - Temporal probability: the probability that a given triggering event will cause landslides;
  - Volume/intensity probability: probability that the slide has a given volume/intensity;
  - Runout probability: probability that the slide will reach a certain distance downslope.
- **Landslide intensity:** A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and

may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

- **Landslide inventory:** An inventory of the location, classification, volume, activity and date of occurrence of landsliding.
- **Landslide magnitude:** Measure of the landslide size. It may be quantitatively described by its volume or, indirectly by its area. The latter descriptors may refer to the landslide scar, the landslide deposit or both.
- **Landslide susceptibility:** A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.
- **Lead time:** Time interval comprised between the moment when the occurrence of the event is reasonably certain, and the moment of its actual occurrence.
- **Likelihood:** Used as a qualitative description of probability or frequency.
- **Mass-movement indicator:** Any monitoring parameter, which characterizes directly or indirectly the dynamic state of mass-movement processes. Also called **geo-indicator**.
- **Mitigation measures:** A series of mitigation options which**,** for landslides, consist of:
  - Stabilization – measures which increase the "margin of safety" of the slope or that intercept the run out (structural measures);
  - Restrictions on the use of the element at risk – permanently or temporarily;
  - Restrictions on land usage – through land-use planning tools, to limit the presence of elements at risk in the area threatened by the landslide (non-structural measures);
  - Actions by the Civil Protection authorities – which allow to remove from the area threatened by the landslide within a suitably short reaction time most valuable elements at risk, including as a minimum human life (emergency plans).
- **Monitoring:** Defined as the systematic repetition of observations of a particular object or area.
- **Monitoring parameter:** Any phenomenon or factor related to slope (area of interest), which could be quantified and monitored in time.
- **Preparedness:** The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions. Preparedness is based on a sound analysis of disaster risks and good linkages with early warning systems, and includes such activities as contingency planning, stockpiling of equipment and supplies, the development of arrangements for coordination, evacuation and public information, and associated training and field exercises. These must be supported by formal institutional, legal and budgetary capacities.
- **Probability:** A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event. There are two main interpretations:
  - Statistical-frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

- Subjective probability (degree of belief) – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.

- **Public awareness:** The extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards. Public awareness is a key factor in effective disaster risk reduction. Its development is pursued, for example, through the development and dissemination of information through media and educational channels, the establishment of information centres, networks, and community or participation actions, and advocacy by senior public officials and community leaders.
- **Qualitative risk analysis:** An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.
- **Quantitative risk analysis:** An analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.
- **Residual risk:** The degree of existing risk given the presence of both stabilization and protection measures.
- **Response:** The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.
- **Risk:** A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.
- **Risk analysis:** The use of available information to estimate the risk to individuals, population, property, or the environment, from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification, vulnerability evaluation and risk estimation.
- **Risk assessment:** The process of risk analysis and risk evaluation. In some communities (for instance those dealing with flood) risk assessment differs from risk evaluation by the fact that it includes subjective aspects such as risk perception.
- **Risk control** or **risk treatment:** The process of decision making for managing risk, and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.
- **Risk estimation:** The process used to produce a measure of the level of health, property, or environmental risks being analyzed. Risk estimation contains the following steps: frequency analysis, consequence analysis, and their integration.
- **Risk evaluation:** The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.□
- **Risk management:** The complete process of risk assessment and risk control (or risk treatment).

- **Risk perception:** The way how people/communities/authorities judge the severity of the risk, based on their personal situation, social, political, cultural and religious background, economic level, their level of awareness, the information they have received regarding the risk, and the way they rate the risk in relation with other problems.
- **Societal risk:** The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental, and other losses.
- **Temporal - spatial probability:** The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.
- **Threshold:** Value of a mass-movement indicator representative of high landslide probability, set to issue warnings. This value is defined based for instance on modeling and/or on past events.
- **Tolerable risk:** A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.
- **Vulnerability:** The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide. Vulnerability could also refer to the propensity to loss (or the probability of loss), and not the degree of loss.
- **Zoning:** The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

1.1.2 Landslide triggering

Landslides can be promoted by different factors (geological, morphological, physical among the others), while the term “trigger” commonly refers to an external stimulus that causes an immediate response in terms of landslide activity. Landslide triggering is treated with details in SafeLand deliverable D1.1 entitled “*Landslide triggering mechanisms in Europe – Overview and state-of-the-art*” and for the sake of brevity we only list the different triggering factors here:

- **Rainfalls:** In most of the cases, the main trigger of landslides is heavy or prolonged rainfall. Generally, a landslide triggered by rainfall is usually related to an exceptional short lived event, such as the rainfall associated with a particularly intense thunderstorm, or in the opposite a long duration rainfall event with lower intensity, or a combination of both. Reduction of effective material strength by percolating water is generally considered as the primary cause of rainfall induced landslides.
- **Erosion:** Failures can be triggered by undercutting of the slope by a river, especially during a flood, or by bank and lateral erosion in coastal settings, especially within clay slopes and fissured material. Undercutting and excavation reduces stability by increasing the gradient of the slope and by removing toe weighting. Landslides such as debris flows may initiate by mobilization of a channel bed due to surface erosion due to water flow

- **Snowmelt:** Particularly in mountain areas, snowmelt can be a key mechanism in the landslide initiation by a sudden increase of temperature, leading to rapid melting of the snow pack. Then, the water infiltrates into the ground and, in the presence of underlying impervious layers of frozen soil or rock, leads to a rather rapid increase of soil pore pressure. Such an effect can be enhanced by precipitation, adding groundwater to the system and accelerating at the same time the rate of thawing.
- **Weathering:** Prolonged weathering of bedrock causes the reduction of material strength, leading to the creation of a regolith layer weaker than the parent rock, which may slide.
- **Earthquakes:** Several areas prone to landslides have experienced at least moderate ground motion intensities in recorded times. The occurrence of earthquakes in steep landslide-prone areas greatly increases the likelihood that landslides will occur, due to the ground shaking itself or caused by the induced dilation of soil materials, which allows rapid infiltration of water right afterwards. Strong earthquakes may cause widespread landsliding and other ground failure (i.e. liquefaction).
- **Volcanic processes:** Magmatic intrusions or phreatic explosions are among the most prominent factors at triggering the failure in volcanic edifices. Volcanic lava may induce high rates of thawing, causing volcanic debris flows (also known as lahars) constituted by a deluge of rock, soil, ash, and water that accelerate rapidly on the steep slopes of volcanoes.
- **Human processes:** Man-made constructions and major earthworks can cause landslides to occur with mechanisms which would not have occurred naturally.

1.1.3 Landslide monitoring

Landslide monitoring means the comparison of landslide conditions like areal extent, speed of movement, surface topography, soil humidity from different periods in order to assess landslide activity (Mantovani et al., 1996). Landslide monitoring comprises a number of different tasks defined as follows:

- **Detection:** new landslides recognition from space- or airborne imagery;
- **Rapid mapping:** fast semi-automatic image processing for change detection and/or target detection; hotspot mapping;
- **Fast characterization:** retrieving information on failure mechanism, volume involved, and run-out length;
- **Long-term monitoring:** processing data for retrieving deformation patterns and time series. Long-term monitoring is the key element to implement an EWS, even if long term series might not be stable and might not represent a single homogeneous process. The past might not be the key of the future in all the cases.

SafeLand deliverable D4.1 entitled “*Review of monitoring and remote sensing methodologies for landslide detection, fast characterisation, rapid mapping and long-term monitoring*” reviews in details existing techniques for landslide monitoring. An ultimate “universal” methodology does not exist; every technology has its own advantages and disadvantages. End-users should carefully consider them to select the methodology which represents the best compromise between pros and cons and which better meets their needs. The technical features to take into consideration for the selection of the most proper technique are: **accuracy level**, **coverage**, **spatial resolution**, **temporal resolution**, **alternatives**, and **cost**. The aim of subchapter 3.1.2 of this document is to provide guidelines for choosing the right monitoring technology based on these criterions. The range of revisiting times is very large, as the various techniques are employed in very different ways in the monitoring process. Real-time monitoring is the fastest end of that range (Figure 1).

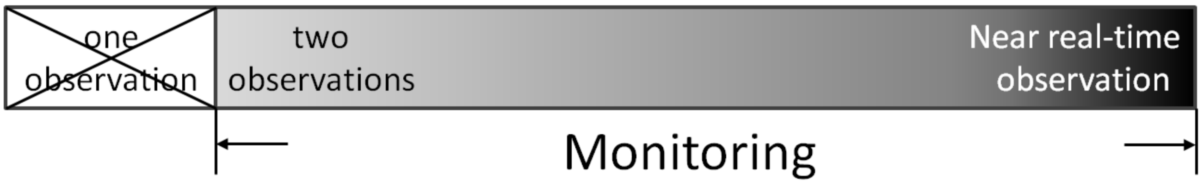


Figure 1: Definition of monitoring as the systematic repetition of observations.

1.1.4 Early warning systems

A people-centred EWS necessarily comprises five key elements (UN-ISDR, 2004): (1) **knowledge of the risks;** (2) **monitoring**, **analysis and forecasting of the hazards**; (3) **operational centres**; (4) **communication or dissemination of alerts and warnings**; and (5) **local capabilities to respond to the warnings received**. The expression "end-to-end warning system" is also used to emphasize that EWSs need to span all steps from hazard detection through to community response. The aim of chapter 3.1 of this document is to provide guidelines for establishing those five key components for landslide EWSs.

EWSs are usually associated with plans for emergency evacuation or safe sheltering. As explained in SafeLand deliverable D5.1 entitled "*Compendium of tested and innovative structural, non-structural and risk-transfer mitigation measured for different landslide types*", it is worth noticing that these measures are often classified as measures to reduce vulnerability. However, keeping to the distinct definitions of "vulnerability" and "elements at risk", these systems are best classified as measures to reduce (temporarily and selectively) the elements at risk, rather than their vulnerability.

A **risk management cycle** was implemented in SafeLand deliverable D4.4 entitled "*Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides*" to highlight the importance of different tasks of the monitoring in different phases (Figure 2). The main phases of risk management can be defined as mitigation, preparedness, response and recovery (Alexander, 2002). Decisions on the optimal observation strategies for a particular area should ideally be based on a thorough hazard and risk assessment, which incorporates all previous observations and experience and priority for more detailed (spatially and temporally) observations should be given to areas with higher risks.

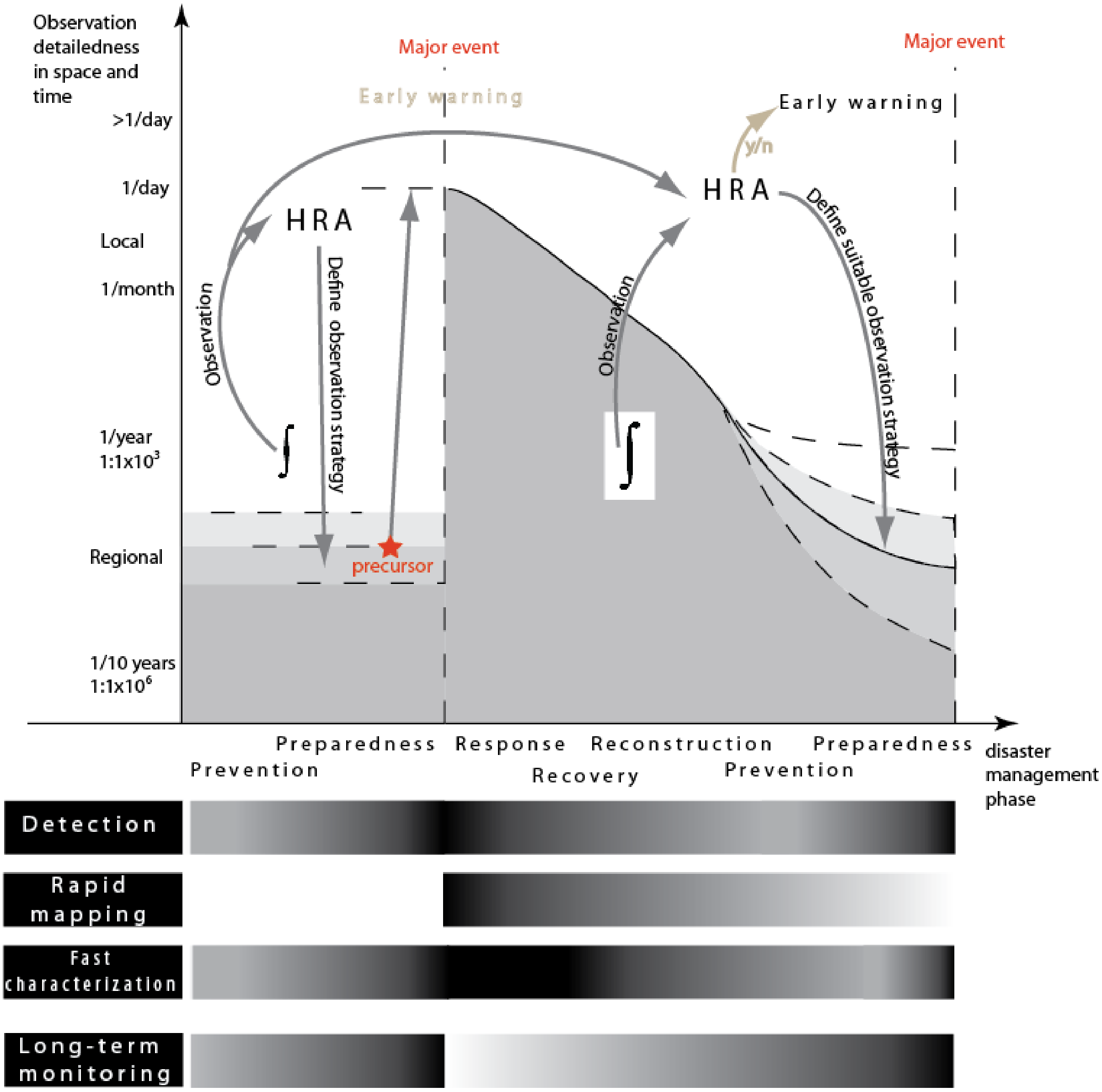


Figure 2: Abstraction of the interrelationships between risk management strategies (HRA = hazard and risk assessment) and observation strategies. The shading of the bars below the graphic gives an indication for the importance of different tasks during the different management phases.

1.2 PREREQUISITE FOR IMPLEMENTING AN EWS

There are many factors governing the choice of an EWS. The main factor is the type of landslide. The EWS also depends largely on the scale of the landslide that needs to be monitored. Other factors such as the lead time to expect are imperative to consider.

1.2.1 Types of landslide

Landside risk varies with landslide types. As noted by Sassa et al. (2009), landslides are often classified with regard to depth and speed. Deep and rapid landslides are most dangerous.

Shallow and rapid landslides can also be dangerous when many landslides occur during the same triggering event. Slow landslides are relatively safe for people since they allow evacuation even during motion. However, often villages are constructed on reactivated landslides (previously landslide occurred and relatively flat areas are provided by past landslide events). The velocity is not so high, and travel distance is not great in this type of landslides. However, landslide movement can be enough to destroy houses, schools, and other buildings. The failure of houses and other structures may give damages to humans. Shallow and slow landslides are relatively not dangerous and they are rarely monitored with EWS. Deep and shallow, rapid and slow movements have different mechanisms, so the same criteria of early warning cannot be applied. In general, risk is very different in urban environment or rural area.

In order to discuss adequate risk assessment and monitoring a more detailed classification is necessary. This document follows Cruden and Varnes (1996) taxonomic classification which considers, in addition to the movement mechanism at the initial stage of motion and the material, the state of activity and the rate of movement. The applicability of different monitoring methods is presented in details in SafeLand deliverable D4.4 entitled "*Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides*" for the major landslide types. The main landslide types are illustrated in Figure 3:

- **Slides:** mass movements characterised by a distinct zone of weakness that separates the sliding portion from the more stable underlying material, leading to the definition of a so-called sliding boundary. The shape of the rupture surface permits one to classify slides in rotational and translational as following:
    - Rotational slide where the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis parallel to the ground surface and transverse across the slide.
    - Translational slide in which the sliding mass moves along a roughly planar surface with little rotation or backward tilting.

  A block slide is a translational slide in which the moving mass consists of a single unit, or a set of few closely related units, moving downslope as a relatively coherent mass.
- **Falls:** abrupt movements of rocks masses and boulders that become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, while the movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.
- **Topples:** distinguished by the forward rotation of a rock/soil unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.
- **Flows:** characterised by the presence of a gravity driven mass movement involving a significant internal distortion. The flow category includes several typologies differing one from the other in fundamental ways:
    - Debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope. Debris flows are commonly caused by intense surface-water flow caused by heavy precipitation or fast snowmelt, leading to the erosion and

mobilization of loose soil or rock on steep slopes. Debris flows can be ignited also by nearly-saturated shallow landslides that occur on steep slopes.
  - Debris avalanche which consists of a very rapid to extremely rapid mass movement of non saturated material which remains laterally unconfined and unchannelled along most of its length.
  - Earthflow as intermittent flow-like movement of plastic clayey earth. The flow is elongate and usually runs on moderate slopes, under saturated conditions. Dry flows of granular material are also possible.
  - Mudflow which consists of an earthflow of material wet enough to flow rapidly, containing at least 50 percent sand-, silt-, and clay-sized particles. In some reports of mudflow occurrences, generally found in newspaper or TV news, mudflows and debris flows are commonly referred as “mudslides.”
  - Creep, as an imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure.
- **Lateral Spreads:** mass movement dominated by lateral extension and accompanied by shear or tensile fractures as usually occur on very gentle slopes or flat terrain. The failure is caused by liquefaction of saturated, often loose and cohesionless sediments (usually sands and silts), usually triggered by a strong ground motion from high magnitude events. When coherent material, either rock or soil, rests on a liquefying stratum, the upper unit may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or flow. Lateral spreading in fine-grained materials on shallow slopes is usually a progressive phenomenon: the failure starts suddenly in a small area and spreads rapidly afterward. Often, the initial failure is a rotational landslide, but in some materials movement occurs for no apparent reason.

Combination of two or more of the above types is known as a **complex landslide**.

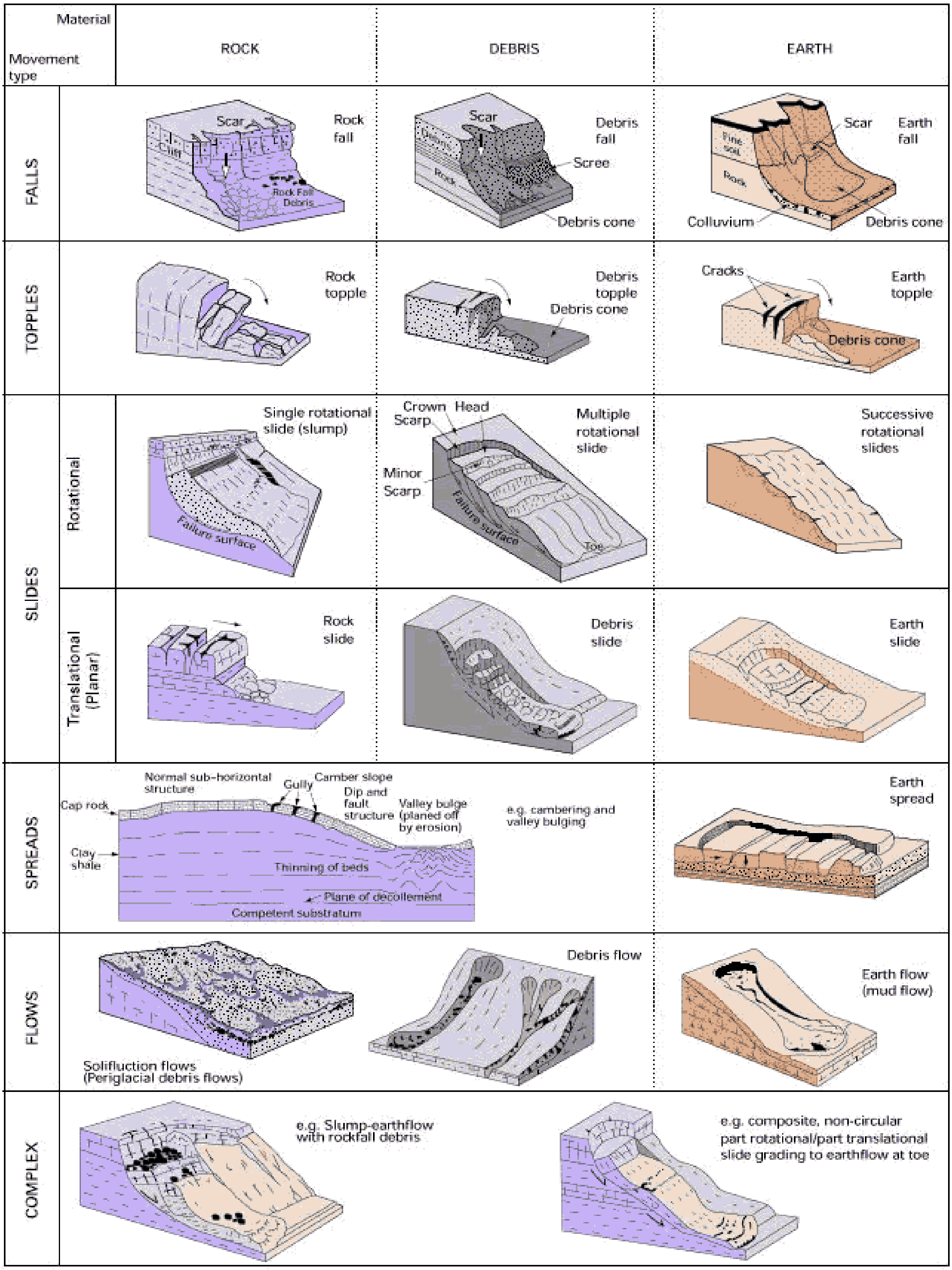


Figure 3: Classification of type of landslides (modified after Varnes (1978)).

1.2.2 Scale

As seen in subchapter 1.2.1 and Figure 3 the scale of a landslide often depends on its type. The present report focuses on site-specific EWS on a local scale. Indeed, the flow chart approach presented in chapter 4 is so far only valid for a slope-scale EWS. In the present paragraph however, we present the main differences between local and regional systems:

- **multiple slope system**

A multiple slope EWS aims at determining the likelihood of landslides in different areas, each of them being monitored independently on a slope scale. In this case, only the operational aspects of the EWS for the communication and the dissemination of the warning are common.

- **slope scale system**

A slope scale EWS aims at determining the likelihood of landslides occurring on a terrain unit. This is obtained by implementing a set of monitoring technologies; usually geophysical methods operated either remotely or on site.

- **regional scale system**

As described in SafeLand deliverable D4.2 "*Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technologies and validation at selected test sites*", shallow landslides (i.e. slides, debris slides and debris flows) are often not recurrent at a given site. They are recurrent within a region and frequency analysis may be then conducted on a regional basis, its results being extrapolated to specific locations on the landslide density map. Shallow landslides in a region may occur:

- either as scattered failures occurring throughout the study area over time;
- or as multiple slope failures generated by particular landslide-triggering events (i.e. rain storm or earthquake) acting over a large area. Crozier (2005) defined the latter as multiple-occurrence of regional landslide events (MORLE). One single MORLE may usually involve hundreds to tens of thousands of individual landslides in areas extending from some hundreds to tens of thousands of square kilometres.

For shallow landslides triggered by meteorological events, it is necessary to design and to develop simulation models able to produce regional warning maps. Meteorological hazards such as severe rain or convective outbreaks can set off shallow landslides with a rapid velocity. The goal of deliverable D4.2 is to design and develop real-time warning systems for shallow landslides, at large scale or basin scale, based on forecasted meteorological variables as precipitation (rain and snow) and also atmospheric parameters at the soil level. This is obtained by developing a set of connected numerical simulations able to realize an early warning procedure for the prevention of hydrological instabilities phenomena (landslides) due to meteorological events. It is important to mention that this is a developing research theme and new ideas are being tested.

1.2.3 Timing

EWSs have now been employed for many years for protection against natural risks. In some cases, as for volcanic eruptions, they prove quite efficient, since the lead time available to take action is long enough. Usually the seismic precursors before the eruption allow the evacuation of the population. In other cases, as for flash floods, the lead time is so short that evacuation can be difficult. Lead times for landslides lay usually between these two ends.

Independently of the lead time, we can distinguish two types of EWS for landslides:

- **Pre-trigger:** a probability of landslide occurrence is based on the analysis and elaboration of precursors. A warning is issued when a threshold is reached but the landslide is not really certain (for example heavy rainfall).
- **Post-trigger**: a landslide has occurred and the system provides warning for a potentially dangerous future condition (*event warning system*). For example, an EWS detects a rock fall near a railway and automatically stops train traffic. In this case, falling boulders might not have actually stopped on the tracks. Similarly, an EWS can detect the occurrence of a lahar and can automatically send an evacuation order to the population leaving further down in the valley. However, there is no indication of the final runout and the lahar might end before reaching the inhabited area.

Both types (pre- and post-trigger) can lead to false alarms. When the lead time allows it, a validation procedure should be implemented. In the railway example, a visual inspection (remote camera or human inspection) can clear/validate the warning before the next scheduled train.

EWSs for landslides are monitoring systems specifically designed to detect events that precede a landslide in time to issue an imminent hazard warning and initiate mitigation measures. The key to a successful EWS is to be able to identify and measure small but significant indicators that precede a landslide, and to issue warnings early enough to allow sufficient lead time to implement actions to protect life and properties. They can therefore be adopted only for very limited goals. The case of rapid landslides is complicate because the time elapsing between the onset of slope failure and its impact on exposed life and properties can be in the order of tens of seconds and landslides may often occur anywhere within wide areas which lack instrumentation able to validate the events. Research in this field is active, even though just beginning. An example is described in SafeLand deliverable D4.2 with the development of models able to produce regional warning maps for shallow landslides triggered by severe rain. Rainfall forecasts are used to calculate soil saturation and, as the meteorological event approaches, specifically developed algorithms make use of ground-based radar rainfall and satellite observations to determine overall system evolution in the very short term (nowcasting). Precipitation *nowcasting* is a very short-term forecasting of the location and intensity of rainfall. Short-term refers to a time period of up to 6 hours of lead time. Such forecasting already has been of high interest for over 50 years and it turns to be one of the most difficult earth system problems. Numerous models designed specifically to forecast rainfall have been created and analyzed, but each and every one of them imprecise, the reason being the chaotic and transient nature of the precipitation phenomenon. The other reason comes from the fact that rainfall is not directly connected with the landslide occurrence. The transfer function from rainfall to pore pressure and to runoff is not so easy to define and to calibrate; a lot of parameters have to be taken into account for calibrating such as water content, permeability, fracture, etc. A direct link between rainfall event and landslide occurrence can only be efficient in a statistical way, at small scale.

As explained in UNEP guidelines timeliness is often in conflict with the desire to have reliable predictions, which become more accurate as more observations are collected from the monitoring system (UNEP, 2011). There is therefore an inevitable trade-off between the amount of warning time available and the reliability of the predictions provided by the EWS. An initial alert signal may be sent to give the maximum amount of warning time when a minimum level of prediction accuracy has been reached. However, the prediction accuracy for the location and size of the landslide will continue to improve as more data is collected by the monitoring system part of the EWS network. Subsequently, the **temporal resolution of the monitoring technology** that is employed plays in important role. For example, DInSAR is a promising technique for monitoring landslides but the time-interval between successive passages of satellites is unsuitable for a systematic monitoring of relatively rapid movements (Figure 4). Quantitative information on landslide activity can be obtained in the case of extremely slow movements (velocity less than a few cm per month), affecting large areas with sparse vegetation (Fruneau et al., 1996).

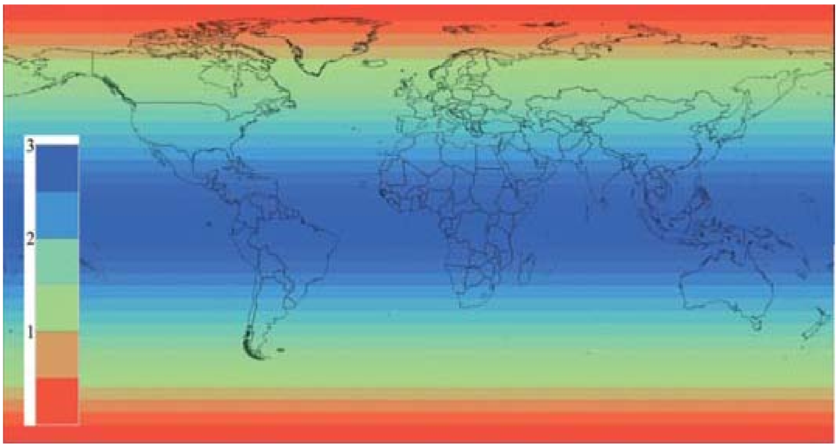


Figure 4: Average revisit time (in days) across the world for the Sentinel-1 constellation: Two satellites in 12-day repeat orbits with 250 km swath widths. The blue around the equator reflects the 3-day revisit period, improving towards the poles. (Source: ESA bulletin 131 - august 2007)

1.2.4 Elements at risk and their exposure

Elements-at-risk (EaR) are the population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area (UN-ISDR, 2004). They are also referred to as assets and feature spatial and non-spatial characteristics. EaR may include buildings, transportation systems, lifeline utilities, service facilities, natural resources and of cause humans populating an area temporarily or permanently. The way in which the quantity and quality of EaR are characterized (e.g. as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented.

The interaction of EaR and hazard defines the risk, based on three characteristics, the exposure, the vulnerability and the value (which can be economic or not) of the EaR (Figure 5). Exposure indicates the degree to which the EaR are actually located in the path of a particular hazardous event. The spatial interaction between the EaR and the hazard footprints can be depicted in a GIS map by overlaying of the hazard map with the EaR map (Van Westen, 2009). Vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UN-ISDR, 2004). The assessment of vulnerability is mostly focused on physical characteristics of the EaR (physical vulnerability) that determine the potential structural damage caused by landslide events of different magnitudes and types. The relationship between the landslide intensity and the potential is frequently expressed in the form of vulnerability curves. Structural damages can lead to dysfunction (road network, lifelines, industrial production …), which can lead in the end to societal dysfunction. Social or community vulnerability, on the other hand may be described either as this societal dysfunction or as “people’s differential incapacity to deal with hazards, based on the position of the groups and individuals within both the physical and social worlds" (Clark et al., 1998). Similar to physical vulnerability it should be assessed with respect to a particular landslide intensity and type but can hardly be expressed in absolute values or losses alone. Indices for the quantification and comparison of social vulnerability among different regions have been proposed (Cutter et al., 2003) and include different variables which are typically derived in community-based assessments and/or census data. EaR inventorization can be carried out at various levels, depending on the requirements of the study. EaR data should be collected for certain basic spatial units, which may be grid cells, administrative units (countries, provinces, municipalities, neighbourhoods, census tracts) or so-called homogeneous units with similar characteristics in terms of type and density of EaR. Risk can also be analyzed for linear features (e.g. transportation lines) and specific sites (e.g. a damsite). Population data have a static and dynamic component. The

Risk = probability of losses occuring

Risk = (phenomenom ★ temporal probability) ★ (EaR ★ spatial probability)

Risk = Hazard ★ Exposure ★ Vulnerability ★ Value

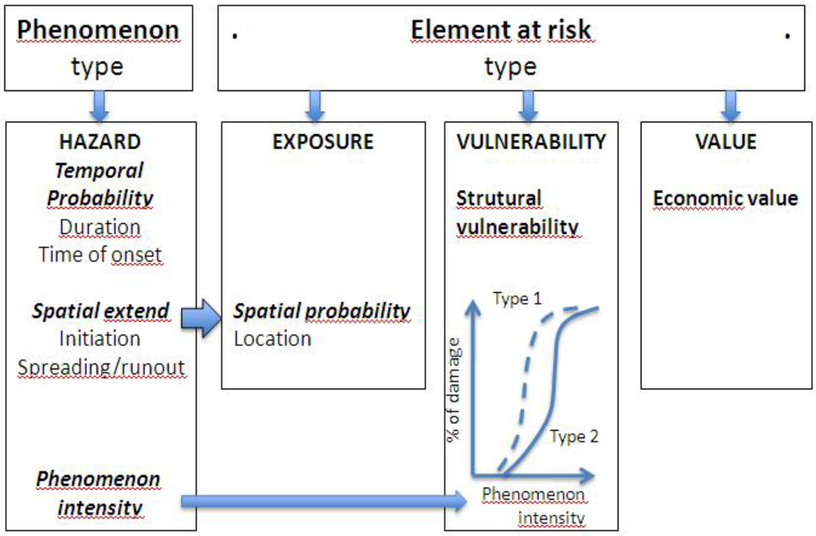


Figure 5: Components of the risk analysis.

static component relates to the number of inhabitants per mapping unit, and their characteristics, whereas the dynamic component refers to their activity patterns, and their distribution in space and time. Population distribution can be expressed as either the absolute number of people per mapping unit, or as population density. Census data are the obvious source for demographic data. However, for many areas census data is not available, outdated, or unreliable. Therefore also other approaches have been used to model population distribution with remote sensing and GIS, to refine the spatial resolution of population data from available population information (so-called dasymetric mapping). Building information can be obtained in several ways. Ideally data is available on the number and types of buildings per mapping unit, or even in the form of building footprint maps. If such data is not available, building footprints maps can be generated using screen digitizing from high resolution images. Automated building mapping techniques gain increasingly greater importance as high resolution satellite images, InSAR, and specifically LiDAR datasets become available more frequently. It has also been demonstrated that remote sensing provides physical proxies for the approximation of social vulnerability that are particular useful in data sparse regions (Ebert et al., 2009).

As explained in deliverable SafeLand D2.4 entitled "*Guidelines for landslide susceptibility, hazard and risk assessment and zoning*", landslides are only of consequence and interest when damage can be caused, i.e. where elements that can suffer damage are present. This implies that we require information on the presence of EaR, but also whether they are truly at risk given the present landslide hazard. For example, a bridge and an adjacent building may both be destroyed in a debris avalanche, while in a less energetic debris flow only the weaker building might be damaged or destroyed. Those differences in performance are evaluated via their vulnerability to present mass movement types and their magnitude (Papathoma-Kohle et al., 2007). It is, therefore, meaningful to begin with a complete inventory of all EaR of importance in a landslide hazard zone, even if some of them turn out to be unaffected by certain events (vulnerability, V = 0). Landslide-prone areas that are inhabited tend to be characterized by different EaR types, not all of which are physical and can be quantified in monetary terms. The typical physical elements include buildings, roads, railways, bridges, land used for production (e.g. agriculture or forestry), and industrial facilities (Castellanos Abella and Van Westen, 2008). Also people are in principle physical EaR, although a loss quantification similar to the other classes, i.e. in financial terms, is less meaningful. They also differ fundamentally in terms of physical presence, showing a dynamic that is comparable to vehicles, another important physical EaR. Even cattle led on landslide-affected roads in some countries are dynamic EaR of economic value. Current landslide risk assessment work tends to focus on the permanent physical infrastructure categories, in particular buildings and roads. In addition to direct physical damage, however, infrastructure also serves an important economic function that may suffer due to a hazardous event. It is possible to calculate the economic effect of a temporary or permanent disruption of a transport corridor due to landsliding, considering actual amounts and values of transported goods or services, alternative routes, etc. However, this type of economic study is rare and rather local (Guzzetti and Tonelli, 2004). Similarly, it is very difficult to model or calculate the potential or actual losses to protected areas (e.g. national parks), wildlife, biodiversity, or other such EaR, not least because of potential secondary effects, such as on tourism. These different aspects can be investigated in terms of the specific physical, social, environmental, economic or political vulnerability of the present EaR (see SafeLand deliverable D2.5 entitled "*Physical vulnerability of elements at risk to landslides – Methodology for evaluation, fragility curves and damage states for buildings and lifelines*").

1.2.5 Economical and other constraints

Implementing an EWS requires several types of costs and faces several types of constraints; this chapter aims at listing some of them.

1.2.5.1 Monitoring and operational costs

Traditional methodologies for continuous landslide monitoring usually rely on instruments that measure one or more physical features of the terrain in a limited portion of space. Assessments over large areas require consequently either the installation of networks composed by many instruments, or the accomplishment of a field work in which many measures are performed at many discrete points. As a result, when working over large areas, the costs and the time needed to gather the required amount of data may increase dramatically. This point is very important, as cheapness is commonly considered one of the main advantages of traditional techniques, but this judgment can be considered as scale-dependent: even the most up to date remote-sensing techniques may become more affordable, for applications in very large areas. They can for example help to focus detailed field investigations and monitoring on sites that show signs of activity (displacements, small shallow landslides or small rock falls within a larger landslide, decrease in vegetation cover etc.).

Different types of monitoring cost needs to be taken into account in the overall cost. The following are example costs for remote sensing technologies that are described in SafeLand deliverable D4.4 entitled "*Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides*":

- The **costs for input data** is the price of data per spatial unit. In few cases, input data can be even acquired for free. As an instance, the cost for metric cameras can be null as long as historical images are. Moreover, DInSAR image processing which allows, even over large areas, the retrieval of around 20-year displacements of the topographic surface at fairly affordable costs. The opposite edge of the range of the input data costs is occupied by airborne LiDAR: very high density point clouds (60 points/m^2) typically cost about 7k€/ m^2.
- **Additional costs for rapid response** are minimal or inexistent for ground based passive optical sensors and for most part of the airborne ones. Ground based and airborne active optical sensors typically require a more marked increase of the costs in case of rapid response. For passive space-borne data the additional costs are even greater, but they could be obtained for free with the activation of the International Charter Space and Major Disasters.
- **Additional costs for processing**, software acquisition and instruments installation vary significantly even between different methods of employment of the same technology. As an example, the processing cost of permanent scatterers ranges from 2,000€/100km^2 (retrospective analysis for up to 7 years over large areas) to 35,000€/100km^2 (retrospective analysis for up to 7 years over small areas). Spaceborne technologies also exist which have reduced processing costs: some

satellites data can even be processed with free software. On average, ground-based passive optical sensors have the most reduced processing costs, since often just a camera calibration is needed.

In addition to the direct cost related to the monitoring technologies, there are other costs that should be covered:

- **Maintenance costs** are the financial allocations necessary to maintain the system over its life time.
- **Communication costs** for the data transmission and people communication**.**
- **Resource costs** are the expenses required to fully operate an EWS. Normally this will be connected to experts using the EWS, interpreting data. It is also connected to the cost of obtaining a sufficient level of education and preparedness to allow the EWS to function with the community to be able to be effective in an evacuation system.
- **Costs due to critical situations** such as for an evacuation for example, are uneasy to predict but should be taken into account.

When implementing an EWS, the total life time cost of the system should be addressed. This may be performed for example by adding the net present value of both direct and indirect cost then evaluating the total **life cycle cost** (LCC) of the system. Several landslide EWS have been stopped in the past for lack of funding, and this events should be avoided as much as possible as they cause much frustration and distrust in the population.

1.2.5.2 Site accessibility

In mountain regions, the use of ground-based instrumentation to perform a systematic control of natural phenomena is not always possible because of both huge extension and inaccessibility of the investigated areas. Remote-sensing techniques represent therefore a valuable tool for landslide monitoring.

The strict need to be on site may bring other limitations, such as the need of carrying heavy equipment on site, the necessity of electrical power, the overcoming of natural obstacles, the obtainment of bureaucratic permissions. Some of these limitations become particularly crucial when time is a factor (e.g. in emergency scenarios); to this end, it should be also considered that a minimum lead-time is always constituted by the time needed to gather the equipment (and personnel) and for travelling to the site of study. Again, the employment of the most recent remote-sensing techniques allows being immediately operative and in many cases the possibility of performing back-monitoring allows to regain the lost time.

1.2.6 Risk acceptance criteria

A risk estimate alone has limited benefits. To serve as a decision tool, it should be compared with other risk estimates or with risk acceptance criteria defined prior to the analysis. The nature of the risk determines its acceptability. This is associated with for example (Osei et al., 1997):

- Voluntary (e.g. mountain climbing) vs. involuntary (imposed)
- Controllability vs. uncontrollability
- Familiarity vs. unfamiliarity
- Short vs. long-term consequences

- Presence of existing alternatives
- Type and nature of consequences
- Derived benefits
- Presentation in the media
- Information availability
- Personal involvement
- Memory of consequences
- Degree of trust in regulatory bodies
- Other aspects

Voluntary risk tends to be higher than involuntary risk. If under personal control (e.g. driving a car), the risk is more acceptable than the risk controlled by other parties. For landslides, choosing to live close to a natural slope is a voluntary risk, while having a slope engineered by the authorities close to one's dwelling is an involuntary risk. Societies that experience geohazards frequently may have a different risk acceptance level than those experiencing them rarely. Risk perception is a complex issue. Figure 6 illustrates how perceived and "objective" risk can differ. Whereas the risk associated with flooding, food safety, fire and traffic accidents are perceived in reasonable agreement with the "objective" risk, the situation is very different with issues such as nuclear energy and sport activities.

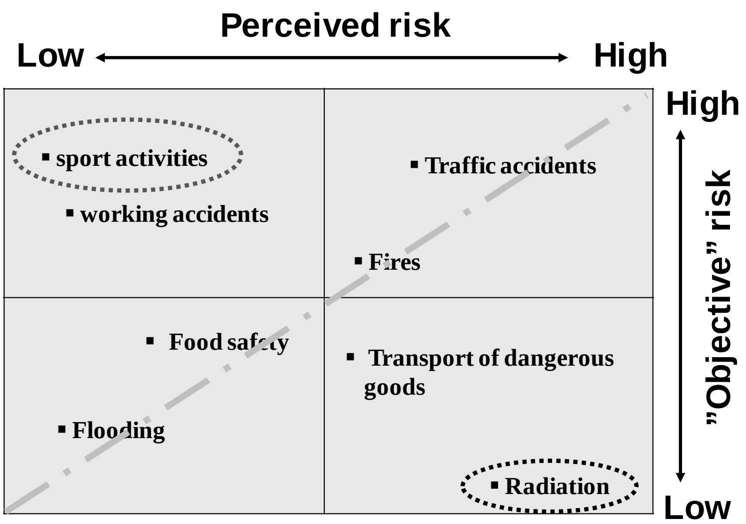


Figure 6: Perceived versus "objective" risk (Geldens Stichting, 2002).

IUGS (1997) listed some common general principles that can be applied when considering tolerable risk criteria:

- The incremental risk from a hazard to an individual should not be significant compared to other risks to which a person is exposed to in everyday life.
- The incremental risk from a hazard should, wherever reasonably practicable be reduced.
- If the possible loss of life from a landslide incident is high, the risk that the incident might actually occur should be low. This accounts for society's particular intolerance to incidents that cause many simultaneous casualties, and is embodied in societal tolerable risk criteria.
- Persons in society will tolerate higher risks than they regard as acceptable, when they are unable to control or reduce the risk because of financial or other limitations.

- Higher risks are likely to be tolerated for existing slopes than for planned projects, and for workers in industries with hazardous slopes, e.g. mines, than for society as a whole.

There is a distinction between "acceptable risk" and "tolerable risk":

- **Acceptable risk** is a risk which everyone impacted is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.
- **Tolerable risk** is a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible, and needing to be kept under review and reduced further if possible. For risk within the tolerable limit (but above the acceptable risk) the ALARP (As Low As Reasonably Practicable) principle is applied. The ALARP principle states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly in disproportion (depending on the level of risk) to the improvement gained.

Risk assessment criteria may relate to loss of life, financial and socio-environmental values. Each of these may be considered in several ways (Leroi, 2005;Leroi et al., 2005):

- Loss of life:
  - Individual risk
  - Societal risk
  - Annualized potential loss of life
  - Cost to save a life
- Financial:
  - Cost benefit ratio
  - Financial capability
  - Annualized cost
  - Corporate impact
  - Accidents per million tons of freight hauled

Several countries have risk accept criteria for individual risk and societal risk:

- **Individual risk**

The individual risk is the probability of an individual losing its life due to the hazard within a given period of time (most commonly within a year). Thus the dimension of the individual risk is a temporal probability. Examples of individual risk criteria for Australia and Hong Kong are given in Table 1.

Table 1 Individual life loss risk criteria

Country/Organization	Description	Risk/annum	Reference
Australian Geomechanics Society guidelines for landslide risk management	Suggested tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum public most at risk, new slope	(AGS, 2000)
Hong Kong Special Administrative Region Government	Tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum public most at risk, new slope	(ERM, 1998)

- **Societal risk**

Societal risk is defined as the risk of widespread or large scale detriment from the realization of a defined risk, the implication being that the consequence would be on such a scale as to provoke a socio/political response. In this perspective, risks having low hazard and high consequence are taken into account. For societal risk, the unit of risk is the loss of life/yr. Societal risk is generally expressed by F-N curves, which display frequency and consequence of events. Frequency (F) of events causing at least N fatalities is plotted against N in a log-log diagram. Figure 7 shows two examples of F-N curves including the risk acceptance criteria for landslides in Hong Kong. The term "N" can be replaced by other quantitative measure of consequences, such as costs. The curves can be used to describe the safety levels of particular facilities. Man-made risks tend to have a steeper curve than natural hazards in the F-N diagram (Proske, 2004). On the log-log F-N diagram, lines with slope equal to 1 are curves of equi-risk (the risk is the same). A slope greater than 1 reflects risk aversion, where society is less tolerant when a large number of lives are lost in a single event, than if the same number of lives is lost in several separate events. An example is the public concern at the loss of large numbers of lives in airline crashes compared to the much larger number of lives lost in separate road traffic accidents.

