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D101.1 Inventory of tools for natural hazard risk assessment

Work Package 303: Multi-Hazard atlas and Risk Analyzer
Partner: ITC

Author:
Cees van Westen

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CIRCULATION LIST

Name	Institution
Florence Beroud	EC/REA
…	

CONTRIBUTORS LIST

Name	Institution
Cees van Westen	UT/ITC
Haydar Hussin	UT/ITC
Mohammad Patwary	WUR/UT/ITC

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Date	Name	Institution	Role in project
	Stefan Jaeger	Geomer	Contributor to WP302
	Steve Kass	Geoville	Contributor to WP302
	Marc Mueller	SISA	Lead WP 101
	Marc Mueller	SISA	Project coordinator
		EC/REA	…

ACRONYMS

EC	European Commission
REA	Research Executive Agency
UT/ITC	University of Twente, Faculty ITC

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1. Executive Summary

The aim of this deliverable is to give an overview of the available tools for loss estimation of natural hazards, focussing on the publicly available tools, and analyze their applicability in a European context. Loss estimation has been carried out in the insurance sector since the late 1980's using geographic information systems. Since the end of the 1980's risk modelling has been developed by private companies resulting in a range of proprietary software models for catastrophe modelling for different types of hazards. Unfortunately these are not publicly available, which is a major obstacle to the development of risk assessment for many parts of the world by government organizations. The best initiative for publicly available loss estimation thus far has been HAZUS developed by the Federal Emergency Management Agency (FEMA) together with the National Institute of Building Sciences. The first version of HAZUS was released in 1997 with a seismic loss estimation focus, and was extended to multi-hazard losses in 2004, incorporating also losses from floods and windstorms. HAZUS was developed as a software tool under ArcGIS. Several other countries have adapted the HAZUS methodology to their own situation. The HAZUS methodology has also been the basis for the development of several other software tools for loss estimation. One of these is called SELENA.

Another interesting development has been going on in the development of standalone software modules for multi-hazard risk assessment, which are not running as a component of an existing GIS. A good example of this is the CAPRA Probabilistic Risk Assessment Program supported by the World Bank. The methodology focuses on the development of probabilistic hazard assessment modules, for earthquakes, hurricanes, extreme rainfall, and volcanic hazards, and the hazards triggered by them, such as flooding, windstorms, landslides and tsunamis. Another recent development is towards Open Source web-based modules for multi-hazard risk assessment. A tool which is currently under development as part of the Global Earthquake Initiative (GEM), called OpenQuake, is most probably going to be the standard for earthquake loss estimation, as there are also plans to expand it into a multi-hazard risk assessment tool. Apart from the above mentioned tools, this deliverable gives an overview of a larger number of tools. It is remarkable that there are many more tools for earthquake loss estimation as compared to other hazards. This deliverable forms the basis for the development of the web-based risk atlas and risk analyzer, or the Spatial Decision Support System for risk assessment and the evaluation of risk reduction alternatives, which will be developed within WP 303 of the INCREO project, and simultaneously in the Marie Curie FP7 CHANGES project.

2. Introduction

Risk can be described in its simplest way as the probability of losses. The classical expression for calculating risk (R) was proposed by Varnes (1984) considered risk as the multiplication of H (Hazard probability), E (the quantification of the exposed elements at risk, and V (the vulnerability of the exposed elements at risk as the degree of loss caused by a certain intensity of the hazard).

Hazard and risk assessment requires a number of steps which are illustrated in Figure 1, based on Van Westen et al. (2008). The figure gives the framework of multi-hazard risk assessment with an indication of the various components (A to I).

The first component (A) deals with the input data required for a multi-hazard risk assessment, with the data needed to generate susceptibility maps for initiation and runout of hazardous events, for the analysis of the triggering factors, multi-temporal inventories and elements at risk (Van Westen et al., 2008). Several of the maps indicated in section (A) need to be collected over a period of time (e.g. land use changes, population changes, and slope hydrology).

The second component (B) in Figure 1 focuses on the susceptibility assessment. A susceptibility map shows the subdivision of the terrain in zones that have a different likelihood that hazards may occur. The likelihood may be indicated either qualitatively (as high, moderate low, and not susceptible) or quantitatively (e.g. as the density in number per square kilometres, area affected per square kilometre, Safety Factor, height or velocity of runout).

The third component (C) in Figure 1 deals with hazard assessment, which requires information on temporal, spatial and intensity probabilities. The analysis of these probabilities is very different for different hazard types. For example, in the case of flood hazard assessment, flood inundation scenarios are generated for flood discharges that are related to a specific return period, which can be analyzed using magnitude/frequency analysis of historical discharge data. The resulting flood scenarios already indicate the areas that are likely to be flooded (hence the spatial probability of flooding in these areas is 1), and the intensity of flooding (in terms of water depth, flow velocity or impact pressure).