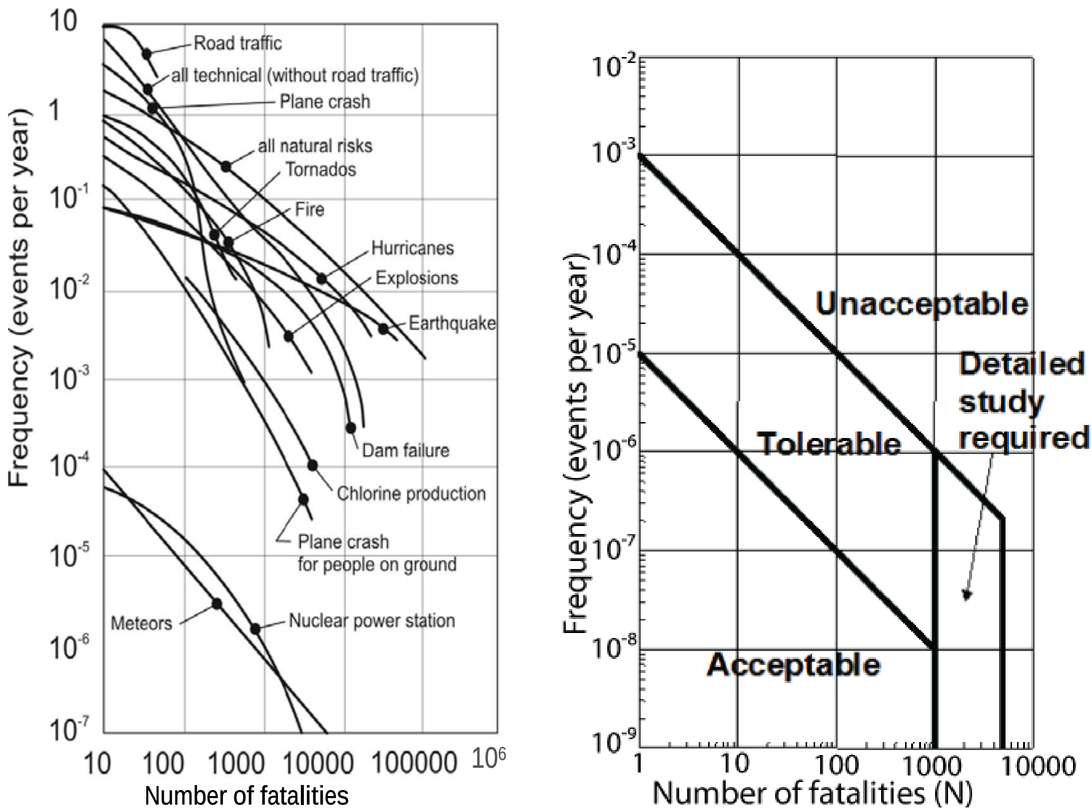


Figure 7: Examples of F-N curves. Left: US Nuclear Regulatory Commission (Proske, 2004). Right: Societal risk criteria for landslides in Hong Kong (GEO, 1998).

1.2.7 Key Actors

Developing and implementing an effective EWS requires the contribution and coordination of a diverse range of individuals and groups. UN-ISDR (2004) compiled a list that provides a brief explanation of the types of organizations and groups which should be involved in an EWS and their functions and responsibilities:

- **Communities**, particularly those most vulnerable, are fundamental to people-centred EWSs. They should be actively involved in all aspects of the establishment and operation of EWSs; be aware of the hazards and potential impacts to which they are exposed; and be able to take actions to minimize the threat of loss or damage.
- **Local governments**, like communities and individuals, are at the centre of effective EWSs. They should be empowered by national governments, have considerable knowledge of the hazards to which their communities are exposed and be actively involved in the design and maintenance of EWSs. They must understand advisory information received and be able to advice, instruct and engage the local population in a manner that increases public safety and reduces the possible loss of resources on which the community depends.
- **National governments** are responsible for high-level policies and frameworks that facilitate early warning and for the technical systems that predict and issue national hazard warnings. National governments should interact with regional and international governments and agencies to strengthen early warning capacities and ensure that warnings and related responses are directed towards the most vulnerable populations. The provision of support to local communities and governments to develop operational capabilities is also an essential function.
- **Regional institutions and organizations** play a role in providing specialized knowledge and advice which supports national efforts to develop and sustain early warning capabilities in countries that share a common geographical environment. In addition, they encourage linkages with international organizations and facilitate effective early warning practices among adjacent countries.
- **International bodies** can provide international coordination, standardization, and support for national early warning activities and foster the exchange of data and knowledge between individual countries and regions. Support may include the provision of advisory information, technical assistance, and policy and organizational support necessary to aid the development and operational capabilities of national authorities or agencies.
- **Non-governmental organisations** play a role in raising awareness among individuals, communities and organizations involved in early warning, particularly at the community level. They can also assist with implementing early warning systems and in preparing communities for natural disasters. In addition, they can play an important advocacy role to help ensure that early warning stays on the agenda of government policy makers.
- **The private sector** has a diverse role to play in early warning, including developing early warning capabilities in their own organizations. The media plays a vital role in improving the disaster consciousness of the general population and disseminating early warnings. The private sector also has a large untapped potential to help provide

skilled services in form of technical manpower, know-how or donations (in-kind and cash) of goods or services.

- **The science and academic community** has a critical role in providing specialized scientific and technical input to assist governments and communities in developing EWSs. Their expertise is central to analysing natural hazard risks facing communities, supporting the design of scientific and systematic monitoring and warning services, supporting data exchange, translating scientific or technical information into comprehensible messages, and to the dissemination of understandable warnings to those at risk.
- **The media** plays a vital role in improving the disaster consciousness of the general population and disseminating early warnings.

2 OVERVIEW OF EXISTING LANDSLIDE EWS IN OPERATION

2.1 INTRODUCTION

The project SafeLand is intended to develop generic risk management tools and strategies for landslides. A screening study was completed in order to provide guidelines that will help and facilitate the establishment of new EWSs and to increase the quality of existing systems. Consequently, one of the first steps is to merge actual knowledge and expert judgments. Thus, as part of this study, we gathered experiences from organizations in charge of landslide EWSs and risk management in order to compile information about the state of the art technologies and existing strategies.
To ensure those objectives, a questionnaire was produced by ICG and UNIL (c.f. Appendix A in this document) and improved with pertinent remarks from ÅTB who designed 5 EWSs in Norway. Then it was sent in June 2011 to about hundred organizations in charge of one or several EWS (Quote 1). Divided in 5 numbered parts, the questionnaire collected information about:

1. General information on the unit in charge of the EWS;
2. Monitored landslide situations;
3. Pre-investigations used to design the EWS;
4. Monitoring parameters, thresholds and sensors evaluation;
5. Warnings, communication and decision making process.

Finally, 14 institutions from 8 countries sent the questionnaires back to UNIL during the summer and autumn 2011, speaking about 23 landslides. The following section compiles and summarizes the most interesting answers of the questionnaire, according to the five parts.

Oslo and Lausanne, the 23rd of June 2011.

Subject: Invitation to participate to a screening survey about landslides Early Warning Systems

To whom it may concern,

The large, integrating project SafeLand, funded by the European Commission in the 7th Framework Programme, is intended to develop generic risk management tools and strategies for landslides. SafeLand is a collaborative project between 27 partners from 12 countries and coordinated by the International Centre for Geohazards (ICG) in Oslo, Norway. One of the main objectives of the Safeland project is to merge experience and expert judgment and therefore to create synergies on EC-level and to make these results available to end users and local stakeholders. More information on this project is available at www.safeland-fp7.eu.

As part of this study, we are gathering information about the responsible organizations for landslide early warning system and risk management in selected countries. You have been identified on internet or by colleagues as an organization in charge of one or several Early Warning System(s). Thus, we would very appreciate that you fill the attached form. This short (four-page) questionnaire aims to compile information about the state of the art technologies and existing strategies. The intention of this screening study is to provide guidelines that will facilitate the establishment of new Early Warning Systems. Additional information could be sent as attached documents. As our project is limited in time, we would very much appreciate if you return this form before the 15th of September 2011 to safeland@igar.org.

Do not hesitate to spread this questionnaire to other people involved in Early Warning Systems. Of course, if you have any additional question, do not hesitate to contact us. We look forward to receiving your information.

Sincerely yours,

Sara Bazin for SafeLand Project Coordinator, Norway
Clément Michoud and Prof. Michel Jaboyedoff, for University of Lausanne, Switzerland
safeland@igar.org

Quote 1 : Invitation sent in June 2011 to more than 100 organizations identified as in charge of landslides monitoring and/or EWSs.

2.2 GENERAL INFORMATION ON THE UNIT IN CHARGE OF THE EWS

As introduced before, the answers to the questionnaire came from 14 institutions of 8 different countries in charge of landslides monitoring and/or EWSs. Indeed, there are from:

1. Canada : the *Alberta Geological Survey* and the *Université Laval*;
2. Czech Republic: the *Geo-Tools* office and the *National Park Bohemian Switzerland*;
3. France: the *Calvados Préfecture* and the *Institut de Physique du Globe de Paris à la Martinique (French West Indies)*;
4. Hong-Kong (Chinese province): the *Geotechnical Engineering* office;
5. Italy: the *Centro Monitoraggio Geologo Lombardia*, the *Servizio Geologo Aosta* and the *Università degli Studi di Firenze*;
6. Norway: the *Åknes/Tafjord Beredskap (ÅTB)* and the *Nebbet Monitoring Centre*;
7. Slovakia: the *State Geological Institute of Diunyz Stur*;
8. Spain: the *Universitat Politècnica de Catalunya*.

Operating mostly at national and regional levels, all these institutions are totally financed by public funds, except one which also received private resources. Needing every year about 160 000 € in average (with a minimum of about 59 000 € for the Hong-Kong Geotechnical Office and a maximum of about 500 000 € for the Centro Monitoraggio Geologico Lombardia) to be operational, these units employ between 0 (universities) and 15 people (IPGP - Martinique) dedicated to EWS. Furthermore, two thirds of them have to monitor other natural processes, such as earthquakes and/or weather conditions. We also noted that yearly costs are difficult to estimate and/or still taboo since only 7 institutions answered to this question.

1. GENERAL INFORMATION ON THE UNIT IN CHARGE OF THE EWS

Name of the operational unit	14 UNITS		
Country	8 COUNTRIES	Location	CA, CZ, FR, HK, IT, NO, SK, SP
Person in charge of the operational unit	Name		
	Email address		
Level of operational unit	[5] National [8] Regional [0] Local [1] Private		
Source of funding	13 PUBLIC / 1 MIXED	Yearly cost of unit	MEAN : ~160'000 EUR
Are there any codes for EWS in your country?	[1] Yes [7] No	Are there any guidelines for EWS in your country?	[1] Yes [7] No
Is the unit also responsible for monitoring other than landslides?	[10] Yes [4] No If yes, specify [2] volcanoes [3] earthquakes [2] tsunamis [5] weather [2] other (specify):	Number of monitored landslides with implemented EWS?	32
		Number of monitored landslides without EWS?	252
Scale of landslide	[9] Single slide [5] Multiple slide [2] Regional slide		
Are the warning systems in operation?	[11] Yes [3] No	If not, is it: [0] planned [1] under construction [1] damaged [1] stopped	
Number of persons employed at the unit	MEAN : ~6	A person is present on duty 24/7 [2] Yes [12] No A person is on call 24/7 [12] Yes [2] No	
Confidentiality/ Access to data	[5] Public (full access of general data (e.g. Topography, geology, structural, borehole, hazard/risk etc.), detailed monitoring data accessible on request) [9] Not Public (specify whether authorization is already available/requested):		
Web site	/		

Figure 8 : Compiled answers related to general information on the units in charge of the EWS.

Regarding in details landslides issues, the first main conclusion is simply obvious: operational units in charges of EWS have to look for scientific and practical supports thanks to collaborations with other expert groups, and/or reading international recommendations. Actually, from the 8 participating countries, only Norway legislated on EWS in order to define the roles of institutions in charge on landslides EWS and to direct them and only Slovakia produced a guideline about general strategies to adopt. Finally, the second conclusion is also clear: monitoring centers are in charge of sensitive and complex data. Indeed, even if they are all partially or totally financed by public funds, they still do not open a free and easy access to data for local populations. It can be also a question about letting the public having access to raw data that can be difficult to interpret due to much noise. This could certainly led to major misunderstandings and unnecessary concerns.

2.3 MONITORED LANDSLIDES

Part 2 relates to the different types, mechanisms and previous activities of the monitored landslides (Figure 9). This include a wide specter of landslides, from small rock falls of less than 10 m^3 and regional shallow earth slides or debris flows, to large rockslides of 54 million m^3. The monitored landslides considered here are mainly related to natural slopes.

2. MONITORED LANDSLIDES

Please fill this table for each landslide that you monitor

Name of the site:	23 LANDSLIDES		
Slide has occurred yet?	[19] Yes [3] No (slide prone)	If yes, potential for future sliding?	[22] Yes [0] No
Type of landlside	[14] rock [6] debris [6] earth [0] other (specify):	Type of slope	[19] natural cliff [3] quarry or mine [3] redesigned slope [0] other (specify):
Triggering mechanism	[17] rainfall [0] earthquake [4] erosion [4] human activity [6] other (specify):	Volume of landslide m^3	10 < 8'000'000 < 54'000'000

Elements at risk, specify and quantify for each case	[14] buildings (private, public…) [20] infrastructure (railways, roads, bridges, power lines…) [12] people (inhabitants, workers, tourists…) [8] indirect risk (tsunami, flooding…) [1] other (specify):

Human losses (death and injuries) due to previous events	[3] Yes	[20] No	If yes, quantify: SUM: 131 FATAL INJURIES
Economic loss due to previous events	[10] Yes	[12] No	If yes, quantify in €: SUM: 602'000 EUR / MEAN: 200'000.-
Social consequences due to previous events	[9] Yes	[13] No	If yes, specify: INJURIES, ISOLATION, TRAUMA, NEW BUILDING CODES
Mitigation (already performed or envisaged)	[9] Yes	[13] No	If yes, describe (structural/non-structural): EWS, PURGES, RETAINING WALL, BASINS
Land planning already established for the case	[15] Yes	[5] No	If yes, specify: LAND-USE RESTRICTION, CIVIL PROTECTION PLAN

Figure 9 : Compiled answers related to monitored landslide situations.

Even if only 23 landslides do not represent a high statistical significance, we begin in this chapter to extract interesting statistic that should be confirmed with a higher number of answers. The recorded landslides triggered by rainfalls, snowmelt, permafrost, erosion, anthropogenic activities, tectonic, and/or intrinsic dynamic issues. For more than 44% of the monitored instabilities, they are mainly triggered by rainfalls (Figure 10). Furthermore, considering the four physical agents responsible of slope destabilizations identified by Terzaghi (1950), i.e. (1) material transport, (2) tectonic stresses, (3) water, and (4) weight of slope-forming material, the agent *water* is incontestably the most important one, being a destabilizing factor for more than 87% of the slopes (Figure 11).

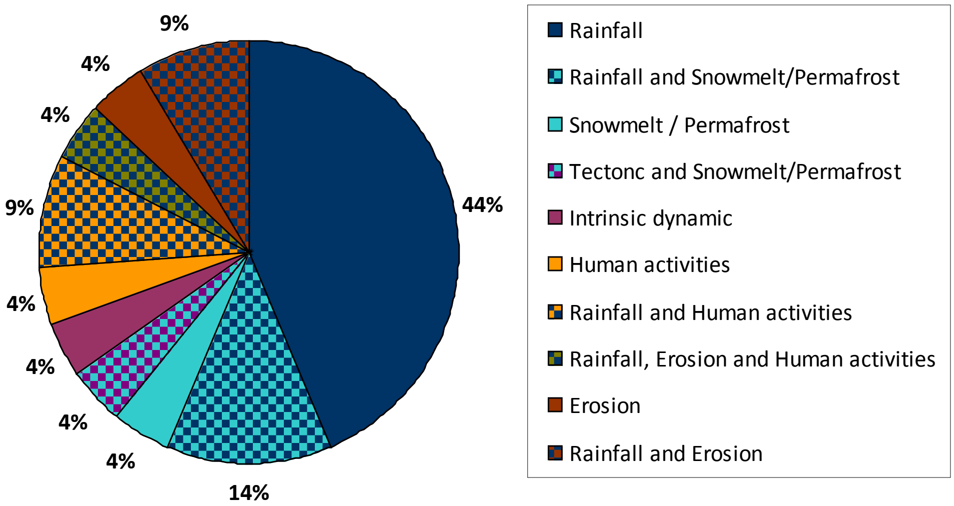


Figure 10 : Triggering mechanisms of the total of the 23 monitored landslide situations.

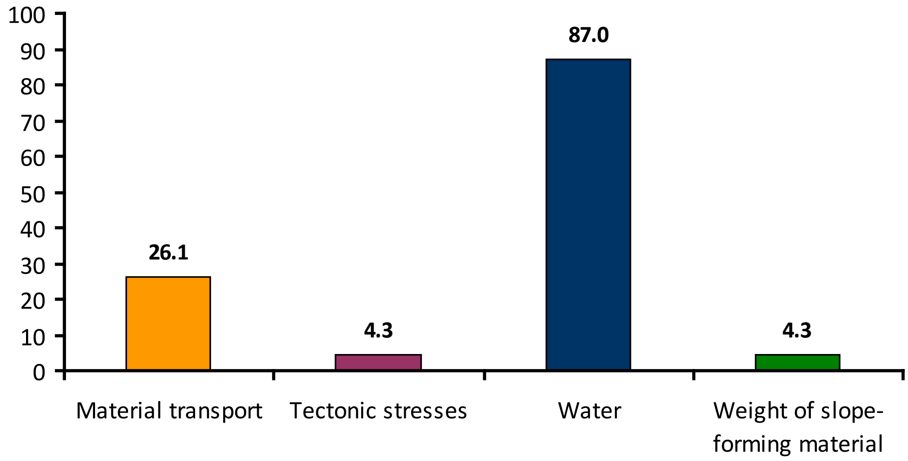


Figure 11 : Percentage of the physical agents being a destabilizing factor for the monitored landslide situations. The total percentage is over than 100, due to multiple factors.

Obviously, an EWS is setup only if there is a risk (Figure 12). Up to now, these 23 landslides threaten essentially transport infrastructures (for 87% of them), buildings (for 60.9% of them) and people (for 52.2% of them). They can still have indirect consequences (for 34.8% of them), due to rockslide-induced tsunamis for example. In the past, the previous events caused huge economic losses that are difficult to quantify now and had important social consequences with injuries, trauma, etc. Indeed, burying and destroying roads and even villages, these landslides isolated populations and killed more than 131 people: in Turtle Mountain (Canada), the rock avalanche buried directly about 90 citizens; in 1934 in Tafjord (Norway), an instability indirectly killed 40 people after a tsunami-induced rockslide destroyed several small villages along the fjord.

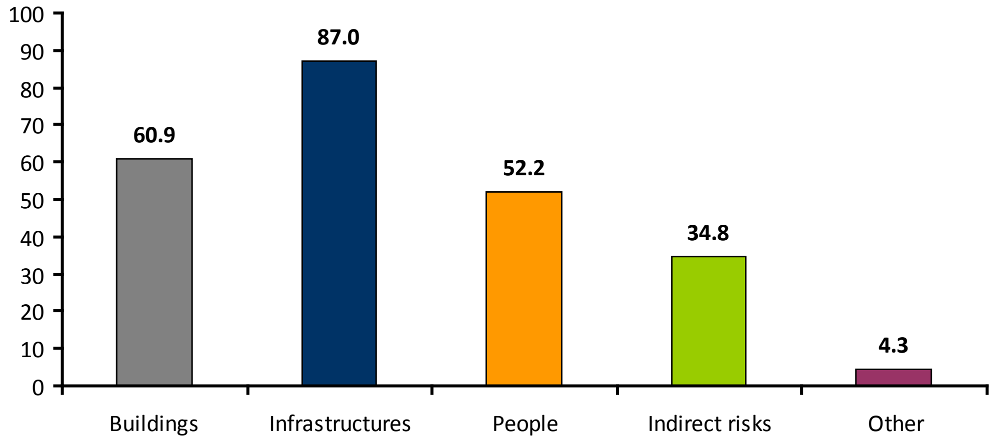


Figure 12 : Percentage of landslides that endanger buildings, infrastructures, people or cause indirect risks and other issues. The total percentage is over 100, because instabilities can threaten more than one element.

In order to prevent new catastrophic events, some mitigation works have been realized when the context and/or the size of the instability allowed it, such as retaining walls, purges and retaining basins for debris flows. Moreover, land planning has been established for 75% of the monitored landslides, creating mainly land-use restriction and civil protection plans. Nevertheless, EWSs can also be considered (but not in this questionnaire) as the main non-structural mitigation measure that all operational units have deployed.

2.4 PRE-INVESTIGATIONS USED TO DESIGN THE EWS

Part 3 relates to pre-investigation works made before the design of the EWS (Figure 13). Indeed, several criteria have to be taken into account in order to well understand landslides and de facto setup a robust and relevant monitoring system.

3. PRE-INVESTIGATIONS USED TO DESIGN THE EWS

Was geology or geomorphology a design criterion?	18 Yes 5 No	If yes, specify: FIELD MAPPING MAINLY
Were geophysical data a design criterion?	10 Yes 13 No	If yes, specify (technique, profiles, scale etc.): RESISTIVITY, SEISMIC MAINLY
Was hydrogeology a design criterion?	12 Yes 11 No	If yes, specify (piezometers, suction etc.): PIEZOMETER & PLUVIOMETERS MAINLY
Were geotechnical data used to design the EWS?	In situ data: 10 Yes 13 No	If yes, specify (type of test, drilling depth, location, maps availability etc.): CORE DRILLING & TEST
	Lab data: 4 Yes 19 No	If yes, specify (type and number of tests, material tested): SHEAR TESTS
Were surface movement data used to design the EWS?	14 Yes 9 No	If yes, specify type (technique), scale and date: CF. NEXT PART
Was modeling used to design the EWS?	12 Yes 11 No	If yes, specify type (technique): STABILITY CONDITION, RUNOUT, TSUNAMI MAINLY

Figure 13 : Compiled answers related to pre-investigation used to design the EWS.

The most important criteria used to design the EWS (Figure 14) are the geological and geomorphological features (for about 82% of the investigations), completed by surface displacements data (for about 64% of the investigations). Indeed, a geological and geomorphological mapping is decisive in order to understand the total landslide system and its behavior; identifying back scarps, open fractures, sliding planes, compression areas, evidences of recent activities, etc. Moreover, investigating surface displacement data, the qualitative activity state determined during the field mapping can be confirmed and improved in a quantitative way. The geomorphic and geological maps together with the displacement field are essential in order to design and located the sensor network and instrumentation. As illustrated on the Figure 15, the monitoring network on the Mannen rock slide in Norway is based on instrumentation in the accessible areas on top close to the open fractures and back scarps, and a ground-based system in the valley to cope with the inaccessible step lower parts.

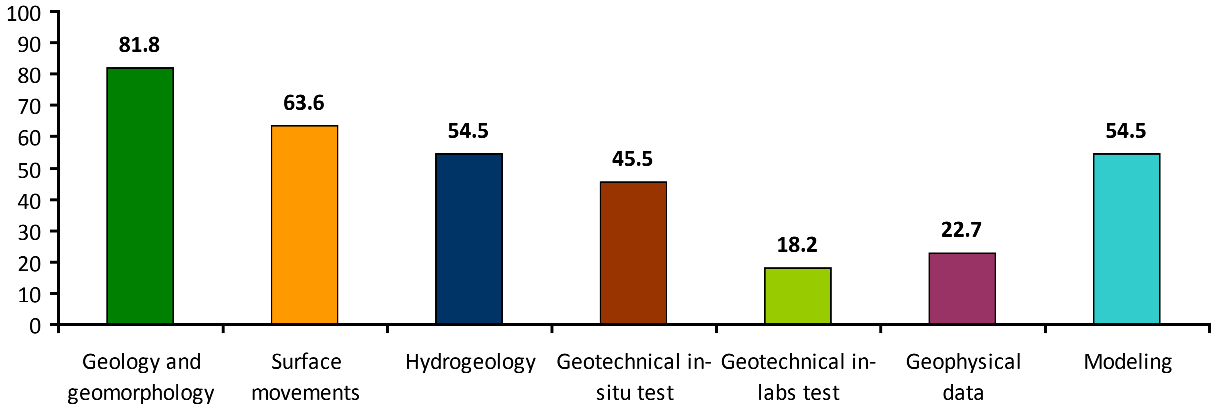


Figure 14 : Percentage of pre-investigation criteria performed to design the EWS of the 23 monitored landslide situations. The total percentage is over 100, because many works required the investigation of several criteria.

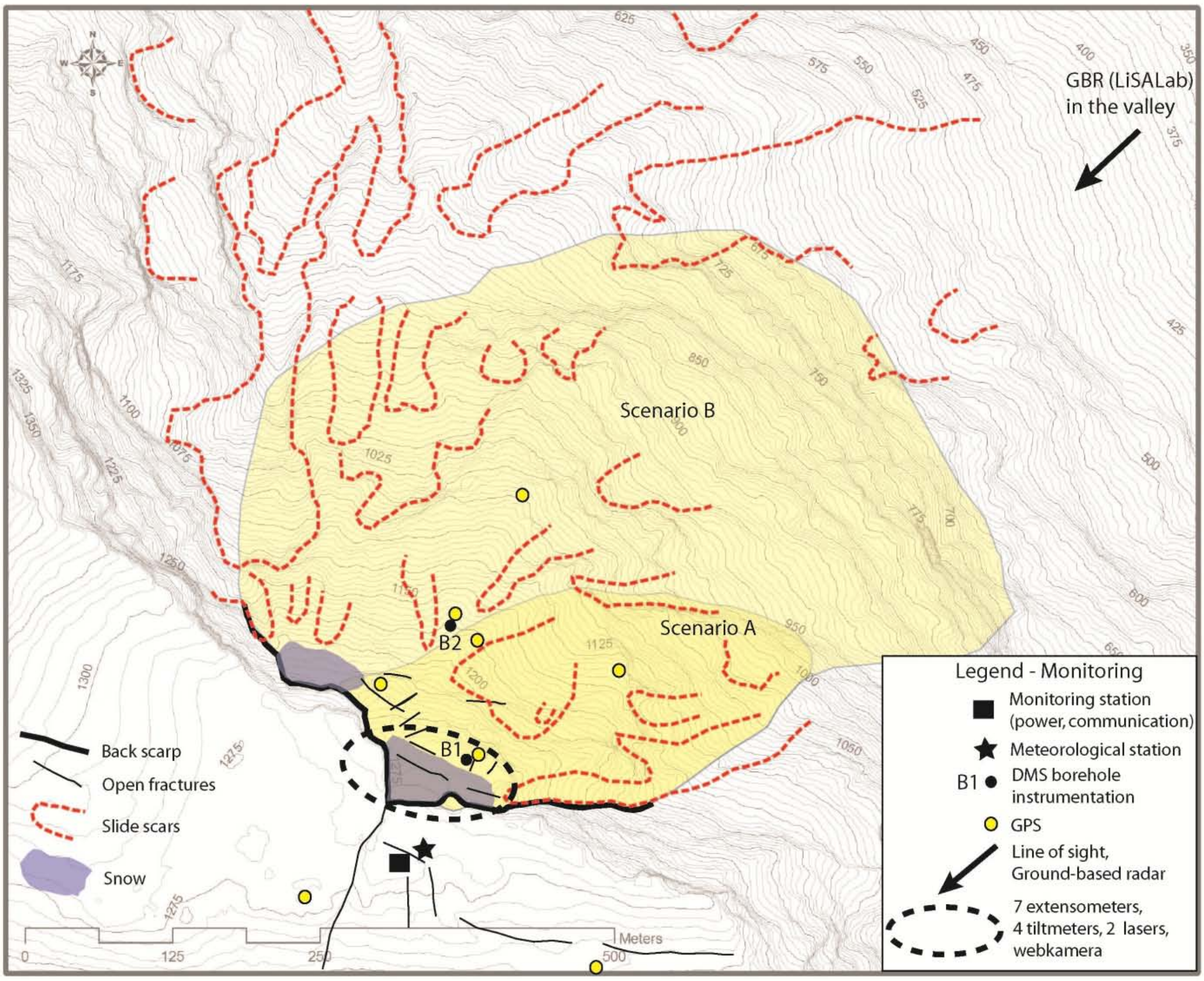


Figure 15 : In the Mannen rock slide (Norway), the monitoring network is concentrated next to the open fractures and back scarps identified during previous field works (courtesy of ÅTB).

Surprisingly, hydrogeology is only studied for half of the cases (Figure 14), whereas the water is the physical agent that contributes to destabilize 87% of the monitored slopes (Figure 11). Models are calculated for more than 50% of the investigated landslides, in order (1) to map potential runout areas of rock falls/avalanches as well as tsunami-induced rock slides, and (2) to compute stability factors for the instabilities. Geotechnical in-situ tests are often performed during drilling campaigns, such as the Standard or Cone Penetration Tests (SPT and CPT), to provide information on geomechanical properties of the slope. Finally, geophysical measures (mainly 2D electrical resistivity and seismic refraction) and geotechnical in-lab tests are less used than the other criteria.

It is also interesting to mention the importance of a multi-criteria approach during the pre-investigations period. Indeed, EWS are often designed taking into account more than one criterion. Thus, as shown in the Figure 16, operational units have mainly investigated between 4 and 6 criteria (for 57% of the landslides), since using one specific criterion is an approach used only in particular cases, such as the investigation of hydrogeological conditions in debris flows contexts for example.

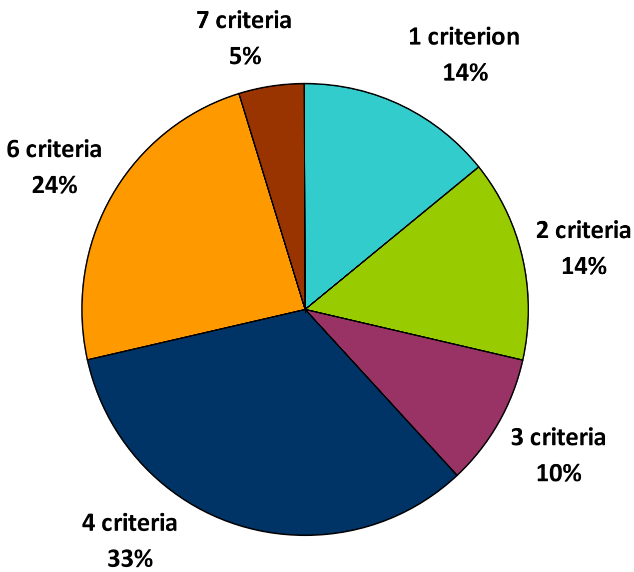


Figure 16 : Percentage of number of criteria investigated to design the EWS of the monitored landslides.

Regarding the particular case of the *Geotechnical Engineering* office, they are investigating shallow landslides induced by rainfalls for the whole Hong-Kong province's scale. Thus, they have built a regional system based on statistical analysis of rainfalls and shallow landslides data. This section of the questionnaire is de facto not applicable and no conclusions have been obtained from this case.

2.5 MONITORING PARAMETERS, THRESHOLDS AND SENSORS EVALUATION

Part 4 relates to the instruments used to monitor landslides (Figure 17). It is based on a table about instrumentation and number of sensors, thresholds, duration, frequency of measures, qualitative reliability, etc. But our partners had some difficulties to fill it and we mainly received information regarding only instrument types, numbers of sensors installed and threshold used for 21 monitored landslides. Nevertheless, interesting statistics can still be extracted.

4. MONITORING PARAMETERS, THRESHOLDS AND SENSORS EVALUATION

Please provide for each landslide or selected landslides, a map as attached file and a description of the monitoring system using the following table:

NUMBER OF LANDSLIDES MONITORED BY:

Monitoring parameter	Threshold level	Sensor type	Sensors number	Sensor reliability	Active	Duration	Frequency	MM indicator	EW parameter
CRACKMETER:	7		TOTAL STATION:	3		GEOPHONES:	4		
GNSS:	9		DMS:	2		PLUVIOMETER:	11		
LASER:	4		TILTMETER:	2		HUMIDITY:	1		
GB-INSAR:	4		INCLINOMETER:	3		TEMPERATURE:	3		
INSAR:	1		PIEZOMETER:	5		WIND:	2		
EXTENSOMETER:	10		STREAMGAUGE:	2		BAROMETER:	2		

Explanations:

Monitoring parameter	*phenomenon or factor related to slope/area of interest, which could be quantified and monitored in time*
Threshold level	*a warning is issued when the monitoring parameter reaches this critical value*
Sensor type	*specify type of technology (e.g. 3C broad-band seismometer)*
Sensor reliability	*evaluate the instrument dependability based on time frequency of measurements and down time with values from 1 to 10 (maximum)*
Active	*is the monitoring still in use? (tick = yes)*
Duration	*duration of monitoring in years*
Frequency	*frequency of reading per day (D), month (M) or year (Y), for example 6xD*
Mass-movement (MM) indicator	*monitoring parameter characterizing directly or indirectly the dynamic state of mass-movement processes. Evaluate the parameter with values from 1 to 10 (maximum)*
Early warning (EW) parameter	*mass-movement indicator allowing to detect an impending or existing critical activation or acceleration of the landslide(s) by its threshold. E valuate the parameter as an EW parameter with values from 1 to 10 (maximum)*

List of eventual monitoring parameters related to landslides:

Displacement *(Cummulative, Differential, Acceleration, Velocity, Settlement),* ***Microseismicity*** *(also microcracks/strain),* ***Rockfall event frequency, Macrocracks and surface fissures, Stress*** *(direct measurements),* ***Mass loss/increment balance*** *(areal 3D deformation at individual slopes-based e.g. on TLS or GB-InSAR),* ***Precipitation, Snow cover, Wind velocity, Solar radiation, Air temperature, Ground Water Level, Pore-Water Pressure, Soil Suction, Discharge, Ground/superficial water quality*** *(chem. composition, el. conductivity, pH, etc.),* ***Electrical ground resistivity, Electrical self-potential, Density, Seismic velocity, Temperature*** *(air, water, substrate),* ***IP effect, Dielectric permittivity*** *(GPR repeated measurements for monitoring),* ***Soil humidity, Radon emanation,*** *Factor of Safety (monitoring parameter derived from triggering factors),* ***Regional precipitation*** *(weather forecast for e.g. hurricanes, etc.),* ***Volcanic activity, Regional seismicity*** *(activity/shaking/acceleration).*

Advantages and limitations of your monitoring system	⊕ SIMPLE / ROBUST; MULTIPLE SENSORS / BACK-UPS ‖ ⊖ DAMAGE BY EVENTS / WEATHER; BASED ONLY ON DISPLACEMENTS
How could it be improved?	1. MONITORING MORE PARAMETERS / LOCATIONS 2. BETTER INTEGRATION

Figure 17 : Compiled answers related to monitoring parameters, thresholds and sensors evaluation.

First of all, more than 81% of the EWSs are based on displacement monitoring (Figure 18), certainly because it is the direct evidence of deformation. Then the weather conditions are monitored for more than half of the cases. It is also an essential parameter since rainfalls are a destabilizing factor for more than 80% of the studied landslides (Figure 10). We can also note that for regional shallow landslide EWSs, such as in Hong-Kong, only rainfall forecasts are taken into account to prevent new events. The other monitored parameters are water level in aquifers and rivers (for about 33% of the instabilities), angle change in boreholes (for 19% of them) and seismic activity (for about 14% of them).

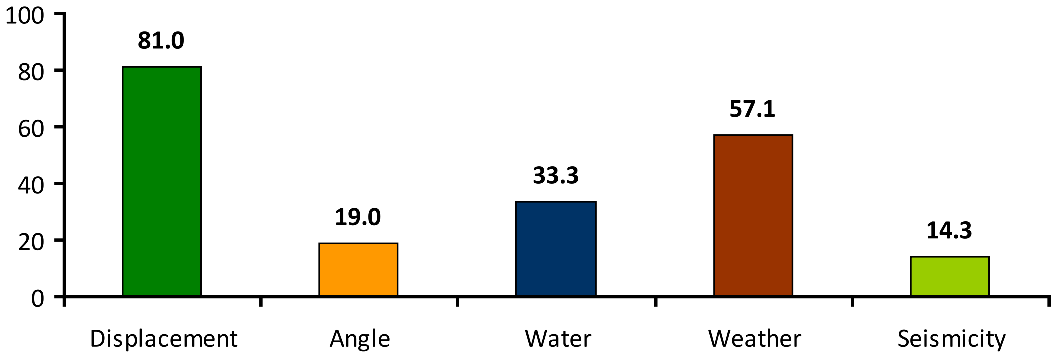


Figure 18 : Percentage of the 21 landslides for which those parameters are monitored. The total percentage is over 100, because several parameters can be monitored per instability.

Regarding the 15 landslides for which we know how threshold values for alert systems are built, the alarms are mainly based on displacement and/or rainfall data (Figure 19). Indeed, 13 landslides (on the 15 for which this information is known) are monitored with displacement data, amongst them 50% are also monitored with rainfall data. Finally, two earthslides in Slovakia use water table level monitored with piezometers as threshold parameters.

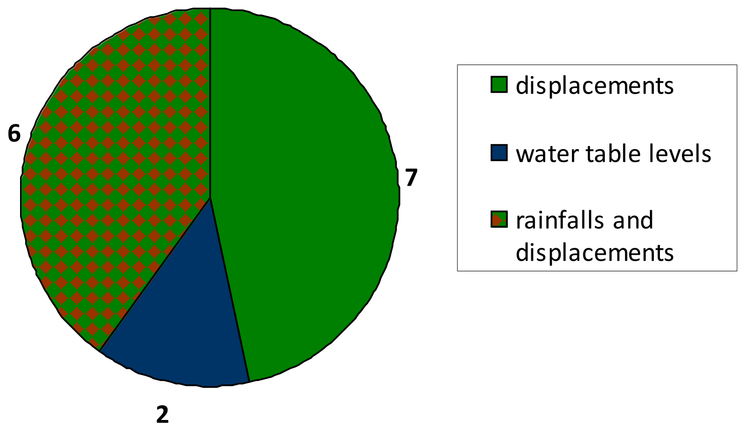


Figure 19 : Number of landslides classified into type of threshold parameters for the EWS.

Regarding the type of sensors used, the important issues that have to be taken into considerations for the design of the monitoring network are (1) the reliability, (2) the robustness, (3) the price, (4) the level of real-time data, (5) the importance for understanding the landslide deformation and (6) the noise level. Also Figure 20 sums up the type of instrumentation used in the analyzed landslides. These monitoring techniques are explained in subchapter 3.1.2.2. The most used ones are the extensometers and the pluviometers (for about 48% of the 21 landslides), the GNSS antennas (for about 43% of them) and the crackmeters (for about 33% of them). It can be explained because those instruments are reliable, robust and cheap. Nevertheless, some instruments as crackmeters become fragile in harsh environments and good protections (for example against snow load and snow creep) have to be built to protect them. Moreover, GNSS antennas are more expensive than other systems and processing their data can be complicated also, but they have the major advantage that they provide 3D displacement information. Conversely, new technologies, such as ground-based radar, lasers, DMS columns and/or geophones, are less often used. Indeed, they are considered as too much expensive as well as too difficult to setup and process data in comparison with simpler techniques that can produce the same type of monitoring (such as an extensometer for example). Moreover, even if subsurface displacements are important to well understand 3D mechanisms, it is important to note that this information is rarely monitored because DMS columns or inclinometers are not often used compared to sensors on surface.

Interesting comments can be added about pluviometers and piezometers. Concerning rockslides, relations between displacements and ground-water table level are important to understand slope dynamics. But direct links between rainfalls and displacements are not always obvious. Then, it could explain why ground water tables are monitored by piezometers coupled with pluviometers when possible (such as for example in *La Saxe* or *Gascon*, contrary to the karstic *Turtle Mountain* which only has pluviometers).
Finally, one landslide is monitored using spaceborne InSAR techniques. Even if it is not a real-time monitoring and de facto cannot be used for alerts, it allows to extract historical dynamic using images from space agencies' archives and to have an overview of the regional stability around the monitored landslide.

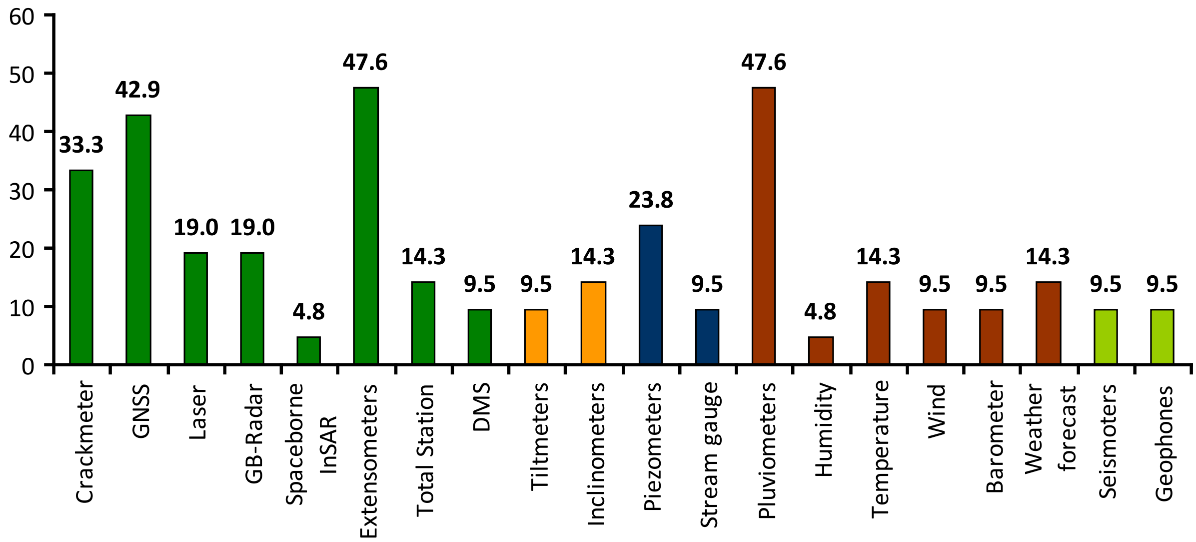


Figure 20: Percentage of the 21 landslides which use those instruments in order to monitor displacement (in dark green), angle changes (in orange), water level conditions (in blue), weather (in brown), and seismic activity (in light green). The total percentage is over 100, because a landslide can be monitored using several instrument types.

The redundancy and the multiplicity of the sensors are judged as a positive point to design an EWS. For example, as shown in Figure 21, in the 7 landslides monitored with crackmeters, the mean number of installed instruments is 13 (with a minimum of 1 and a maximum of 28 sensors). This logic is respected for all cheap and robust instruments which monitor slope displacement, angle changes, and seismic activity (cf. example of the Åknes monitoring network, Figure 22). It allows to (1) monitor different areas that can have differential dynamics and (2) to avoid unwanted false alerts coming from one defective device. On the contrary, to monitor weather conditions, only 1 weather station is usually used since landslides are confined in small areas.

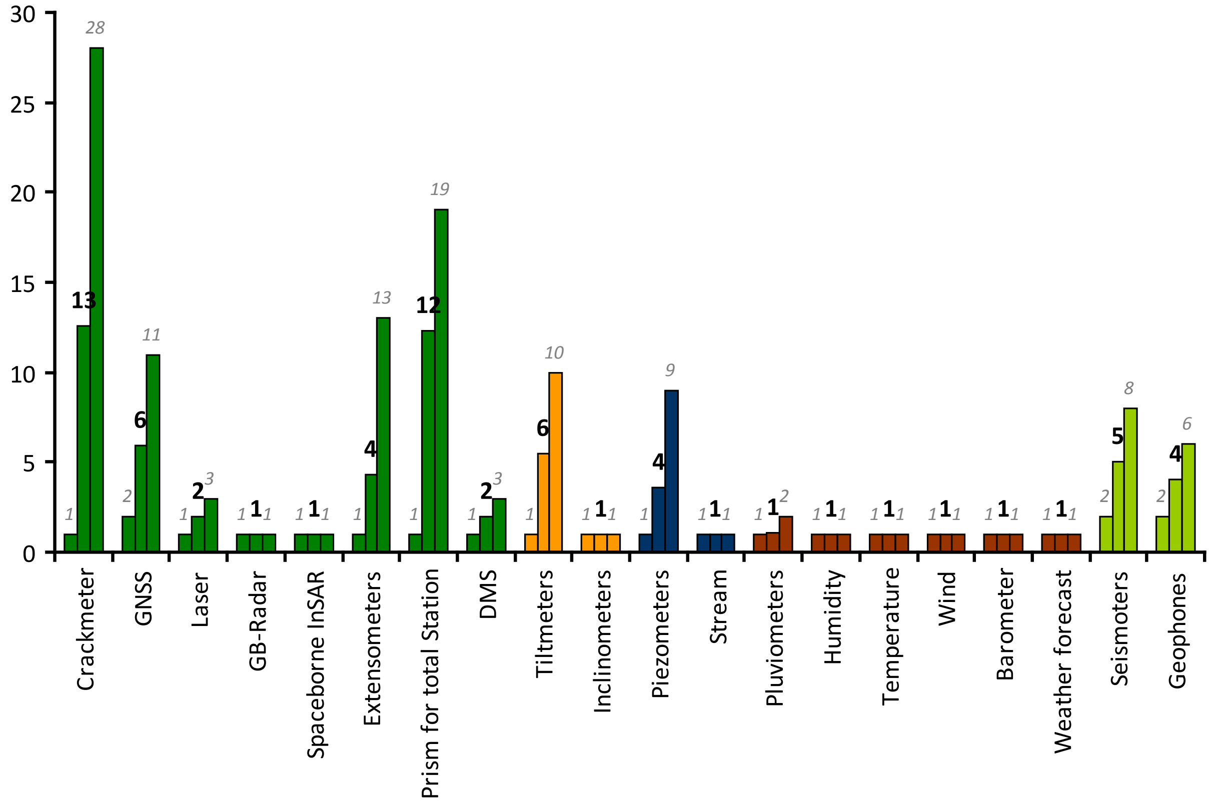


Figure 21 : Minimum, mean and maximum number of instruments per landslide when used.

The last point concerns the power supply and communication back-ups. To be sure that the EWS can succeed in any circumstances, two thirds of the monitoring networks have power supply and communications back-ups for sensors in the field and for the operational centres (Figure 23).

The conclusions on monitoring network are clear: a good system is (1) simple, (2) is robust, (3) has multiple sensors and (4) has power and communication back-ups. On the other hand, a system is limited if it is based only on surface displacements and if it can be damaged by weather conditions and/or the landslide itself before sending alarms to the operational centre. In general, present systems can be improved studying a better integration of all monitored data about displacement, seismic activity, water level, etc.

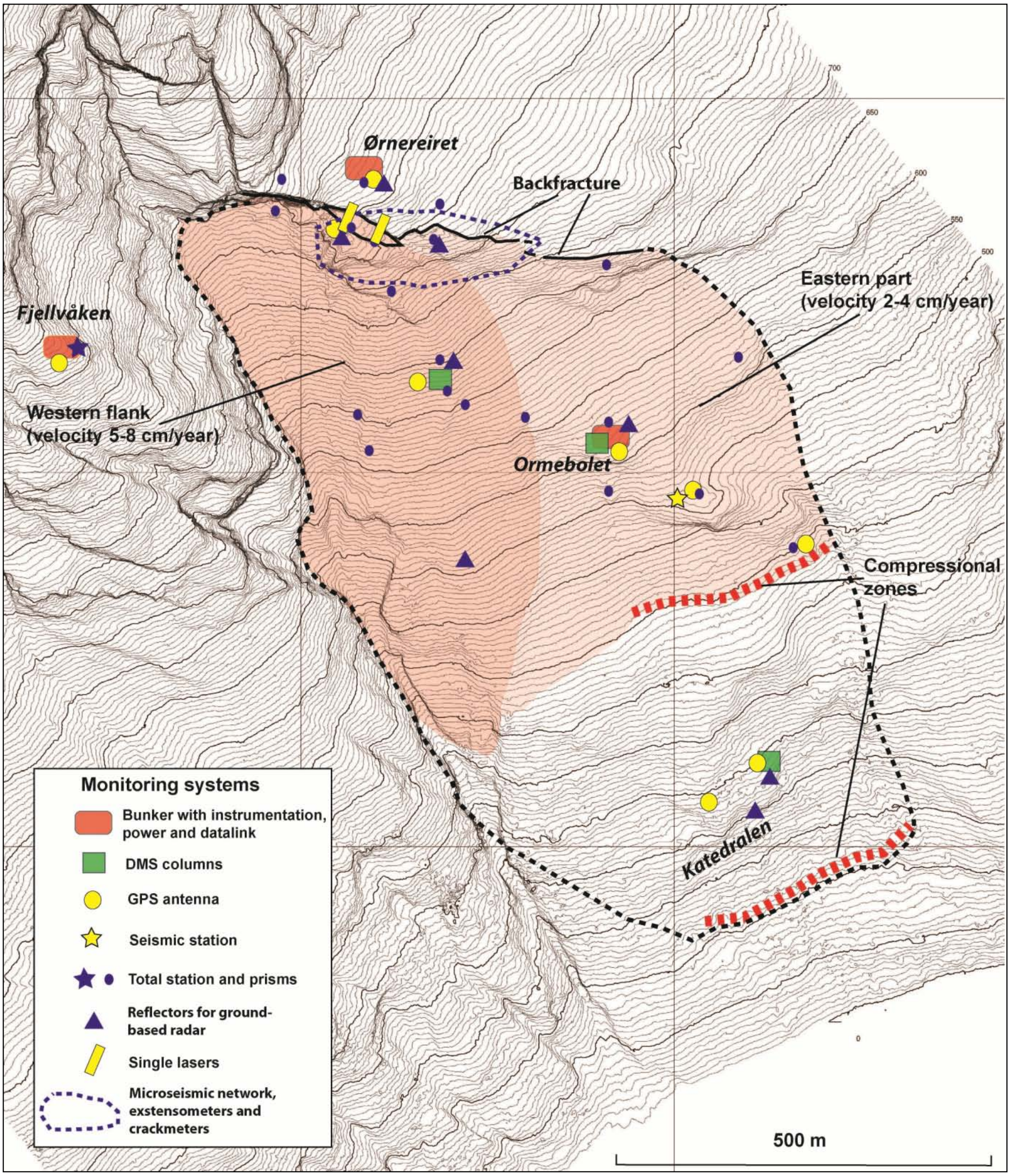


Figure 22 : The location of the multiple and redundant monitoring system in Åknes, Norway (courtesy of ÅTB).

2.6 WARNINGS, COMMUNICATION AND DECISION MAKING PROCESS

Part 5 aims at compiling the main information about warnings, communication and decision making process (Figure 23). In order to protect the endangered populations and/or infrastructures once an event is occurring, threshold values and levels of alerts with associated responses have to be established in advance.

5. WARNINGS, COMMUNICATION, AND DECISION MAKING PROCESS

How is operated the data monitoring?	[22] automatic, then specify by [14] SMS, [1] voice message, [8] e-mail, [3] other [5] manual, then specify the frequency of data check and operator:
Are the warning based on thresholds set on?	[15] single sensors [14] multiple sensors Are thresholds based on minimum resolution and noise level? [8] yes [13] no
Are there any power supply back-ups?	[14] for the sensors [13] for the operational center [15] for the communication
Are there any back-ups for communication?	[15] for the data transfer [20] for the operational center communication (internet, phone,radio…)
Type of software and integrated systems?	WEB-BASED SYSTEM, EXCEL, MATLAB, …
Who designed the alarm chain?	[16] responsible of operational unit [8] local authorities [9] governmental/regional institutions [3] other, specify
Are there several levels of warning?	[13] Yes [8] No [3] Envisaged If yes, specify how it works : /
Do you have different thresholds for different scenarios?	[6] Yes [10] No [3] Envisaged If yes, specify how it works : /
Can you perform direct field observations in case of a warning?	[16] Yes [1] No Is there a procedure to cancel the warning once issued? [9] Yes [4] No If yes, describe:
Procedure in case of a warning?	/
Evacuation time after a warning?	0.1 h < ~41 h < 72 h
How is issued the warning to the population?	[6] siren [7] SMS [6] TV [8] radio [12] other, specify PHONE / INTERNET / TRAFFIC LIGHTS / DOOR TO DOOR
Do you have review procedures?	[15] operational check list [8] report to review group [2] other, specify:
How do you communicate with the public?	[10] public reports specifying status of the landslide, if yes specify frequency: [9] public meetings, if yes specify frequency: [10] public website [6] newspaper [1] other, specify:
Tests and evacuation exercises performed?	[12] Yes [9] No [0] Envisaged If yes, specify extent and frequency: 1 OR 2 EXERCICES PER LANDSLIDE (IF MADE)
What are your practical challenges for the EWS?	[20] installation and maintenance of the sensors [11] installation and maintenance of the operational unit [10] weather conditions [12] site conditions [3] human resources [8] funding [5] population response [ ] other, please specify:
How could the actual EWS be improved?	/

Figure 23 : Compiled answers related to warnings, communication and decision making process.

Automatic alarms from the sensor network prompt the responsible person on duty to inspect and look at the monitored data. Threshold values for defining alarm levels are normally based on the evaluation of different sensors and an expert interpretation of the stability conditions. Indeed, according to Figure 23, thresholds values (defined on displacement and rainfall data as seen in chapter 2.5) are mainly based on multiple sensors to ensure the redundancy and the reliability of the monitored data. Curiously, only less than half of the threshold values take into account minimum resolution and noise levels. Moreover, even if a majority of EWS have several warning levels, only a minority of them have determined several associated scenarios. Once a threshold value is reached, 22 of the 23 monitoring networks automatically notify alerts to operational units, using mainly SMS and/or e-mails services. Then the operator can perform direct field observations in almost all cases and can choose to cancel the warning for two thirds of the systems. Thanks to these automatic notifications and remote field checking, only two units have person present on duty 24/7 and the other 12 centres have only person on call 24/7.

When circumstances require evacuations of local populations, the most used communication systems to inform people are radio, TV, phone and SMS (Figure 24). Lead times are from 10 minutes (in debris flows contexts) to 72 h (in rock slides contexts). In some situations, even sirens can be activated in endangered streets and policemen walk door-to-door to be sure all the inhabitants received the information. Websites and e-mails are less used, because they do not notify immediately to the population the imminent danger. Regarding the closing of road sections, the most frequent system is simple traffic lights, sometimes coupled with the intervention of policemen. In order to ensure the quality and the good progress of the designed system, the procedures have been largely controlled reviewing operational check lists. Moreover, public have been informed of the existence and the operational workflows thanks to public meetings and websites. Furthermore, evacuation exercises have been performed once or twice for 7 EWSs.

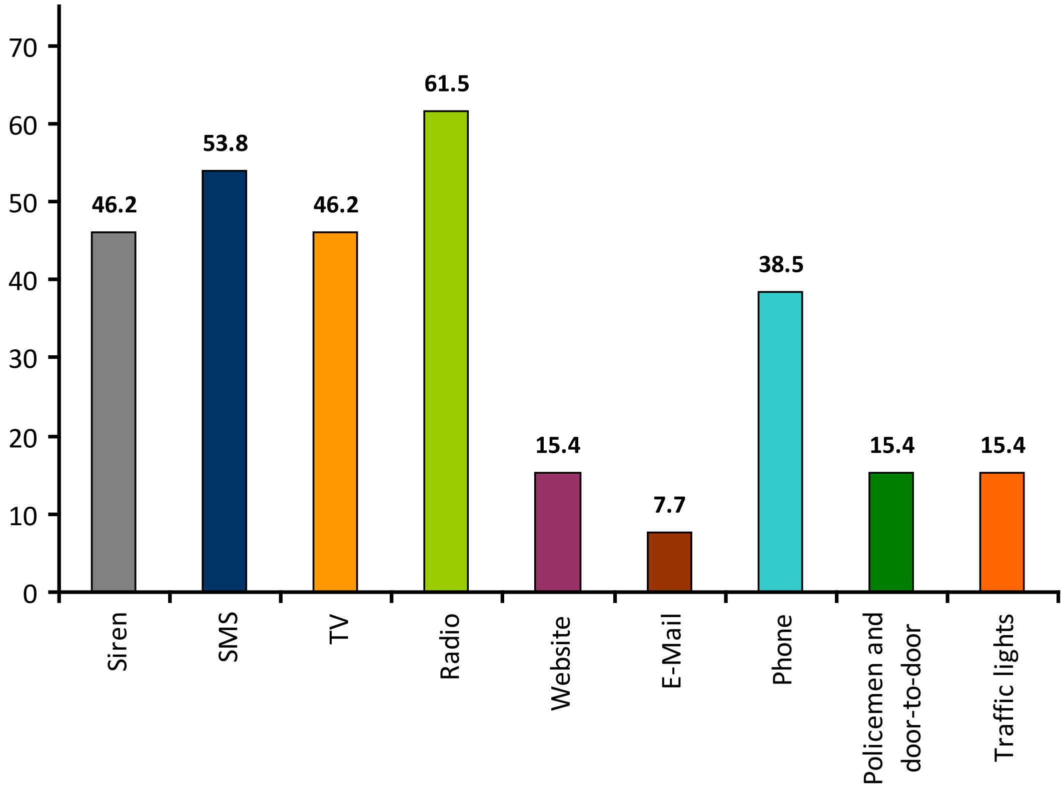


Figure 24 : Percentage of the different ways to issue the warning to the population, for the 13 EWS for which we received those data. The total percentage is over 100, because an EWS can use more than one communication device.

Finally, the last considerations relate to practical challenges encountered during the design, the construction and the maintenance of the EWS (Figure 25). Obviously, 87% of the monitoring systems posed some problems during the sensor's installation and their maintenance. Indeed, more than 50% of the instrumentation is suffering due to strong site conditions (heavy rainfall, ice, snow, wind, avalanches, etc.). Curiously, on the other hand, funding, population responses and human resources create complicated issue for less than one third during the setup of the EWS. Nevertheless, fundamental questions related to threshold determinations have not been taken into account by this questionnaire and should be answered to considerer this essential aspect. Indeed, we should ask: "How did you define the threshold values of alarm levels? How reliable are they? Do you trust the alarm warnings you receive? How many false alarms do you receive?".

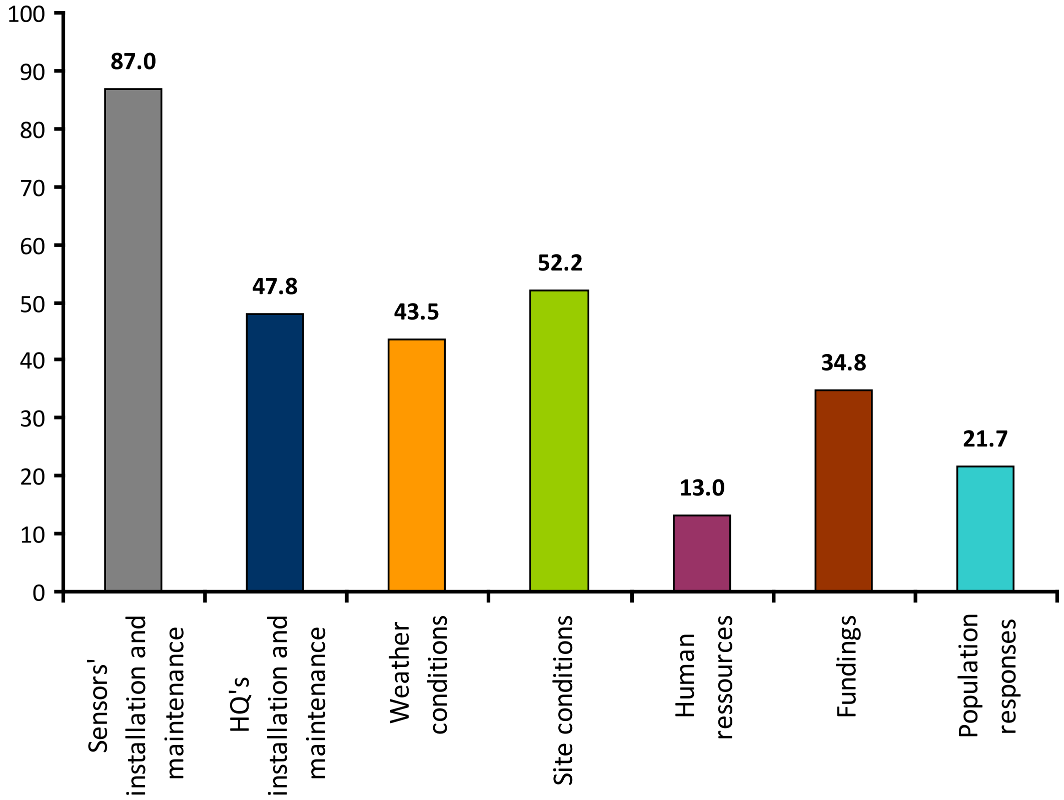


Figure 25 : Percentage of practical challenges met by the 23 EWS. The total percentage is over 100, because an EWS can encounter several challenges during its life cycle.

2.7 CONCLUSIONS

First, there are no common requirements to design and operate EWSs. Only Norway and Slovakia have produced codes or recommendations for this purpose. Secondly, advantages and limitations of existing EWs are clearly defined. An EWS has to be:

- robust;
- simple;
- redundant;
- protected from power blackout and communication loss.

An EWS should avoid to be:

- vulnerable to the landslide that it is monitoring;
- based only on surface displacements data.

For future improvement, the 14 operational units who answered advise to:

- monitor more than one parameter, such as water table level, weather conditions, surface displacement, etc.;
- integrate well all monitored data in order to continuously have the overview of the stability situation.

It is important to note that the conclusions of this screening study do not reflect SafeLand recommendations about best monitoring practices. This study only reveals a snapshot of exiting EWSs. For example, some of the EWSs were installed a long time ago and do not use up-to-date technologies. SafeLand deliverable D4.6 "*Report on geo-indicator evaluation*" presents a more specific description of possible monitoring parameters and subchapter 3.1.2 provides guidelines for EWS monitoring systems.

3 GUIDELINES FOR EWS

3.1 KEY COMPONENTS OF AN EWS

3.1.1 Risk knowledge

3.1.1.1 General

The development of an effective EWS depends on the generation of accurate risk scenarios showing the potential impacts of hazards on vulnerable groups. Authorities of warning centres need to define acceptable levels of risk to communities to determine whether and when to warn. Making this determination requires capabilities to analyse not only the hazards, but also the vulnerabilities to the hazards and the consequential risks.

EWSs allow the adoption of strategies for the mitigation of landslide risk not involving the construction of expensive and environmentally damaging protective measures. On an operational basis, landslide inventories, landslide hazard, and risk maps, movement identification and monitoring need to be coupled with "real-time" continuous measurement and with observations of possible "triggering" events. The output should call for action at different levels, involving local, regional, national and even international authorities.

Optimal decisions on applicable monitoring systems and early warning strategies should not be purely based on knowledge about the landslide hazards but must be elaborated in the local and regional context. This should include aspects such as the hazards concerned, the risk involved and the recent history of the concerned area. Since such aspects are complex it is not practical to provide a detailed strategy for each possible case but the main dimensions of the interrelationships between early warning and risk management are highlighted in the following:

- Decisions about the optimal EWS for a particular area should ideally be based on a thorough hazard and risk assessment, which incorporates all previous observations and past events.
- Monitoring for early warning should involve the collection of landslide inventory-related variables and the provision of information on factors conditioning hazards and risks; this is described in depth in the SafeLand deliverable D4.3 "*Creation and updating of landslide inventory maps, landslide deformation maps and hazard maps as input for QRA using remote sensing technology*".
- Landslide hazard and risk maps are important tools to raise awareness for more dangerous areas, whereas remote sensing derived data (e.g. Digital Elevation Model or DEM) could provide essential input for the elaboration of such maps (D4.3 "*Creation and updating of landslide inventory maps, landslide deformation maps and hazard maps as input for QRA using remote sensing technology*", Chapter 4).
- Once the landslides are detected, it is important to obtain a fast characterization of the landslides (i.e. topography, movements and run-out lengths), and a rapid and complete mapping of the area. It is also important to identify the triggering factor(s).
- The displacement rate of landslides is a critical factor for assessing the associated risks and human response.

- Priority for more detailed observations and monitoring, both in the spatial and the temporal realm, should be given to areas with higher risks.

For long-term monitoring the observations from the different time intervals should be combined to optimally reconstruct the history of the landslide and increase preparedness for anticipated future scenarios.

3.1.1.2 Knowledge of landslide hazards

Knowledge of landslide hazards provides some of the essential information for the key actors to make appropriate judgement on the most applicable monitoring systems and early warning strategies. Without deep knowledge on landslide occurrence, behaviour, contributing factors and triggering mechanisms, the percentage of missed classification in delineating landslide prone areas will be high. This will cause incorrect selection of place or location of the monitoring instruments, consequently incorrect monitoring of the triggering factors, and probably false or missed alarms.

Prerequisite knowledge before installing an EWS should be achieved in two steps. First, a susceptibility mapping is necessary on a broad scale. This can then highlight areas where to focus for more detailed hazard characterisation. However, these two steps are often inter-related.

Numerous methods have been developed to assess the probability of landslides but the most commons are divided into inventory, heuristic, statistical and deterministic approaches (Van Westen et al., 1997). The most straightforward initial approach is the compilation of a landslide inventory on a regional or community level and such inventories can be used as an elementary form of hazard map because they show the location of recorded landslides (Dai and Lee, 2002). However a drawback of landslide inventory is that such technique does not identify areas that may be susceptible to landsliding unless landslides have already occurred.

The observation of landslide inventories and the gathering of hazard and risk related information can facilitate the establishment of effective monitoring systems and early warning strategies. Comprehensive landslide inventories are the most commonly used source for quantitative landslide hazard and risk assessment at regional scales (Van Westen et al., 2006). Due to historically rather larger intervals between field surveys and acquisition of aerial photographs, the term landslide inventory is most commonly understood as a snapshot of an area at a certain point of time, whereas in some cases statements on the activity and a coarse differentiation of the particular landslide types might be possible from remote-sensing data alone (Mantovani et al., 1996). Such inventories may at best provide suitable input to susceptibility models but are not sufficient input to assess in detail the landslide hazards.

Today, global satellite data can be employed to produce landslide inventories and risk assessment maps over wide areas and remote sensing data from optical and radar sensors (SAR) are applicable to landslide mapping due to multispectral and textural information, high repetition cycles and global coverage. New techniques such as DInSAR and high resolution optical image processing are increasingly exploited for risk assessment studies. DInSAR is a powerful technique to measure displacements from satellite and has been successfully applied to detect subsidence and landslides, earthquakes or volcanic activity. Ground-based interferometric radar devices such as Linear SAR (LiSA) are capable of assessing the deformation field of an unstable slope in the areas characterised by high radar reflectivity.

DEM and their derivatives became an indispensable sources for hazard and risk assessment and at the latest since the release of the Shuttle Radar Topography Mission (SRTM) data in 2003, available on a near-global scale from 56°S to 60°N. The cost-free ASTER GDEM released in 2009, though often not as accurate as SRTM, has brought significant enhancements in terms of spatial resolution. For higher resolution DEMs (sub 10m), which are generally desirable for landslide hazard analysis (Van Westen et al., 2008), the user can today choose among a great variety of potential sources (stereo-photogrammetry, airborne and ground-based LiDAR, interferometric DEMs), whereas such datasets become increasingly available for entire countries (airborne LiDAR in Denmark and Switzerland).

There is a need to perform relatively extensive investigations for site-specific landslide knowledge (Blikra and Kristensen, 2011). The design of the investigation program is important for several critical issues. Firstly, the landslide scenarios need to be defined as the base for run-out modeling and secondary effects (e.g. tsunamis). Realistic volume and scenarios has vital impacts on the risk management in the hazard areas. Secondly, the distribution of the unstable area and the displacement pattern is the most important knowledge for the design and implementation of a proper and qualitatively acceptable monitoring system. Thirdly, an extensive knowledge platform is needed in order to be able to perform reliable and real-time operational monitoring and early warning. The understanding of the deformation dynamics is especially important during critical events, when decisions regarding alarm levels and evacuation have to be taken on relatively short notice. There exist no guidelines or handbooks that define specific requirements for the type and level of investigations needed in order to perform reliable monitoring and early-warning of large landslides. However, the European Standard EN 1997-2:2007 (Eurocode 7) describes principles and requirements related to geotechnical design and ground investigations. Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides are given in SafeLand deliverable D4.4 entitled "*Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides*". However, the final design of the investigations needs to be based on the local conditions. The pre-investigations need to include both surface and subsurface investigations, in addition to analysis and modeling. Subsurface geological data, including the depth of the instability and the related deformation should provide a realistic 3D geometric model of the instability. There will thus normally be need for some selected borehole drillings combined with geophysical measurements. The instrumentation in boreholes is essential for both the investigation of subsurface characteristics (sliding planes, volumes etc) and for real-time operational early-warning (for systems and instrumentation see subchapter 3.1.2 of this document). The investigation programme should include stability modeling, run-out analysis and modeling of secondary effects. In order to perform stability modeling, there is a need for samples to be taken in the field or from drill cores for analyzing shear strength and other input parameters. Although a stability model cannot give any conclusive answer about the stability, it should be done in order to understand the critical parameters for an event (sensitivity analysis). The investigations need to be fully documented and reviewed.

Quantitative assessment of landslide hazard and risk can be performed at various scales, whereas landslide inventories with sufficient spatial and temporal coverage are especially important for assessments at medium scales (Guzzetti and Tonelli, 2004;Van Westen et al., 2006;Van Westen et al., 2008). At a regional scale, satellite images can be acquired shortly after a major triggering event and used to make an inventory of new landslides and landslide dams (Dunning et al., 2007;Sato and Harp, 2009). This inventory is not only important for the organization of emergency operation, but equally important for the assessment of the subsequent and future monitoring systems and early warning strategies.

The understanding of the critical factors in landslide behaviour and the manifestation of critical processes as anomalies within the set of available monitoring parameters (geo-indicators) represents a fundamental basis for early warning. Advanced knowledge on the correlation between different indicators, their role as early warning parameters and the quantification of thresholds is still lacking. For this reason, an in-depth study on the process-monitoring parameter relation is part of the SafeLand work-package 4.3 "*Evaluation and development of reliable procedures and technologies for early warning*". The detailed evaluation of the role of geo-indicators as early warning parameters is presented in SafeLand deliverable D4.6 "*Report on geo-indicator evaluation*".

3.1.1.3 Landslide risk management

The societal awareness of natural risks has gradually changed. In the past, population was quite fatalist, considering natural risk as something unavoidable to be accepted. This, naturally, was a consequence of the relatively high return period of catastrophic events in the same area, which lead to forget what happened in the past, especially when nothing occurred passing from a generation to another. Recently, this attitude has been changing because of a number of reasons such as: the growing number of catastrophic events caused by the increasing quantity of elements-at-risk (EaR); the role played by the mass-media which offer ample account of catastrophes occurring in other parts of the world which had never been covered before; the increasing sensibility to safety, which is related to the growth in individual and social wealth.

Faced with landslide hazards, society's only recourse is to adapt and learn to live with them. It is therefore important to understand and predict landslide behaviour. One can live with a threat, provided the risk associated with it is acceptable or provisions are made to reduce the risk to an acceptable level. A variety of strategies can be adopted to deal with the risk which may be grouped into planning control, engineering solution, acceptance, and monitoring and warning systems. For specific landslides or potential slopes of such a large magnitude that stabilization works or engineering solutions cannot be adopted not only because impracticable but also because they would not be cost-effective in relation to the property in risk, monitoring and early-warning would be an alternative option to effectively reduce the risk.The role of landslide monitoring and early warning is to gather information useable for avoiding or reducing the impact of landslide activity by warning or evacuation of people in advance of slope failure.

The characteristics of risk are usually presented through risk mapping, frequency distributions, scenario plans and exercises, and qualitative measures. Risk assessment should also consider the cumulative effects of multiple hazards and related vulnerability. At present, there are relatively few truly comprehensive multi-hazard assessments including all potentially damaging natural hazards in a given location. A few countries, including Turkey and Montserrat, have developed multi-hazard maps or expect to have total national coverage of hazard maps as planned by Austria by 2008. In Switzerland, multi-hazard assessments are a requirement for all cantons. The general lack of multi-hazard assessments arises partly because the preparation of hazard maps is rarely a legal requirement.

Similar to the selection of landslide mitigation strategies, the selection of an appropriate EWS should be based on a future-oriented, quantitative risk assessment; coupled with useful knowledge on the technical feasibility and costs and benefits of the risk-reduction measures. Designers of EWS need to analyse data on the magnitude, duration, location and arrival time of hazard events. In addition, they should extract information on hazard frequency and severity from observational data sets, which requires:

- on-going, systematic and consistent observations of hazard-relevant parameters;
- quality assurance and proper archiving of the data into temporally and geographically referenced and consistently catalogued observational data sets;
- capacities to locate and retrieve needed data and to freely disseminate data to public users;
- sufficient dedicated resources to support these activities.

Populations are often unaware of their vulnerability to specific hazards and how their vulnerability is changing and influenced by policy and practices such as environmental degradation or urbanisation. EWSs should therefore integrate regular vulnerability analysis. EWSs can also underestimate the risks communities face because of inadequate risk assessment for particular target groups. There is need for better integration of risk knowledge in the authoritative, official warnings at the national level. This requires close collaboration between the operational technical agencies that are responsible for warning generation and the agencies and authorities involved in risk assessment and social protection. Due to the historical emphasis on the technological and hazard-related aspects of early warning, there has been inadequate attention to the use of traditional and local knowledge, experience and forecasting practices in considering risk scenarios.

In many situations, technical experts acting alone may not be able to choose the most appropriate measures. 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. Risk communication and stakeholder involvement has the added bonus that participation enables the addition of local and anecdotal knowledge of the people most familiar with the risk and problem. The decision may ultimately be made by political representatives, but stakeholder involvement, combined with good risk-communication strategies, can often bring new options to light and delineate the responsibilities for agreement. Indeed, several SafeLand reports bring to light the advantage of involving local stakeholders. Among them work package 5.2 entitled "Stakeholder process for choosing an appropriate set of mitigation and prevention measures" describes how to foster public engagement for selecting risk mitigation measures that are considered most appropriate from the technical, economic, environmental and social perspective. This project was held in Nocera Inferiore, a town in Southern Italy highly exposed to landslide risk.

3.1.2 Monitoring systems

Landslides EWSs are monitoring systems specifically designed to detect events that precede a landslide in time to issue an imminent hazard warning and initiate mitigation measures. They are composed of an array of several single sensors, the infrastructure of power supply, data transfer, and data collection and processing units to observe different early-warning parameters in quasi-real time. This chapter (1) summarizes **general design guidelines**, (2) presents the **review of monitoring techniques** (sensors), (3) evaluates **efficiency of the monitoring techniques for EWS** and (4) deals with the **infrastructure for the monitoring sensors**.

3.1.2.1 General design guidelines

The key to a successful EWS is to be able to identify and measure small but significant indicators that precede a landslide. The selection of the appropriate monitoring systems to be adopted in specific situations must take into account the following aspects:

- factors which determine the hazard, in terms of the type, rate, depth and the probability of occurrence of the movement or landslide, such as, for example:
  - the physical characteristics of the geosystem, including the stratigraphy and the mechanical characteristics of the materials, the hydrological (surface water) and the hydrogeological (groundwater) regime;
  - the destabilizing and triggering factors;
  - the morphology of the area;
  - the actual or potential causative processes affecting the geosystem, which can determine the occurrence of movement or landslides;
- factors which affect the nature and quantification of risk for a given hazard, such as the exposure and vulnerability of elements at risk, both in the potentially unstable area and in areas which may be affected by the run-out;
- factors which affect the actual feasibility of specific monitoring systems, such as, for example:
  - phase and rate of movement at the time of implementation;
  - morphology of the area in relation to accessibility and safety of workers and the public;
  - environmental constraints, such as the impact on the archaeological, historical and visual/landscape value of the locale;
  - pre-existing structures and infrastructure that may be affected, directly or indirectly;
  - capital and operating cost, including maintenance.

The key steps in the design of a landslide monitoring system would normally include the following:

- gather as much site information as possible, including maps, geological and topographical data, geotechnical data, records of previous slides and extent of potential sliding mass;
- perform a stability analysis and hazard assessment to gain an improved understanding of the hazard;
- define the objectives of the monitoring and select the type of instruments and measurements to be included in the monitoring programme, assigning a priority to the measurements;
- on the basis of cost, availability and reliability of information, decide on the measurement methods to be used and select the appropriate instruments;
- determine the optimum number of instruments and locations; if available, use theoretical or empirical models to optimise the number and placement of instruments;
- decide on the preferred method of data acquisition, e.g. manual or automatic recordings;
- arrange for proper installation, protection and marking of instruments and reference points in the field;
- plan for data flow, data management and analysis. Insure that there are sufficient funds to properly analyse the measurement data; and
- plan for adequate powering and maintenance of the monitoring system.

As a general rule, one should use the simplest and most reliable monitoring methods and equipment possible. Instrumentation systems to monitor landslide behaviour are normally employed in many different locations, often in conjunction with surface mapping and sub-surface investigations, for a diverse range of landslide types in many different geological settings and landscapes. Advance remote sensing techniques used in combination with geomorphological data and traditional surveying methods could provide an integrated tool for landslide detection, characterization, rapid mapping and monitoring. Special techniques for landslide characterization based on remote sensing and on-site instrumentation are described in depth in the SafeLand deliverable D4.1 entitled "*Review of monitoring and remote sensing methodologies for landslide detection, fast characterisation, rapid mapping and long-term monitoring*"and in the SafeLand deliverable D4.5 entitled "*Evaluation report on innovative monitoring and remote sensing methods and future technology*". From the characteristics of landslides, such as the topography, movements and run-out lengths, it is possible to deduce the failure mechanisms and to provide a rapid estimation of the volume involved. Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides are given in SafeLand deliverable D4.4 entitled "*Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides*".

In landslide monitoring, one needs to consider the likely modes of failure and the stability limit (e.g. brittle versus ductile failure) controlled, among others, by material and mass properties. Engineering judgement is an important element in the process of forecasting and setting threshold values. The monitoring system must also be so flexible that the threshold parameters can be changed as more information becomes available on the performance of the monitoring system and the behaviour of the slope being monitored.

3.1.2.2 Review of monitoring techniques

Consistent information about individual unstable slopes, especially in very vulnerable areas, on their internal structure, and of dynamics, triggers, history and possible magnitude of deformation is an essential base for any early warning of people before a catastrophic event in advance. Such knowledge is obtainable only through a complex long-time monitoring of deformation, its related parameters, and triggering factors.

For the EWSs, there have been many space/air-borne sensors, remote ground-based (GB) sensors and in-place superficial and subsurface GB sensors available in the past decades. This chapter presents an overview of the most common sensors referred to be applied in EWSs, and also will present some of those ones that have relatively high potential to be used for landslide EWS, but because of different reasons they are nowadays not that common (e.g., high cost, difficult commercial availability, research state, etc.).

For this purpose, the information was compiled in a form of tables. The table summarize basic information on each monitoring sensor. This information includes, i.e.: ***Main monitored parameters***, the ***sensors´ applicability*** (for which type of landslide, spatial resolution, what is the accuracy, scale of observation, evolution stage of observed instability, its activity state, for what mass-movement velocity), information on ***data reading, transfer and processing*** (reading-frequency range, whether the readings are automated, and the data transfer is remote, processing software, processing automation, duration of the data processing), what are the ***technical constraints*** (special conditions for the correct performance, power-supply constraints, maintenance requirements, other field constraints), what is the ***EW potential*** of the sensor (low, medium, high), what are ***the costs*** (estimated approximate price of a unit, cost of additional processing software, yearly cost of maintenance; however the prices could significantly differ in each country), and what is the ***commercial availability*** (commercial products, producers). The table was filled by scientists in and outside the SafeLand Consortium who have a good expertise with the respective techniques.

The airborne and spaceborne monitoring techniques are presented in Table 2, the remote ground-based (GB) sensors are listed in Table 3, and the on-site sensors are listed in the 5 following tables. Table 4 presents the dGPS and the inclinometers. Table 5 presents extensometers and rod dilatometers. Table 6 lists TM71 (3D extensometer), TDR (Time-Domain Reflectometer), optical fibers and contact earth-pressure cell gauges. Sensors for monitoring of geophysical parameters are listed in Table 7, and the hydro(geo)-meteorological sensors are presented in Table 8.

Table 2: Review of the airborne and spaceborne monitoring techniques of displacement and deformation monitoring.

		Passive optical systems	DInSAR	PS InSAR
Author (Institute)		*A. Stumpf (CNRS)*	*V. Tofani (UNIFI)*	*V. Tofani (UNIFI)*
General	Monitored parameter	affected area, landslide type	small ground deformation	displacement
	Other parameters	3D topography / topography changes (volume) from stereo images, horizontal displacement from multi-temporal datasets		
Aplicability	Type of landslide	Rotational and translational slides, flows, lateral spread, less for topples and rockfalls	Rotational slides, Translationa slides, flows, complex and compound	Rotational slides, Translationa slides, flows, complex and compound
	Spatial resolution / Accuracy	~ 10sq.m with VHR satellite and aerial images	depending on radar wavelength	XY pointwise, LOS≈ 1mm
	Scale	local-regional	slope and local scale	from slope scale to regional scale
	Evolution stage of observed instability	failure, post-failure	pre-failure and post-failure	pre-failure and post-failure
	Activity state	active	all	all
	Mass-movement velocity	Very slow-moderate, faster movements can only be detected in the pre-failure stage	< 3.2×10^{-7} mm/sec (ERS)	< 5×10^{-5} mm/sec
Data reading, transfer and processing	Reading-frequency range	Theoretical max. 1-2 image per day with youngest generation satellite systems (Rapid Eye, Pleiades), typically 1-2 images/ year	24-35 days	24-35 days
	Automated readings?	yes	yes	yes
	Remote data transfer?	yes	yes	yes
	Processing software	ENVI IDL, Erdas Imagine, eCognition, Orfeo Toolbox, etc.	yes	yes
	Automated processing?	possible but no operational system available	yes	yes
	Duration of the data processing	days-weeks for image correlation and stereo photogrammetry, month for manual inventory mapping	n/a	days
Technical constraints	Special conditions for the correct performance	satellites: no data for cloudy areas, airborne: weather conditions, UAV: weather conditions (more sensible to wind than planes), all: daylight	severely affected by atmospheric effects and noise	low atmospheric humidity
	Power-supply constraints	operating time for UAVs << 1h, but batteries or fuel can be carried easily in the field	no	no
	Maintenance requirements	n/a	memory	memory
	Other field constraints	operating UAVs requires open space for start and landing	slope exposure, vegetation, low-reflectivity areas	slope exposure, vegetation, low-reflectivity areas
EW potential		**low**	**none**	**low**
Costs	Approx. price of a Unit	UAVs: 1000-60000 €, Satellite and aerial images: 1-10 €/sq.km	n/a	0.6-16 €/sq.km (15 scenes)
	Cost of processing software	free OpenSource solutions, 500-2000 €/year	n/a	> k€
	Yearly cost of maitenance	n/a	n/a	n/a
Commercial Availability	Commercial products	no commercial vendour on landslide application, for raw data and UAV sytems, see below	ground defomormation maps (subsidence, co-seismic displacements)	wide scale ground displacement maps
	Producers	//www.rapideye.de, ///www.digitalglobe.com, //www.geoeye.com, //www.microdrones.com/index-en.php, //www.mikrokopter.de, //www.universalwing.com	Gamma remote sensing, sarmap	Altamira Information, T.R.E. s.r.l, Gamma Remote Sensing, E-Geos

Table 3: Review of the remote GB sensors of displacement and deformation monitoring.

		GB InSAR	TLS	Single Laser	Passive optical systems	Automatic Total Stations
Author (Institute)		*V. Tofani (UNIFI)*	*C. Michoud (UNIL)*	L.H. Blikra (ÅTB)	*A. Stumpf (CNRS)*	*J. Gili, J. Moya (UPC)*
General	Monitored parameter	Displacement along the LOS.	topography	Displacement along LOS	displacement, changes of the surface characteristics	displacements
	Other parameters		by extension: displacements, erosion rates, accumulated materials		3D surface reconstruction (experimental)	
Aplicability	Type of landslide	Rotational Slides, Translational Slides, Complex and Compound Slides	All types	All types	All types	All types
	Spatial resolution / Accuracy	range: 0.5-1 m Azimuth (at 500 m distance): 2-5 m	landslides up to m2	Punctual, 1 mm per 20-200 m distance. Noise of c. 10 mm	depending on the camera distance, up to > 100 pixel/sq.m	as high as necessary
	Scale	Local and Slope Scale	Slope scale	Local and slope scale	slope scale, local	slope scale
	Evolution stage of observed instability	Pre-failure, Failure, Post Failure	All stages, according to velocities limits	All stages, but difficult in late stage during large displacements	pre-failure, failure, post-failure	all stages
	Activity state	all	all	all	active	all
	Mass-movement velocity	$<5 \times 10^{1}$ mm/sec	Extremely slow to slow	Extremely slow to slow	very-slow to extremly rapid (frame needs to be increased for fast movements)	very slow to slow
Data reading, transfer and processing	Reading-frequency range	From minutes to months	up 1500 nm to 500nm	1 to 10 s	flexible: typically betwenn 1/week and 1/hour (24/s for video)	variable (1 /hour to 1/day)
	Automated readings?	Yes	no	yes	yes	yes
	Remote data transfer?	Yes	no	yes	typically not or only with strong compression	yes
	Processing software	Yes	internal	yes	Research software,	available (Leica 'Geomos' or Trimble '4D Control Software' for instance)
	Automated processing?	Yes	Yes, for raw data	yes	semi-automatic for image correlation with research software	yes
	Duration of the data processing	Minutes	in the same time of the acquisition	real time	days	seconds
Technical constraints	Special conditions for the correct performance	Low humidity and temperature	Dry atmosphere	Severely affected by fog, rain and snow	object has to be in the line of sight of the camera, daylight, direct sun into the lense hinder acquisition of suitable images	no mist or fog
	Power-supply constraints	power supply and broadband access required	Portable batteries (8 small batteries = 1 day of acquisition)	power supply and broadband access required	solar paner requiered, additional fuel cell desirable for energy backup during winter month	batteries or solar
	Maintenance requirements	Periodical Check of components	Batteries reload, cleaning USB disks, annual checkup by the manufacter	annual check of components	regular (2-3 /year) cleaning of the lense and readout of the memory card	periodical checks (i.e. monthly...)
	Other field constraints	Accessibility, Power Lines in the area, Frontal Position to the target.	Direct line of sight, transportable by 2 men but not in too steep terrains	Power line, heating reflectors to avoid ice and snow	viewing angle should be as close to Nadir as possible	the Total Station must be protected against vandalism, animals, and weather
EW potential		**High**	**Low without continual readings**	**High**	**medium**	**high**
Costs	Approx. price of a Unit	Few hundreds of €	~150 k€	10 k€ (laser+ PC) + cost for infrastructure (power, comm.) and field installation	~ 1 k€ for high end single lense reflex camera, 1500 € for packages including box, time lapse system and camera	30 k€ per tipical installation
	Cost of processing software	Very low for permanent and periodical monitoring less than few thousand of Euros	From open sources to ~10 kE		free research software and open source librarys	included or shared
	Yearly cost of maintenance	n/a	~6 kE	3 k€ including new laser after 6 years	~ 100 €	depends on the equipment fault; monthly check for 5 k€
Commercial Availability	Commercial products	Interferograms, Displacement maps, Coherence maps, Power Images	Optech Ilris, Leica Scan Station	Leica, OEM laser	e.g. Nikon D700, CC5MPX, //www.harbortronics.com/Products/	Leica (TCA2003), Trimble (S8), Topcon, Sokkisha.
	Producers	Ellegi Srl-LisaLAB, IDS	Optech, Leica, Trimble, Reigl	Leica	//www.harbortronics.com/Products/, Nikon, Canon, Pentax, Campell Scientific	The above producers + companies providing complete management & maintenance

Table 4: Review of the dGPS and the inclinometers for landslide EWS.

		dGPS	classical inclinometer	nodular inclinometer	superficial inclinometer	D.M.S. combined unit
Author (Institute)		J-P. Malet (CNRS)	M. Lovisolo (C.S.G.)	M. Lovisolo (C.S.G.)	M. Lovisolo (C.S.G.)	M. Lovisolo (C.S.G.)
General	Monitored parameter	absolute 3D displacement at the surface	horizontal displacement	horizontal displacement	tilt	displacement, water table, settlement
	Other parameters					pore pressure, temperature, vibrations
Aplicability	Type of landslide	Rotational and translational slides, mud/earthflows, lateral spread	Slides and slow flows	Slides and slow flows	All	RS, TS, FL, DG
	Spatial resolution / Accuracy	point measurement (50 cm)				
	Scale	local scale	slope scale	slope scale	slope scale	slope scale
	Evolution stage of observed instability	pre-failure, failure, post-failure (according to landslide velocity)	pre-run out or/post run out	pre-run out or/post run out	all stages	all stages
	Activity state	all (but preferably active)	all	all	all	all
	Mass-movement velocity	very slow to slow (from 1mm/week to m/day)	very slow	very slow	slow	slow
Data reading, transfer and processing	Reading-frequency range	Variable: typically 1 hr to 24hr, but 10 min is possible for relatively rapid movements	no	variable	variable	variable 100 Hz-0.01Hz
	Automated readings?	yes	no	possible	yes	yes
	Remote data transfer?	yes	no	possible	possible	yes
	Processing software	research software for automated processing; commercial software for non automated processing	yes			yes
	Automated processing?	yes	no	possible	possible	yes
	Duration of the data processing	10 min	hours			real time
Technical constraints	Special conditions for the correct performance	The GPS antenna has to be kept vertical above the ground surface; accumulation of snowpack on top of the antenna has to be avoided	probe constant temperature		constant temperature	no
	Power-supply constraints	solar panel sufficient	battery	battery or solar	battery or solar	solar
	Maintenance requirements	regular (essentially to control verticality of the antenna, and possible breaks in the cable)	periodical checks (i.e. monthly...)	periodical checks		self test on board
	Other field constraints	clear sky conditions, no orographic mask, no dense tree canopy	access for borehole	access for borehole		access borehole
EW potential		**high**	**low**	**medium**	**medium**	**high**
Costs	Approx. price of a Unit	25 k€ (commercial price); 7k€ (scientific price through UNAVCO agreement)	10 k€	2 k€	2.5 k€	1 k€/module
	Cost of processing software	free open source software	2 k€			
	Yearly cost of maintenance	1 k€				
Commercial Availability	Commercial products	Trimble NetR9 / NetRS, Leica, Topcon				DMS 2D, DMS3D
	Producers	Trimble NetR9 / NetRS, Leica, Topcon	Slope Indicator, RST, SisGeo, etc	Slope Indicator, RST, SisGeo, etc		CSG

Table 5: Review of the extensometers and rod dilatometers for displacement monitoring.

		Superficial wire extensometers	Borehole extensometers	Borehole Wire extensometers	rod dilatometers
Author (Institute)		J. Gili, J. Moya (UPC)	J. Gili, J. Moya (UPC)	J. Gili, J. Moya (UPC)	J. Gili, J. Moya (UPC)
General	Monitored parameter	distance changes between two points	borehole longitudinal displacements	borehole transversal displacements	divergence between sides of a crack
General	Other parameters				
Aplicability	Type of landslide	All	RS	RS, TS, FL	RS, TS, LS, TP
Aplicability	Spatial resolution / Accuracy	3 mm	0.2 mm	0.5 mm	0.1 mm
Aplicability	Scale	slope scale	slope scale	slope scale	slope scale
Aplicability	Evolution stage of observed instability	all stages	all stages	all stages	all stages (depending on the type of the landslide)
Aplicability	Activity state	all	all	all	all
Aplicability	Mass-movement velocity	very slow to slow	very slow	very slow	extremely slow
Data reading, transfer and processing	Reading-frequency range	variable (1 Hz a 1/day)	variable (1 Hz a 1/day)	variable (1 Hz a 1/day)	variable (1 Hz a 1/day)
Data reading, transfer and processing	Automated readings?	yes	yes	yes	yes
Data reading, transfer and processing	Remote data transfer?	yes	yes	yes	yes
Data reading, transfer and processing	Processing software	any advanced datalogger software	any advanced datalogger software	For instance: Campbell Scientific LoggerNet	any advanced datalogger software
Data reading, transfer and processing	Automated processing?	Yes	Yes	Yes	Yes
Data reading, transfer and processing	Duration of the data processing	Real Time	Real Time	Real Time	Real Time
Technical constraints	Special conditions for the correct performance	Prone to vandalism; Temperature correction needed	No allowance for transversal movements larger than the borehole diameter. Due to the extend range of forecast movements, the wire is more applicable than the rod extensometer	no	Temperature correction needed
Technical constraints	Power-supply constraints	batteries and solar	batteries and solar	batteries and solar	batteries and solar
Technical constraints	Maintenance requirements	periodical checks (i.e. monthly...)	periodical checks (i.e. monthly...)	periodical checks (i.e. monthly...)	periodical checks (1 or 2 times per year)
Technical constraints	Other field constraints		Access for the borehole drilling equip.	Access for the borehole drilling equip.	
EW potential		**high**	**medium-low**	**high**	**high**
Costs	Approx. price of a Unit	1k€-2 k€	5 k€ + drilling	5 k€ + drilling	750 €
Costs	Cost of processing software	3 k€	3 k€	3 k€	3 k€
Costs	Yearly cost of maintenance	Variable	2.8 k€ per slide	2.8 k€ per slide	
Commercial Availability	Commercial products	See Angeli et al (2000)	E.g.: Slope Indicator Inc; Geokon	See Angeli et al (1996) and Corominas et al (2000)	For Instance: Roctest Ltd, Montreal, Canada; ICG-NGI at Åknes
Commercial Availability	Producers			IRPI, CNR, Perugia (Italy) and UPC, Barcelona (Spain)	

Table 6: Review of the TM71, TDR, optical fibers and contact earth-pressure cell gauges.

		TM 71 (opto mechanical cack-gauge)	TDR	Optical fibres
Author (Institute)		*J. Klimes (IRSM CAS)*	*E. Damiano (AMRA)*	*E. Damiano (AMRA)*
General	Monitored parameter	3D displacement along discontinuities	soil moisture	deformation
	Other parameters	2D rotations along discontinuities and temperature	soil moisture profiles in homogeneous soils	
Aplicability	Type of landslide	RS, TS, LS, TP	RS,TS, FL, DA	RS,TS, FL, DA
	Spatial resolution / Accuracy	one gauge per site / 0.007mm	1cm	1m
	Scale	slope scale	local information	slope scale
	Evolution stage of observed instability	pre- , post-failure and failure	pre-failure and failure	pre-failure
	Activity state	all	all	all
	Mass-movement velocity	best for 2mm/year	slow, medium	slow, medium
Data reading, transfer and processing	Reading-frequency range	1/h up to 1/month	1 measurement per minute	1 measurement per minute
	Automated readings?	yes	yes	yes
	Remote data transfer?	yes	yes	yes in the future
	Processing software	yes		MATLAB
	Automated processing?	no	yes	yes
	Duration of the data processing	minutes	minutes	from minutes to tens of minutes depending on the fiber length
Technical constraints	Special conditions for the correct performance	none	none	constant temperature
	Power-supply constraints	batteries, fuel cells, electric current only if in automated mode	batteries or solar	batteries or solar
	Maintenance requirements	once per year or less when automated data reading is not engaged	periodical checks (i.e. monthly...)	periodical checks (i.e. monthly...)
	Other field constraints	site needs to be accessible, possible damage by falling stones	Access for inspection of the installation areas	Access for inspection of the installation areas
EW potential		**medium**	**medium**	**low at the present, high in perspective**
Costs	Approx. price of a Unit	2 k€ (+ 500 € for automated mode)	5 k€	50 k€
	Cost of processing software			
	Yearly cost of maintenance	cost of travelling	500 €	1 500 €
Commercial Availability	Commercial products	the gauge is a commercial product	yes	available for single module not for the entire system
	Producers	GESTRA Sedloňov, Czech Republic	CAMPBELL SCI	OMINSENS, OZ OPTICS, NEUBREX

Table 7: Review of the sensors for monitoring of geophysical parameters for landslide EWS.

		Geophons	Geoelectric sounding systems	PEE measuring tool in boreholes
Author (Institute)		*J-P. Malet (CNRS)*	*B. Jochum, D. Ottowitz (GSA)*	*P.Wagner, P. Ondrejka (SGUDS, SK), V.Vybiral (Sensor, SK)*
General	Monitored parameter	microseismicity / acoustic noise	resistivity, IP, SP	passive/pulse EM emission
	Other parameters		indirectly water content, porosity	
Aplicability	Type of landslide	All	All	RS, TS
	Spatial resolution / Accuracy	not applicable	depending on electrode spacing	depending on readings spacing
	Scale	local scale	local scale	slope-scale
	Evolution stage of observed instability	pre-failure, failure	all stages	mature
	Activity state	active	all	active, dormant
	Mass-movement velocity	very slow to slow (from 1mm/week to m/day)	slow	0,1 - 100 mm/year
Data reading, transfer and processing	Reading-frequency range	variable, form 2000mHz to Hz	hours	2 - 6 times/year (possibly more often)
	Automated readings?	yes	yes	no (theoretically yes)
	Remote data transfer?	no (except if 220V power line and LAN cable ethernet connection on-site)	yes	no (theoretically yes)
	Processing software	research software	Res2DInv, Earthimager	Excel, Grapher
	Automated processing?	no	partly	no (theoretically yes)
	Duration of the data processing	Weeks	hours	5 hours per 100 m borehole
Technical constraints	Special conditions for the correct performance	The seismometers have to be coupled to the soil, and in horizontal position, burried in the soil; the best is to install them in the landslide body directly, not outslide of the landslide	no	no active EM radiation sources (PC) nearby
	Power-supply constraints	battery & large solar panel (> 100W)	230V or solar combined wth fuel cell	life of accumulator
	Maintenance requirements	monthly check (reading out memore cards, control digitize and installaiton of seismometers)	only when damage occurs	one operator
	Other field constraints	Access, and possibility to bury the seismometers and the cables	Accessibility	probe cable flexible at low temperature
EW potential		**inapropriate because of complex data processing**	**low**	**High but technology needs to be developed more**
Costs	Approx. price of a Unit	An array of 4 to 6 sensors is the minimum (cost ~20 k€)	25 k€	about 5000€, depends on quantity and development cost
	Cost of processing software	free open source software	2.2 k€	standard spreadsheet processing SW
	Yearly cost of maintenance	2 k€	~ 1 k€	about 100€, battery or accu.
Commercial Availability	Commercial products	Agecodagis, Reftek, Nomis,Lennartz, Streckeisen, and many others		individual prototypes
	Producers	-id-	BGS, AGI	any producer of industrial electronic devices, after development based on customer's specification, e.g. ***Sensor**, Bratislava, SK*

Table 8: Review of the hydro(geo)-meteorological sensors for landslide EWS.

		Piezometers	Meteostations: Pluviometer	Meteostations: Thermometer	Meteostations: Barometer	Inplace - thermometer	Flowmeters
Author (Institute)		*M. Lovisolo (C.S.G.)*	*M. Lovisolo (C.S.G.)*	*M. Lovisolo (C.S.G.)*	*M. Lovisolo (C.S.G.)*	*M. Lovisolo (C.S.G.)*	*F. Zott (Inst. of Mountain Risk Engineering, BOKU - University of Nat. Res. & Life Sci., Vienna)*
General	Monitored parameter	GW level, pore pressure	rainfall	air/water temperature	air pressure	soil/rock temperature	In-/outflow, Discharge
	Other parameters	temperature					Temperature & Relative Humidity , Precipitation
Aplicability	Type of landslide	RS, TS, FL	All	All	All	All	landslide
	Spatial resolution / Accuracy						l/sec
	Scale	slope scale	slope scale	slope scale	slope scale	slope scale	slope scale
	Evolution stage of observed instability	pre-run out or/post run out				pre-run out or/post run out	
	Activity state	all	all	all	all	all	in use
	Mass-movement velocity	very slow (pipe damage)	all	all	all	slow	slow
Data reading, transfer and processing	Reading-frequency range	variable	10 minutes	10 minutes	10 minutes	variable	10 min
	Automated readings?	possible	yes	yes	yes	yes	yes
	Remote data transfer?	possible	yes	yes	yes	yes	yes
	Processing software	yes	yes	yes	yes	yes	Logger Net - Campbell Scientific
	Automated processing?	possible	yes	yes	yes	yes	yes
	Duration of the data processing		real time	real time	real time	real time	year
Technical constraints	Special conditions for the correct performance	not operating <0°C	no	no	no		N/A
	Power-supply constraints	batteries or solar	solar / power supply for heaters	solar	solar	solar	Solar cell,
	Maintenance requirements		periodical checks	periodical checks	periodical checks		N/A
	Other field constraints	access borehole				borehole or excavation	
EW potential		**medium**	**medium-high**	**low**	**low**	**medium**	**N/A**
Costs	Approx. price of a Unit	1.5 k€	4 k€	1 k€	1 k€	500 €	5 Units at 8 k €
	Cost of processing software		2 k€				900 €
	Yearly cost of maintenance						Approx. 1500€
Commercial Availability	Commercial products						Data-Logger Radarsensor
	Producers	Slope Indicator, RST, SisGeo, etc					Campbell Scientific Ltd.(UK), VEGA Grieshaber KG (DE)

3.1.2.3 Efficiency of the monitoring techniques for EWS

For landslide monitoring, different techniques and sensors provide different kind of information with also different reliability. Different approaches have also diverse potential for early warning process. A questionnaire on National State of Landslide Site Investigation and Monitoring was disseminated among different worldwide institutes and representatives within the frame of the SafeLand project in order to gather information such as relative occurrence, reliability and early warning potential of the individual techniques. The more detailed description of the aim, methods and results of the questionnaire are presented in SafeLand deliverable D4.5 entitled "*Evaluation report on innovative monitoring and remote sensing methods and future technology*" and in D4.6 entitled "*Report on geo-indicator evaluation*". This study gathered information from 89 monitored sites from Andorra, Austria, Switzerland, Czech Republic, France, Great Britain, Italy, Japan, Kyrgyzstan, Martinique (FWI), Norway, Russian Federation, Slovenia, Slovak Republic and Spain.

It is obvious that the most relevant monitoring parameter for any landslide EWS is displacement, and its derivatives - the velocity and the acceleration. These parameters could be obtained by a variety of remote and on-site sensors. Figure 26 summarizes a review of the ground-based sensors for displacement and deformation monitoring, presenting their relative occurrence within all 89 collected monitoring sites and ordered by their relative early warning potential. The most reliable sensors with highest EW potential are the classical and automated inclinometers, wire extensometers, dGPS, optical imaging systems and total stations.

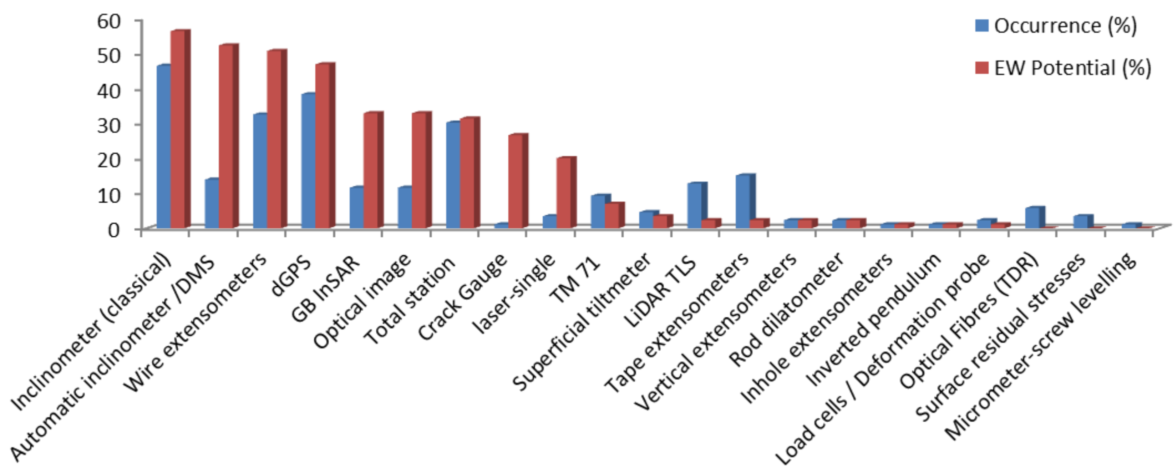


Figure 26: Review of sensors of displacement and deformation monitoring, presenting their relative occurrence within all 89 collected monitoring sites and ordered by their relative early warning potential.

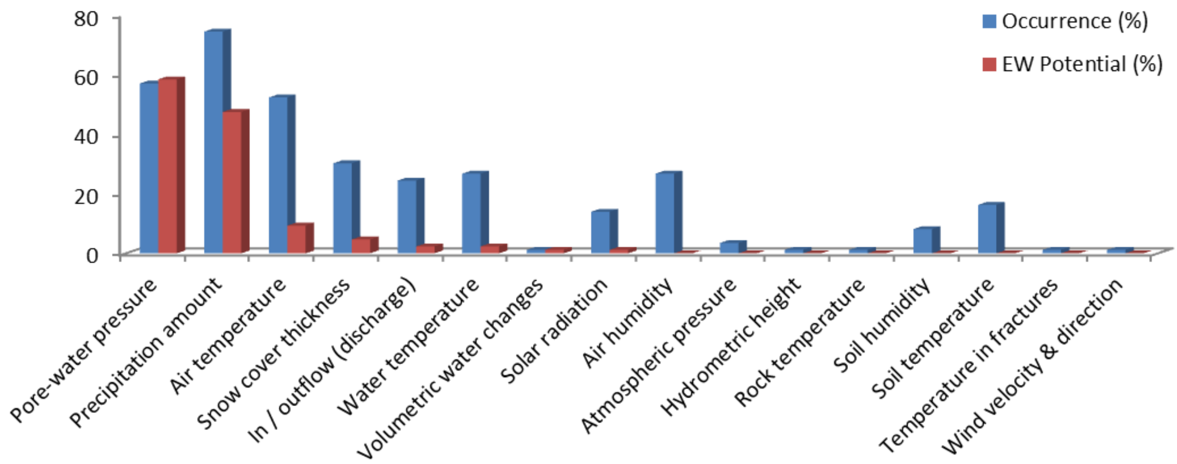


Figure 27: Review of hydro-meteorological monitoring parameters presenting their relative occurrence within all 89 collected monitoring sites ordered by their relative early-warning potential.

The pore-water pressure and precipitation amount were evaluated as the most abundant hydro-meteorological monitoring parameters with the highest early warning potential (Figure 27). The passive seismic/acoustic emissions, electromagnetic emission and DC resistivity were evaluated as the most reliable geophysical parameters for EWS by the questioned experts (Figure 28).

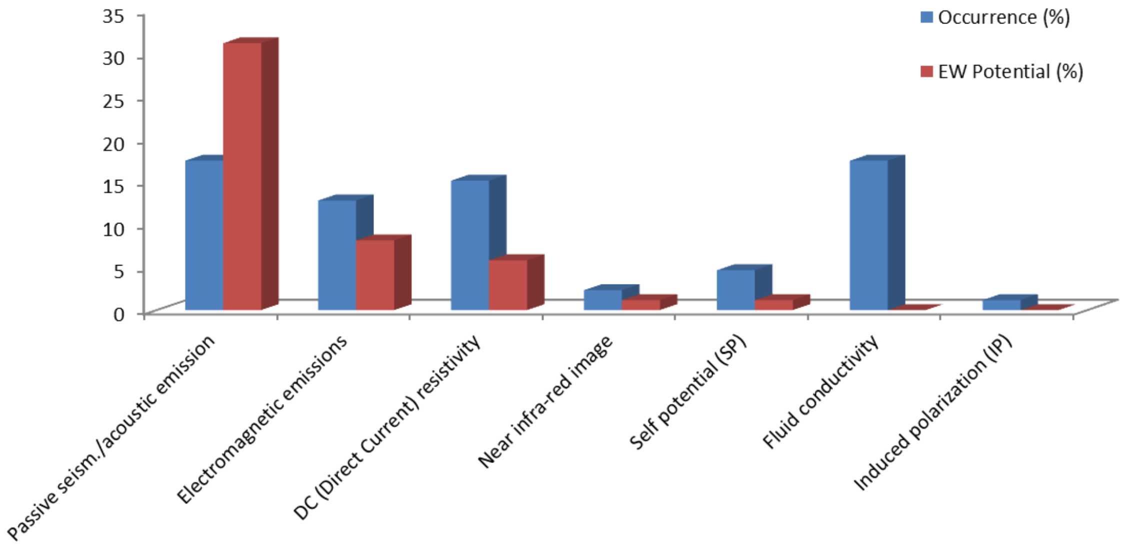


Figure 28: Review of geophysical monitoring parameters presenting their relative occurrence within all 89 collected monitoring sites ordered by their relative early-warning potential.

All of these results are based on the expert knowledge and practical experience from the field. Although, the evaluation differed individually due to respondent´s expertise, country and other factors, we believe that the evaluation brings a good general picture on the techniques reliability and could be an inspiration for selecting the appropriate sensors for a new EW system.

3.1.2.4 Infrastructure for monitoring sensors

During the design, installation and operation of the monitoring sensors, one should consider:

- **Damage caused by electrical storms**: long cables can suffer high induced voltages during lightning that can damage sensors and data loggers. Overvoltage protections should be included during installation.
- **Vandalism**: monitoring instruments are often subject to vandalism and thefts when located in unguarded areas. Protective measures have to be taken (DiBiagio and Kjekstad, 2007).
- **Adequate power supplies**: one of the major causes of system failures is the lack of power, for this reason the design and the maintenance of power supply systems should be done with care. Depending on the site characteristics and the power consumptions of sensors and data transfers, the power supply can be provided by different sources. The most abundant sources are power lines, solar panels and oil generators. Unfortunately, some sensors are power hungry and the landslides to be monitored are often in remote areas with little or no infrastructure. It can be very costly to install new power lines. For example, the Austrian Service for Torrent and Avalanche Control had to pay about 13,000 € for a 900 m long cable in Gschliefgraben.

As an example for the power supply challenge, the system for ground resistivity monitoring installed by the Department of Geophysics of the Austrian Geological Survey is presented here in detail. The Geomon^{4D} needs 40 watt in idle mode, while it needs from 100 up to 500 watt in acquisition mode (depending on the underground resistivity and thus the injected current). One measurement takes 90 minutes to complete, 4 measurements per day are ideal, more when the landslide is moving. Consequently, the monitoring instrument needs a charging capacity of 600Wh/ day. Running a conventional gasoline-driven generator is not possible since it has to be refilled at least every 24 hours. A battery only system with 2*60Ah would have an autonomy of only 5 days. Solar cells alone could operate under cloudy or foggy conditions a maximum of 7 days.

Table 9: Power supply specifications based only on solar panels:

	Solar cell setup
Panels	6 * 135 W
Batteries	6 * 130 Ah
Charge regulator	3 * 30 A

Due to the amount of panels and batteries that would be necessary (Table 9), it was decided to use a new technology combining a fuel cell with solar cells (Figure 29). The fuel cell closes the energy gap when the sun does not deliver enough energy during the night and in winter (Figure 30). The fuel cell generates electricity from methanol, a liquid alcohol with an extremely high energy density of 11.1 kilowatts from 10 l of methanol weighing only 8.4 kg. Methanol and oxygen undergo an electrochemical process called “cold combustion“ to transform into electrical energy and the by-products CO_2 and water vapour. (© SFC Smart Fuel Cell).

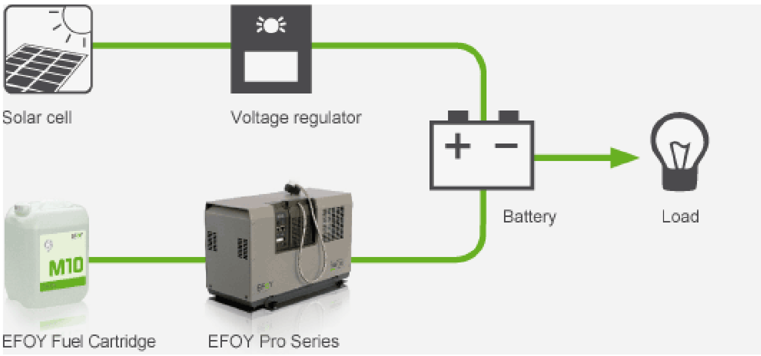


Figure 29: Example of new power supply: a combination of fuel cell and solar cell ©SFC

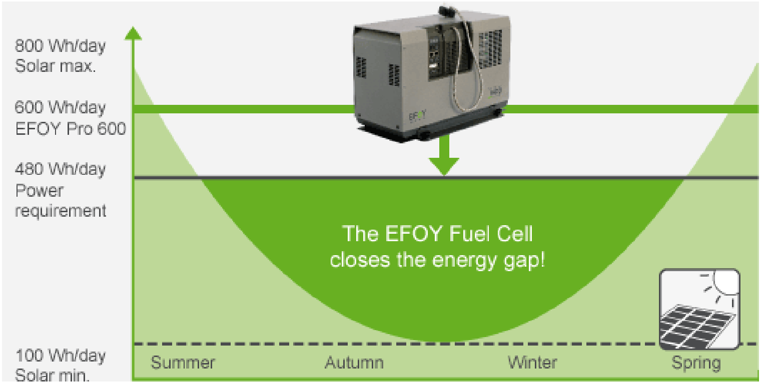


Figure 30: The fuel cell usage during the year ©SFC

The fuel cell system chosen in this example uses the SFC Efoy Pro© 600 (Figure 30) with a charging capacity of 600Wh/ day and a current of 1A. It is connected to batteries with 72Ah and recharges them as needed (Table 10). In the winter time, as soon as the temperature inside the fuel cell box drops below 4°C, the fuel cell starts the anti-freeze cycle to generate some heat. The excess warm exhaust gases (warm water vapour) can be led into the Geomon4d. The fuel cell is remotely controlled by a GSM modem, which sends the status data to a web server. The system is equipped with 2 x 28 l methanol canisters (Figure 31). In the long term, this fuel cell turns out to be a reliable, maintenance free and an autonomous power supply. Three examples of the monitoring sites using this new technology are presented in Table 11.

Table 10: Power supply specifications for a fuel cell combined with solar power.

	Fuel cell + solar panel setup
Fuel cell	600 Wh
Tank	2 x 28 l
Panels	235 W
Batteries	72 Ah

Figure 31: Left: Monitoring system with fuel cell and solar panel. Right: Fuel cell with 2x28 l methanol canisters and GSM modem.

Test site Mölltaler Glacier, Austria

The Mölltaler Glacier permafrost monitoring instrument has to withstand rather extreme weather conditions. Snow cover and the strong wind conditions prevent the use of solar panels. The fuel cell works perfectly even at an altitude of 2770 m and temperatures below -25°C and with a snow cover of up to 3m. The methanol usage is constant, independent of the temperature (Figure 32). With one measurement per day and the rest of the time the instrument turned off, the 56 l of methanol are sufficient for one year of operation.

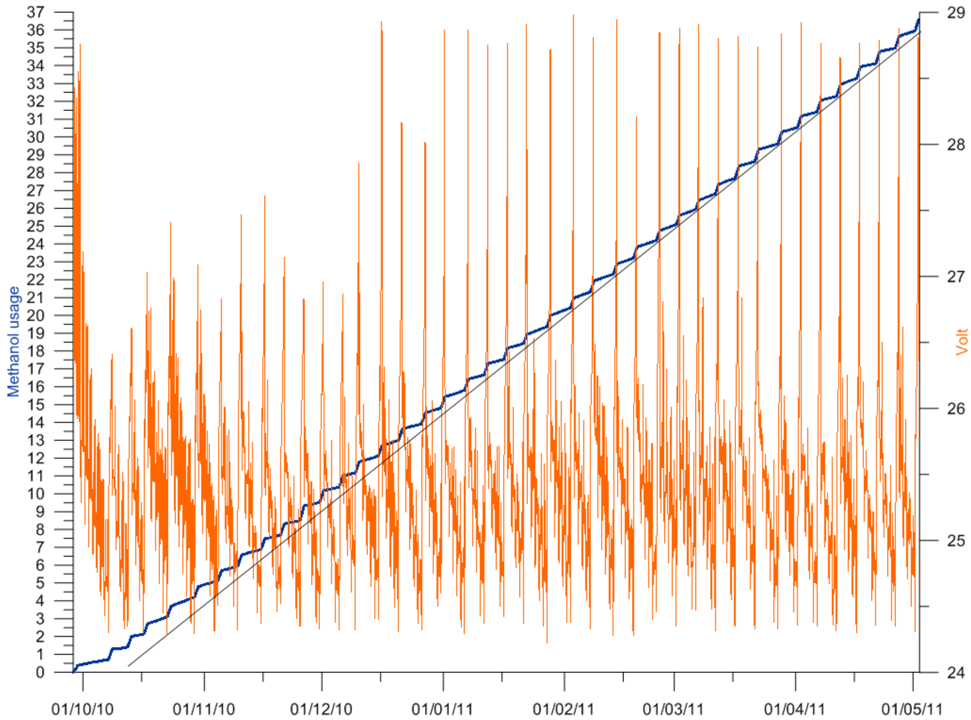


Figure 32: Example of the fuel cell performance. Methanol usage and battery voltage over time since installation on the Mölltaler Glacier, Austria.

Test site Bagnaschino, Northern Italy

The Bagnaschino site is equipped with a stronger unit (Efoy Pro© 2200, 2160 Wh) since the producing company SFC (www.sfc.com) kindly provided the fuel cell free for testing. The methanol consumption in Bagnaschino is higher (28 l in 108 days during the winter months) since the instrument runs 24 h, measures every hour self-potential and every 4 hours the profile. The first fuel cell stopped working after several failures and less than 3 months after installation, but was replaced within 2 weeks free of charge.

Table 11: Review of examples of the monitored sites of GSA with the power supply specifications.

	Installation Date	Fuel cell	Average power consumption	Number of measurements	Altitude a.s.l.	Climate
Mölltaler Glacier	September 28, 2010	EFOY Pro 600	14 W	Once a day	2770 m	High alpine
Bagnaschino	October 22, 2010	EFOY Pro 2200 + solar	100 W	2 long, 2 short + SP hourly	600 m	Mediterranean
Super Sauze	May 25, 2011	EFOY Pro 600 + solar	80 W	every 12 hours+ SP every 2 hours	1820 m	Alpine

Final recommendations

This chapter on monitoring systems reviewed the applicability, reliability, EW potential and infrastructural aspects of different sensors to be applied for EW of slope failures of different types. To conclude the chapter, the major comment is that each slope failure is very site-specific and type-specific, thus there is just one general rule on what should be the monitoring system for landslide EW.

Landslide EW monitoring systems should be as simple, and as user-friendly as possible alongside its sufficient complexity.

The user has to choose the right technologies according to the site, while keeping the overall system simple, sturdy, redundant and heterogeneous. This chapter and review tables, hopefully, could serve as a useful guide.

3.1.3 Operational aspects

The main aim of an EWS is to achieve a reliable knowledge of the geology and the deformation model, in addition to a robust and redundant monitoring system and related infrastructure for the early warning (Blikra and Kristensen, 2011).

3.1.3.1 Combination of geo-indicators and thresholds

In designing an EWS, the correct setting of alarm thresholds is a core element and must never be underestimated. It is yet a very difficult task and thresholds will also be very site-dependent (for example Blikra (2008)). When setting these thresholds, two kinds of wrong decisions may occur (Grasso, 2007): Missed Alarm (or False Negative) when the mitigation action is not taken when it should have been or False Alarm (or False Positive) when the mitigation action is taken when it should not have been. For adequate preventive actions, it is important to reduce the number of False Alarms and, at the same time, not to lose the capacity to detect the warnings. For this reason it is better to design a EWS with more than one alarm level based on more than a single parameter; for instance, if a good correlation exists between pore pressure and displacement, alarm thresholds should be set using both parameters (cf Ancona example in Figure 33).

The use of multiparametric instruments allows setting up alarm thresholds on several parameters while managing a single instrument. Moreover it is important to install both surface and subsurface instruments in order to gain a deep knowledge of the landslide (Blikra and Kristensen, 2011).

Time histories of landslide behavior must also be analyzed and used to set the correct alarm thresholds; moreover the management software should be able to adjust the values in function of the monitoring data available.

A single instrument is not reliable enough to correctly detect displacements. Limited monitoring areas, sensors damages/malfunctions and inadequate data sets are the main obstacles. Instruments redundancy can avoid these limitations and provide to the staff more parameters on which to perform the analysis.

Sensors type	Attention	Early alert	Alert	Early warning	Warning
Signals	New cracks on the road	Cracks on the road in evolution with holes > 5 cm and lowering steps	Subsidence of roads, niches of detachment, cracks on the ground	Cracks on houses, crunches	Displacement in place of houses and soil
Rain	Consecutive rainfall > 3 days Rain > 9mm in 3 days maintain for 20 days		Consecutive rainfall > 5 days Rain > 120mm in 5 days maintain for 20 days	Consecutive rainfall > 5 days Rain > 120mm in 5 days maintain for 20 days	
GPS			Displacement of 1 house (validate before by TCA and after by site inspection)	Displacement of 2 houses in the same area (validate before by TCA and after by site inspection)	Displacement of >2 houses in the same area (validate by site inspection)
TCA			Displacement of 1 house (validate before by TCA and after by site inspection)	Displacement of 2 houses in the same area (validate before by TCA and after by site inspection)	Displacement of >2 houses in the same area (validate by site inspection)
NIVEL			Displacement 2 mm (validate by site inspection)	Displacement 4 mm (validate by site inspection)	Displacement 8 mm (validate by site inspection)
DMS	Piezometric: DMS1 > 7m DMS3 > 5 m	Piezometric: DMS1 > 5m DMS3 > 4 m	Inclinometers: displacement 6 mm in 1 day (validate)	Inclinometers: displacement 6 mm in 3 hours (validate)	Inclinometers: displacement 6 cm in 1 hour (validate)

Figure 33: Example of warning levels for a landslide EWS (Ancona EW centre).

Alarm thresholds should be set on several parameters, some of them could directly correlate to the landslide physics while some of them could less correlate. The most common geo-indicators are: displacement, velocity, acceleration, water table level, pore pressure, soil moisture, rainfall, earthquake, and floods (for details see Deliverable 4.6 entitled "*Report on geo-indicator evaluation*"). An example of alarm thresholds set on velocity is shown in Figure 34. Multi-level alarm thresholds are defined on the base of velocity of displacements: activities and responses are implemented in function of the threshold value that is exceeded. In many cases, the decision to change an alarm level is not only based on these parameters but also on an expert evaluation of the total stability conditions.

Velocity	Alarm level	Activities and alarms	Response
0,1-0,5 mm/d	Level 1 Normal situation	Minor seasonal variations No alarm	EPC staff only Technical maintenance
0,5-2 mm/d	Level 2 Awareness	Important seasonal fluctuations for individual and multiple sensors Values<excess thresholds for Level 2	Increase frequency of data review, compare different sensors Call in geotechnical/geological/monitoring expert
2-5 mm/d	Level 3 Increase awareness	Increased displacement velocity, seen on from several individual sensors Values<excess thresholds for Level 3	Do continuous review, do field survey, geo-expert team at EPC full time Inform police and emergency/preparedness teams in municipalities
5-10 mm/d	Level 4 High hazard	Accelerating displacement velocity observed on multiple sensors Values<excess thresholds for Level 4	Increase preparedness, continuous data analysis Alert municipalities to stand prepared for evacuation
> 10 mm/d	Level 5 Critical situation	Continuous displacement acceleration Values>excess thresholds for Level 4	Evacuation

EPC = Emergency Preparedness Centre in Stranda

Figure 34: Example of alarm levels and responses to be implemented (document from the Emergency Preparedness Centre in Stranda, Norway).

3.1.3.2 Data analysis

Monitoring data are not only used to activate warnings and alarms, but their analysis is also very important to **adjust the thresholds** themselves, and define the landslide model and its evolutionary phases. An accurate analysis on a landslide should start from the analysis of its time histories and the correlation between different parameters. The correlation between parameters is not always the same for every site: in some sites it could be strict while in other sites it could be very low. Performing a site specific analysis is for this reason a core requirement.

The use of innovative instruments that **monitor several parameters** can facilitate data processing and correlations between parameters. In addition, **real time monitoring** reduces the intervention time. The study on evolutionary and forecasting models requires instruments working in continuous; in this way a good quantity of data will be available to perform quantitative analysis on the forecasting model.

Besides, instrument performance needs to be kept under observation. One of the most important factors is the voltage check; the choice of a not **suitable power supply** system or an error in its capacity could cause the failure of the entire system, with additional cost to change or resize it. Also taking into account the communication capacity (e.g. cell phone coverage) is important during the design phase; receiving data flow is fundamental and an

EWS with low communication signal could be useless. One important step in this process is to include **data quality control** measures in data acquisition and processing to ensure that erroneous data is not used in analysis and forecasting of landslide activity.

3.1.3.3 Alarm

"Predictions are not useful unless they are translated into a warning and action plan the public can understand and unless the information reaches the public in a timely manner" (Glantz, 2003). The main target of a EWS is to protect lives and properties (Grasso, 2007). For this purpose, the monitoring system and the public protection plan have to be totally integrated; the action defined in the protection plan has to be taken rigorously in function of the data of the monitoring system and in collaboration with the Civil Protection. An **internal protocol** for the procedures to be taken in case of alarm needs to be established (Figure 35). These procedures must involve all the staff in charge of the protection plan.

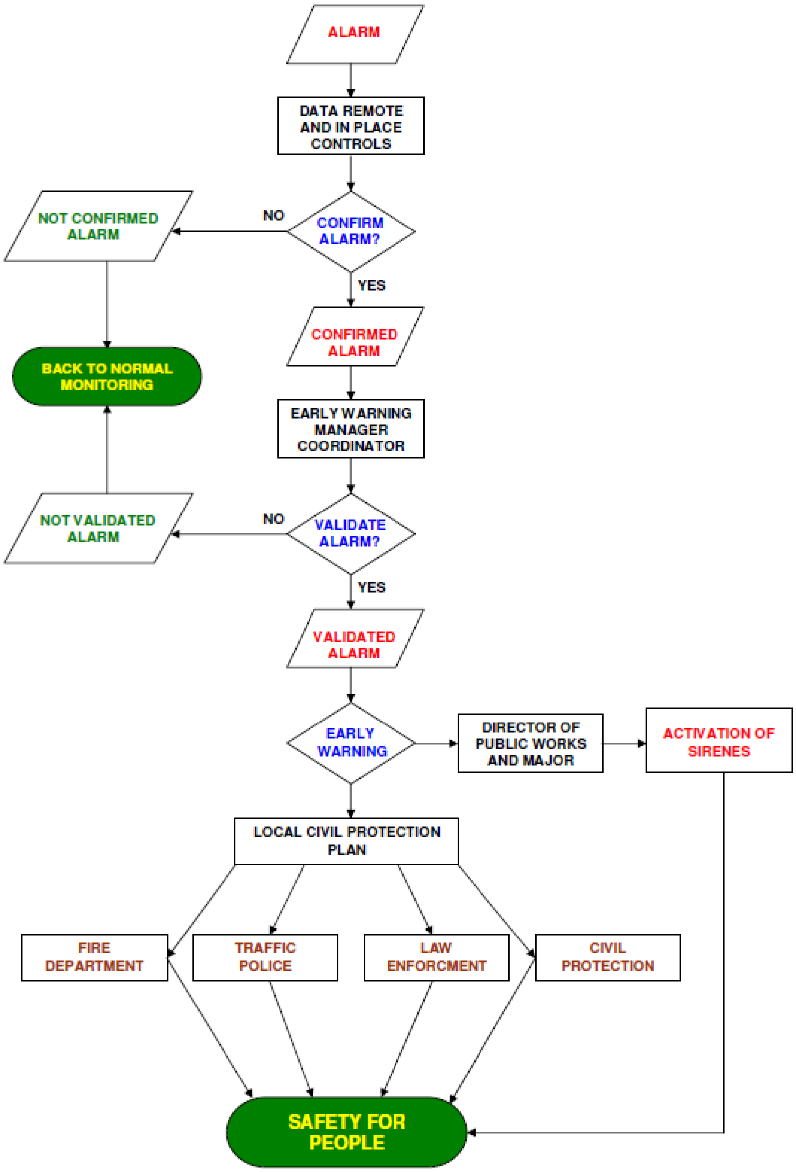


Figure 35: Codified structure of the steps to follow in case of an alarm (Ancona EW Centre).

Alarms must reach the population in the shortest time and in the clearest way possible; the main methods used are: sirens, SMS, direct call, media (TV, radio), web service and traffic and warning lights (Figure 36). The actual procedure for the alarm and evacuation needs to be adjusted to the local conditions and the time available. In many cases, the evacuation can be done by the normal police procedures.

Figure 36: Traffic lights can stop car traffic during high hazard level (Capo di Noli, SV, Italy) while sirens can transmit evacuation signals (Canton Ticino, Switzerland).

3.1.3.4 Management software

All the monitoring data should be available and usable in an easy way and should be visualized in a user friendly interface, allowing fast and simple analysis. Data download, storage, analysis and communication must be performed, sometimes simultaneously. This requires a high usage of computer resources. It may be advisable to use **a single management software** that handle the main data elaborations. However, several independent systems need to be evaluated due to the need of redundancy. The management software should be robust and reliable. It is very important to avoid crashes during the warning periods.

Data sharing between different users represents one of the most encountered problems. Indeed lack of information can cause a delay in response and a failure of the protection plan. The management software must be able to share all the information between the users in the shortest time. One solution is to send the monitoring data to a **web data server** and allowing their download through FTP protocol; to guarantee confidentiality only authorized persons could download them. The possibility to download data outside of the monitoring room improves the reliability of the entire system. Indeed using different devices, such as Smartphone or mobile/notebook through GSM/GPRS, Wi-Fi, Ethernet connection, from the field is an important aspect. Internet connection to the server, in which the database is stored, could alas open a door to external intrusion like virus, Trojan or hackers which could damage or steal sensible information. In order to avoid or reduce this risk, it is prudent to employ commercial software (not open source) and secured Internet connections.

As the EWS needs to work continuous, the management software must guarantee **automatic data download** from the field as well as automatic data upload to the web server. It should also notify the user when data transfer cannot be executed.

A **standardized data format** should be used in order to improve data integration, simplify correlation between different parameters and facilitate data exchange. Data standards and data harmonization are covered in chapter 5 of this deliverable.

The management software must advise the staff on duty when a threshold is reached; this procedure must be implemented in the shortest time as possible. Another solution is to equip instruments with **modems**, which can send in real time a SMS/direct call to a preset list of phone numbers: the central processing unit (CPU) analyzes data in real time and command the modem.

It is also suggested to implement the possibility to remotely perform a **self test** on the sensors; this procedure allows to identify malfunctions on sensors or to validate data, reducing the uncertainty without having to go to the field.

3.1.3.5 Infrastructure

The infrastructure must be **specifically designed** for the typology of the area to monitor and for the number and types of instruments. It is important to consider every element of the EWS: sensors, power supplies, communication systems and monitoring centre. Environment conditions, technological constraints and economic availability (for short and long period) must also guide the design phases.

The instrumentation architecture has to be built in a **redundant** way in order to avoid data gaps due to failures or malfunctions of sensors. For the same reason the power supplies and transmission systems must also be redundant. The monitored sites are often in harsh environment, difficult to reach for maintenance or repairing works, so the redundancy of the system has a crucial role during its design phase.

Figure 37: Monitoring laser station at Åknes. The reflector plate (upper left) is heated to cope with harsh Norwegian climate conditions. From (Blikra, 2008).

Continuity of service is a primary need in EWS applications; failure of sensors or loss of power could stop data transmission, slowing or interrupting the intervention procedures. For this reason during the design phase the cost for maintenance and repairing works should be taken in account, the **robustness and reliability** of the instruments are core elements during the design because they reduce maintenance work allowing long-term saving (Figure 37). For instance, extractability, easy maintainability and high robustness are crucial in borehole monitoring.

To guarantee a reliable monitoring centre, the software and hardware must comply with the requirements of the EWS and maintenance procedures also have to be followed at the centre. The EWS should be in operation continuously (24 h, 7 days) but it does not mean that the staff has to be on site 24 h and 7 days. It is often possible to control data and warnings remotely. As seen in 3.1.3.2, monitoring data could be downloaded or visualized in many ways (i.e. by direct connection to the data loggers through GSM/GPRS, Wi-Fi, Ethernet or by FTP connection to the data web server, or by browser visualization). The staff in charge of the EWS has a double role: to analyze monitoring data and to communicate with coordinators and civil protection staff (Figure 38). Finally the messages have to be clear and without scientific jargon, but at the same time they should be complete and should include uncertainty levels (Grasso, 2007) and general warning information (type of warning, severity…).

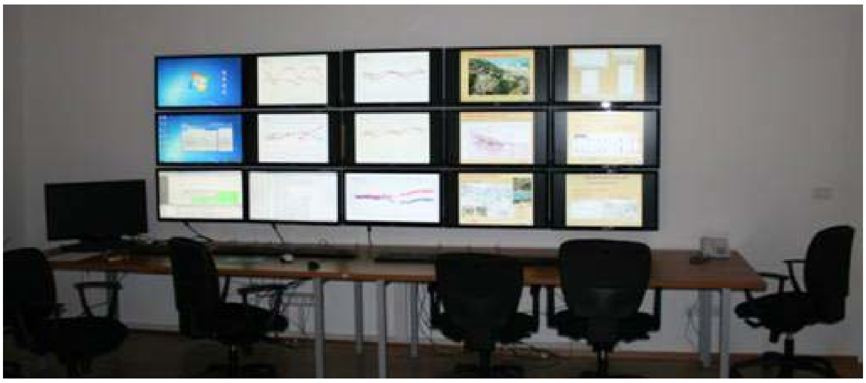


Figure 38: Monitoring room at the Ancona landslide EW Centre.

3.1.4 Operational check-lists

A fully operational EWS requires a systematic organisation, check and evaluation of possible failure of the technical systems that are the basis for the measured data. In addition, there is a need for continuous interpretation of the geo-indicator data. Some of these requirements are described in Blikra and Kristensen (2011). The following gives an overview of some of the key elements that should be structured, including both technical systems and the geological interpretations.

Technical systems:

- Total structure/flow chart of the technical systems, including individual sensors, power supply, communication (data transfer) and warning systems.

- Redundant systems ensuring that acceptable amount of measuring data for the geological interpretation can exist during failure of parts of the technical systems. This needs backup system on sensors, power supply (field and monitoring centre), data transfer and data servers.
- Automatic messages (SMS) from the technical system during failure to the technical person on duty.
- Alarms on the technical systems need to be checked out. The response time is dependent on the type of failure. A plan for the response time for different type and extent of failure should be outlined.
- Annual inspection and maintenance (maintenance plan for the different systems).

Geological check list:

- Document describing the task of the geologist on duty, including communication routines during different alarm levels and during change of the levels.
- Define sensors that can be used for automatic SMS. Threshold values need to be defined for each of the selected sensors, depending largely on the accuracy and the precision. In practice, SMS messages from the sensors may be used as a pre-alert to the geologist on duty, but not for automatic redefining of alarm levels.
- Automatic SMS messages are checked to see if the data overcoming the threshold values are due to noise (e.g. weather conditions) or due to increased deformation (for example).
- Daily check of all measured data and interpret the conditions in terms of increased deformation or change of other geo-indicators (e.g. rainfall/snowmelt or water pressure).
- Daily log and weekly reports as part of the quality control.
- Decision of change in the alarm level is normally done in dialogue with the leader of the geological group. Routines need to be documented.
- Yearly review of the conditions and reporting. This may also include review by an expert panel.

3.1.5 Community and response capability

Designing an end-to-end EWS spanning from hazard detection to community response is not only a matter of selecting appropriate technology and quality of the technical arrangements. On the contrary as proposed by Basher (2006) the **linear technical warnings service** is only a part of an integrated system involving several stakeholders and functions (Figure 39).

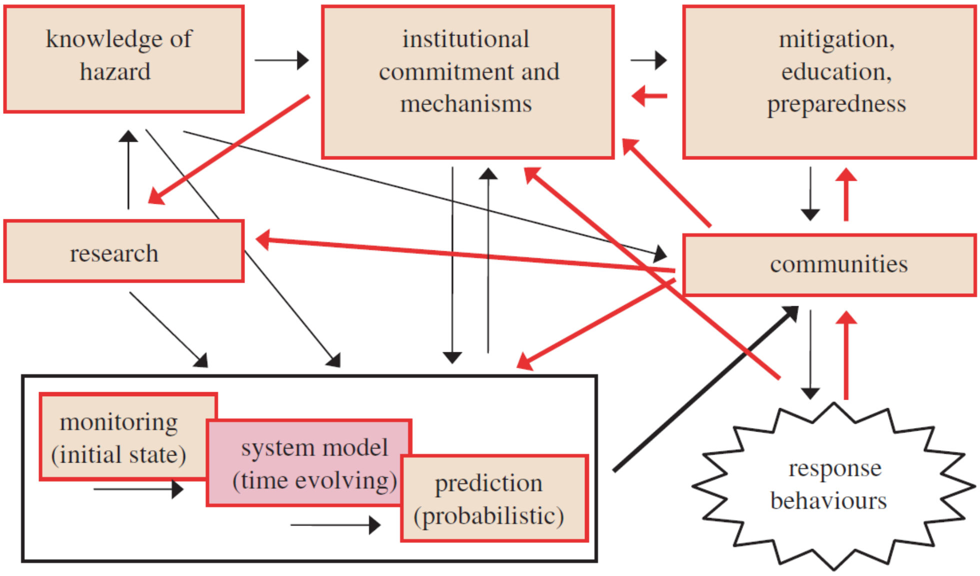


Figure 39: Integrated systems model of EWS. The linear technical warning service is in box at bottom, while the feedback paths are indicated as red arrows.

When designing the integrated system it is therefore important to bear in mind that the EWS should be designed to guide a proper response behaviour through involvement of several functions. It is therefore important to consider the community and response capability as well as input from other stakeholders when designing the system. Several aspects are important to consider:

- Experts have often detailed knowledge of the hazard and will be important for the functionality of the EWS. In addition to give important design parameters, they can also be an integrated part of the system by collecting and analyzing data.
- Institutional functions like national authorities, police, etc, that will have an interaction with the EWS, both by giving premises to the system such as required response time, means of information distribution and as a receiver for information from the system. These functions may therefore give important premises for system design.
- Mitigation, education and preparedness are other topics closely related to the EWS. The information given has to trigger a response which can have significant impact for the people involved. The early warning given by the system has to match the possibilities for response in the community. People also have to be educated and informed of their required response and this competence has to be regularly maintained. Full-scale tests should be regularly conducted allowing for proper identification of the shortcomings of the system. All these parts are equally important as the technical components in the integrated EWS.
- The structure of the community for which the system is constructed can give direct input to the design of EWS. This can be geographical factors, technical infrastructure, and area vulnerability. Alerting and evacuation advice by use of cell phone alert may for example be highly relevant in certain communities, but may be totally irrelevant in other areas where cell phone use is not distributed.

3.2 DECISION MAKING PROCESSES

3.2.1 Stakeholders and responsibilities

Decisions making processes are described in SafeLand deliverable D5.3 entitled "*Quantitative risk-cost-benefit analysis of selected mitigation options for two case studies*". The formulation of a decision problem depends very much on the decision maker. This makes it important to establish the stakeholders, the beneficiaries and the responsible parties for the decision problem. Each possible decision maker may have different viewpoints in regard to preferences, attributes and objectives. It is important to identify the decision maker, since the selection and weighting of attributes must be made on behalf of the decision maker. In this regard, the following general decision making levels can be identified – supranational authority, national authority and/or regulatory agencies, multinational/international private company, local authority, local private owner, private operator and specific stakeholders. Balance should be found between the wishes of the different stakeholders and solutions should be designed regarding responsibilities and budget of each of them. Dialogue and exchange should be the key words on whether an EWS is necessary, but it has to be clearly stated that consensus, if useful and required, should not necessarily be reached. Antagonist requirements are generally the rule between stakeholders, and the choices have to be defined based on ranked responsibilities and on available budgets.

As discussed previously, the EWS is a combination between technical installations and human interactions. This system should be designed as an integrated system. The interface between the actual measuring system and further action should be clearly defined. This requires equal focus on designing the upstream and downstream side of the EWS (Figure 40). If expert competence is required to make predictions this function should be an integrated part of the system. This means extensive focus on how alert is initiated, through what channels the alert is transmitted and how message is received and how to handle feedback.

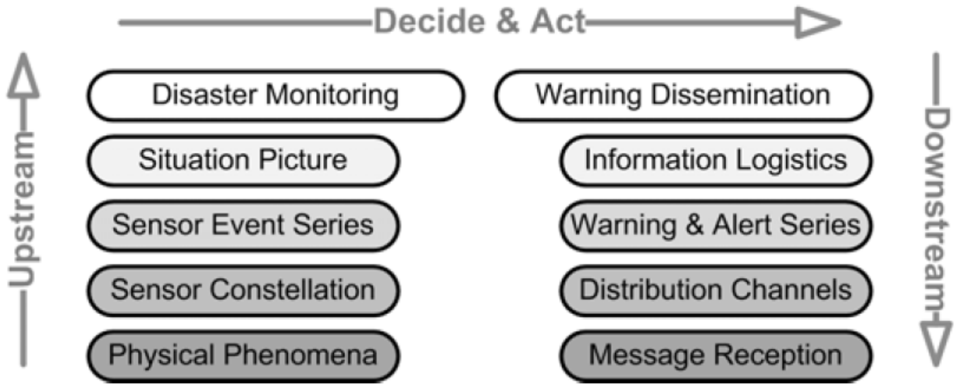


Figure 40: Upstream and downstream event and information flow in an EWS (Lendholt and Hammitzsch, 2011).

Levels of alert and further actions should also be formalized within an emergency preparedness plan which states the action depending on the outcome of the operational centre. The responsibilities for interpreting data from the operational centre and further notification should be decided on beforehand and there should be allocated sufficient resources for these functions. The reliability and redundancy of the system should be sufficient to the requirements and should include also human interactions. The system should be robust enough to function for long time monitoring.

3.2.2 Economical constraints

In a quantitative risk-cost-benefit analysis, a decision may be understood as a **committed allocation of resources**. This process is also described in SafeLand deliverable D5.3 entitled "*Quantitative risk-cost-benefit analysis of selected mitigation options for two case studies*": the decision maker is an authority or person who has authority over the resources being allocated and responsibility for the consequences of the decision to third parties. The intention of the decision maker is to meet some objective, the value of which is at least in balance with the resources allocated by the decision. The decision maker faces the problem of choosing between a set of decision alternatives which may lead to different consequences in terms of losses and benefits. The objective aimed for by the decision making represents the preference of the decision maker in weighing the different attributes which may be associated with the possible consequences of the decision alternatives.

3.2.3 Legislation

There are major differences with respect to the level of implementation of the legislation regarding natural hazards in the European countries and we cannot list all of them here. In some countries, a central authority is dominant, while in other countries the regional authorities are dominant . In countries with regional authorities, one can expect different practical implementations of measures, for example in relation to risk assessment or to communication and warning dissemination.

SafeLand deliverable D5.5 entitled "*Five scoping studies of the policy issues, political culture and stakeholder views in the selected case study sites – Description of methodology and comparative synthesis report*" studies how different political, scientific and cultural contexts influence the character and application of risk mitigation policies through a comparative study of the situation in Italy, France, Romania, India and Norway. The analysis is based on a desk study of national legislation and administrative structures of landslide risk management in the selected countries. As an example in this report and based on D5.5, we have chosen to describe the Italian and French legislations in order to point out their differences.

3.2.3.1 Italy

The Italian legislation about landslides and risk mitigation is a process of more than 100 years, strongly linked to the disasters have occurred (Figure 41). The first legislative act on the construction of protection works and risk zoning came into effect in 1904. The development of risk management practices in Italy can be separated into four key phases. Each of these phases were characterised by the domination of building restrictions, water and soil integrated risk management, risk assessment and risk governance, respectively.

In Italy most people have access to risk data. The hazard and risk information are given to administrative bodies at regional, provincial and municipal level. In addition, risk and hazards maps are accessible by the public on the webpage of the River Basin authorities and in the municipal technical offices. However, at the same time there are many different interests groups operating in the policy domain that are in conflict with public safety. Because building constraints often hinder urban, industrial and tourism development, there are continually negotiations about the validity of hazards and risk zones. It is also reported that technical officers at the local level not always agree with the risk zoning of the River Basin Plans and that they therefore are open for negotiations. Such local level actors are often put under pressure from private actors and lobbies to reduce the extension of areas designated as 'high risk' such that local plans may differ from requirements set in the River Basin Plan.

In the last decades the State created a database to Regions, Provinces or Communes to provide an exhaustive knowledge of the territory and to provide technical agencies for reference and control, able to help the Administrations for correct territory management. The PAI (River Basin Authority) implementation rules contain also clear indications to a correct management of high risk areas. An example can be found in "NTA PAI 26/04/2001 Title IV Art.49 – River Basin Authority of the Po river: "In areas with high hydrogeological risk, a monitoring system has to be implemented, aimed to a correct definition and evaluation of the risk of the instable phenomena, to a detection of triggering events, to design the emergency plan, and to verify the effectiveness and the efficiency of any works carried out." An example of regional legislation can be shown in Central Italy by Regione Marche, starting in 1994 with L.R. n.36 of 29/08/1994 extraordinary financing for the completion of stabilisation works on the landslide, following in 1997 by L.R. n.55 of 02/09/1997 where it was disposed that the Ancona Commune was responsible for the planning, the execution and the approval of the consolidation works. But only recently the regional law L.R. n.5 of 03/04/2002 mentions the principle of starting of the Ancona EWS.

	Building restrictions (1920-1965)	*Water and soil integrated risk management* (1966-1991)	*Risk assessment* (1992-2000)	*Risk governance* (2001-present)
Priority of values	Economic growth and building speculation (uncontrolled building also in risky areas)	National security and welfare standards	Ecological sustainable development	Public participation for decisions concerning landslide risk mitigation
Focus of the policy mechanism	Investments in structural defense	River basin plans	Hazard, risk and vulnerability mapping and assessment	Hydrographic district plans
Major events	1951 Polesine flood (84 deaths) 1954 Salerno landslide/debris flows (318 deaths) 1963 Vajont landslide (1,917 deaths)	1966 Firenze flood (112 deaths) 1968 Belice earthquake (270 deaths) 1976 Friuli earthquake (965 deaths) 1980 Irpinia earthquake (2,914 deaths) 1985 Stava landslide (269 deaths) 1987 Valtellina landslide (53 deaths)	1994 Piemonte landslide (70 deaths) 1998 Sarno landslide (161 deaths) 1999 Soverato flash flood (12 deaths)	2009 L'Aquila earthquake (308 deaths) 2009 Messina flash flood (36 deaths)
Key laws	R.D. 3267/1923 – Limitation to private property – building restrictions	L. 183/1989 - Soil and Water Integrated Risk Management	L. 225/1992 – Establishment of the national civil protection service L.493/1993 – Watershed management plans L. 267/1998 - Actions for coping with hydro-geological risk	2000/60/CE Water framework Directive L. 152/2006 - Norms regarding environmental issues
Key innovations	Building restrictions established on the national territory in a fragmented but accurate way	Identification of river basins Establishment of River Basin Authorities River basin plans	Watershed management plans Classification of risky areas in four classes	Identification of hydrographic districts
Key scientific developments	First criteria to identify risky areas	Interdisciplinary approaches for soil and water management	Risk assessment Development of monitoring, forecasting and warning systems	Remote sensing, radar and monitoring, laser scanning, warning systems

Figure 41: Timeline for legislation regarding landslides in Italy.

3.2.3.2 France

France has a long history of experiencing natural disasters, with documented events dating back to the middle-ages, with some events erasing entire cities and their populations. Thus, dealing with natural hazards has been on the agenda of authorities for over two centuries. Due to the centralised legal and political organisation of the country and a long tradition of codification, risk management policies have been addressed by several laws, codes and plans over the years.

Natural disasters in the early 1990s led to a revision of prevention and management systems (Figure 42). In 1995, existing documents were replaced by a more flexible PPR (risk prevention plan). These new risk prevention plans could be single or multi hazard oriented. They were legally binding, but excluded retrospective application to existing buildings. Compulsory public consultations were enforced as a prerequisite to any environment related decision making. The compensation system funding was further clarified and, for the first time, it was possible for the authorities to expel residents from dangerous zones if deemed appropriate for risk management reasons.

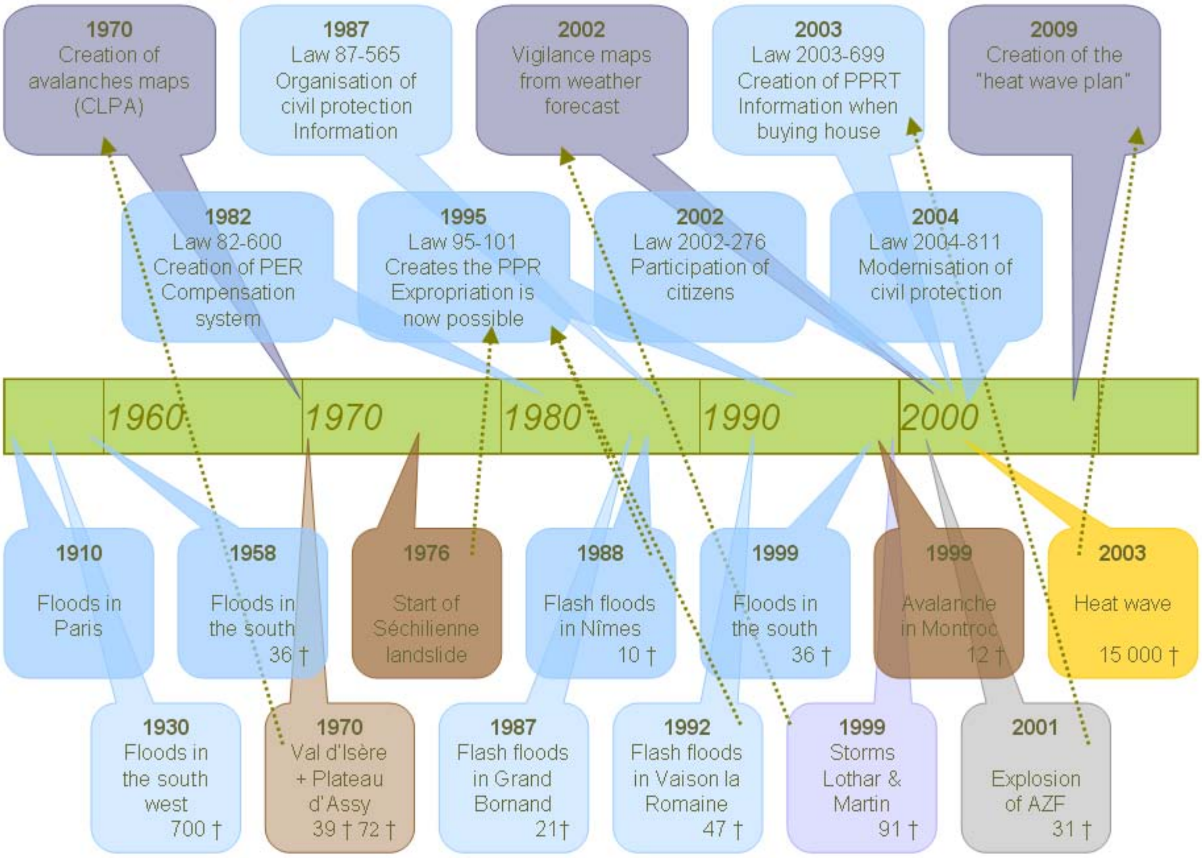


Figure 42: Timeline for legislation regarding natural disasters in France.

3.2.3.3 Comparison of the two types of legislation

In France, unlike Italy, laws can only be national and there are no regional laws. Therefore the legislative framework is supposed to be applied evenly across the entire territory. National laws cannot be adapted to the variety of landscapes existing in France, where plains, mountains and littoral coexist. Therefore some laws are viewed as unfair or inadequate in their application (e.g. the requirement of a building-free strip of 50 meters behind a dam cannot be adapted to mountains with tight valleys). Overall, although the centralised nature of risk management in France bears a disproportionate impact on geographically and socially variegated regions, clear structures of responsibility in risk prevention and management provide a sound framework for landslide risk management in the country. In the contrary, conflicts between national, regional and local authorities in Italy result in a lack of co-operation in terms of managing and developing landslide risk management.

3.2.4 Cultural elements

Risk assessment based on statistical calculations of likelihood and consequences has been considered as the main focus in landslide risk assessment and management. In recent years more attention has been given to those affected by risks. While statistical estimations are of great importance for choosing risk management strategies, it is also argued that it is important to understand how people assess and perceive risk.

People’s perception of risk is often complex and diverse. As a consequence people’s reactions to risk differ considerably, both within a community, and more significant, with the judgments of the scientific experts. In many communities the expert’s judgment is in conflict with that of the general public and because there is no trust between the public and those undertaking risk assessments, the results are often questioned and opposed (Lee and Jones, 2004a). Therefore, faced with people’s skepticism, it is important that decision-makers and risk managers take people’s risk perceptions seriously and focus on how to build trust between the experts and the public.

In a totally rational world, people should be less concerned about a specific risk when technical solutions to the problem exist. But in real life it does not necessarily work that way because people do not trust the expert knowledge. In fact, it does not help much that scientists set limits for acceptable risk and install monitoring and warning systems, if the people themselves do not trust the experts and the technology used. In order to reduce the gap between the experts and the general public it is important to have more dialogue between the parties.

How individuals and groups of people perceive risk is related to many social and cultural factors. It is a question about beliefs and values, knowledge and experiences, as well as human interaction, geographical location and dependence on the natural environment (Harmsworth and Raynor, 2005). The difference in the way people perceive landslide risk is also related to frequency and magnitude, media presentation and how landslide risk is dealt with by the authorities. In general, it can be argued that much media attention and lack of belief in authority are factors that are tending to increase risk perceptions, while little media attention and belief in authority tend to decrease public risk perception (Smith, 2004).

Taken that trust is identified as a key element in implementing new politics, and also is seen as essential in achieving cooperating and collective action (Ostrom, 1997;Putnam, 2011;Rothstein, 2005), landslide risk management should be based on risk communication that facilitate trust and trust building. Risk decisions and the successful implementation of new risk management strategies should be based upon ideas of trust, which depends on openness, involvement and good communication. By having an open and inclusive dialogue at an early stage, tension between the experts and the general public can be reduced. If risk management strategies are perceived as imposed on those affected and risk information is based on very technical concepts and models, it can be hard to establish trust. Further, given that risk communication involves the multiple flow of information between scientists, decision-makers, the media and the public, it is also most important to think about how this can be improved and balanced. Today, little attention is paid to the perceptions, experience and knowledge of those who live in landslide prone areas and mistrust often becomes an obstacle for effective landslide risk management.

There are many different cultures of landslide risk management. To fully understand the dynamics and transitions of landslide risk management and development, it is necessary to understand the possibility for learning, cooperation and change within different socio-political contexts. In some Europeans countries, the population expects to have an open and inclusive dialogue with the experts due to small power relations and strong democratic traditions. In societies with large power distances between the experts and the general public, on the other hand, power relations are much more autocratic or paternalistic. As a result it will often be difficult to establish a good environment for transparency, participation and trust in management processes. Several stakeholders studies in different countries are provided in appendix B. For example, the implementation of an EWS in the Storfjord region in Western Norway is discussed. The study, which looks at how people in a highly exposed area perceive and manage risk, addresses the relationship between risk perception and risk-communication. In particular it focuses on the importance of trust building and knowledge exchange in the local community. One of the arguments put forward is that landslide risk management should be based on equal, face to face relations in the formal and informal space.

4 EARLY WARNING SYSTEM TOOLBOX

Designing an EWS toolbox is a complex task. Many factors are to be considered and the landslides variability is large. For example a slope scale EWS differs dramatically from a regional scale one. Moreover, there are many constraints that influence the features of the EWS itself. These constraints are basically conditions that are imposed by the type of landslide, risk scenarios, available resources, etc. Therefore it is impossible to develop a single EWS valid in any case. For all these reasons a certain degree of simplification is required when building such a toolbox. Also, EWSs must operate during emergency; in such conditions it must be clear which actions must be taken, and they have to be as **direct** and **simple** as possible. In fact, confusion and loss of time can generate a whole new kind of emergency. Therefore if simplicity is a key factor for an EWS, there is also the need for a **flexible** toolbox which favours straight-forward, graphic methods that lead the end-user towards the most suitable EWS. The importance of other fundamental elements such as robustness, reliability, communication and earliness will be stressed further on. The idea behind this toolbox is to furnish an assisting instrument for expert end-users but especially to help those who are not familiar with EWSs. The aim is to provide them with a fast tool for defining the main elements of an EWS considering how several factors can vary. By applying the toolbox to one’s case study, the basic structure of the system is defined; further customization should be considered in order to fit the system for particular circumstances.

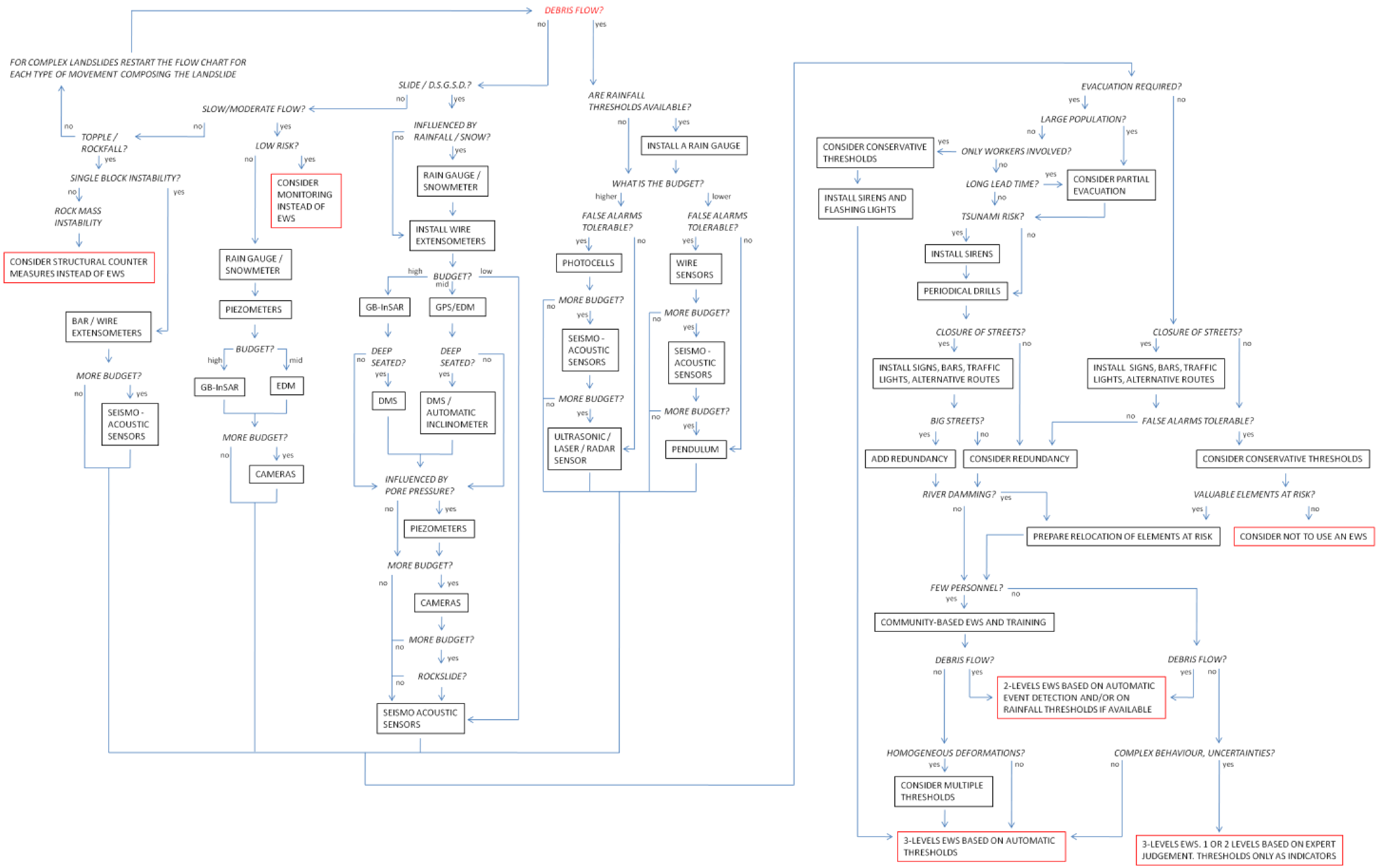
4.1 DESCRIPTION OF THE TOOLBOX

The characteristics of an EWS (such as monitored parameters, sensors, thresholds, etc.) are constrained by the boundary conditions of the site. By studying and decomposing many EWSs operating throughout the world into their features and constraints, the basic ingredients for designing an EWS for landslide can be identified. The combination of these ingredients permits to obtain many different EWSs, suitable for most circumstances.

4.1.1 Possible flow chart architecture

In order to realize a simple and direct toolbox which enables one to delineate the main features of an EWS, a flow chart approach is developed (Figure 43). By following the chart the end-user is asked about some information concerning the type of landslide, some of its characteristics, the elements at risk, etc. Depending on the answers given, this graphic-based method indicates which instruments, procedures and so on should be introduced in the EWS. The toolbox developed here is valid for a slope scale system (i.e. EWS for an individual slope). The validity of this flow chart has been tested on well known case studies where efficient systems are described in literature (Blikra, 2008;Iovine et al., 2006;Lacasse and Nadim, 2009). The resulting synthetic EWSs are very similar to the real ones.

Figure 43: Flow chart-based guidelines: by answering some questions concerning the site, the end-user is provided with the main structure for his EWS. This is valid for single landslides (slope scale systems).



4.1.2 Technical description of the flow chart elements

The flow chart of Figure 43 is constituted by two kinds of nodes: the ones written in *italics* contain short questions about the type of landslide and about qualitative estimations of the budget at disposal (left part of the flow chart), as well as questions about the elements at risk and risk scenarios (right part). These represent the constraints imposed by the case study. On the other hand the contoured nodes indicate possible features that should be introduced within the EWS to remediate the constraints. These are cumulative, which means that once the end-user has reached the end of the flow chart, he should consider all the suggestions furnished by the contoured boxes encountered in the way. The nodes contoured in red represent the ends of the flow chart, while the start is at the very top of the chart.

The first part of the chart (left side) helps in selecting the monitoring instruments, which choice is mainly due to the type of landslide and the budget. The right side concerns the organization of the system in general. For a technical description of the toolbox, we can follow the different nodes starting from the left side of the flow chart:

- *Debris flow*: this type of landslide is often faced with basin/regional scale EWSs. This is due to the strong correlation with rainfall and therefore to the possibility of predicting debris flow by installing rain gauges through the area and implementing rainfall thresholds. For this reason, rain gauges should always be considered when rainfall thresholds are defined or can be derived from literature. Beyond using rainfall correlations there are no other as much efficient means to forecast the occurrence of a debris flow; however there are several instruments that can detect its mobilization (event warning system). These methods have been divided depending on their cost, their proficiency and their reliability in relation with false alarms.
- *Slide/D.S.G.S.D.*: rotational slides, translational slides and deep-seated gravitational slope deformations (DSGSD), though very different, can usually be monitored by the same kinds of instruments. Rain gauges (and in certain regions snow-meters) should be installed in most cases, especially when rainfall thresholds can be defined. Concerning displacement monitoring devices, the priority has been given to extensometers, due to their robustness, reliability, versatility, and relatively low cost. Other instruments (such as GB-InSAR, GPS) are suggested only when a higher budget is available, while others (DMS, inclinometers) are suggested when dealing with deep-seated landslides.
- *Slow/moderate flow*: while rapid flows can be largely considered together with debris flows, slow and moderate flows should be faced with different EWSs. However, due to their nature, they do not always require the implementation of an EWS.
- *Topple/rock fall*: these types of landslide are hardly managed with EWSs. However, whether they involve single unstable wedges of a few cubic meters or many smaller blocks widespread along the rock mass, extensometers or seismo-acoustic sensors can be installed.

The instruments present in the flow chart are contoured nodes (for further details on their specificities see SafeLand deliverable D4.1 entitled "*Review of monitoring and remote sensing methodologies for landslide detection, fast characterisation, rapid mapping and long-term monitoring*" and section 3.1.2 of this deliverable): rain gauges/snow-meters, photocells, wire-sensors, pendulums, ultrasonic/laser/radar sensors, seismo-acoustic sensors, extensometers, ground-based InSAR, GPS, EDM, DMS, inclinometers, piezometers, and cameras.

The actions suggested in flow chart as contoured nodes are:
Evacuation required: evacuation is required when pre-emptive relocation of the EaR is not feasible and whenever people are endangered. It should be used only during the highest level of alarm, due to its costs and consequences, especially in the case of large scale evacuations. People must be well informed about their presence in a risky area and about the action to be taken in case of alarm. Evacuation is typically associated with the use of sirens, flashing lights and broadcasted messages. Signs should be present to inform people about the risk and how to reach the closest safe area.

Partial evacuation: evacuation should start with the pre-alarm level only in few cases; that is when the evacuation probably requires too much time with respect to the time of the alarm, or when some EaR are particularly vulnerable. For instance this can happen when the population is very large or when a hospital must be evacuated. However, this action should be taken considering expert judgement or at least instrumental redundancy in order to reduce the possibility of false alarms.

Conservative thresholds: in cases where false alarms are more tolerable (for example when the landslide threatens small streets or workers that can easily evacuate, as in the case of open-pit mines) alarm thresholds can be slightly lowered, which results in increasing the safety factor. This should be done carefully because too many false alarms can result in economic losses and reduce the trust in the EWS.

Sirens/flashing lights/traffic lights/bars/signs/alternative routes: sirens and flashing lights are the most common and economical media to transmit an alarm; they can be used in almost any case and installed by the landslide, along the streets, along the coastline and in any other susceptible areas. Together with sirens a few different types of message can be spread (for example “this is only a test”, “emergency - evacuate immediately”, “the area is now secure”, etc.). Signs are a very versatile and simple means to inform people and direct them towards the closest safe area through appointed routes during emergencies. Albeit they alone, without any public education, are not sufficient. Bars, traffic lights and alternative routes are of common use for endangered streets or railways; if enough time is available there should be appointed people in charge of clearing the area. In case of secondary streets they can be closed since the pre-alarm level. If possible, local TV channels and radios can be very effective to broadcast the alarm, especially in regional scale EWSs. If high budget is available and the area at risk is frequented even by people who may not be aware of the risk (such in the case of touristic places) an automatic SMS system can be implemented.

Periodical drills: public awareness is one of the most important and, at the same time, cost-effective parts of an EWS. Typically the actions to be taken can vary from case to case, depending on risk scenarios. The cheapest way to inform people is simply by using signs that warn the public about the possible risks. Even the use of leaflets is reasonably cheap but also not as much effective. On the other hand awareness campaigns involving periodical drills, meetings, events and education are a valuable tool but require a good level of organization. In some cases, when private slopes are involved in a regional scale EWS, education campaigns aimed at teaching owners how to maintain their slopes are very useful. Probably the best way to increase awareness is via radio and especially via TV (Yu et al., 2011); these two methods however are not always feasible. Although special attention on public awareness should be regarded in every EWS, periodical drills are particularly important when evacuations can occur.

Redundancy: redundant solutions help to considerably reduce the number of false alarms. When dealing with kinematic thresholds redundancy can be achieved by checking if the threshold is exceeded over a long time, or with different instruments or even with instruments located in different areas. Redundancy can also be exploited by monitoring the same parameter with different devices, or by routing data transmission through multiple channels, by adopting multiple models for data interpretation, by selecting next-in-charge personnel, etc (Nadim and Intrieri, 2011). A certain degree of instrumental redundancy is usually convenient. However, a high level of instrumental redundancy can eliminate false alarms as well as the real ones.

River damming: a landslide falling into a river can produce different consequences. In general, if the volume of the material damming the river is large with relation to the drainage of the basin, the barrier can become stable and a lake can develop. If the volume is small the material will be easily eroded without further complications (Casagli and Ermini, 1999). In the cases in-between it is possible that the dam collapses producing a flash flood (Durville et al., 2011) or that a partial blocking of the river causes its wandering. In any case the effects of a river damming must be studied carefully and countermeasures are often strongly case-specific.

Valuable elements at risk: in some cases among the EaR there can be valuable objectives besides people, infrastructures and common buildings. These can be cultural heritage, natural heritage (such as particular plants and animals), strategic buildings, waterworks, power lines, environmental resources, telephone wires etc. In such cases the relocation of the most important EaR or at least a backup solution, should be considered since the early stages of the warning.

Community-based system and training: community-based systems are most common in small towns with few personnel and low budget. They are cheaper and have also the advantage of increasing the awareness of the population in charge of the system. However, given the lack of experience of people involved, this kind of system should be simple and used only when there is no possibility of permanent specialized personnel. Expert judgement is usually not an option even if it can be used occasionally. Appropriate training is required.

Multiple thresholds: sometimes a landslide displays differential movements that may represent different mechanical behaviours; in these cases it is logical to assign different kinematic thresholds for different parts of the landslide. At a regional scale different rainfall thresholds can be defined if conditions are not homogeneous through the area. However, in order not to complicate the system, they should be clustered in few groups.

2 warning levels system: this kind of system is only composed by two different states: ordinary and alarm. It should be used when it is not possible to assess a behaviour in-between the ordinary level and the alarm level (collapse). This may happen for debris flows, very brittle materials and for small landslides with very short lead time (such as in mines or along cut slopes). It is usually associated with regional scale EWSs (Yu et al., 2011), especially for debris flows, and thresholds based on rainfalls or movement sensors (event detection).

3 warning levels system: 3 levels are usually enough for landslide that shows some displacements before the failure. Medina-Cetina and Nadim (2008) showed that 3 levels are typically the most cost-effective solution. The first level (ordinary) requires normal activity and real-time monitoring; the second level (pre-alarm) is set when the landslide shows displacements above the seasonal oscillation and consists in increased monitoring and preparation for the alarm; the third level (alarm) is set when the landslide shows acceleration that prefigures the imminent collapse. In the latter case all possible countermeasures must be taken.

Rainfall thresholds: since the correlation between rainfall and displacement is less direct than the correlation between deformation (or velocity or acceleration) and failure, false alarms are much more likely to occur when adopting rainfall thresholds (Lacasse and Nadim, 2009). However, warnings can be cast more in advance since rain can be relatively easily forecasted. A mixed use of rainfall and kinematic thresholds can be adopted (cf. 3.1.3.1). They are useful for regional scale EWSs when it is not possible to install displacement monitoring systems for every landslide. They are also recommended when kinematic precursors are not available (e.g. debris flow) and for landslides characterized by high velocity, where the alarm must be cast in advance.

Kinematic thresholds: velocity and acceleration thresholds are used for most of the landslides that show some movement before the failure. Absolute displacements, on the other hand, do not seem valuable thresholds (cf. 3.1.2.2). They are not suitable for regional EWSs since they require instrumented landslides.

Automatic alarm: this considerably reduces the time needed for casting alarms but also increases the number of false alarms. It should be coupled with robust instrumental redundancy and noise filtering or visual verifications. It is not suitable for cases which require large evacuations.

Expert judgement: instead of using pre-set thresholds the warning level is increased according to the personal interpretation, mostly based on monitoring data, of one or more people that have experience in that field. This method is useful with landslides whose behaviour is not fully understood or too complex to be modelled with simple thresholds. Its main advantage is that it permits to reduce the number of false alarms. On the other hand it requires the presence of qualified personnel, and a longer time is needed for spreading the alarm. In addition, it must not be disregarded that human factor is involved in this subjective method. This procedure usually replaces the use of thresholds; however a proficient combination of the two can consist in using thresholds for the pre-alarm level and expert judgement for the alarm. Expert judgement can integrate the use of forecasting methods.

4.1.3 Strengths and weaknesses of the toolbox

The aim of this toolbox is to create a user-friendly tool, keeping in mind that most end-users may not have any experience about EWSs, nor they have the possibility to develop a deep knowledge about them. Instead they may prefer to be driven to the most optimal solution through a series of guided choices which reasons are concealed from them. Because of this the guidelines should be very practical, straight-forward and almost automated. In fact a deeper insight of EWSs can be exploited through the reading of the rest of this deliverable; the state of the art provided and the explanations furnished should make the reader able to criticize the output of the toolbox, to customize his own EWS and should give him inputs for studying EWSs more accurately in order to go more into detail.

As the toolbox should be synthetic and graphical, a flow chart based approach appears to be the most suitable solution. The present flow chart was calibrated by taking into account several EWSs working throughout the world. Each suggested choice is based on geological and geotechnical criteria that are concealed from the user in order to allow even inexperienced ones to use this method. This toolbox is easy to understand and can comprehend a great variety of conditions. It is a flexible instrument that can be adapted to many different cases. Moreover, thanks to its modularity, this flow-chart can easily be expanded in order to face even more situations, rendering it a more complete tool. For example a new part could be added in order to cover also basin- or regional-scale EWSs; this flow chart itself can be attached to a bigger tree as guidelines for landslides risk management, of which the EWS approach could represent just a branch, and so on. This flow chart can also be easily implemented as interactive software.

However, it should be noted that the approach proposed here only gives the framework and the first input for designing an EWS, as it cannot possibly encompass all the cases that can occur in reality, given the great variability of natural phenomena. Hence it may be necessary to fix or complete some of the results according to the specific needs of the site. This is a drawback of it being a semi-automatic approach; in fact some choices are given as the unique or the most recommended solution, but the end-user is encouraged to develop new possibilities for his EWS; the next subchapter goes in this direction.

4.2 DEVELOPING CASE-SPECIFIC EWS

As stated before, this toolbox cannot possibly be completely exhaustive and its results must be viewed just as suggestions rather than strict rules; they must be fixed, adapted, integrated, customized and mixed in order to achieve a complete EWS. For example many other monitoring instruments or devices can be used to transmit alarms, even for experimental purposes, other than the ones indicated above. There are many other **variables** that can influence an EWS, some of which are listed as follows:

- **Scale**: these guidelines are mostly focused on EWSs at slope scale. However, regional/basin EWSs often represent the cheapest if not the only countermeasure against landslides in a wide area. The typical situation for this kind of systems is that there is a very large area with diffuse instability problems and there is no knowledge of where the landslide will occur exactly or, even if it is known, it is not possible to monitor each landslide individually. This usually happens when there are many landslides and none of them justifies the cost of a dedicated monitoring system. In this case, rainfall thresholds are normally adopted. Usually they are much more reliable here than in slope scale EWSs because they are calibrated on actual failures happened in the past, rather than on reactivation periods, accelerations and so on. Debris flows are the typical landslides where regional/basin scale EWSs are implemented, since they are mainly controlled by rain and are not easily monitored with other means.

Also, due to their high velocity, they allow a very short time for taking action and so weather forecasts play a very important role.

- **Rainfall threshold**: several types of rainfall thresholds exist (for example the measured rainfall, the forecasted rainfall or a combination of the two, as described in SafeLand deliverable D4.2 "*Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technologies and validation at selected test sites*"). In many cases, EWSs operating with rainfall use only 2 levels (ordinary and alarm) with an automatic alarm as a consequence of exceeding thresholds but, depending on the reliability of the thresholds and the weather forecasts, expert judgement can be added in the process. The value used as threshold should depend on the type of landslide, the material, the zone and the climate (especially for very large regional scale EWSs).
- **Type of trigger**: the main triggers are encompassed in the toolbox in case of landslides triggered by rain, rising in pore water pressure or governed by creep. Kinematic thresholds were usually suggested except for those cases where rainfall and pore-water pressure play a major role. However, there can be many other possible triggers not considered here. They should be studied in detail for every landslide. Among the most common there are landslides triggered by earthquakes, volcanic activity, human work, erosion, reservoir level, etc. Different triggers may require different monitoring systems; for example landslides triggered by volcanic activity could comprehend instruments and parameters typical of volcanic environments (Casagli et al., 2009); EWSs for landslides placed above reservoirs can take advantage of thresholds based on water level, flow, etc. (Lacasse and Nadim, 2009); landslides with particular behaviours can have custom approaches, such as Séchilienne (France) landslide where it is not possible to establish a fixed velocity threshold due to its continuous acceleration and for this reason a method based on relative changes of past velocity has been adopted (Durville et al., 2011). These observations show that detailed geological and geomechanical studies are the first fundamental step of every EWS.
- **Risk**: EWSs are strongly influenced by the risk scenario. For example, the presence of countermeasures that mitigate the risk (such as retaining walls, ditches, anchors, reinforcements on existing buildings, etc) can lead toward less conservative thresholds. On the contrary, highly vulnerable EaR (hospitals, schools, power stations, etc.) may require lower thresholds. Even associated risks must be considered for the alarm and civil protection plans as a landslide can cause many different kinds of collateral damage depending on what it is going to hit: tsunami, fire, river damming, pollution, damaging of structures that can become unstable, triggering other landslides, etc. In each case, the most appropriate countermeasure must be planned in advance. Also the possible evolution of the landslide must be taken into account as it can experience lateral expansion, retrogradation, flow transformation or evolving into other types of landslide.

A list of all possible cases that could be encountered would always stay partial. However, even though EWSs are extremely site-specific, there are some **design criteria** that can be considered valid in general. When conceiving an EWS every choice should be done according to these criteria which can help the end-user in the process:

- **Communication**: at all levels (among stakeholders and toward the population) and in every moment (both in ordinary and in alarm situations). If communication fails the whole system results in a failure. Communication encompasses public education, notifications among stakeholders, alarm transmission, etc.
- **Earliness**: data must be collected and elaborated quickly and in case of emergency it must be known in advance which actions must be taken. Sufficient time for possible evacuation must be granted. Monitoring must be as close as possible to real-time.
- **Simplicity**: in emergency conditions everything must be clear and straight-forward, as confusion and loss of time can result in a new kind of emergency. Besides, the population is not likely to understand too complex systems or messages.
- **Reliability**: it refers to the capability of catching real events and avoiding false alarms, but also to having always knowledge of what is happening on the site; this implies that the system must be precise, accurate, robust and able to work 24h in all weather conditions.

Some **recommendations** descend directly from these design criteria; their general validity will help the end-users in those cases not contemplated by the presented toolbox.

- Keep a deep and complete knowledge of the landslide (failure mechanism, trigger, risk scenarios, elements at risk, countermeasures, etc.).
- Define clearly the responsibilities of each stakeholder.
- Warn the population about the risks (meetings, leaflets, signs, websites, TV, radio, etc.).
- Define the conditions required to cancel the alarm level after a false alarm or after the failure. Keep on monitoring even after the failure in order to assess the residual risk.
- Communicate about any changes in the system, passages of level, malfunctions, etc.
- Provide a handbook and checklist including thresholds, actions to be taken, instructions for maintenance, contact list of the stakeholders, etc. It is useful for EWSs designed to work for years and for new personnel involved. Useful also during emergencies as a reference handbook.
- Keep basic maintenance unfailing (reboot the system, turn on a switch and so on). In many cases monitoring systems could stop just because of the lack of someone in charge of doing very simple operations that do not require a real technical maintenance.
- Use several warning levels: ordinary (no particular action), pre-alarm (increased monitoring, prepare for alarm) and alarm (evacuation and all other possible countermeasures). A basin/regional scale EWS may even require only two. If a level has not a well defined purpose it must be eliminated.
- Prefer real-time monitoring.
- Prefer automatic monitoring as it is faster than manual monitoring and can grant 24h activity. If manual monitoring is necessary (for instance for economical reasons) it should be limited to remote monitoring.
- Consider to implement a forecasting method.

- Provide power supply even for emergency conditions.
- Filter or average data when they are too noisy. This may also reduce the number of false alarms but on the other hand it increases the time needed for data elaboration, so the right equilibrium must be found. Thresholds must be used always with respect of the same filtering; by changing the filtering method, thresholds must be changed accordingly.
- Install the instruments in order to prevent as much as possible damages from rock falls, accidental movements, disturbance by animals, temperature effects, vandalism, etc.
- Define the action to be taken in case instruments do not work either before or during an emergency.
- Update thresholds according to new data (especially for a regional scale EWS after that new failures have occurred).

5 LANDSLIDE EWS AND EC STANDARDS FOR DATA HARMONISATION

5.1 INTRODUCTION ON THE EC FRAMEWORK DIRECTIVES

Rising impacts of natural hazards on people, infrastructure and economy have resulted in several international initiatives fostering the development of the promotion of EWSs. Contemporaneously, the European Commission undertook several initiatives to increase prevention, preparedness, protection and response to natural and technological hazards in general and to promote research and acceptance of risk prevention measures within the society. Several frameworks such as the Water Framework Directive (EC, 2000) and the Floods Directive (EC, 2007b) are currently legally binding. As landslides constitute one of eight soil threats, they fall under the Thematic Strategy for Soil Protection, adopted by the European Commission on September 22nd, 2006. The legislative package included a communication on the Strategy (EC, 2006c), a proposal for a Soil Framework Directive (i.e the strategy implementing tool EC (2006b) and the impact assessment of the Strategy EC (2006a)). However, to date, the Soil Framework Directive is still under discussion and is not yet approved. Although the Directive is not yet adopted, a European Landslide Expert Group was created by JRC in 2007 (http://eusoils.jrc.ec.europa.eu/library/themes/Landslides) to support the implementation of the Soil Thematic Strategy regarding the landslide threat. This Expert Group has focused mainly on what is defined in the Directive as “the identification of risk areas”, and not on EWS. Therefore, no suggestions for harmonisation or data harmonization for EWS in agreement with the Soil Framework Directive can be given.

In addition to the different Framework Directives, a communication entitled “A Community approach on the prevention of natural and man-made disasters” (EC, 2009) to identify measures which could be included in a Community strategy for the prevention of natural and man-made disasters, building upon and linking existing measures was published. This communication follows up on the commitment made by the EC to develop proposals on disaster prevention and responds to the calls of the European Parliament and the Council for increased action at Community level to prevent disasters and mitigate their impacts. In particular, the EU will seek to reduce the impact of disasters within the EU by three main activities: (1) creating the conditions for the development of knowledge based disaster prevention policies at all levels of government; (2) linking the actors and policies throughout the disaster management cycle; and (3) making existing instruments perform better for disaster prevention. This last activity includes ‘Reinforcing early warning tools’ and ‘Improving the linking between actors’.

The overview above shows that several European initiatives are referring to EWS as important tools for risk reduction, but that currently no specific guidelines for EWS have been published. However, as monitoring systems used for early warning provide spatial data (i.e. at least their location), these spatial data should be stored in infrastructures that follow INSPIRE legislation. In the next section, more detailed information on INSPIRE is provided.

5.2 THE INSPIRE DIRECTIVE

INSPIRE is a Directive adopted by the European Parliament and the Council of the European Union on March 14th, 2007, setting the legal framework for the establishment of the Infrastructure for Spatial Information in the European Community, for the purposes of Community environmental policies and policies or activities which may have an impact on the environment (EC, 2007a). INSPIRE should be based on the infrastructures for spatial information that are created and maintained by the Member States. The components of those infrastructures include: metadata, spatial data themes (as described in Annexes I, II, III of the Directive), spatial data services, network services and technologies, agreements on data and service sharing, access and use, coordination and monitoring mechanisms, processes and procedures.

The guiding principles of INSPIRE are:

> "that the infrastructures for spatial information in the Member States will be designed to ensure that spatial data are stored, made available and maintained at the most appropriate level; that it is possible to combine spatial data and services from different sources across the Community in a consistent way and share them between several users and applications; that it is possible for spatial data collected at one level of public authority to be shared between all the different levels of public authorities; that spatial data and services are made available under conditions that do not restrict their extensive use; that it is easy to discover available spatial data, to evaluate their fitness for purpose and to know the conditions applicable to their use" (http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/D2.5_v3.2.pdf).

The text of the INSPIRE Directive (EC, 2007b) is available from the INSPIRE website (http://inspire.jrc.ec.europa.eu). The Directive identifies what needs to be achieved by the Member States. As the objective of INSPIRE is to create a service that combines spatial data and services from different sources across the Community in a consistent way in order to share them between several users and applications, an important document is the "*Regulation on INSPIRE Data and Service Sharing (29.03.2010)*" (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:083:0008:0009:EN:PDF). In short, EU countries have to share their spatial data. There can be special conditions or charges linked to the accessibility and use of the data, but these should be transparent. Charges could be for example related to database updating and maintenance costs.

The INSPIRE Directive addresses 34 spatial data themes for environmental applications. These themes are subdivided in the three annexes of the Directive. The complete list can be found on http://inspire.jrc.ec.europa.eu/index.cfm/pageid/2/list/7. The definition of the data specifications is an ongoing process. For each theme, a Thematic Working Group (TWG) is currently creating INSPIRE data specifications. The data specifications follow the structure of "*ISO 19131 Geographic information - Data product specifications*" standard. These documents are of prime interest to those organisations that are/will be responsible for implementing the regulation, and include the technical documentation of the GML (Geography Markup Language) application scheme, the UML (Unified Modelling Language) model (that will be the basis for the Implementing Rules), the spatial object types with their properties, and other specifics of the spatial data themes using natural language as well as a formal conceptual scheme language (INSPIRE Thematic Working Group Natural Risk Zones, 2011). The UML diagrams offer a rapid way to see the main elements of the specifications and their relationships. The definition of the spatial object types, attributes, and relationships are included in the Feature Catalogue. People having thematic expertise but not familiar with UML should fully understand the content of the data model focusing on the Feature Catalogue.

Currently, for each theme version 2.0 of the data, specification is available (June 2011; http://inspire.jrc.ec.europa.eu/index.cfm/pageid/2/list/1). The final version is planned to be published soon after April 2012. The information on relevant data specifications provided in this report is based on the version 2.0 documents. Given that the models are not finalised, the TWGs advised us not to provide the application scheme in SafeLand deliverables, but to invite the reader to check the model in the draft guidelines that are available on the INSPIRE webpage. Until the more consolidated version of the data specifications (i.e. the one planned soon after April 2012) is available, no specific recommendations in agreement with INSPIRE can be drawn, but only general ones.

With regard to EWS for landslides several spatial data themes are important. EWSs comprise five key elements: knowledge of the risks; monitoring, analysis and forecasting of the hazards; communication or dissemination of alerts and warnings; and local capabilities to respond to the warnings received. Spatial data related to knowledge on the risk should follow the specifications of Natural Risk Zones model (Annex III theme 12), while the monitoring system should follow those of Environmental Monitoring Facilities (EF; annex II theme 7) in combination with Guidelines for the use of Observations & Measurements and Sensor Web Enablement-related standards in INSPIRE Annex II and III data specification development. The model of Natural Risk Zones can have a link to Area management/restriction/regulation zones and reporting units (Annex III, theme 11). In the following paragraphs we provide some further clarifications.

5.2.1 Natural Risk Zones (NZ)

INSPIRE Directive EC (2007a) defines Natural Risk Zones theme as Vulnerable areas characterised according to natural hazards (all atmospheric, hydrologic, seismic, volcanic and wildfire phenomena that, because of their location, severity, and frequency, have the potential to seriously affect society), e.g. floods, landslides and subsidence, avalanches, forest fires, earthquakes, and volcanic eruptions. The common scheme for NZ covers elements seen as necessary by the TWG NZ, and consists of four components (Figure 44), i.e. hazard areas (including landslide inventory, susceptibility and hazard maps), exposed elements, vulnerability of exposed elements and risk zones (INSPIRE Thematic Working Group Natural Risk Zones, 2011). However, it is possible that for each specific natural hazard additional extensions to this general model are needed, and that in many cases the model will only be partly completed (e.g. when only landslide inventory and susceptibility maps are available). The scheme can have links to the schemes of theme 11 Monitoring of Risk Zones (see below) and theme 7 Area Management and Land-Use (if legal act is present; INSPIRE Thematic

Working Group Area management/restriction/regulation zones and reporting units). Both are important for EWS.

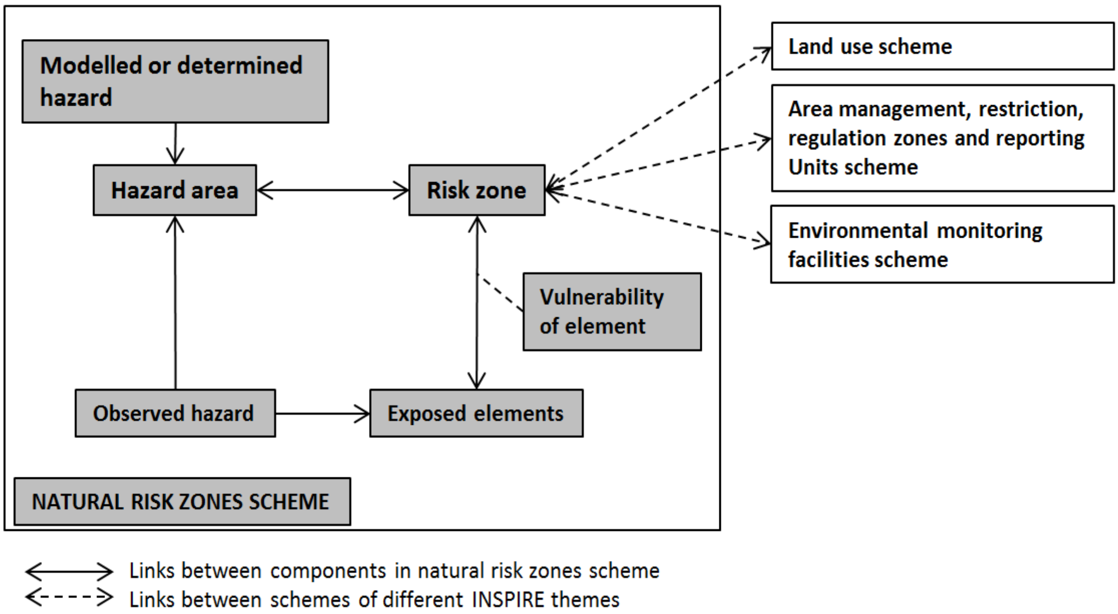


Figure 44: Simplified scheme of the Natural Risk Zones application scheme including eventual links to other INSPIRE Themes that are important for EWS.

When available, spatial data on hazard areas, exposed elements, vulnerability, and risk zones should be stored together with a set of information of which a limited number are mandatory following the UML model. According to version 2 of the data specifications, this additional information includes for:

- Hazard area: INSPIRE id, period for which data is valid, type of hazard, level/likelihood of hazard, hazard category, determination method, observed hazard (name of event, date)
- Exposed elements: INSPIRE id, type, period for which data is valid
- Vulnerability: vulnerability
- Risk zones: INSPIRE id, period for which data is valid, type of risk, determination method, legally binding, legally binding zone, reference to documents providing additional information, level of risk.

For additional information, we refer to INSPIRE Thematic Working Group Natural Risk Zones (2011) or updated versions available on http://inspire.jrc.ec.europa.eu.

5.2.2 Environmental Monitoring Facilities (EMF)

EMF are defined as location and operation of environmental monitoring facilities including observation and measurement of emissions, of the state of environmental media and of other ecosystem parameters (biodiversity, ecological conditions of vegetation, etc.) by or on behalf of public authorities (EC, 2007a). Although the definition does not specifically refer to EWS, they should also follow the EMF data specifications, at least if they are carried out by or on behalf of public authorities. The INSPIRE spatial data theme EMF is cross-cutting to any thematic area dealing with environment. EMF facilities should act “as linking element between spatial data themes as defined by INSPIRE Directive and observations and measurements on specific aspects of the environment” (INSPIRE Thematic Working Group Environmental Monitoring Facilities, 2011). The application scheme, provided by TWG RF, contains both aspects in scope for EF; on the one hand the description of a monitoring facility and on the other hand the link to observations and measurements. The scheme follows a generic approach which should enable thematic communities to use this structure across domains. The specifications and definitions provide sufficient flexibility to the thematic domains to bring their data in. The common elements are reduced to the elements which are seen as essential for accessing EF in a common way.

The actual version 2.0 of thematic area EMF covers the environmental monitoring facility description, i.e. the spatial data. The link to observations and measurements is included in the model provided but as well addressed by a guideline paper (INSPIRE Cross Thematic Working Group on Observations & Measurements, 2011) on the common use of ISO 19156 Observations and Measurements (O&M).

For a detailed description of the UML model we refer to INSPIRE Thematic Working Group Environmental Monitoring Facilities (2011). Here we only provide a narrative description of the UML Overview. The application scheme for Environmental Monitoring Facilities contains 4 spatial object types for which a set of additional information has been defined:

- Environmental Monitoring Facility (a georeferenced object directly collecting and or processing data or hosting other EMF objects collecting data about features which are repeatedly observed/measured using static or mobile, in-situ or remote methods):
    - a site point representation
    - one station/sensor or a platform hosting a number of sensors (fix installed or mobile; operative and not operative) or measurement equipment
    - link to observations and measurements taken

  Different EMF (e.g. within one landslide) can be linked, and the model provides a recursive hierarchical link between EMF (e.g. one EMF site can have several sensors and one EMF site can have old, inoperative sensors and operative sensors).
- Environmental Monitoring Program (a policy relevant description defining the target of a collection of observations and/or the deployment of EMFs on the field):
    - INSPIRE id of area of interest (e.g. a region)
    - legal background
    - responsible party
    - period for which monitoring program is active
- Environmental Monitoring Activity (for monitoring campaigns, especially mobile ones, carried out with specific equipment for a specific period of time):
    - activity time
    - activity condition
- Environmental Monitoring Network (administrative/organisational grouping of EMFs managed the same way for a specific purpose, targeting a specific area; each network respects common rules aiming at ensuring coherence of the observations, especially for purposes of EMFs, mandatory parameters selection, measurement methods and sampling regime):

- online resource
- organizational level (e.g. national or regional)

Again, we refer to INSPIRE Thematic Working Environmental Monitoring Facilities (2011; or updated versions available on http://inspire.jrc.ec.europa.eu) for more detailed information.

5.2.3 Area management/restriction/regulations zones and reporting units (AM)

AM are defined as areas managed, regulated or used for reporting at international, European, national, regional and local levels (e.g. dumping sites, restricted areas around drinking water sources, nitrate-vulnerable zones, regulated fairways at sea or large inland waters, noise restriction zones, prospecting and mining permit areas, river basin districts, relevant reporting units and coastal zone management areas (INSPIRE Thematic Working Group Area management/restriction/regulation zones and reporting units, 2011).

If a legal act is present, both NZ and EMF application schemes of EWS should be linked with an AM application scheme containing the information on the regulation. We refer to INSPIRE Thematic Working Group Area management/restriction/regulation zones and reporting units (2011) for more information on the data specifications of this theme.

5.3 DATA HARMONIZATION DEVELOPMENT INSIDE THE SAFELAND PROJECT

As described in 3.1.2 of this document, several kinds of monitoring instruments can be selected for an EWS. Today, sensors and monitoring sites use databases containing data in incompatible formats (Microsoft SQL Server, Firebird, Oracle, plain text…). Moreover some technologies are complex (GB InSar, DMS) and the process towards the integration is not an easy task. Also the monitoring test sites in the SafeLand Project use different languages. The data harmonisation of these different sensors can help EWS operators and can increase the quality of their geoscientific evaluation and reduce their decision time.

5.3.1 SafeLand Mark-up Language (SLML)

The purpose of SLML is to provide the definitions for the data file structure to support electronic exchange of information inside an EWS. SLML defines the structure and elements of measures, specifies how locations are referenced and provides a mechanism for linking observations with each other. By building on existing Internet standards, SLML expresses site-specific monitoring instruments information in a way that can easily be shared over the World Wide Web. CSG designed this grammar with XML (Extensible Mark-up Language**)** existing standard, which is promoted by World Wide Web Consortium (W3C). XML is the most common tool for data transmissions between all sorts of applications and XML data are stored in plain text format. SLML is an XML-based standard configuration file and CSG had to create a new XSD (XML schema Definition) to describe it. According to a W3C Recommendation, the XSD scheme specifies how to formally describe elements in the XML document. In general, a schema is an abstract representation of an object's features and its relationship to other objects. In the next section, the schema for SLML is provided, with the data structure and the definition of each encountered element.

5.3.2 SafeLand geo- indicators

Geo-indicators need to be defined with a deep knowledge of the landslide for each site, also including the consideration on reliability, noise level and costs. In the first version of SLML, are included the following real-time and automatic monitoring sensors:

- Surface displacement: extensometers
- Water level: piezometers
- Water runoff/input: precipitation
- Temperature: thermometers
- Surface displacement: GPS
- Subsurface displacement: DMS inclinometers
- Electrical impedance: GeoMon

5.3.3 Current data structure

In order to share monitoring data, two files are necessary:

- a file indicating the configuration of each site, called *ConfigFile;*
- a file with the monitoring data, called *DataFile.*

5.3.3.1 Site XSD scheme

The *ConfigFile* header is **<SL:SafeLandSite>**. The name space SL will be defined through the URI http://www.csgsrl.eu/Safeland/SafelandCfg.html. This file must be in compliance with the XSD scheme that can be downloaded at http://www.csgsrl.eu/Safeland/SafelandCfg11.xsd

The element **<SafeLandSite>** contains the following attributes:

- **Version**: The version of SafeLand protocol. This document describes the version 1.0.
- **DateLastCfgUpdate**: date of the last modify to site configuration
- **Name**: name of the reference site

At the second level, under the header **<Site>,** there are the following elements:

- <**CoordinateX**>: coordinate X of the site location [WGS84 or UTM]
- <**CoordinateY**>: coordinate Y of the site location [WGS84 or UTM]
- <**Altitude**>: altitude of the site, [m].
- <**Owner**>: owner of the monitoring site, identified by the two under elements:
  - o <**Name**>
  - o <**Country**>
- <**Note**>: any commentary
- <**GSMField**>: % GSM field
- <**Sensors**>: each sensor must be listed under this node named **<Sensor>**

The <**Sensors>** node must contain the following elements:

- <**ID>:** unique identifier;

- **<Depth>:** sensor depth [m];
- **<Azimuth>:** sensor azimuth [0.001deg];
- **<DateInstallation>:** date of installation;
- **<DateCalibration>:** date of calibration;
- **<Types>:** sensor types.
    - Every child node must be named **<Type>** and one or more child nodes can be present.
        - Pluviometer
        - Thermometer
        - Anemometer
        - Piezometer
        - Inclinometer
        - Extensimeter
        - GPS
        - Ohmmeter
        - Voltmeter
    - child nodes such as electrical impedance tomography lines must be named <**GeoMonData**> with the following parameters:
        - **<LineName>:** can be an alphanumeric name
        - **<CoorXup>:** X coordinate of this line
        - **<CoorYup>:** Y coordinate of this line
        - **<CoorXdown>:** X coordinate of this line
        - **<CoorYdown>:** Y coordinate of this line
        - **<LineLength>** length of line [m]
        - **<NElec>:** quantity of electrodes along this line
        - **<Apos>:** position of the electrode A [m]
        - **<Bpos>:** position of the electrode B [m]
        - **<Mpos>:** position of the electrode M [m]
        - **<Npos>:** position of the electrode N [m]

A diagram representing the *ConfigFile* structure is presented in Figure 45.

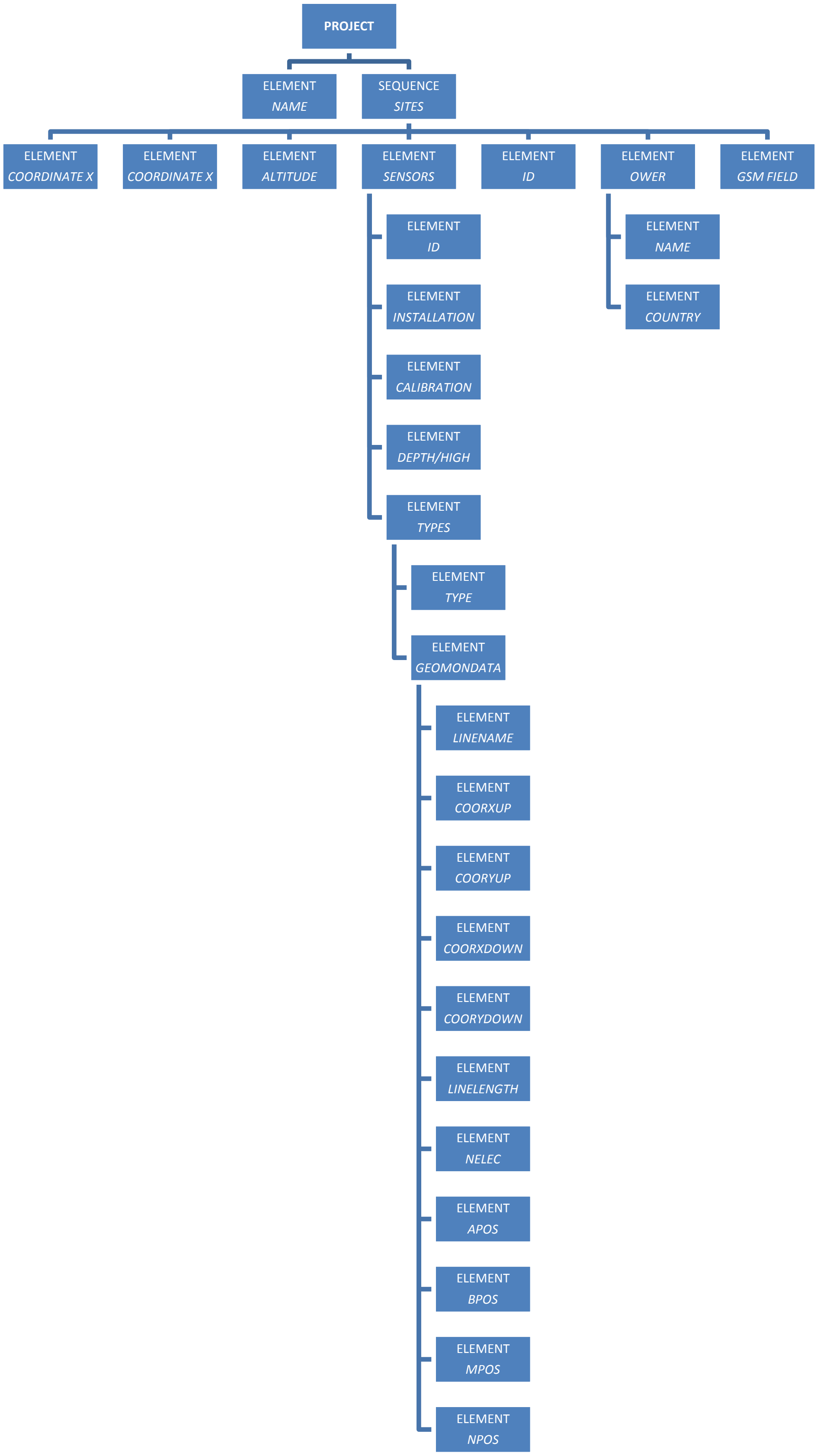


Figure 45: The XSD scheme for the configuration of a monitoring site.

5.3.3.2 Data structure XSD scheme

The *DataFile* header is **<SL:SafeLandData>**. As for *ConfigFile*, the he name space SL must be defined and the file must be in compliance with the XSD scheme.

The element **Project** contains the following attributes:

- **Version**: The version of SafeLand protocol. This document describes the version 1.0.
- **DateLastCfgUpdate**: date of the last modification of the data file.

Under the node **<SL:SafeLandData>** there are one or more **<DataAcquired>** elements. There must be at least one record.
Each **<DataAcquired>** has the attribute:

- **Date**: date and time of the record.

Under the node **<DataAcquired>** there are **<SingleData>** nodes, one per record of a sensor.
Each node **<SingleData>** contains only one of the following elements:

- <**Rain**>: precipitation [mm]
- <**Wind**>: direction [0.01deg] and velocity [mm/s];
- **<Temperature>**: air temperature [0.001° C];
- **<Pressure>**: water pressure [mm H2O];
- <**Pitch**>: for mono-axial sensor, pitch axis [0.001deg];
- **<Roll>**: for mono-axial sensor, roll axis [0.001deg];
- **<Tilt>**, **<Pitch>** and **<Roll>**: for tri-axial sensor [0.001deg];
- **<Deformation>:** extensometer output [0.001mm];
- <**PowerSupply**>**:** voltage [mV];
- **<GPSPosition>:** position
  - <**North**>**:** latitude [0.001deg];
  - **<East>:** longitude [0.001deg];
- **<Resistivity>:** ground resistivity [Ω];
- **<Voltage>:** potential [V];

And the following attribute:

- **IdSensor:** unique identifier.

A diagram representing the *DataFile* structure is presented in Figure 46

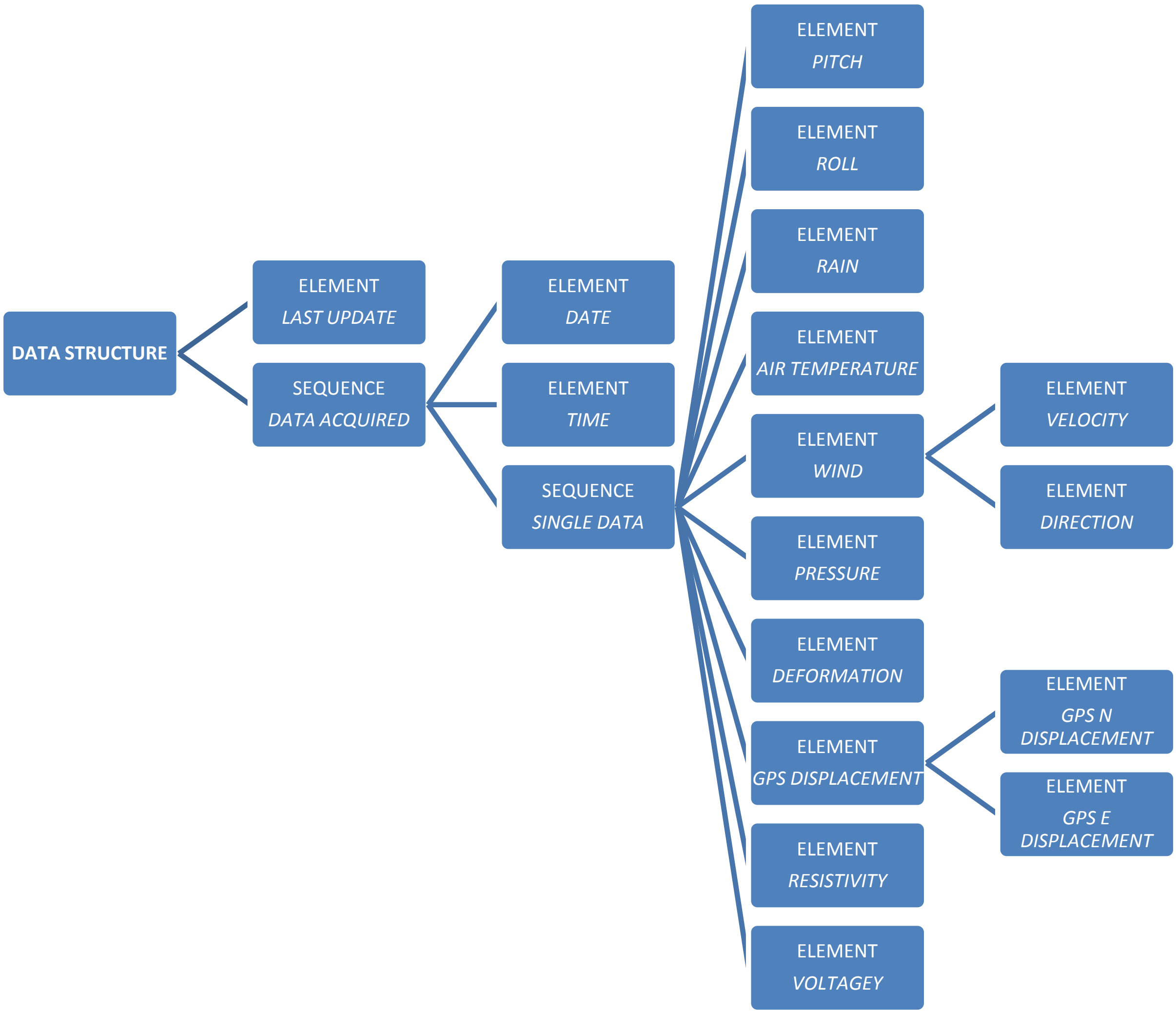


Figure 46: The XSD scheme for the file containing the monitoring data.

6 RELIABILITY OF AN EWS

The core of an EWS is based on prediction, and every prediction is associated with uncertainty. Because of the uncertainties associated with the predicted parameters that characterize the incoming landslide, it is possible that a wrong decision may be made. In making this judgment, two kinds of wrong decisions may occur (Grasso, 2007): **Missed Alarm** (or False Negative) when the mitigation action is not taken when it should have been or **False Alarm** (or False Positive) when the mitigation action is taken when it should not have been. False or missed warnings can compromise the reliability of an EWS. The reliability of measurements is paramount in any monitoring system, but particularly so in an EWS. Here, we list the different uncertainties that exist in an EWS and propose a check list to minimize false or missed warnings.

6.1 DATA RELIABILITY

The occurrence of landslides is governed by complex interrelationships between factors, some of which cannot be determined in detail and others only with a large degree of uncertainty. Some important aspect in this respect is the uncertainty and precision of the input data.

6.1.1 Reliability of the models used for the prediction

The prediction of a landslide occurrence is often based on a model. A good example of model reliability comes from the weather forecast. The numerical models used for the weather forecasts are a simplified schematic representation of physical reality, described through a set of equations that simulate the behaviour of nature. Fluid dynamics and can be described mathematically by equations that are nonlinear and are impossible to solve exactly. Therefore, numerical methods can obtain only approximate solutions. The solution of these equations requires knowledge of the initial condition which itself can be made only in a very approximate way, mainly because observations are sparse and have error. In this example of model prediction, there are three sources of errors:

- **Analysis error**: errors in the background fields, observation data and data assimilation techniques;
- **Model uncertainty**: inadequacy of physical model processes;
- Atmosphere **chaotic nature**: the atmospheric motions follow non-linear dynamic, small errors in the analysis may quickly be amplified. This last is called "butterfly effect".

In order to quantify the uncertainty, a probabilistic approach consists of generating several predictions beginning from very similar initial states. The generated predictions are usually sorted into groups (clusters); depending from the number of prediction that fall in the same clusters it is possible to associate a probability of occurrence to a certain forecast (Figure 47).

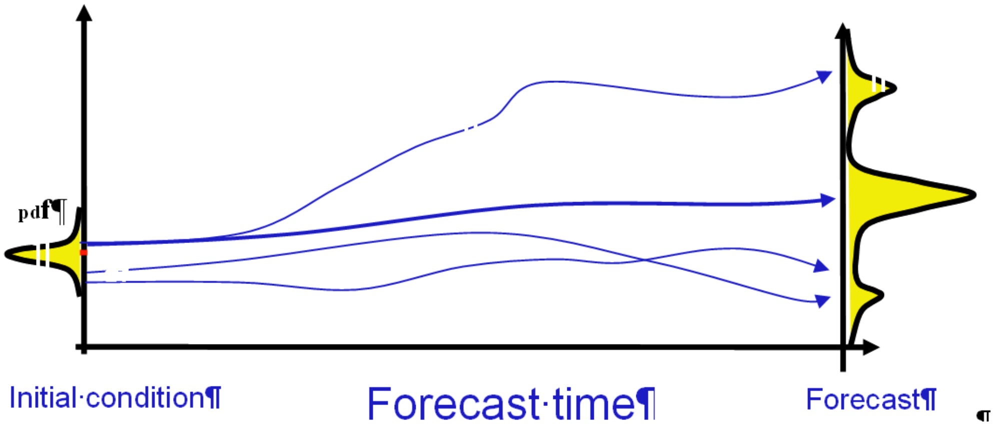


Figure 47: Numerical weather prediction models can be viewed as nonlinear dynamical systems in which the evolution depends sensitively on the initial conditions. The fact that estimates of the current state are inaccurate and that numerical models have inadequacies, leads to forecast errors that grow with increasing forecast lead time. This figure represents the probabilistic approach to the forecast problem. The ensemble forecast permits a complete description of weather prediction in terms of a Probability Density Function (PDF). At the initial state the variable is represented by its mean value and a Gaussian distribution for the error. Due to the model error after a certain time a spread if the initial error is obtained. This figure is taken from SafeLand deliverable D4.2 entitled "Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technologies and validation at selected test sites".

6.1.2 Reliability of the technical system

6.1.2.1 Monitoring system

SafeLand deliverable D4.1 entitled "*Review of monitoring and remote sensing methodologies for landslide detection, fast characterisation, rapid mapping and long-term monitoring*" provides the technical description of all the available monitoring methodologies for landslides, among which some are usable in EWS. The **resolution** (ability to detect a body of a given size), **accuracy** (how much the measurement deviates from the truth) and **precision** (how similar repeated measurements under unchanged conditions are) of each method and sensor are described in D4.1 when available. Deliverable D4.4 entitled "*Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides*" describes in more details 30 different remote sensing techniques for different landslides types. Individual fact sheets provide a range of quantitative accuracy or colour coding for qualitative approximation (Figure 48).

Accuracy level				
very low (e.g. 1 00 m)	low (e.g. m)	medium (dm)	high(cm)	very high (mm)

- description of the accuracy achievable with the technique
- qualitative and/or in spatial units (e.g. m, m^2, m^3)

Figure 48: Excerpt of the facts sheet provided for each remote sensing technology in SafeLand deliverable D4.4.

The main uncertainties of **on-site monitoring technologies** traditionally employed to assess ground deformations are:

- A single instrument provides information about a limited portion of ground that may not be representative of the whole area;
- Instrumentation may be damaged by environmental factors (e.g. lightning) or by the landslide itself (e.g. extensometers broken by sudden accelerations);
- Sensor could malfunction because of misconception or lack of power;
- Most technologies require regular calibration.

These limitations can often be overtaken by numerous (to cover a large area) and redundant (in case of a sensor failure) instrumentation.

The strongest limitations of **remote sensing technologies** are related to the meteorological and illumination conditions. For example, the presence of snow during the winter season can impede reliable correlation results and excessive ground deformations between two consecutive surveys. The presence of shadow zones (unscanned areas) and growth of vegetation are also limiting factors. Similarly, temporal decorrelation and atmospheric disturbances limit the usefulness of traditional differential InSAR techniques. However, by using many images, it is possible to take advantage of the differences in spatial and temporal correlation to distinguish between deformation and atmospheric effects. This is done by assuming that atmospheric effects have a high degree of spatial correlation and are almost random in time (Ferretti et al., 2001). A less obvious limitation of remote sensing technologies occurs when the landslide is related to other geophysical processes. For example, if an area is subject to both landslide and subsidence, the analysis fails to separate these two kinds of mass movement.

Thanks to their different kinds of uncertainties, remote-sensing and on-site technologies are complementary and their joint use therefore allows the most reliable assessments on ground deformation.

SafeLand deliverable D4.2 entitled "*Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technologies and validation at selected test sites*" presents a test case in the Northern Apennine chain that illustrates how ones can estimate the reliability of an EWS. The area of interest is strongly susceptible to mass movements, in particular shallow rapid landslides. In December 2009, the area was hit by a severe rainstorm which triggered during Christmas period around 300 shallow landslides. A statistical study was performed to evaluate the model performances where observations and forecasts are available. For example, Table 12 reports some statistical indices, from which it is possible to understand that there is a quite good agreement between forecast and observation. It was concluded that the simulating chain was able to catch a generalized state of instability probability. In addition, this test case has shown a weakness of the simulation chain that is not able to manage the contribution of the snow at the slope instability mechanism.

Table 12: Example of statistical indices to evaluate an EWS performance. BIAS: Measures the ratio of the frequency of forecast events to the frequency of observed events. Indicates whether the forecast system has a tendency to under forecast (BIAS<1) or over forecast (BIAS>1) events. THREAT SCORE: Measures the fraction of observed and/or forecast events that were correctly predicted. It can be thought of as the accuracy when correct negatives have been removed from consideration. It does not distinguish source of forecast error. Range: 0 to 1. Perfect score: 1. FALSE ALARM RATE: Sensitive to false alarms,

but ignores misses. Range: 0 to 1. Perfect score: 0. HIT RATE RAIN: Sensitive to hits, but ignores false alarms. Good for rare events. Range: 0 to 1. Perfect score: 1.

Threshold 20 mm	THREAT SCORE	BIAS	FALSE ALARM RATE	HIT RATE RAIN
2009-12 -20	n.a.	n.a.	n.a.	n.a.
2009-12 -21	0.2	3.4	0.8	0.6
2009-12 -22	1	1	0.1	1
2009-12 -23	0.7	1.3	0.3	0.9
2009-12-24	0.8	1.3	0.2	1
2009-12-25	0.2	0.7	0.5	0.3
2009-12-26	n.a.	n.a.	n.a.	n.a.
2009-12-27	n.a.	n.a.	n.a.	n.a.
2009-12-28	0	0	n.a	n.a
2009-12-29	n.a.	n.a	n.a	n.a
2009-12-30	0	0	n.a.	0
2009-12-31	0.6	0.7	0.1	0.6
2010-01-01	0.5	0.5	0.1	0.5
2010-01-02	n.a.	n.a.	n.a.	n.a.
2010-01-03	n.a.	n.a.	n.a.	n.a.
2010-01-04	n.a.	n.a.	n.a.	n.a.
2010-01-05	0	7.4	0.9	0.6

6.1.2.2 Communication system

A reliable EWS needs a reliable communication system (Grasso, 2007). Communication systems are made of two main components:

- **Communication infrastructure hardware** (Figure 49) that must be reliable and robust, especially during the natural disasters;
- Appropriate and effective **interactions among the main actors** of the early warning process such as the scientific community, stakeholders, decision makers, the public, and the media.

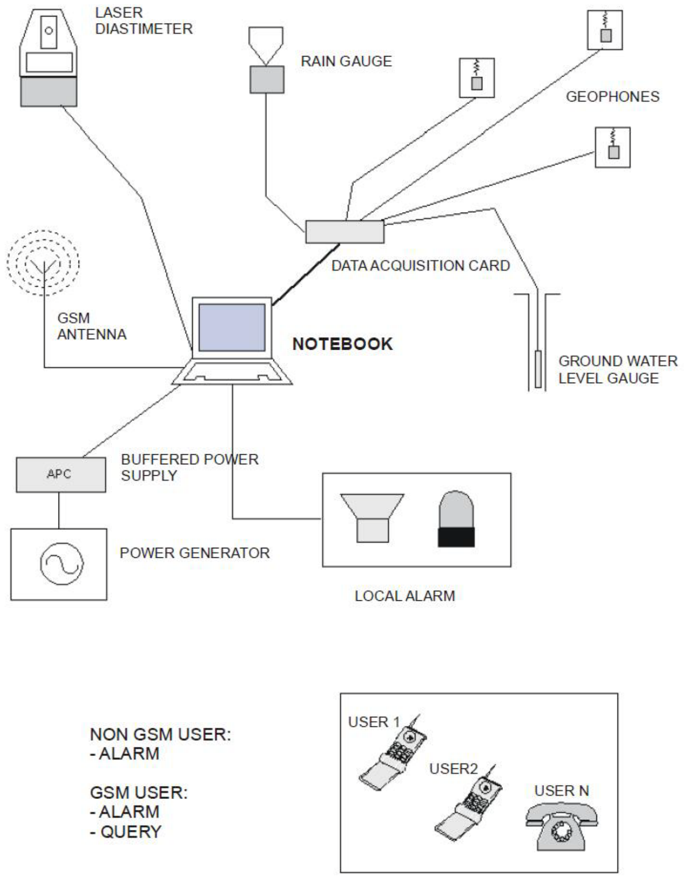


Figure 49: Example of communication infrastructure hardware in an EWS for landslide (from Zan et al. (2002)).

Communication hardware can fail to operate for several reasons:

- hardware is damaged (e.g. antennas are destroyed by lightning or landslide);
- hardware is not powered (e.g. solar panels or electric cables are destroyed by landslide);
- communication link is congested (e.g. mobile network is jammed by numerous phone calls).

Redundancy of communication systems is essential for disaster management, while emergency power supplies and back-up systems are critical in order to avoid the collapse of communication systems after disasters occur. Many communication tools are currently available for warning dissemination such as Short Message Service (SMS), e-mail, radio, TV, and web service. Several types of communication tools should then be used for each link. In addition, in order to ensure reliable and effective operation of the communication systems during and after disaster occurrence, and to avoid network congestion, frequencies and channels must be reserved and dedicated to disaster relief operations. Satellite communication appears at the most reliable tool for data collection, data transfer, Internet and phone access.

Communication between main actors can fail for several reasons:

- monitoring data not usable (e.g. two scientists using different data formats cannot easily share information);

- message not well understood (e.g. the warning message is too complicate for the reader/listener);
- one actor is missing (e.g. a critical person is in vacation or his phone number is not available);
- warning cannot reach the population at risk in due time.

In order to avoid these malfunctions, monitoring data formats are being standardized and this is described in chapter 5.3 of this document and in SafeLand deliverable D4.7 entitled "*Report on the development of software for early-warning based on real-time data*". In addition EWSs should deliver simple and compelling warnings that everyone can understand: the message should at the same time communicate the level of uncertainty and expected cost of taking action but also be simple so as to be understood by those who receive it. Most often, there is a communication gap between EWS specialists who use technical and engineering language and the users, who are generally outside of the scientific community. To avoid this, these warnings need to be reported without scientific jargon. Standard protocols play a fundamental role in addressing the challenge of effective coordination and data exchange among the actors in the early warning process and it aids in the process for warning communication and dissemination. The Common Alerting Protocol (CAP), Really Simple Syndication (RSS) and Extensible Markup Language (XML) are examples of standard data interchange formats for structured information that can be applied to warning messages for a broad range of information management and warning dissemination systems. CAP contains information about the alert message, the specific hazard event, and appropriate responses, including urgency of action to be taken, severity of the event, and certainty of the information. Globalization and rapid communication provides an unprecedented opportunity to catalyze effective action at every level by rapidly providing authorities and general public with high-quality, scientifically credible information in a timely fashion. Dissemination of warnings often follows a cascade process, which often starts at national level and then moves downwards in the scale, reaching regional and community levels. EWS should send warnings at different authoritative levels to avoid the alarm chain to break breakdown.

In order to test and improve its communication system, an EWS should regularly conduct **full-scale drills**. Testing the communication infrastructure hardware and alarm chain as well as evaluating response time is important.

6.1.3 Reliability of the geo-indictors

The monitored parameters also called geo-indicators (e.g. ground deformation) exceeding a theoretical pre-fixed threshold is usually the trigger for issuing a warning. The reliability of the EWS depends on both the a**dequacy of the geo-indicator** and the reliability of the **pre-fixed threshold**.

SafeLand deliverable D4.6 entitled "*Report on geo-indicator evaluation*" provides a description and evaluation of the parameters that can be monitored for landslide EWS. It describes how each geo-indicator is correlated (or not) to the landslide itself. For example, some geo-indicator are very easy to monitor but are not directly related to the physics of the landslide (e.g. rainfall). In the present deliverable, we emphasize what should be done for a reliable EWS. The effectiveness of an EWS improves with the number of monitoring technologies: combining several types of geo-indicators increases the reliability of an alert. In addition, the integration and the interpretation of a **multi-source data** can allow proposing possible landslide evolution scenarios.

Quantifying thresholds is a complex process that requires experience and understanding of the physics involved. **Thresholds should be recurrently reassessed** with incoming knowledge and monitoring data.

One important step for reliable EWS is to include **data quality control** measures in data acquisition and processing to insure that erroneous data is not used in analysis and forecasting of landslide activity.

6.1.4 Reliability of the risk assessment

As described in SafeLand deliverable D2.4 entitled "*Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technologies and validation at selected test sites*", landslide hazard assessment is a complex process that requires many input parameters. The preparation of probabilistic maps, the calibration of physically-based and deterministic models and the quantification of all involved factors can be very time consuming; emergency situations sometimes require rapid hazard assessments and expert judgment. The amount of uncertainty in risk assessment is strongly related to **subjectivity** and to **data uncertainty**. The degree of subjectivity indicates whether the various steps taken in the determination of the degree of hazard are verifiable and reproducible by other researchers, or whether they depend upon the personal judgment of the researcher. The degree of data uncertainty is related to many factors, such as the scale of the analysis, the time and money allocated for data collection, the size of the study area, and the availability and reliability of existing maps. A compilation of the main sources of uncertainty of input data for landslide risk assessment is listed in Table 13. Landslide inventory map are an important data layer, since they contain information on the locations where landslides have actually taken place. Information should be stored related to the type of landslide, the state of activity, and (if possible) the date of occurrence and damage caused. Some detailed information (e.g. geotechnical parameters) can only be obtained for relative small areas and a large amount of data points is required in order to be able to model the spatial variation of these phenomena. In another hand, large-scale remote sensing data for which image interpretation plays an important role, and for which the quality of the product depends largely on the experience of the interpreter, will produce the greatest inconsistencies. These maps will be quite erroneous if not based on thorough field checks. Susceptibility, hazard and risk maps must be validated to be reliable. A rigorous validation implies statistical test of hypothesis and checking of the predicted landslides. Validation should include review of the type, magnitude, intensity, location and occurrence time of the predicted landslides.

Table 13: Main sources of uncertainty of input data for landslide risk assessment

Group	Type	Example
Source data	Use of data from different sources that have not been checked in the field	Use of fault and lineament maps derived from different organisations
	Use of input data with different map scales	Combination of 1:100.000 lithological map with a 1:10.000 topomap
	Inappropriate scale of the source data	DEMs with high resolution derived from topographic maps with 50 m contour interval
	Geometric (positional) errors in the source data	Use of data with inaccurate coordinate systems
	Semantic errors in the compilation of maps	Use of wrongly classified landslide inventory maps
	Temporal errors in the compilation of maps	Use of outdated land-use maps
	Availability of incomplete data sets	Use of incomplete historical landslide inventories, or rainfall records
Image analysis	Non availability of imagery from right period	Images from suitable period after the occurrence of a major triggering event
	Non availability of imagery of the right type	Cloud cover in optical imagery that prevents mapping of phenomena
	Inexperience of image interpreter	Not enough experience to map landslides, or other thematic information
	Too limited time for image interpretation	The study area is too large, and time for interpretation limited
	Inaccuracies due to the vague ("fuzzy") character of natural boundaries.	Changes between land-use types that have a gradual change
	Too much dependency on automated techniques	Generalization of rule sets used in image classification
Field data collection and map generation	Too limited time for field checking	Not enough fieldwork for landslide mapping and characterisation
	Spatial variation of data which cannot be represented	Lithological differences relevant to landslide occurrence that cannot be mapped at scale
	Uncertainty on subsurface conditions	Soil depth variations over larger areas are very difficult to model
	Lack of sufficient samples to represent spatial characteristics	Characterization of spatial variation of geotechnical characteristics
	Lack of sufficiently long period of measurement	Groundwater fluctuations in relation to major events are not recorded in project period.
	Lack of spatial units to link samples to	Characterization of elements at risk data to homogeneous units
GIS Processing	Errors in data entry	Digitizing errors, or errors in matching spatial and attribute data
	Errors in data storage	Errors due to the limited precision
	Errors in data analysis and manipulation	Errors in the conversion of data, errors in generating derivative maps.
	Errors in data output and application	Wrong legends, colour usage, combination with topographic data

6.2 UNCERTAINTIES RELATED TO DECISIONS

Decision making under uncertainty is an essential aspect of risk management – the larger the uncertainty and the closer to critical, the greater the need for evaluating its effect(s) on the results and consequences. As explained in subchapter 6.1, estimates of risk are pervaded by significant uncertainty due to the uncertainty in data and indicators, and uncertainty in models which use data and indicators as inputs. Neglecting uncertainties could lead to an unsafe estimate of loss, thereby hindering the desired reduction of risk to acceptable levels, or to an overestimation of risk, resulting in un-economic mitigation countermeasures. SafeLand deliverable D0.3 entitled "Dealing *with uncertainties in modelling, prediction, and decision-making*" focuses on this subject, and this subchapter only summarizes the main ideas.

Decision making may be defined as the process of select a logical choice from among several available options. When trying to make a good decision, a person must weigh the positives and negatives of each option, and consider all the alternatives. For effective decision making, a person must be able to forecast the outcome of each option as well, and based on all these items, determine which option is the best for that particular situation. Most of decision theory is normative or prescriptive, i.e., it is concerned with identifying the best decision to take, assuming an ideal decision maker who is fully informed, able to compute with perfect accuracy, and fully rational.

The practical application of this prescriptive approach (how people actually make decisions) is called decision analysis. The objective of a decision analysis is to discover the most advantageous alternative under the circumstances. Among management tools for decision analysis we find statistical tools such as decision tree analysis, multivariate analysis, and probabilistic forecasting. The most systematic and comprehensive software tools developed in this way are called decision support systems.

In a formal decision analysis handling of uncertainties is of significant importance. Whereas uncertainties in the data material, methodologies and criteria may be handled with various analytical processes there is still a subjective part of weighing in decision analysis. This may be simple scoring performed by experts in a consensus setting or a formal multi-criterial involvement process (Sparrevik et al., 2011).

6.3 EFFECT OF FALSE ALARMS AND MISSED EVENTS

The consequences of false alarms and missed events are so serious that every possible action must be taken to eliminate them. There are three main aspects that need to be taken into account: cultural aspects, legal aspects, and economic aspects.

6.3.1 Cultural aspects

Missed events can happen for several reasons but one of them has more impact on the population at risk: EWSs that are stopped because of staff reduction and budget cuts cause much frustration and distrust. For example, federal budget cuts have forced the US Geological Survey (USGS) to stop operating gauges in the past years. In effect, 363 monitoring stations for flood forecasts were stopped from 1990 through 1996. The impact of those closings was felt when the National Weather Service blamed a discontinued river gauge that hampered them to forecasting a flood: five people died in Falmouth in 1997 (Braykovitch M., 1997). **Discontinuous EWSs** are counter-efficient and future funding (including budget for upgrades and maintenance) should be secured before installing such systems.

It is difficult to assess the "psychological cost'' of a false alarm. The adverse reaction of humans to false alarms is likely to have deep psycho-physiological roots, as indicated by Breznitz (1984). The author used laboratory experiments to study physical reactions (i.e. changes in heart rates and skin conductance) to repeated false alarms. His extensive experiments showed that human responses to false alarms include reductions in probability of engaging in protective behaviour, reductions in protective behaviour intensity, and increases in latency between the warning and the beginning of taking protective measures. Barnes et al. (2007) argue that Bresnitz' study fails to account for the effects of social context or media attention that would lend credibility to an event. In studies conducted over a 2-yr period of several earthquake "near predictions" in Los Angeles County, Turner (1983) found that a threat is more credible the more frequently it is discussed, both through media and informal discussion. Other studies reiterate that false alarms are not necessarily detrimental to appropriate responses. A study of a dam-failure false alarm in which 14 000 people were in the inundation zone in Ventura, California, found that, although surveyed populations may have experienced frustrations, the respondents were not negatively affected by the false alarm (Carsell, 2001). Rather, the **false alarm provided a learning opportunity** of appropriate responses such as attaining knowledge of evacuation plans for future events.

Dow and Cutter (1998) have examined the evacuation behaviour of residents in two South Carolina communities during the 1996 hurricane season. Two hurricanes that approached South Carolina but hit in North Carolina were used to study the impact of repeated false alarms (evacuations ordered based on expectations of a hurricane landfall that proved to be wrong). Differences in evacuation behaviour, specific information and concerns prompting evacuation, and the reliability of information sources between hurricane events were examined to determine the impact of false alarms on the credibility of the EWS. This study has shown that the likelihood of people responding to a warning is not reduced by the so-called ''cry-wolf'' syndrome **if the basis of the false alarm is understood**.

Different people may perceive a potentially dangerous situation differently. At two possible extremes, people could over-rely on an EWS or have no trust in it. One of the important considerations in setting detection thresholds is the fact that the **perception of what is considered to be a false alarm may vary** from one person to another and even for any individual in different situations (Zabysshny and Ragland, 2003).

Socio-cultural differences have likely significant consequences for the perception of warnings and consequently of false warnings. These differences result from previous exposure, knowledge and training. Intuitively, one expects a more obedient response from a well-trained Japanese community that trusts their high-technology EWS, than from a poor-neighbourhood in a less-prepared country. The effect of false alarms on human trust in warning systems and on credibility of warnings should be considerable even for low false alarm rates. Increasing resistance by local population to evacuate with repeated evacuations without significant landslide events should be taken into account. It is a difficult task to find out what false alarm rate the recipients will perceive as appropriate. Often this question is addressed more intuitively than objectively. In order to include this aspect, more research is needed because people's response to warnings is generally complex.

6.3.2 Legal aspects

Millions of homeowners and businesses rely on private alarm systems to summon help for burglaries, fires and medical emergencies. Yet most of the calls are false alarms, tripped inadvertently because of user error and faulty equipment. False alarms result in unnecessary use of manpower and ineffective utilization of police, ambulance, fire and rescue equipment. As a consequence, most countries have established legal caution/penalty in case of false alarms triggered by these private alarm systems.

Similarly, when running an EWS for landslides, there are legal issues that need to be taken into account. The legislation is different for each country and it is necessary to be informed of the legal consequences of missed and false alarms. The recent Aquila case in Italy has provided an historical example of a missed event. In 2009, an earthquake devastated the Italian city of L'Aquila and killed more than 300 people. Now, scientists are on trial for manslaughter in connection with the case (Hall, 2011). Six leading Italian scientists and one government official are charged for failing "to alert the population of L'Aquila of an impending earthquake". The trial has nothing to do with the ability to predict earthquakes, and everything to do with the failure of government-appointed scientists serving on an advisory panel to adequately evaluate, and then communicate, the potential risk to the local population. These charges serve as a word of warning to researchers, who may find themselves in legal trouble because of the way that non-scientists such as public officials or journalists translate their risk analyses for public consumption. Given the novelty of the issues, the academic community will be watching this case with great interest.

6.3.3 Economic aspects

It is quite intuitive that the tolerable threshold for a false alarm decreases as the cost of mitigation action increases. The tolerable threshold also decreases when the cost savings due to mitigation decrease. In general, because shorter time scale forecasts are more reliable, the probability of a false alarm decreases as the lead time for the predicted onset of the landslide decreases. However, shorter lead time also means less occasion for preventive measures and therefore reduced cost savings due to less damage avoided. Thus the trade-off between timeliness, warning reliability, the cost of false alert, and damaged avoided as a function of lead time, which must be modelled to determine the cost efficiently of the outcome (Schröter et al., 2008). A major factor in realizing the benefit is the capacity and commitment to act on the information in the appropriate time and manner.

Evacuations in vain have only the relatively low cost in monetary terms. Huggel et al. (2010) have modelled the cost and benefit of issuing and ordering evacuation for landslides in the Combeima valley in Columbia. Figure 50 represents four different scenarios for which damage estimates are calculated in their model: 1) damage to buildings and evacuation costs when a landslide occurs; 2) no cost when there is no landslide and no evacuation; 3) damage to buildings and loss of lives when there is a landslide but no evacuation; and 4) costs when there is no landslide but the population is evacuated. They fixed evacuation cost (USD 10,000) and expected loss of life (USD 5,000,000 total per one landslide) and calculated the expected losses for different parameters (e.g. rainfall threshold). These numbers represent estimates for a typical situation for a town potentially affected by a landslide in this region. The number for loss of lives is based on a scenario of loss of 10 lives, where one life is set equal to USD 0.5 million. Defining a monetary value for life can be controversial from an ethical point of view but is a common practice in risk management for cost–benefit analyses of hazard protection and prevention measures. They concluded that errors in rainfall measurement lead to the **exponential growth of expected losses**. They were also able to show that the adjustment of the evacuation threshold is to a certain degree not sensitive to the absolute value of loss of life (that is difficult to define). This study can be used to find improved cost-benefit for rainfall measuring stations. It is a first step for an integrated numerical modelling of EWS that allow the investigation of aspects that have not been studied systematically so far.

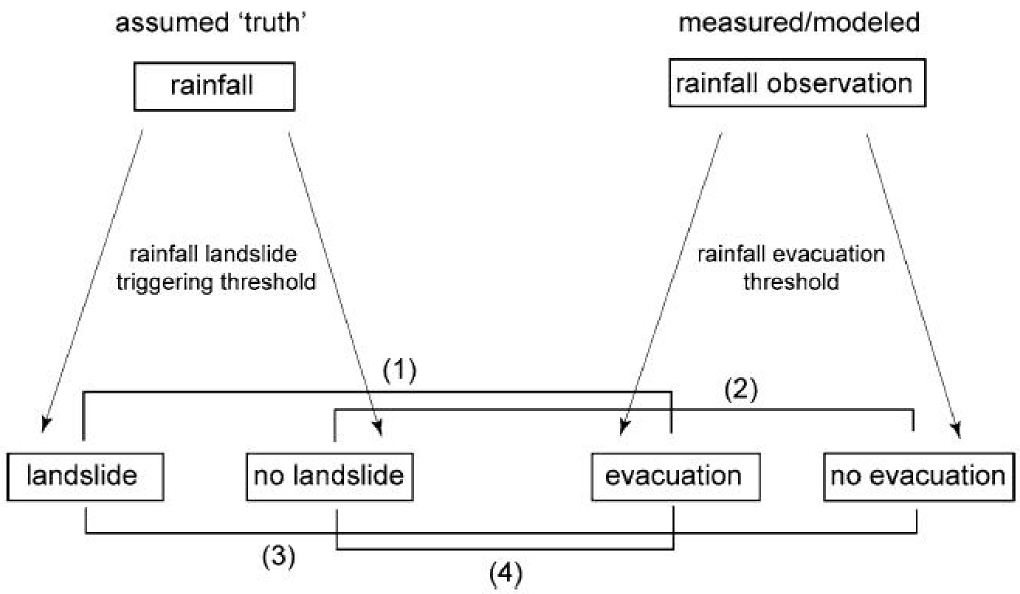


Figure 50: Scheme demonstrating the four scenarios in Huggel et al. (2010) model to evaluate the cost and benefit of ordering evacuation for landslides.

7 REFERENCES

Agderposten, Demonstrerte ras, p. 15, Arendal, Norway, 2008.

AGS, Landslide risk management concepts and guidelines, edited by AGS Landslide Risk Management Sub-Committee, 2000.

Alexander, D. E., Principles of Emergency Planning and Management, 2002.

Aven, T. and O. Renn, Risk Management and Governance: Concepts, Guidelines and Applications, Springer, London, 2010.

Barnes, L. R., E. C. Gruntfest, M. H. Hayden, D. M. Schultz and C. Benight, False Alarms and Close Calls: A Conceptual Model of Warning Accuracy, *American Meteorological Society, Weather and Forecasting,*(22), 1140-1147, 2007.

Basher, R., Global early warning systems for natural hazards: systematic and people-centred, *Philosophical Transactions of the Royal Society A-Mathematical Physical and Engineering Sciences*, *364*(1845), 2167-2180, 2006.

Blikra, L. H., The Åknes rockslide; monitoring, threshold values and early-warning, 2008.

Blikra, L. H. and L. Kristensen, Monitoring concepts and requirements for large landslides in Norway, Rome, 2011.

Blikra, L. H., O. Longva, C. Harbitz and F. Løvholt, Quantification of rock-avalanche and tsunami hazard in Storfjorden, western Norway, in Landslides and Avalanches ICFL 2005 Norway , edited by K. Senneset, K. Flaate and J. O. Larsen, pp. 57-64, Taylor & Francis Group, London, 2005.

Braykovitch M., Gauge closings called foolish - Water monitors say lives at risk, 1997.

Breznitz, S., Cry Wolf: The Psychology of False Alarms, Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1984.

Bye, L. M., The risk/policy issues of landslides in Norway, Norwegian University of Science and Technology, Tronheim, Norway, 2010.

Carsell, K., Impacts of a false alarm: The January 29, 2000 Ventura, California experience. Dept. of Geography and Environmental Studies, University of Colorado, Colorado Springs, 2001.

Casagli, N. and L. Ermini, Geomorphic analysis of landslide dams in the Northern Apennine, 1999.

Casagli, N., A. Tibaldi, A. Merri, C. Del Ventisette, T. Apuani, L. Guerri, J. Fortuny-Guasch and D. Tarchi, Deformation of Stromboli Volcano (Italy) during the 2007 eruption revealed by radar interferometry, numerical modelling and structural geological field data, *Journal of Volcanology and Geothermal Research, 182*(3-4), 182-200, 2009.

Castellanos Abella, E. A. and C. J. Van Westen, Qualitative landslide susceptibility assessment by multicriteria analysis: A case study from San Antonio del sur, Guantanamo, Cuba, *Geomorphology*, *94*(3-4), 453-466, 2008.

Clark, G. E., S. C. Moser, S. J. Ratick, K. Dow, W. B. Meyer, S. Emani, W. Jin, J. X. Kasperson, R. E. Kasperson and H. E. Schwartz, Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, Ma., USA , *Mitigation and Adaptation Strategies for Global Change, 3*, 59-82, 1998.

Crozier, M., Multiple-occurrence regional landslide events in New Zealand: Hazard management issues, *Landslides, 2*(4), 247-256, 2005.

Cruden, D. M. and D. J. Varnes, Landslide types and processes, in landslides, edited by A.K.Turner and R.L.Schuster, pp. 36-75, Transport Research Board, National Research Council, Washington DC, 1996.

Cutter, S. L., B. J. Boruff and W. L. Shirley, Social vulnerability to environmental hazards, *Social Science Quarterly, 84*(2), 242-261, 2003.

Dai, F. C. and C. F. Lee, Landslide characteristics and, slope instability modeling using GIS, Lantau Island, Hong Kong, *Geomorphology, 42*(3-4), 213-228, 2002.

DiBiagio, E. and O. Kjekstad, Early Warning, Instrumentation and Monitoring Landslides, Phuket -Thailand, 2007.

Dow, K. and S. L. Cutter, Crying wolf: Repeat responses to hurricane evacuation orders, *Coastal Management*, *26*(4), 237-252, 1998.

Dunning, S. A., W. A. Mitchell, N. J. Rosser and D. N. Petley, The Hattian Bala rock avalanche and associated landslides triggered by the Kashmir Earthquake of 8 October 2005, *Engineering Geology*, *93*(3-4), 130-144, 2007.

Durville, J. L., C. Bonnard and P. Potherat, The Sechilienne (France) landslide: a non-typical progressive failure implying major risks, *Journal of Mountain Science, 8*(2), 117-123, 2011.

Ebert, A., N. Kerle and A. Stein, Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data, *Natural Hazards*, *48*(2), 275-294, 2009.

EC, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, 2000/60/EC, L327, 2000.

EC, Impact assessment of the Thematic Strategy on Soil Protection, SEC(2006)620, 2006a.

EC, Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC, COM(2006) 232, 232, 2006b.

EC, Thematic Strategy for Soil Protection, COM(2006) 231, 231, 2006c.

EC, Directive 2007/2/EC of the European Parliament and the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), 2007/2/EC, L108, 2007a.

EC, Directive 2007/60/EC of the European Parliament and the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), 2007/60/EC, L288, 2007b.

EC, A Community approach on the prevention of natural and man-made disasters, COM(2009) 82, 82, 2009.

ERM, Landslides and boulder falls from natural terrain: Interim risk guidelines, ERM-Hong Kong Ltd., 1998.

Ferretti, A., C. Prati and F. Rocca, Permanent scatterers in SAR interferometry, *Ieee Transactions on Geoscience and Remote Sensing*, *39*(1), 8-20, 2001.

Fruneau, B., J. Achache and C. Delacourt, Observation and modelling of the Saint-Etienne-de-Tinée landslide using SAR interferometry, *Tectonophysics, 265*(3-4), 181-190, 1996.

Geldens Stichting, M., Als je leven je lief is, 2002.

GEO, Landslides and boulder falls from natural terrain: Interim risk guidelines, Geotechnical Engineering Office, Gov of Hong Kong, 1998.

Gjerding, M. L., Slakter bevilgning til rasoverføring, Oslo, Norway, 2006.

Glade, T., M. Anderson and M. Crozier, Landslide hazard and risk, John Wiley & Sons, Chichester, 2005.

Glantz, M. H., Usable Science 8: Early warning systems: Do's and Don'ts., 2003.

Grasso, V. F., Early Warning Systems: State-of-Art Analysis and Future Directions, edited by United Nations Environment Programme (UNEP), 2007.

Guzzetti, F. and G. Tonelli, Information system on hydrological and geomorphological catastrophes in Italy (SICI): a tool for managing landslide and flood hazards, *Natural Hazards and Earth System Sciences*, *4*(2), 213-232, 2004.

Hall, S. S., Scientists on trial: At fault?, *Nature, 777*, 264-269, 2011.

Harmsworth, G. and B. Raynor, Cultural Consideration in Landslide Risk Perception, in Landslide Hazard and Risk, edited by T. Glade, M. Anderson and M. J. Grozier, pp. 220-249, John Wiley & Sons, Chichester, 2005.

Huggel, C., N. Khabarov, M. Obersteiner and J. M. Ramirez, Implementation and integrated numerical modeling of a landslide early warning system: a pilot study in Colombia, *Natural Hazards, 52*(2), 501-518, 2010.

INSPIRE Cross Thematic Working Group on Observations & Measurements, Guidelines for the use of Observations & Measurements and Sensor Web Enablement-related standards in INSPIRE Annex II and III data specification development, 2011.

INSPIRE Thematic Working Group Area management/restriction/regulation zones and reporting units, D2.8.III.11 Data Specification on Area management/restriction/regulation zones and reporting units - Draft Guidelines, 2011.

INSPIRE Thematic Working Group Environmental Monitoring Facilities, D2.8.III.7 Data Specification on Environmental Monitoring Facilities- Draft Guidelines, 2011.

INSPIRE Thematic Working Group Natural Risk Zones, D2.8.III.12 Data Specification on Natural Risk Zones – Draft Guidelines, 2011.

Iovine, G., O. Petrucci, V. Rizzo and C. Tansi, The March 7th 2005 Cavallerizzo (Cerzeto) landslide in Calabria - Southern Italy, Nottingham, 2006.

IUGS, Quantitative risk assessment for slopes and landslides – the state of the art, pp. 3-14, Cruden & Fell , Balkema, Rotterdam, 1997.

Lacasse, S. and F. Nadim, Landslide risk assessment and mitigation strategy, edited by K. Sassa and P. Canuti, pp. 31-61, Springer, Berlin, 2009.

Lee, E. M. and D. K. C. Jones, Landslide risk assessment, Thomas Telford, London, 2004a.

Lee, E. M. and D. K. C. Jones, Landslide risk assessment, Thomas Telford, 2004b.

Lendholt, M. and M. Hammitzsch, Generic Information Logistics for Early Warning Systems, 2011.

Leroi, E., Global rockfalls risk management process in 'La Desirade' Island (French West Indies), *Landslides, 2*(4), 358-365, 2005.

Leroi, E., C. Bonnard, R. Fell and R. McIness, Risk assessment and management, *Landslide Risk Management*, 2005.

Mantovani, F., R.Soeters and C.J.Van Westen, Remote sensing techniques for landslide studies and hazard zonation in Europe, *Geomorphology*, *15*(3-4), 213-225, 1996.

Medina-Cetina, Z. and F. Nadim, Stochastic design of an early warning system, *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 2*(4), 223-236, 2008.

Nadim, F. and E. Intrieri, Early warning systems for landslides: challenges and new monitoring technologies, 2011.

NGI, Fjellskred kan skape flodbølger i Norge, 2011.

Osei, E. K., G. E. A. Amoh and C. Schandorf, Risk ranking by perception, *Health Physics, 72*(2), 195-203, 1997.

Ostrom, E., A Behavioral Approch to the Rational Choice Theory of Collective Action: Presidental Adress, *The American Political Science Review, 92*(1), 1-22, 1997.

Papathoma-Kohle, M., B. Neuhauser, K. Ratzinger, H. Wenzel and D. Dominey-Howes, Elements at risk as a framework for assessing the vulnerability of communities to landslides, *Natural Hazards and Earth System Sciences, 7*(6), 765-779, 2007.

Proske, D., Katalog der risiken, Eigenverlag, Dresden, 2004.

Putnam, R. D., Making Democracy Work: Civic Traditions in Modern Italy, Princeton University Press, Princeton, 2011.

Røsjø, B., Norges vakreste trussel, pp. 18-23, 2005.

Rothstein, B., Social Traps and the Problem of Trust, New York, 2005.

Rovick, A., Bølgefare gir byggeforbud, Oslo, Norway, 2006.

Sassa, K., S. Tsuchiya, K. Ugai, A. Wakai and T. Uchimura, Landslides: a review of achievements in the first 5 years (2004-2009), *Landslides, 6*, 275-286, 2009.

Sato, H. P. and E. L. Harp, Interpretation of earthquake-induced landslides triggered by the 12 May 2008, M7.9 Wenchuan earthquake in the Beichuan area, Sichuan Province, China using satellite imagery and Google Earth, *Landslides, 6*(2), 153-159, 2009.

Schröter, K., M. Ostrowski, M. Gocht, B. Kahl, H. P. Nachtnebel, C. Corral and D. Sempere-Torres, EWASE - Early Warning Systems Efficiency: Evaluation of flood forecast reliability, Oxford, 2008.

Slovic, P., The perception of risk, Earthscan, London, 2000.

Smith, K., Environmental hazards. Assessing risk and reducing disaster, London, 2004.

Sparrevik, M., D. N. Barton, A. M. Oen, N. U. Sehkar and I. Linkov, Use of multicriteria involvement processes to enhance transparency and stakeholder participation at Bergen Harbor, Norway, *Integr Environ Assess Manag, 7*(3), 414-425, 2011.

Terzaghi, K., Mechanism of Landslides, pp. 83-123, The Geological Society of America, Berkeley, 1950.

Turner, R. H., Waiting for disaster: Changing reactions to earthquake forecasts in southern CA, *Int. J. Mass Emergerceny Disasters, 1*, 307-334, 1983.

UN-ISDR, Terminology of disaster risk reduction, Geneva, Switzerland , 2004.

UNEP, Early Warning Systems: State-of-Art Analysis and Future Directions, edited by V.F.Grasso, 2011.

Van Westen, C. J., Distance education course on the use of spatial information in multi-hazard risk assessment, 2009.

Van Westen, C. J., E. Castellanos and S. L. Kuriakose, Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview, *Engineering Geology, 102*(3-4), 112-131, 2008.

Van Westen, C. J., N. Rengers, M. T. J. Terlien and R. Soeters, Prediction of the occurrence of slope instability phenomena through GIS-based hazard zonation, *Geologische Rundschau, 86*(2), 404-414, 1997.

Van Westen, C. J., T. W. J. van Asch and R. Soeters, Landslide hazard and risk zonation - why is it still so difficult?, *Bulletin of Engineering Geology and the Environment, 65*(2), 167-184, 2006.

Varnes, D. J., Slope movements. Types and processes, edited by R. L. Schuster and R. J. Krizek, pp. 11-35, National Academic of Sciences, Transportation Research Board, Washington DC, 1978.

VG, Dette kan rase ut, Oslo, Norway, 2006.

VG HELG., Dette fjellet er dødelig, Oslo, Norway, 2006.

Yu, Y. F., J. S. Lam, Siu C.K. and Pun W.K., Recent advance in landslip warning system, 2011.

Zabysshny, A. A. and D. R. Ragland, False alarms and human-machine warning systems, p. -13, University of California, Berkeley, 2003.

Zan, L., G. Latini, E. Piscina, G. Polloni and P. Baldelli, Landslides early warning monitoring system, *Geoscience and Remote Sensing Symposium, 1*, 188-190, 2002.

Appendix A Facts about the EWS screening study

Appendix A1. Invitation letter

SafeLand

Oslo and Lausanne, the 23rd of June 2011.

Subject: **Invitation to participate to a screening survey about landslides Early Warning Systems**

To whom it may concern,

The large, integrating project SafeLand, funded by the European Commission in the 7th Framework Programme, is intended to develop generic risk management tools and strategies for landslides. SafeLand is a collaborative project between 27 partners from 12 countries and coordinated by the International Centre for Geohazards (ICG) in Oslo, Norway. One of the main objectives of the Safeland project is to merge experience and expert judgment and therefore to create synergies on EC-level and to make these results available to end users and local stakeholders. More information on this project is available at www.safeland-fp7.eu.

As part of this study, we are **gathering information about the responsible organizations for landslide early warning system and risk management in selected countries**. You have been identified on internet or by colleagues as an organization in charge of one or several Early Warning System(s). Thus, we would very appreciate that you fill the attached form. **This short (four-page) questionnaire aims to compile information about the state of the art technologies and existing strategies**. The intention of this screening study is **to provide guidelines that will facilitate the establishment of new Early Warning Systems**. Additional information could be sent as attached documents. As our project is limited in time, we would very much appreciate if you **return this form before the 15th of September 2011** to safeland@igar.org.

Do not hesitate to spread this questionnaire to other people involved in Early Warning Systems. Of course, if you have any additional question, do not hesitate to contact us. We look forward to receiving your information.

Sincerely yours,

Sara Bazin for SafeLand Project Coordinator, Norway
Clément Michoud and Prof. Michel Jaboyedoff, for University of Lausanne, Switzerland
safeland@igar.org

Appendix A2. Questionnaire

Questionnaire

on landslide early warning systems

1. GENERAL INFORMATION ON THE UNIT IN CHARGE OF THE EWS

Name of the operational unit			
Country		Location	
Person in charge of the operational unit	Name		
	Email address		
Level of operational unit	☐ National ☐ Regional ☐ Local ☐ Private		
Source of funding		Yearly cost of unit	
Are there any codes for EWS in your country?	☐ Yes ☐ No	Are there any guidelines for EWS in your country?	☐ Yes ☐ No
Is the unit also responsible for monitoring other than landslides?	☐ Yes ☐ No If yes, specify ☐ volcanoes ☐ earthquakes ☐ tsunamis ☐ weather ☐ other (specify):	Number of monitored landslides with implemented EWS?	
		Number of monitored landslides without EWS?	
Scale of landslide	☐ Single slide ☐ Multiple slide ☐ Regional slide		
Are the warning systems in operation?	☐ Yes ☐ No	If not, is it: ☐ planned ☐ under construction ☐ damaged ☐ stopped	
Number of persons employed at the unit		A person is present on duty 24/7 ☐ Yes ☐ No A person is on call 24/7 ☐ Yes ☐ No	
Confidentiality/ Access to data	☐ Public (full access of general data (e.g. Topography, geology, structural, borehole, hazard/risk etc.), detailed monitoring data accessible on request) ☐ Not Public (specify whether authorization is already available/requested):		
Web site			

2. MONITORED LANDSLIDES

Please fill this table for each landslide that you monitor

Name of the site:			
Slide has occurred yet?	☐ Yes ☐ No (slide prone)	If yes, potential for future sliding?	☐ Yes ☐ No
Type of landlside	☐ rock ☐ debris ☐ earth ☐ other (specify):	Type of slope	☐ natural cliff ☐ quarry or mine ☐ redesigned slope ☐ other (specify):
Triggering mechanism	☐ rainfall ☐ earthquake ☐ erosion ☐ human activity ☐ other (specify):	Volume of landslide	
Elements at risk, specify and quantify for each case		☐ buildings (private, public...) ☐ infrastructure (railways, roads, bridges, power lines...) ☐ people (inhabitants, workers, tourists...) ☐ indirect risk (tsunami, flooding...) ☐ other (specify):	

Human losses (death and injuries) due to previous events	☐ Yes ☐ No	If yes, quantify:
Economic loss due to previous events	☐ Yes ☐ No	If yes, quantify in €:
Social consequences due to previous events	☐ Yes ☐ No	If yes, specify:
Mitigation (already performed or envisaged)	☐ Yes ☐ No	If yes, describe (structural/non-structural):
Land planning already established for the case	☐ Yes ☐ No	If yes, specify:

3. PRE-INVESTIGATIONS USED TO DESIGN THE EWS

Was geology or geomorphology a design criterion?	☐ Yes ☐ No	If yes, specify:
Were geophysical data a design criterion?	☐ Yes ☐ No	If yes, specify (technique, profiles, scale etc.):
Was hydrogeology a design criterion?	☐ Yes ☐ No	If yes, specify (piezometers, suction etc.):
Were geotechnical data used to design the EWS?	In situ data: ☐ Yes ☐ No	If yes, specify (type of test, drilling depth, location, maps availability etc.):
	Lab data: ☐ Yes ☐ No	If yes, specify (type and number of tests, material tested):
Were surface movement data used to design the EWS?	☐ Yes ☐ No	If yes, specify type (technique), scale and date:
Was modeling used to design the EWS?	☐ Yes ☐ No	If yes, specify type (technique):

Questionnaire on landslide EW systems SafeLand

4. MONITORING PARAMETERS, THRESHOLDS AND SENSORS EVALUATION

Please provide for each landslide or selected landslides, a map as attached file and a description of the monitoring system using the following table:

Monitoring parameter	Threshold level	Sensor type	Sensors number	Sensor reliability	Active	Duration	Frequency	MM indicator	EW parameter

Explanations:

Monitoring parameter	*phenomenon or factor related to slope/area of interest, which could be quantified and monitored in time*
Threshold level	*a warning is issued when the monitoring parameter reaches this critical value*
Sensor type	*specify type of technology (e.g. 3C broad-band seismometer)*
Sensor reliability	*evaluate the instrument dependability based on time frequency of measurements and down time with values from 1 to 10 (maximum)*
Active	*is the monitoring still in use? (tick = yes)*
Duration	*duration of monitoring in years*
Frequency	*frequency of reading per day (D), month (M) or year (Y), for example 6xD*
Mass-movement (MM) indicator	*monitoring parameter characterizing directly or indirectly the dynamic state of mass-movement processes. Evaluate the parameter with values from 1 to 10 (maximum)*
Early warning (EW) parameter	*mass-movement indicator allowing to detect an impending or existing critical activation or acceleration of the landslide(s) by its threshold. E valuate the parameter as an EW parameter with values from 1 to 10 (maximum)*

List of eventual monitoring parameters related to landslides:

Displacement *(Cummulative, Differential, Acceleration, Velocity, Settlement),* ***Microseismicity*** *(also microcracks/strain),* ***Rockfall event frequency, Macrocracks and surface fissures, Stress*** *(direct measurements),* ***Mass loss/increment balance*** *(areal 3D deformation at individual slopes-based e.g. on TLS or GB-InSAR),* ***Precipitation, Snow cover, Wind velocity, Solar radiation, Air temperature, Ground Water Level, Pore-Water Pressure, Soil Suction, Discharge, Ground/superficial water quality*** *(chem. composition, el. conductivity, pH, etc.),* ***Electrical ground resistivity, Electrical self-potential, Density, Seismic velocity, Temperature*** *(air, water, substrate),* ***IP effect, Dielectric permittivity*** *(GPR repeated measurements for monitoring),* ***Soil humidity, Radon emanation,*** *Factor of Safety (monitoring parameter derived from triggering factors),* ***Regional precipitation*** *(weather forecast for e.g. hurricanes, etc.),* ***Volcanic activity, Regional seismicity*** *(activity/shaking/acceleration).*

Advantages and limitations of your monitoring system	
How could it be improved?	

Please return this form to safeland@igar.org *Page 3*

Questionnaire on landslide EW systems SafeLand

5. WARNINGS, COMMUNICATION, AND DECISION MAKING PROCESS

How is operated the data monitoring?	☐ automatic, then specify by ☐ SMS, ☐ voice message, ☐ e-mail, ☐ other ☐ manual, then specify the frequency of data check and operator:
Are the warning based on thresholds set on?	☐ single sensors ☐ multiple sensors — Are thresholds based on minimum resolution and noise level? ☐ yes ☐ no
Are there any power supply back-ups?	☐ for the sensors ☐ for the operational center ☐ for the communication
Are there any back-ups for communication?	☐ for the data transfer ☐ for the operational center communication (internet, phone,radio…)
Type of software and integrated systems?	
Who designed the alarm chain?	☐ responsible of operational unit ☐ local authorities ☐ governmental/regional institutions ☐ other, specify
Are there several levels of warning?	☐ Yes ☐ No ☐ Envisaged If yes, specify how it works :
Do you have different thresholds for different scenarios?	☐ Yes ☐ No ☐ Envisaged If yes, specify how it works :
Can you perform direct field observations in case of a warning?	☐ Yes ☐ No — Is there a procedure to cancel the warning once issued? ☐ Yes ☐ No If yes, describe:
Procedure in case of a warning?	
Evacuation time after a warning?	
How is issued the warning to the population?	☐ siren ☐ SMS ☐ TV ☐ radio ☐ other, specify
Do you have review procedures?	☐ operational check list ☐ report to review group ☐ other, specify:
How do you communicate with the public?	☐ public reports specifying status of the landslide, if yes specify frequency: ☐ public meetings, if yes specify frequency: ☐ public website ☐ newspaper ☐ other, specify:
Tests and evacuation exercises performed?	☐ Yes ☐ No ☐ Envisaged If yes, specify extent and frequency:
What are your practical challenges for the EWS?	☐ installation and maintenance of the sensors ☐ installation and maintenance of the operational unit ☐ weather conditions ☐ site conditions ☐ human resources ☐ funding ☐ population response ☐ other, please specify:
How could the actual EWS be improved?	

Please return this form to safeland@igar.org *Page 4*

Appendix A3. Results of EWS survey

SEVENTH FRAMEWORK PROGRAMME

SafeLand

Questionnaire

on landslide early warning systems

1. GENERAL INFORMATION ON THE UNIT IN CHARGE OF THE EWS

Name of the operational unit	14 UNITS		
Country	8 COUNTRIES	Location	CA, CZ, FR, HK, IT, NO, SK, SP
Person in charge of the operational unit	Name		
	Email address		
Level of operational unit	[5] National [8] Regional [0] Local [1] Private		
Source of funding	13 PUBLIC (1 MIXED)	Yearly cost of unit	MEAN : ~160'000 EUR
Are there any codes for EWS in your country?	[1] Yes [7] No	Are there any guidelines for EWS in your country?	[1] Yes [7] No
Is the unit also responsible for monitoring other than landslides?	[10] Yes [4] No If yes, specify [2] volcanoes [3] earthquakes [2] tsunamis [5] weather [2] other (specify):	Number of monitored landslides with implemented EWS?	32
		Number of monitored landslides without EWS?	252
Scale of landslide	[9] Single slide [5] Multiple slide [2] Regional slide		
Are the warning systems in operation?	[11] Yes [3] No	If not, is it: [0] planned [1] under construction [1] damaged [1] stopped	
Number of persons employed at the unit	MEAN : ~6	A person is present on duty 24/7 [2] Yes [12] No A person is on call 24/7 [12] Yes [2] No	
Confidentiality/ Access to data	[5] Public (full access of general data (e.g. Topography, geology, structural, borehole, hazard/risk etc.), detailed monitoring data accessible on request) [9] Not Public (specify whether authorization is already available/requested):		
Web site	/		

Questionnaire on landslide EW systems SafeLand

2. MONITORED LANDSLIDES

Please fill this table for each landslide that you monitor

Name of the site:	23 LANDSLIDES		
Slide has occurred yet?	[19] Yes [3] No (slide prone)	If yes, potential for future sliding?	[22] Yes [0] No
Type of landlside	[14] rock [6] debris [6] earth [0] other (specify):	Type of slope	[19] natural cliff [3] quarry or mine [3] redesigned slope [0] other (specify):
Triggering mechanism	[17] rainfall [0] earthquake [4] erosion [4] human activity [6] other (specify):	Volume of landslide m^3	10 < 8'000'000 < 54'000'000
Elements at risk, specify and quantify for each case		[14] buildings (private, public...) [20] infrastructure (railways, roads, bridges, power lines...) [12] people (inhabitants, workers, tourists...) [8] indirect risk (tsunami, flooding...) [1] other (specify):	
Human losses (death and injuries) due to previous events	[3] Yes [20] No	If yes, quantify: SUM: 131 FATAL INJURIES	
Economic loss due to previous events	[10] Yes [12] No	If yes, quantify in €: SUM: 602'000 EUR / MEAN: 200'000.-	
Social consequences due to previous events	[9] Yes [13] No	If yes, specify: INJURIES, ISOLATION TRAUMA, NEW BUILDING CODES	
Mitigation (already performed or envisaged)	[9] Yes [13] No	If yes, describe (structural/non-structural): EWS, PURGES, RETAINING WALL, BASINS	
Land planning already established for the case	[15] Yes [5] No	If yes, specify: LAND-USE RESTRICTION, CIVIL PROTECTION PLAN	

3. PRE-INVESTIGATIONS USED TO DESIGN THE EWS

Was geology or geomorphology a design criterion?	[18] Yes [5] No	If yes, specify: FIELD MAPPING MAINLY
Were geophysical data a design criterion?	[10] Yes [13] No	If yes, specify (technique, profiles, scale etc.): RESISTIVITY, SEISMIC MAINLY
Was hydrogeology a design criterion?	[12] Yes [11] No	If yes, specify (piezometers, suction etc.): PIEZOMETER & PLUVIOMETERS MAINLY
Were geotechnical data used to design the EWS?	In situ data: [10] Yes [13] No	If yes, specify (type of test, drilling depth, location, maps availability etc.): CORE DRILLING & TEST
	Lab data: [4] Yes [19] No	If yes, specify (type and number of tests, material tested): SHEAR TESTS
Were surface movement data used to design the EWS?	[14] Yes [9] No	If yes, specify type (technique), scale and date: CF. NEXT PART
Was modeling used to design the EWS?	[12] Yes [11] No	If yes, specify type (technique): STABILITY CONDITION, RUNOUT, TSUNAMI MAINLY

Please return this form to safeland@igar.org *Page 2*

Questionnaire on landslide EW systems

SafeLand

4. MONITORING PARAMETERS, THRESHOLDS AND SENSORS EVALUATION

Please provide for each landslide or selected landslides, a map as attached file and a description of the monitoring system using the following table:

NUMBER OF LANDSLIDES MONITORED BY:

Monitoring parameter	Threshold level	Sensor type	Sensors number	Sensor reliability	Active	Duration	Frequency	MM indicator	EW parameter
CRACKMETER:	7		TOTAL STATION:	3		GEOPHONES:	4		
GNSS:	9		DMS:	2		PLUVIOMETER:	11		
LASER:	4		TILTMETER:	2		HUMIDITY:	1		
GB-INSAR:	4		INCLINOMETER:	3		TEMPERATURE:	3		
INSAR:	1		PIEZOMETER:	5		WIND:	2		
EXTENSOMETER:	10		STREAMGAUGE:	2		BAROMETER:	2		

Explanations:

Monitoring parameter	*phenomenon or factor related to slope/area of interest, which could be quantified and monitored in time*
Threshold level	*a warning is issued when the monitoring parameter reaches this critical value*
Sensor type	*specify type of technology (e.g. 3C broad-band seismometer)*
Sensor reliability	*evaluate the instrument dependability based on time frequency of measurements and down time with values from 1 to 10 (maximum)*
Active	*is the monitoring still in use? (tick = yes)*
Duration	*duration of monitoring in years*
Frequency	*frequency of reading per day (D), month (M) or year (Y), for example 6xD*
Mass-movement (MM) indicator	*monitoring parameter characterizing directly or indirectly the dynamic state of mass-movement processes. Evaluate the parameter with values from 1 to 10 (maximum)*
Early warning (EW) parameter	*mass-movement indicator allowing to detect an impending or existing critical activation or acceleration of the landslide(s) by its threshold. E valuate the parameter as an EW parameter with values from 1 to 10 (maximum)*

List of eventual monitoring parameters related to landslides:

Displacement *(Cummulative, Differential, Acceleration, Velocity, Settlement),* ***Microseismicity*** *(also microcracks/strain),* ***Rockfall event frequency, Macrocracks and surface fissures, Stress*** *(direct measurements),* ***Mass loss/increment balance*** *(areal 3D deformation at individual slopes-based e.g. on TLS or GB-InSAR),* ***Precipitation, Snow cover, Wind velocity, Solar radiation, Air temperature, Ground Water Level, Pore-Water Pressure, Soil Suction, Discharge, Ground/superficial water quality*** *(chem. composition, el. conductivity, pH, etc.),* ***Electrical ground resistivity, Electrical self-potential, Density, Seismic velocity, Temperature*** *(air, water, substrate),* ***IP effect, Dielectric permittivity*** *(GPR repeated measurements for monitoring),* ***Soil humidity, Radon emanation,*** *Factor of Safety (monitoring parameter derived from triggering factors),* ***Regional precipitation*** *(weather forecast for e.g. hurricanes, etc.),* ***Volcanic activity, Regional seismicity*** *(activity/shaking/acceleration).*

Advantages and limitations of your monitoring system	⊕ SIMPLE, MULTIPLE SENSORS, ROBUST, BACK-UPS ‖ ⊖ DAMAGE BY EVENTS / WEATHER, BASED ONLY ON DISPLACEMENTS
How could it be improved?	1. MONITORING MORE PARAMETERS / LOCATIONS 2. BETTER INTEGRATION

Please return this form to safeland@igar.org *Page 3*

Questionnaire on landslide EW systems **SafeLand**

5. WARNINGS, COMMUNICATION, AND DECISION MAKING PROCESS

How is operated the data monitoring?	[22] automatic, then specify by [14] SMS, [1] voice message, [8] e-mail, [3] other [5] manual, then specify the frequency of data check and operator:
Are the warning based on thresholds set on?	[15] single sensors [14] multiple sensors Are thresholds based on minimum resolution and noise level? [8] yes [13] no
Are there any power supply back-ups?	[14] for the sensors [13] for the operational center [15] for the communication
Are there any back-ups for communication?	[15] for the data transfer [20] for the operational center communication (internet, phone,radio...)
Type of software and integrated systems?	WEB-BASED SYSTEM, EXCEL, MATLAB, ...
Who designed the alarm chain?	[16] responsible of operational unit [6] local authorities [9] governmental/regional institutions [3] other, specify
Are there several levels of warning?	[13] Yes [8] No [3] Envisaged If yes, specify how it works : /
Do you have different thresholds for different scenarios?	[6] Yes [10] No [3] Envisaged If yes, specify how it works : /
Can you perform direct field observations in case of a warning?	[16] Yes [1] No Is there a procedure to cancel the warning once issued? [9] Yes [4] No If yes, describe:
Procedure in case of a warning?	/
Evacuation time after a warning?	0.1h < ~41h < 72h
How is issued the warning to the population?	[6] siren [7] SMS [6] TV [8] radio [12] other, specify PHONE / INTERNET / TRAFFIC LIGHTS / DOOR TO DOOR
Do you have review procedures?	[15] operational check list [8] report to review group [2] other, specify:
How do you communicate with the public?	[10] public reports specifying status of the landslide, if yes specify frequency: [5] public meetings, if yes specify frequency: [10] public website [6] newspaper [1] other, specify:
Tests and evacuation exercises performed?	[12] Yes [9] No [0] Envisaged If yes, specify extent and frequency: 1 OR 2 EXERCICES PER LANDSLIDE (IF MADE)
What are your practical challenges for the EWS?	[20] installation and maintenance of the sensors [11] installation and maintenance of the operational unit [10] weather conditions [12] site conditions [3] human resources [8] funding [5] population response [ ] other, please specify:
How could the actual EWS be improved?	/

Please return this form to safeland@igar.org *Page 4*

Appendix B EWS stakeholder example studies

This appendix was intended to provide examples of EWSs with different scales and strategies. Two countries, Norway and Slovenia, have supplied details about their EWS, with an emphasize on the difficulties they met during their installation.

Appendix B1 Norway
Author: L. M. Bye

This appendix addresses local responses to early warning in the Storfjord region in western Norway where a massive rock slide at Åkneset represents a dramatic threat to the many communities placed along the big fjord because of its potential to trigger a tsunami (Figure 51).

The present study shows that peoples risk perceptions are strongly related to the risk communication strategies chosen by the risk managers. Arranging public meetings and inviting people to engage in the discussion about Åkneset, the Early-Warning Centre has managed to reduce the gap between the experts and the public. The success factors in implementing EWS it based on good risk communication, openness and involvement. By having an open and inclusive dialogue with the public at an early stage, and by facilitating education and knowledge exchange based on equal, face-to-face relationships with the experts, trusting relationships has been established between the experts and the residents.

Figure 51: The Storfjord region with the high risk objects at Åkneset and Hegguraksla.

In Storfjorden, notified testing of the alarm system is mainly seen as positive. It is described as a visible sign that the system is operative. However, one can assume that peoples risk perceptions will increase in case of a false alarm. Peoples trust in the expert knowledge and technology used to monitor the risk can also easily be put to the test if there comes to any close calls. Among people in the region, the Centre is known as an important premise provider for settlement and development. For those who live in the region, it is unthinkable to give up the confidence which the Centre provides them. If the Centre must close due to lack of funding it will have severe consequences for people's risk perceptions and the socio-economic development of the region. The data collected for this study is based on semi-structured interviews with 20 respondents living and working in the some of the most affected communities in Storfjorden.

a) Introduction

Åkneset has been described as Norway's most beautiful threat (Røsjø, 2005). The reason for this is that the massif at Åkneset is a developing landslide that most certainly will trigger a tsunami in the Storfjorden region. The worst case scenario for Åkneset is that 50-100 million m^3 of rock will drop into the fjord and trigger a wave that will ruin the many communities placed along it. For communities such as Hellesylt and Geiranger, which are situated at the head of the Synnulvsfjord, the damage will be devastating. But other communities, such as Stranda, Valldal and Tafjord, are also at high risk. A wave simulation model and numerical calculations shown that such a rock volume can cause run-up waves of respectively 70 and 90 m at Geiranger and Hellesylt. At Tafjord, another fjord branch to Storfjorden, the run-up heights is estimated to be 14 m (NGI, 2011). The last decade, scientists and engineers has worked closely together with local and regional authorities in Møre and Romsdal county in the effort to establish an EWS to prevent fatalities. In 2007, after several years with intense work and lobbying, the Storfjord region got an operative monitoring, warning and evacuation system that makes it possible to warn and evacuate people if the risk suddenly increases. Unlike most emergency centre in the world, Åknes Centre is locally run and owned.

The present study examines more closely local people's responses to the EWS to identify and understand the social effects of having an operative service in the Storfjord region. Since risk does not exist independent of a person's feelings or judgments about risks, and often matter as much as rational calculation when considering how to respond to risks (Slovic, 2000), it is important to study landslide risk as an individual and subjective construction. Considering that the ways people construct their own reality and evaluate risks is closely related to the actual performance, competence and trustworthiness of those who manage risk (Aven and Renn, 2010), it is also significant to study how people relate to the experts and the Centre, and how they perceive the expert knowledge and technology used to monitor the risk.

A dilemma in landslide risk management is often that the experts and the public disagree about risk assessment and the implementation of technical solutions that can protect them from high risk objects (Lee and Jones, 2004b). Because an implementation of EWS can lead to scepticism and resistance as it often affect new investments and development, it can be difficult to establish trust between the public and those undertaking risk management strategies. Thus, faced with people's skepticism, it is important to take peoples risk perceptions seriously and to focus on how to implement new technology and build trust in the system. The purpose of this study is, in other words, to say something about local responses to EWS and how to facilitate, design and implement an early warning system that makes people feel safe.

The key questions asked, which all generate a number of secondary questions, are as follows:

1) How do people assess and perceive the risk at Åkneset and what is the relationship between EWS and peoples risk perception?
    - What kind of knowledge and technology are required by the people in terms of feeling safe?
    - In what way are emergency drills and testing of the system affecting people’s risk perception?
   - To what extent can a false alarm weaken the credibility of the EWS?

2) What role are EWSs playing in terms of the decision making processes and what is the connection between risk communication and risk perception?
   - Who are involved in the EWS and what kind of risk communication are taking place between the experts and the public?
   - What will the consequences be if the Centre must close down due to lack of resources?

The questions asked provides a focus on the relationship between risk perception, risk communication and early warning, which are important elements to discuss in terms of providing guidelines for how to implement an effective EWS. Knowing about how local people perceive risk and how they respond to EWS can help on how landslide risks should be managed and governed at the local level and how to implement new technology. The emphasis is, in other words, to deploy more information to policy-makers, public administrations, researchers and other stakeholders how to structure, manage and interact in this field in order to reduce peoples risk perceptions.

b) The risk policy of Åkneset

Åkneset is located at the entrance of the scenic and world famous Geiranger Fjord, which was listed as a UNESCO World Heritage Site in 2005. Every year more than one million tourists come to see the narrow and step fjord with small abandoned mountain farms and foaming waterfalls that plunge into the deep blue from jagged peaks. The spectacular landscape bear witness of rough climatic conditions. Snow avalanches and landslides are not unusual, rather the contrary. Traces in the landscape, both above and below water, shows that there have been several large rock falls in the region in resent and historic time. The 1731 rock fall at Skafjell and the 1934 Tafjord disaster remains vivid memories of the havoc brought about by big rock falls. Triggering flood waves in the big fjord, the events caused respectively 17 and 40 fatalities.

The unstable massif at Åkneset is located on the west side of Synnylsfjorden. About 900 meters above the surface there is a 700 meter long fracture that winds down the rock face. The fracture, called *Åknesrenna*, is the most visible evidence that the mountain is moving. Today, it is a lot of uncertainty regarding when the rock will fall into the fjord but according to Lars Harald Blikra, the chief geologist at the Åknes/Tafjord project, it will probably happen within 50-100 years (Agderposten, 2008). According to Blikra and others it is most likely that the slide will consist of smaller blocks of stone. At the same time, they cannot exclude the possibility for one big slide triggering a big flood wave in the Fjord.

The first signs of movements were registered by a local hunter in the 1950s. Raising the alarm in the 80s and 90s he was not meet with any resonance. Local authorities did not pay the fracture any interest as they were worried that it would harm the regions reputation and development as a tourist destination and a place for industry enterprise (Bye, 2010). In 1987 and 1989 some early, manual investigations was carried out at the site. Some year's later researchers from NGI concluded that there was no risk at Åkneset.

During the 90s local people started to mistrust the scientific results and the local authorities handling the situation (Bye, 2010). From the bottom-up arose a requirement that one had to examine the risks at Åkneset. In 1993, three tension rods were installed for continuous measurement of the upper crack. It was documented movement of 1-4 cm a year. However, little was done to reduce peoples risk perceptions before Frank Sve, became major in Stranda community in 2002. One of his aims was to find out what was going on in the mountain and how to provide safety for the public. He contacted Ottar Berfring, the county governor in Møre and Romsdal, in order to get help. A year later Møre and Romsdal county and Geological Survey of Norway (NGU) took the initiative to more extensive investigations. Using better and more fine-tuned techniques and methods it was acknowledged that the fracture was widening at an accelerating rate and that it was part of a bigger system of deep fractures and sliding plates.

When the experts from NGU displayed the different scenarios for Åkneset in 2004 it was no way of return. Measurements showed that the unstable rock massif could involve a rock volume of 10-40 mill. m^3 but most likely a volume of 30-40 mill. m^3. A worst-case scenario for Åkneset involved a rock volume of more than 50 mill. m^3 and run-up heights of 30-40 m at the bottom of the fjord (Blikra et al., 2005). The potential risk at Åkneset was defined as many times as big as the most dramatic rock falls in Norway's history; Loen in 1905 and 1936, and Tafjord in 1934. In comparison, the Tafjord disaster involved a rock volume of 3 mill. m^3 and a 64 meters high flood wave.

Facing the potential rock fall at Åkneset the county governor in Møre and Romsdal had no other choice than to induce a building stop in the region. The affected communities, which counted at least 6, were asked to carry out essential emergency and preparedness actions. Since early 50s the visible crack has stretched out with two meters. In some parts it increased with 10-20 cm a year. It was acknowledged that the risk at Åkneset was extensive and that the consequences could be fatal if nothing was done.

Because there were to potential rock falls in the region, Åkneset in Sunnulvsfjorden and Hegguraksla in Tafjorden (see map), the Åknes/Tafjord project was established as an inter-municipal cooperation. Thanks to an offensive front in the national media and the 2004 Indian Ocean tsunami triggering a stronger focus on monitoring, warning and evacuation system, the project managed to raise 2/3 of the money that was needed to establish an EWS (Bye, 2010). In 2007, after years of intense work, the Storfjord region got an operative EWS in Stranda community. Today, the mountain is kept under constant 24/7 observation by a variety of high-tech installations. Both reflectors and measuring rods have been installed, and every tiny little movement is measured by GPS, laser, radar and seismic.

The Centre is financed with help from the state, the county governor and the affected communities but at the moment it is not provided long-term funding from the government. In the last few years it has been discussed whether or not Åknes Centre should become a national centre for rock slide monitoring. Because of an already squeezed local economy and some communities refusing to be part of the Dutch treat, the current funding arrangement is very stressful. According to Sve it is essential to deal with the financial strain on a national level since the Centre is an important provider for future settlement and development in the region (Bye, 2010). It is argued that the centre must be regarded as an important competence centre as it can provide both expertise and technology that can be used elsewhere. At present, the Centre is monitoring the risk at Åkneset and Hegguraksla in Møre and Romsdal County, and Mannen which is located in Sogn and Fjordane.

c) Methodological approaches

In order to understand how people in the Storfjord region perceive risk and how they respond to the early warning system, the study is based on interviews. People living in some of the most exposed areas in Storfjorden, namely Hellesylt (680 inhabitants), Geiranger (250 inhabitants), and the community centre of Stranda (3500 inhabitants) where most people live and work, were interviewed. Attempting to compare and examine how different people assess and cope with risk and how they deal with warning and evacuation drills, this study focuses on a «cross-section» of the grown-up population in these communities. The national register of taxpayers was used to select informants for the study. The register, which is accessible through the web, makes it easy to find people of different age, gender and income. A request to 36 persons by letter, describing the aim of the research project received 16 positive feedback. In total the study includes 16 semi-structured interviews with 20 respondents in the age of 28-66. 10 women and 10 men were spoken to through individual interviews as well as interviews with couples,. The interviews, which lasted from 1-1 ½ hour, were all recorded, typed and analysed manually.

The data collected for this study do not constitute a representative sample of those living in the area. Instead it says something about how some residents experience and respond to EWS In other words, by adopting a qualitative approach to local peoples risk perceptions this project is not been concerned about the prevalence of a phenomenon. Rather, it has promoted knowledge and variations that do not appear in statistical surveys because they are hard to intercept. A study of how different people perceive landslide risk, gives voice not only to the mainstream dwellers but also to others who may perceive things differently. Because there is no such thing as «a public» and risk managers have to deal with different and diverse segments of the general public, one should think about how different people respond to risk and how one best can communicate and design such information in order to decrease people's risk perceptions. The empirical data was collected autumn 2011.

d) Local responses to landslide risk and EWS

Landslide risk assessment and management by means of probability and consequences have for a long time guided landslide risk management strategies (Glade et al., 2005;Lee and Jones, 2004b) . However, to acknowledge a statistical approach to risk management does not mean that this is the only way to assess risk and inform new risk politics. Even if a quantitative approach to risk is regarded as highly important for landslide risk management as it tells us something about the magnitude of the potential loss and the probability that the loss will occur, the approach should be supplied with a qualitative approach to risk and an understanding of people's perception of risk. Landslide risk can be assessed either quantitatively or qualitatively, and in the following describes the different ways local people perceive, assess and manage the risk related to Åkneset. Moreover, this study addresses local people's responses to the Centre and how different activities, events and economies may influence local peoples risk perception.

- Media attention and risk exposure

Asking the informants about Åkneset and how they experienced to live close to the big threat, most informants declared that they did not think much about Åkneset in their day to day life. The explanation given was that they had grown up in the region, was accustomed to live with landslides and that they had «chosen» to believe in warning. According to the people interviewed, they had no second thoughts about living in the area and they believed that most people felt the same way. If anyone was unequipped to cope with the threat, it was the newcomers. Those who have not grown up with avalanches, had little experience and knowledge about landslides, and who had little information and understanding of the criteria for monitoring, warning and evacuation.

Studies on landslide risk reveals that risk perception varies between nations and cultures, and that people's risk tolerance is a matter of uncertainty avoidance, social capital and their possibility to influence policy (Harmsworth and Raynor, 2005). For instance, in cultures with small power distances between the powerful and the less powerful, such as in Norway, there are good opportunities to be heard, while in societies with large power distances between the people and the experts, such as in India, it will often be difficult to establish participation, transparency and trust in risk management processes.

This study shows that local peoples risk perception is a question about a person's mental premises to cope with landslide risk, his or her knowledge and experiences with such risk, the beliefs and values that prevail among those living in the fjord, and the ways the experts interact with the local people. The difference in the way people perceive landslide risk is also a question about media attention, the frequency and magnitude of the threat, and how landslide risk is communicated and dealt with by authorities and experts.

In Stranda community most people got very troubled and anxious when they first heard about the extensive threat at Åkneset. At the beginning, much media attention and focus on the wide-ranging scale of the potential rock fall caused a lot of fear and uncertainty about the future. The newspaper headlines, which told the story about «the deadly mountain» and «the monster wave» (Rovick, 2006;VG, 2006;VG HELG., 2006), were extremely unpleasant for those living in the fjord and the presentations tended to increase their risk perceptions. It was not that people in the region were unfamiliar with the fracture in Åkneset but their acquaintance of its potential risk was new and shocking to them. Many spoke about sleepless nights after they had seen the pictures and graphics showing the run-up heights for specific locations. A tsunami demonstration, which was shown on TV, gave life to people's thoughts about the risk and made it more real to them. In Hellesylt parents were afraid that both the kids and the school would be washed away by the flood-wave.

In the beginning many were upset and angry at major Sve, who knew to speak up about the risk in the news Medias. In the early phase, he used the 2004 Indian Ocean tsunami as a trigger point for political action and funding. Being the driving force in the Åknes/Tafjord project, he used images that people would rather not be reminded of. He said that if it were not allocated more money to monitor the risk at Åkneset, one could easily run the risk of facing a situation of floating corpses in the Storfjord region (Gjerding, 2006). For many young families, in particular, the horror scenarios caused a very stressful situation. Parents

talked about weeks with restless nights, and about big brothers and sisters who had nightmarish dreams about siblings who could not outrun the flood wave. However, quick action by local authorities led to calm the situation for those living in the area. When people understood that Sve used the Indian Ocean tsunami as «a policy window for change» and saw that local and regional authorities worked hard to establish a EWS, they gradually became more relaxed.
In order to calm the situation and clarify the criteria for warning and evacuation, public meetings were arranged in several communities. Those who attended the meetings were very satisfied with the information given. The presentation held by the experts was well prepared and easy to understand and follow for most people. Academic concepts were reduced to a minimum and questions from the audience were well received. Both adults and children got the opportunity to ask questions to those who worked to improve people's safety. Meeting the residents face-to-face, the experts explained the criteria for monitoring, warning and evacuation and focused on the current risk level which gave them time to find a good solution. Looking back at the early days it seems that the situation not only caused uncertainty and worries, it also led to local engagement and involvement. Several interviewed people explained that Åkneset became a trigger point for education and learning. They search information and literature on the topic, participated at meetings and lectures, and gave voice to their concerns at public meetings.
Having an open and inclusive dialog in the early phase the experts managed to take control of the situation. Good communication and easy access to information on rock falls and early warning became important in terms of decreasing peoples risk perceptions. It appears that no one living in Geiranger, Hellesylt or Stranda has actually moved from the region because of Åkneset. As soon as they learned about the criteria for monitoring, warning and evacuation, people started to cope with the risk at Åkneset in a more rational way.

- Coping strategies

What people perceive as risk is affected by individual as well as social and cultural elements. Risk perception depends on the degree to which landslide risk is understood to affect people's lives, the values and belief systems that people are part of, and how risk is being managed at the local level. In her study, the social expert Linda Bye has found three overlapping strategies that can tell something about how people in Storfjorden deal with the threat from Åkneset. The risk coping strategies, which she has called; 1) «*Experience and local knowledg*e», 2) «*Moral stories of local identity*», and 3) «*Believe, hope and love*», are all telling something about how local people assess, perceive and cope with landslide risk in the Storfjord region. The strategies provide both a framework to advance our knowledge about landslide risk perception and to find out more about local responses to EWS.
First of all, the interviewed people often said to her*:* «*You have to listen to nature*» *or* «*You must learn to take account of the weather*». The story told was that, they were accustomed to live with avalanches and that they had learned to live with risk and to take precautions. Through generations they had possessed experience and local knowledge that made it possible for them to live with different landslide risks. They knew from stories told and by experience that nature alerts itself beforehand. Likewise, they knew that by paying attention to sounds and changes in the landscape they could minimise the risk of, for instance, being hit by avalanches. In winter they often stayed home when weather conditions warranted it, but if they had to set off they always drove with the window open to make sure that it was safe to

pass a snow-avalanche site. Because they had strong self-discipline and confidence in local knowledge, they often cancelled important meetings, whether in Oslo or Bangkok. It seemed that they possessed some kind of knowledge and skills that helped them to live and cope with landslide risks in everyday life.

Second, to mentally cope with landslide risks, their emotions or feelings are often controlled or formed by moral stories about local identity. A common statement put forward by the informants was that; *«People think we are crazy to live here but we are used to avalanches, and we are not of the scared type». We have always known about it, we live with it and we take things as they come"*. The story about the people in the fjords as not easily scared is a moral tale about robustness and endurance. It is a story about the "real" fjord people which are mentally strong and who will not be stopped by the avalanche threat; they are "stayers". Living with the big treat from Åkneset, they think it is important to stay cool and calm. We may say that local peoples risk perceptions are related to a «stayer culture» where images about moral acts and local identity help them to overcome their fear.

A third story told, is to *«choose to believe»* or *«choose to rely»* on experts. One of the informants, for instance, said that; «*I choose to trust that the experts have control because if not I would become dubious.... It is most important to think positively and to hope for the best*». The informants talk about choosing to believe in the experts as a survival strategy. Because they are strongly attachment to the place, it seems that they have agreed to submit to the experts. However, many of my informants do not think that anything will happen to Åkneset in near future. They do not consider the risk at Åkneset to be very high. In fact, there are many locals who think that the worst case scenario is «out of place». One informant explained «*I believe that the scientific experts have become a little bit to zealous in this matter. I understand that it is interesting to investigate Åkneset from a research's point of view but I don't think they are solemn in their risk analysis. I have heard that they have announced that it will happen within 50 years but I don't believe in it. It might be some smaller rock falls but never one gigantic block of rock falling… It just doesn't work that way*». It seems reasonable to say that many people have developed a subjective immunity towards Åkneset and that many also hold a «healthy» skepticism towards the experts. Because there will be huge socio-economic consequences if the risk scenarios becomes real, people tend to underestimate the risk at Åkneset. To believe that the disaster will not affect them is a rationalization of their choice to stay and live in the region. It is also a way to create optimism and hope for the future. The fact that large firms dare to invest in the region, has also a positive signal effect on people's risk perception. *«When they dare to invest, it can't be that dangerous for us to stay either…?!»*.

The tendency toward using different coping strategies is highly influenced by peoples love for the place and their decision about creating a meaningful life for themselves and the next generations. Their risk perceptions are largely managed and formed by prevailing ideas about local risk knowledge, risk exposure and moral beliefs about being a «stayer». Moreover, people's perceptions of risk are related to their trust in warning and their relationship with the experts and the EWS. The latter will now be discussed in more detail.

- Facilitating trust in technology and experts

Local peoples risk perceptions are closely related to people's trust in the EWS, or more precisely their trust in the experts and the technology used to monitor the risk. While the locals were rather sceptical to the experts in the 80s and 90s, there is a more positive attitude towards science and technology today. With the establishment of the Centre at Stranda there has grown optimism among the residents. It is pointed out that the Centre uses high-tech equipment and that scientist from all over the world comes to «little Stranda» to see and learn about early warning. One of my informants, for instance, said that: *«Today, we live in the world's safest fjord. The EWS is so sensitive that it even captures a weasel yawn»*. Another expressed herself as follows: *«A life without the Early-Warning Centre is devise. It is just not possible! I feel I have become dependent on the Centre and the safety and confidence it gives me»*.

However, huge investments in modern technology are not alone the reason why the public opinion has changed. In Storfjorden, the success can be attributed to quick action from the local government as well as the expert's ability to take people's risk perceptions seriously. From the very start in 2005, when the Åknes/Tafjord project was established and news Medias hunted sensations about Åkneset, local people were informed about the process of having Åkneset monitored. An open and inclusive dialog took place between the authorities, the experts and the public. In order to ensure participating processes, public meetings were held in different communities in Storfjorden. Furthermore, when the Åknes Early-Warning Centre started to test the alarm system it was established a two-way risk communication between the Centre and the public. Testing the EWS representatives at different workplaces were asked to give feedback on its functionality. The knowledge exchange that took place in these dialog meetings were most important as people felt more included in the management process and also got the feeling that their input and experiences were valuable in developing an effective EWS. I believe we can assume that trusting relationships have been achieved because local authorities and experts have open up for more dialog, participating processes and co-operation.

Another element that has been most important for people’s ability to facilitate trust in the system, is that fact that the Centre is located in the region. Being locally established means that one allows for closer relations to develop. From the interviews, it appears that the many different formal meetings with the experts are important in terms of trust-building. For example, at least one person from each family has been attending the public meetings. In Hellesylt and Geiranger, parents have also established a good relationship to the manager, Kjell Jogerud, as he has participated in several parents' evenings at the school. Others have taken part at lectures and guided tours at the Centre. All these face-to-face meetings have facilitated trusting relationships between the residents and the experts at the Centre.

Likewise, it appears that locals cite the informal meetings as important for their confidence in the experts. A common comment is that because *«they know them»*, and «*they live and act in the community like other people*» it is easier to make contact and trust them. The informal meetings taking place at the corner shop, at leisure activities or at school arrangement as they have children the same age, are important social arenas for knowledge exchange and trust building. As the experts are living with the same risk as the residents more equal relations have been developed. The gap between the experts and the residents has been successfully reduced.

A last aspect that was highlighted as important by the residents was that it was someone from the local community working at the Centre. To have someone with local knowledge, experience and interests on the inside was seen as extra reassuring that everything was done to secure peoples safety. Jarle Hole, one of the geologists, was described as «*their man*» at the

Centre. He was a person they trusted and who was easy to talk with. They believed him when he said that they had control of the situation.
In the Storfjorden region there has been an open and including dialog about the implementation of EWS. People's risk perception has been largely reduced as they have come to know the criteria for monitoring and warning. Likewise, they have learned to cope with Åkneset as they have come to know the experts and the monitoring technology better. By ensuring local risk management and formal and informal meetings in the local environment, one has managed to generate good contact and a trust-building atmosphere between the experts and the public. Because locals are involved in the activity at the Centre, residents and experts interact in more equal, face-to-face relations. For this reason, the social expert Linda Bye believes that a successful implementation of EWS is based on ideas about good risk communication, openness and involvement. Local people need to be included and to be heard.

- Sirens, alarms and evacuation drills

During recent years it has been conducted two tests of the siren and alarm system in the Storfjord region. In addition, the police has conducted an emergency exercise in Geiranger, which included physical evacuation of all persons in the run-up heights. Most people living in the region believe it is essential to carry out such tests and to have evacuation drills. When the EWS is tested out it provides answers to whether the system works or not. Generally, one can say that people are positive to the implementation of notified drills as it helps people to increase confidence in the system. However, many stated that they were sceptical to full-scale evacuations as they believed it would be too much for the elderly and sick. One interviewed couple for example was rather sceptical about having more evacuation drills at school. They were worried that alarms and evacuation drills could increase children’s feeling of risk. Most parents, however, had experienced that young children were more excited than frightened by sirens, alarms and evacuation trainings. They argued that it was important for new pupils, to be familiar with the arrangements and procedures in an emergency situation. Only by regular drills and tests people could feel safe. Annual exercises, it was argued, would be less traumatic for the children, than having them more seldom. It would only been seen as «the yearly dill», something that was normal.
Some of the interviewed locals said that they would like to have a new alarm and evacuation drill in Geiranger to see that everything was going smooth. The national drill, called TYR, was primarily seen as a paper exercise for police and legal authorities. This was, of course, very important as it revealed some weaknesses in both the alarm system and the evacuation plan, but several would like to repeat it just to make sure that everything was fine. In general, they believed that this would not upset the population, but rather give them a confirmation that everything would work the day it was needed.
The seniors, in particular, said that they were afraid that hearing loss would cause problems. Some had not heard the alarms last time and they would like to know if this problem was solved. Struggling with poor health and mobility, some were also concerned that they would not receive the alarm on time to get help. Because the elderly, weak and disabled will need additional time and assistance to get away from the flood wave, it is reasonable to find increasing risk perceptions in this group. Therefore, when choosing risk management strategies, risk managers have to think about the rich diversity of people that need to be dealt with. The risk perceptions will always vary within a population and some groups are more vulnerable than others.

- False alarms and close-calls

One can assume that landslide risk perceptions can be greatly increased by a false alarm. Most of the informants think it is difficult to imagine how one would react to a false alarm, but in principle they believe that there must be a good explanation why the alarm was triggered. A false alarm will have to indicate that something is going on in the mountain. In next turn it will be for the experts to explain why the alarm was triggered and why it is safe to return again.

People's first response to a question about having a false alarm was often that it would give them a clear answer whether the evacuation had been successful or not. However, a false alarm will naturally also question the warning procedures and the reliability of the system. A clear message to the experts was that they could not have a system with repeated alarms. One respondent said that: «*We must not get in a situation where the system loses its credibility. By all means we have to avoid a situation with many false alarms. I think we must accept that there will be a false alarm and that we are told that the situation has calmed down and that it is safe to return, but it is serious if people start to think that the Centre is not in control of the situation anymore*».

Apparently, most people think it is better to press the button once too often, than once too few. But when people experience a false alarm, they will most likely feel more vulnerable and start to look for explanations as well as alternatives. A false alarm is a sign that something is happening to the mountain, and even though it can be explained and the situation becomes stable again, it has trigged a new uncertainty in people's head that can be difficult to cope with. One can assume that the good relationship that has been developed between the experts and the public can be severely damaged if the alarm goes off too often. If the locals experience several false alarms they will probably begin to question the systems functionality and be more skeptical towards the technology used to monitor the risk. Many error notifications in a row can also cause people to get a little colder and more calculating when the sirens starts. In worst case, you can get a situation where people do not react to the alarm anymore because they think they are only crying wolf.

A false alarm will have major socio-economic consequences, both for the individuals, the communities, and the investors. All production will stop, and because of the uncertainty it creates, you will most certainly see that people hesitate to go into new projects. The food article industry together with the furniture industry will be hard hit because the factories are located in the run-up heights. If the production stop is prolonged by weeks and months, they could risk losing market share. Those working at the factories would get a lay-off notice and will have to find work in other places. Geiranger as a tourist destination will most certainly also experience a substantial decline. Tourist operators will be more restrictive and look for other destinations. In this situation many families will probably have to start to look for a new place to live due to the fact that they have no job or income. However, a false alarm will most certainly have major consequences for the housing market. Because more people will like to live in safer areas and have more predictability in their lives, one can assume that there will be a drop in the house prices in the most vulnerable places, and an increase in value of those houses that are placed in safer areas. Moving to a new place can be very costly and it is not for sure that everyone can afford it.

As long as the people in the Storfjord region have not experienced any close calls, the majority cope well with the situation. However, the day things change the situation will be quite different. One woman said that if the risk level should increase, a new phase would start in her head. She believed that if it came to any close calls and the authorities decided to close the city-centre, she would become more anxious again. «*Today*, she said, *it can be weeks or months between each time I think about Åkneset, but if the situation changes I will probably face a choice to continue living in Hellesylt or move to another place*». At time being people feel that there is no reason to speculate and worry about Åkneset. They have an operative EWS with no black marks and as long as the risk level is characterised as low, life will go on as usual. At time being Åkneset is described as a utopia, something that is difficult to imagine and relate to. It is a thing of the future and something people do not need to worry about as long as they have an EWS in the region.

- Financial strains and uncertainty

When it comes to the issue of future financing of the Centre, people hope that the authorities soon find a good and stable solution to the problem. People's optimism and willingness to invest time and money in the region rest on an operative Centre in Storfjorden. The clear message to the authorities is that: «*The people are now starting to feel very safe and it is not a good idea to begin to play with the idea to downsize the Centre. Health and safety should be the aim, and it is our hope that the government will go for a full service at the Centre and make it a national assignment. Without the Centre, we cannot continue to build and live in the fjord. Then there is just not possible to live here. We must know that we can plan our lives and for the future because we cannot go and expect the rock fall either ... we must develop the region to have a livelihood*».
People's engagement indicates that the financial strains and questions about cuts in the community budget have a negative impact on peoples risk perceptions as it creates uncertainty about the future. Some interviewed people said that they will not accept any cuts in current service. An operative EWS is essential for their decisions about staying and living in the region, and they believe that the EWS should be a governmental affair. Since 2004, the government has allocated NOK 124 million to build up the Centre of Stranda. In addition, each of the 6 affected municipalities has invested millions to operate the EWS. Today, it costs approximately NOK 20 million a year to run the business. Because the Centre has technology and knowledge that can be used to other places, and it also has been very costly to establish a Centre in Stranda, people in the region think it should be a national Centre for monitoring. The knowledge and expertise available at the Centre is not only helpful for those who live and work in the region, it can also benefit the whole country if it becomes a State owned Centre. Norway is a long stretched country with a lot of landslide prone regions, and a national Centre for rock fall monitoring and warning can help to reduce people's perceptions of landslide risk elsewhere.
Since the establishment of the EWS, people are more optimistic about the future. Once again investors and entrepreneurs are laying their eyes on Storfjorden. At present residents' «only» worry is that the local municipalities cannot afford the cost an operative system in the region. Establishing a national Centre for rock fall monitoring can be the answer to this uncertainty. Now is time to make a decision about future operations.

e) Concluding remarks and recommendations

In order to help risk managers and others to make informed choices about how to implement an EWS, it is important to understand the relationship between risk perception and risk communication. The main argument put forward in this report is that openness, involvement and good communication with the residents at an early stage has a positive effect on people’s perceived risk. As most people are better able to cope with the idea of risk when they understand the criteria for monitoring, warning and evacuation, it is important to focus on education and learning. By triggering people's curiosity and desire to learn more about early warning and inviting them to engage and participate in the discussion, people’s risk perceptions are likely to decrease because they are better informed about landslide risk management. Having an open and inclusive dialog about high-risk objects most people also are less skeptical towards the experts and the implementation of new technology.

Another important lesson learned is that the experts should be visible and participating in the local environment. Working and living in the affected communities means that experts and residents meet more regular and that they share the same interests and worries about the risk. By facilitating more equal, face-to-face relationships with the residents, it is possible to reduce the gap between the experts and the residents, and establish knowledge exchange and trusting relationships. When the residents learn to know the experts and the technology used to monitor the risk, peoples risk perceptions decrease. Having local experts involved in early warning and decision-making, is also something that fosters trust and trust building. A local expert is not only regarded as someone with local knowledge and interests but also someone that can pass on messages and worries to those higher up in the system. Thus, implementing an effective EWS it is important to think about localness as well as local participation.

In order to secure that people’s feelings of risk are controlled, it is important to have a good media strategy. It is essential to get information out to the people and to follow up the case in the local news. The information shared should be consistent and also repeated frequently through different media and networks. Moreover, risk information should be communicated by different sources such as local authorities, geologists, technical experts and engineers. By all means, good risk communication requires that the experts are available for questions, that they have the capacity to communicate with different groups of people, and that they can talk about complicated issues and phenomena in non-technical terms. Arranging public meetings is a good way to communicate with the residents.

Further, implementing an effective EWS, it should be noticed that announced and regular testing of the alarm system is something that can be recommended because it is something that gives residents a feeling of control and security in daily life. In Storfjorden most people agree to tests and evacuation drills as they provide an answer to whether the alarm system and evacuation plan work as intended. A false alarm, however, will most certainly have a negative effect on how people perceive risk. If it happens several times, it can lead to loss of confidence in technology and expert knowledge.

When implementing an EWS it is also important to provide long-term funding to secure that residents feel safe. Establishing a National Centre for Rock Fall Monitoring can be an answer to resident’s worries about the future and peoples willingness to invest time and money in the region. Offering a stable and operative EWS is regarded as an important premise for future settlement and development. Without it, peoples risk perceptions will most certainly increase. Trust in the experts and the technology used to monitor and warn people about a specific risk are, in other words, key to a successful implementation of EWS.

Appendix B2 Slovenia

Author: S. Kumelj

In Slovenia, the monitoring, notification and warning system is comprised of:

- a monitoring network
- several notification centres
- a computer support and telecommunications service

Notification Centres play a pivotal role in the operation of this system. There are 13 regional notification centres and 1 National Notification Centre in Slovenia. The National Notification Centre is mainly responsible for the operation of the information system, while regional centres, in addition to collecting data and responding to emergency 112 calls, are in charge of dispatches for fire-fighting, emergency medical aid, the mountain rescue service, the cave rescue service, the underwater rescue service, Civil Protection and other rescue services.

The emergency call number 112 has been used since the beginning of 1997 in Slovenia. This number can be used by citizens in an emergency or if they need a fire brigade, emergency first aid or aid from any other rescues services. In addition, by dialling this number, people can obtain other important information on weather, water, snow and other conditions, disturbances and interruptions in the supply of potable water and electrical and other energy sources and other areas of life importance.

At the beginning of 1997 new public alarm signals for use in the event of the risk of a natural or other disaster came into effect. In addition to warning, immediate danger and cessation of danger signals, two additional alarm signals were introduced in particular areas to warn of the risk of a chlorine leak and of flooding resulting from the collapse of hydroelectric dams. When sounding these alarms, the notification centre responsible must inform the public via radio and television of the purpose of the signal and the appropriate response to it.

a) Communications systems

A uniform and autonomous system of operational radio communication (ZARE) and personal calls (pagers) was put in place by the administration of protection, rescue and relief operations. ZARE is used by all rescue services. The communication centres of this system are located in regional information centres and are used to connect users to public and other telecommunication systems. The ZARE system guarantees 95% coverage of the territory by radio signal from a stationary network, and complete territorial coverage by means of mobile repeaters (Figure 52).

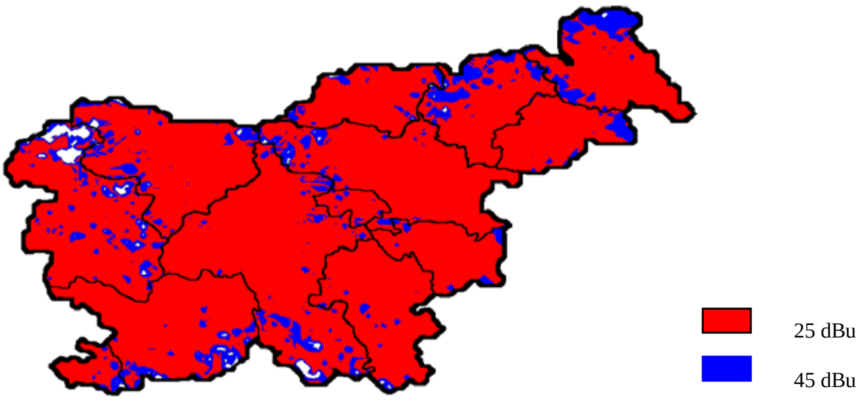


Figure 52: ZARE radio coverage

The ZARE radio communication system operates in the VHF range. There are 32 semi-duplex channels available for over 40 upper transmission layer repeaters and 36 simplex channels for direct connections. The pagers system consists of 40 upper layer transmitters and 50 lower layer transmitters. The ZARE system provides adequate protection against disturbance (sub-tone) and abuse (ID code). The Administration for Civil Protection and Disaster Relief of the Republic of Slovenia plans a gradual transition to a new beam radio communication system after 2010.

b) Computer network and information support

All 13 regional notification centres and the Education and Training Centre of the RS Administration for Civil Protection and Disaster Relief are integrated into one network through a computer network serving the needs of the centres so they can ensure protection against natural and other disasters. For major connections, leased virtual transmission ways via the Internet are used, which allow for a smooth increase in transmission speed on an as needed basis. Information support is provided through tailor made computer applications in the regional notification centres, such as the Geographic Information System (GIS-Ujme), the sound alarm management and triggering system (DUNJA), the system for the acceptance of telephone calls (ROK), the radio traffic control system (KC08), the radio network control system (Nadzor ZARE) and the pager system (ZAPP). All the systems are linked into a uniform application used for the management of interventions (SPU112). There are also web applications available in the computer network, such as GIS and hazardous materials.

c) Decision making processes

Source: *REPUBLIC OF SLOVENIA NATIONAL REPORT AND INFORMATION ON DISASTER REDUCTION for the World Conference on Disaster Reduction (Kobe-Hyogo, Japan, 18-22 January 2005) Prepared by: Administration for Civil Protection and Disaster Relief, Ministry of Defence of the Republic of Slovenia, June 2004*

Disaster management system is one of the three pillars of the Republic of Slovenia national-security system that also encompasses protection, rescue and relief activities. The aim of the system is to reduce the number of disasters and to reduce the number of casualties and other consequences of such disasters. The annual tax that Slovenia pays due to natural and other disasters amounts to more than 2 % GDP on average.

The fundamental tasks of the disaster management system, including the protection of people, animals, property, cultural heritage and environment, are the following: prevention, alertness, protection against risks, rescue and relief operations during disasters, provision of basic living conditions after disasters and reconstruction measures. The system includes the whole range of activities carried out on the national and local levels. On the national level, prevention and reconstruction measures are carried out by competent ministries in their respective sectors, while the activities are coordinated by the government.

- Stakeholders and responsibilities

The system of protection against natural and other disasters is based on the obligation of the state and municipalities to prevent and eliminate dangers and to implement prompt measures in the event of a disaster. It is also based on the obligations of commercial companies, institutions and other organisations that, within the scope of their activities, are responsible for implementing emergency measures relating to the protection and rescue of people and property, and of individuals for the protection of themselves and their property. The system is activated in the event of accident according to the principle of graduallity.

The state and municipalities are responsible for organising protection against natural and other disasters as a uniform and integral national system. The state is mainly responsible for regulating the system, planning development and research activities, organising monitoring, information, alarm and communications systems, development of threat assessments and national emergency response plans, organising and preparing national units for protection, rescue and relief, and adopting education and training programmes for these units. The municipalities are responsible mainly for the monitoring of possible threat, informing the population, implementing protective measures, developing personal and community protection and organising and training municipal units for protection, rescue and relief. The municipalities also organise and conduct protection, rescue, relief and recovery activities in their respective areas.

Commercial companies, institutions and other organisations must provide conditions that make it feasible to provide personal and group protection for their workers and implement the protective measures required in their place of work. They must provide suitable protection and rescue equipment for this purpose at their own expense. Commercial companies, institutions and other organisations whose work process involves the use, production, transportation or storage of hazardous substances, petroleum and petroleum derivatives or fuel gases, and which perform activities or are in charge of work equipment which pose the risk that an accident or disaster might occur, must also draw up risk assessment and protection and rescue plans, organise their own protection, rescue and relief units, provide information and alarm systems for their workers and the local population in the event of an accident, and co-finance part of security preparations in the municipality in which they operate, in direct proportion to the extent and level of the hazards caused by their activities.

Any individual or organisation who intentionally or through extreme negligence causes an event or disaster which incurs costs because of emergency measures taken must cover the costs of intervention, rehabilitation and the restoration of conditions which existed prior to the disaster, and must pay compensation for damages suffered by other individuals or organisations.

- Management and administration

The National Assembly lays down the basic guidelines for organising and implementing protection against natural and other disasters at the national level, adopts the national programme of protection against natural and other disasters and supervises its implementation, and secures funds for the reparation of the effects of major natural disasters.

The government (Figure 53) guides and co-ordinates the organisation, preparation and implementation of protection against natural and other disasters at the national level, adopts the annual plan of protection against natural and other disasters and national protection and rescue plans, manages the protection, rescue and relief and reparation of the effects of major natural and other disasters, and regulates international disaster relief. The government also guides and co-ordinates the operations of the Ministries responsible for the implementation of measures and the prevention of natural and other disasters and their consequences, along with states of readiness and the adoption of measures in the areas under their jurisdiction.

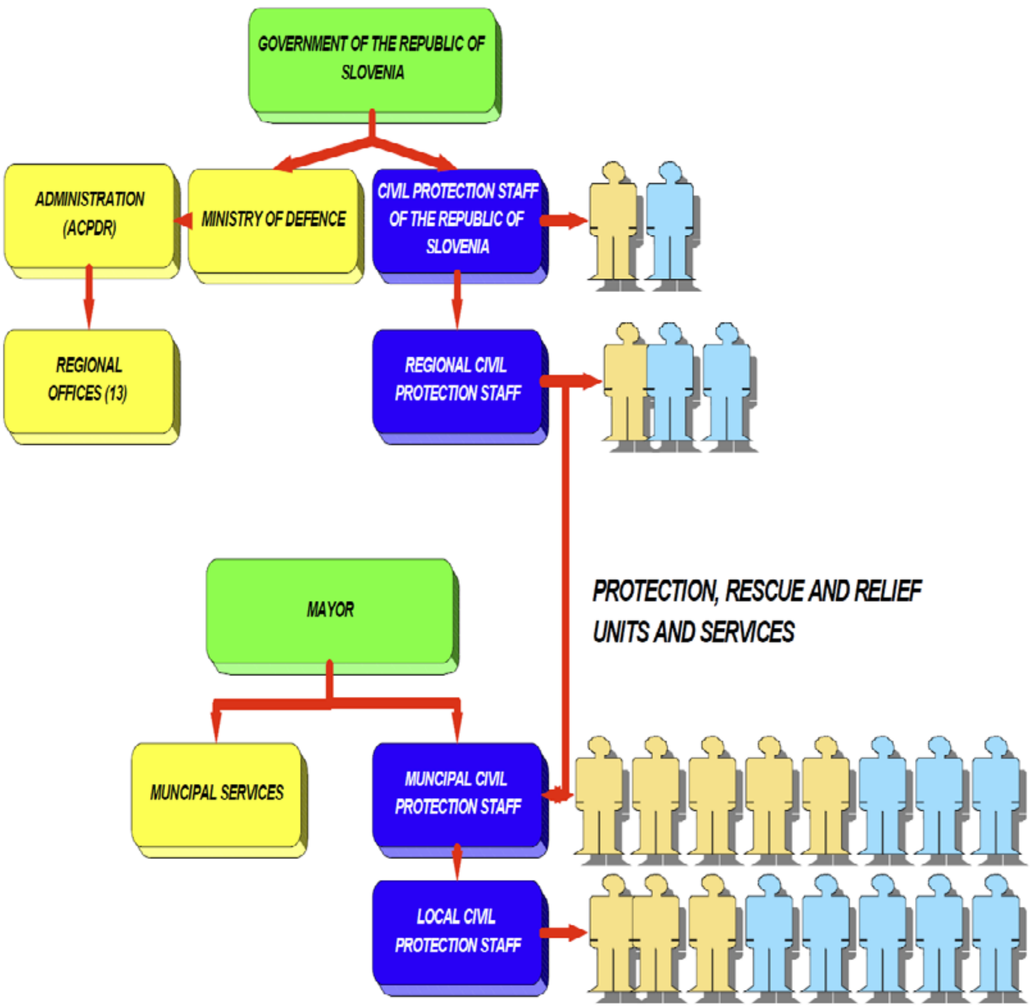


Figure 53: Administration of protection system against natural and other disaster in Slovenia.

Operational management of civil and other protection, rescue and relief forces is organised and carried out as a uniform national system. It is carried out by Civil Protection commanders, headquarters and heads of intervention and rescue units.

The municipalities operate and manage the system of protection against natural and other disasters independently in their areas. Professional protection, rescue and relief tasks are carried out by the municipal administration.

Administrative and specific expert tasks related to protection against natural and other disasters are carried out by the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief (multi-sectoral and coordinating body), which is a constituent body of the Ministry of Defence. It is charged with the following tasks:
- elaboration of proposals of research and development projects relating to the protection against natural and other disasters;
- elaboration of the proposal of the national programme and plan of protection against natural and other disasters;
- providing for the organization and operation of the monitoring, notification and warning system;
- elaboration of threat assessments and other technical documents for the planning of protection, rescue and relief and directing and coordinating of measures for the prevention and mitigation of consequences of natural and other disasters;
- monitoring and announcing of danger of natural and other disasters and giving instructions for handling;
- elaboration of national emergency response plans in co-operation with ministries and governmental services;
- organization, equipment and training of national Civil Protection units and services and other protection, rescue and relief forces and provision of conditions for the work of the commander, the Headquarters of the Civil Protection of the Republic of Slovenia and the national and regional damage assessment committee;
- monitoring and co-ordination of the organization of the Civil Protection and other protection, rescue and relief forces;
- elaboration of programmes as well as organization and delivery of education and training for protection, rescue and relief;
- creation and maintenance of national material reserves for the case of natural and other disasters.

- Economical constraints

Protection against natural and other disasters is financed by the national and municipal budgets and insurance and other funds contributed by commercial companies, institutions and other organisations. Every year the Republic of Slovenia allocates approximately 0.5% of the national budget for protection against natural and other disasters, and municipalities earmark 3% of their annual municipal budgets.

Regular activities of the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief are financed by the national budget of the Republic of Slovenia. Programmes for assistance and activities in cases of major disasters are financed in accordance with the resolutions and intervention laws, which are adopted by the Government of the Republic of Slovenia in the event of disasters. Interventions in the case of minor accidents are financed through regular resources of the system.

As a measure to reduce the impact of disasters, there are only few financial instruments utilised. Slovene insurance companies insure against earthquakes, fires, hail, floods and frost, but not against landslides. Act on the Recovery from the Consequences of Natural Disasters was adopted last year and also the Decree on common methodology for threat assessment in natural disasters is in practice.

- Legislation

New legislation adopted after 1992 separated the system of protection against natural and other disasters from the defence system in order to organise it as an integral interdisciplinary activity based on common goals and principles, and to merge all rescue services and other protection, rescue and relief forces into an organisationally and functionally unified system. Formally and legally prevention has became the fundamental guideline and major task of this system with implementation being carried out mainly within local communities. The basic tasks of the system of protection against natural and other disasters are:

- prevention,
- preparedness,
- protection against threats,
- rescue and relief,
- providing of basic conditions for life,
- recovery.

The most important law, governing the area of protection against natural and other disasters in the Act on Protection Against Natural and Other Disasters (Official Gazette of the Republic of Slovenia, 64/94) and additional special laws govern the areas of fire protection, fire-fighting and protection against drowning, but there is no special law governing the areas of landslide protection. Prevention is as a rule defined by the legislation of the field. All forms of protection, rescue and relief are carried out in accordance with the principles of international humanitarian law and the international law concerning the protection of people, animals, the cultural heritage and the environment against the harmful effects of natural and man-made disasters and international obligations that have been taken on by Slovenia. In addition, it provides the assurance that all of these activities are of humanitarian and non-military nature and that all of the available protection, rescue and relief resources can be used in the implementation of other forms of the humanitarian operations.

In 2001 the Resolution on the National Security Strategy of the Republic of Slovenia was adopted (Official Gazette of the Republic of Slovenia, 56/2001). On the basis of the Resolution the National Programme of Protection against Natural and Other Disasters for the period 2002 – 2007 was adopted (Official Gazette of the Republic of Slovenia, 44/2002). The National Programme is orientated in prevention and its basic aim is to reduce the number of accidents and to prevent or alleviate its consequences.

The priorities of each year are defined in years Programmes which are in accordance with a five-year plan. Finally, on the basis of previously mentioned documents the Doctrine on Protection, Rescue and Relief was adopted (Official Gazette of the Republic of Slovenia, 64/94, 33/00, and 87/01). The Doctrine is a document which is comprised of common principles and views concerning professional and operational guidance, organisation, and conduct of protection, rescue and relief efforts in the event of natural and other disasters.

The control over the implementation of laws governing the area of protection against disasters is executed by the constituent body of the Ministry of Defence – the Inspectorate of the Republic of Slovenia for Protection against Natural and Other Disasters and its branch offices.

d) Research and development linked to disaster reduction

Research and development efforts (R&D) follow the basic aim of protection against natural and other disasters, which is to reduce the number of disasters and to mitigate the consequences. Therefore, R&D is oriented towards the research of causes, types and consequences of disasters, and in obtaining results gathered through the analyses of legal, economic, social, and psychological and other aspects of disasters. These results help answer questions related to the potential consequences of disasters and to the responsive measures taken. In this way, it is possible to keep abreast of the situation in all areas, follow new trends as much as possible, transfer new findings transnational, promote the development of new methods and models and attain the subject-matter documents necessary for good work. The R&D effort is focused on:

- monitoring, notifying and alarming,
- preventing and reducing disasters and their consequences,
- preparedness for protection and rescue,
- recovery and reconstruction after disasters.

The area of protection against natural and other disasters is an interdisciplinary area. The majority of work is accomplished in the following areas: civil engineering, chemistry and chemical technology, water resources management, forestry, geology, health, public relations, fire engineering, computer science, information systems, psychology and insurance companies. It was established that R&D and cooperation with research institutions were necessary in order to maintain the sound development of a system of protection against natural and other disasters in Slovenia.

Protection and rescue plans are drawn up by state bodies, local communities, commercial companies and other organisations (Table 14). The plans are drawn up in accordance with the Decree on Content and Drawing up of the Plans for Protection and Rescue. On all levels the plans must be drawn up and adopted by the relevant bodies responsible. The adopted protection and rescue plans have to be presented in public, particularly to threatened people and to other publics with a vested interest. National protection and rescue plans are drawn up by the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief in co-operation with the ministries and other national bodies. On the national level protection and rescue plans for the potential large-scale disasters are drawn up that could affect several communities or regions. Plans are drawn up based on the information on risk assessments, analysis of vulnerability and research.

Table 14: Level of planning of protection and rescue plans for selected threats.

Threat, disaster	Level of planning			
	Company	Local	Regional	National
Earthquake		X	X	X
Flood		X	X	X
Fire		X	X	X
Landslides and avalanches		X	X	
Heavy snow		X	X	