The fourth component (D) in Figure 1 focuses on the exposure analysis. The aim of an exposure analysis is to analyze the number of elements at risk that are spatially overlapping with a certain hazard scenario. In the case of flooding, the individual flood extend maps for different return periods can be spatially combined in GIS with the footprints of the elements at risk (e.g. buildings) to calculate the number of buildings affected during that specific scenario. In the case of landslides the hazard map, which has basically the same spatial units as the susceptibility map, is spatially combined with the elements at risk. Here the spatial probability that within a certain hazard class a landslide will occur needs to be included in the analysis, leading to a much higher degree of uncertainty then in the case of flood risk assessment. Exposure analysis of physical objects can be carried out by counting the number of elements at risk exposed (e.g. number of buildings), or by expressing them in monetary values (e.g. replacement costs).

Component (E) in Figure 1 refers to the vulnerability assessment and indicates the degree of loss to elements at risk caused by a specific hazard event with a given intensity. For analyzing the physical vulnerability various types of approaches can be used, that can be either quantitative or qualitative, and based on heuristic, empirical or analytical methods. In the case of flooding or earthquakes, vulnerability curves are available that link the flood intensity (water height, velocity or impact pressure) or earthquake acceleration to the degree of damage for different elements at risk. For other hazard types (e.g. landslides) the focus in vulnerability assessment is mostly on the use of expert opinion in defining vulnerability classes, and the application of simplified vulnerability curves or vulnerability matrices. In many situation, when there is not enough information to specify the expected intensity levels of the hazard, or when there is not enough information available to determine vulnerability classes, vulnerability is simply given a value of 1 (completely destroyed). Other types of vulnerability (e.g. social, environmental, and economic) are mostly analyzed using a Spatial Multi-Criteria Evaluation, as part of a qualitative risk assessment.

Component (F) in Figure 1 outlines the concept of direct risk assessment of physical objects which integrates the hazard, exposure and vulnerability components. For each hazard scenario with a given temporal probability the losses or consequences are calculated by multiplying the vulnerability and the amount of exposed elements at risk. The results is a list of specific risk scenarios, each one with its annual probability of occurrence and associated losses (V*A). The specific risk is calculated for many different situations, related to hazard type, return period and type of element at risk. Given the large uncertainty involved in many of the components of the hazard and vulnerability assessment, it is best to indicate the losses as minimum, average and maximum values for a given temporal probability.

Risk assessment can be carried out using either qualitative (H) or quantitative approaches (G).

Qualitative methods for risk assessment are useful as an initial screening process to identify hazards and risks. They are also used when the assumed level of risk does not justify the time and effort of collecting the vast amount of data needed for a quantitative risk assessment, and where the possibility of obtaining numerical data is limited.

The simplest form of qualitative-risk analysis is to combine hazard maps with elements-at-risk maps in GIS, using a simple-risk matrix in which the classes are qualitatively defined (AGS, 2000). This method is widely applied, mostly at (inter)national or provincial scales where the quantitative variables are not available or they need to be generalized. Qualitative approaches consider a number of factors that have an influence on the risk. The approaches are mostly based on the development of so-called risk indices, and on the use of spatial multi- criteria evaluation. One of the first attempts to develop global-risk indicators was done through the Hotspots project (Dilley et al., 2005). In a report for the Inter-American Development Bank, Cardona (2005) proposed different sets of complex indicators for benchmarking countries in different periods (e.g., from 1980 to 2000) and to make cross-national comparisons. Four components or composite indicators reflect the principal elements that represent vulnerability and show the advances of different countries in risk management: 1) Disaster Deficit Index (DDI); 2) Local Disaster Index (LDI); 3) Prevalent Vulnerability Index (PVI); and 4) Risk Management Index (RMI). Each composite index is generated on the basis of a number of indicators. For instance, the DDI can be considered as an indicator of a country's economic vulnerability to disaster. The method has been applied thus far only in Latin America and the Caribbean. Peduzzi et al. (2005, 2009) have developed global indicators, not on the basis of administrative units, but based on gridded maps. The Disaster Risk Index (DRI) (UN-ISDR, 2005b) combines both the total number and the percentage of killed people per country in large- and medium-scale disasters associated with droughts, floods, cyclones and earthquakes based on data from 1980 to 2000. In the DRI, countries are indexed for each hazard type according to their degree of physical exposure, their degree of relative vulnerability, and their degree of risk.

At local scales, risk indices are also used, often in combination with spatial multi-criteria evaluation (SMCE). Castellanos and Van Westen (2007) present an example of the use of SMCE for the generation of a landslide-risk index for the country of Cuba, generated by combining a hazard index and a vulnerability index. The hazard index is computed using indicator maps related to event triggering factors (earthquakes and rainfall) and environmental factors. The vulnerability index was made using five key indicators including housing condition and transportation (physical-vulnerability indicators), population (social-vulnerability indicator), production (economic-vulnerability indicator) and protected areas (environmental-vulnerability indicator). The indicators were based on polygons related to political-administrative areas, which are mostly at municipal level. Each indicator was processed, analysed and standardized according to its contribution to hazard and vulnerability. The indicators were weighted using direct, pair-wise comparison and rank-ordering weighting methods, and weights were combined to obtain the final landslide risk-index map. The results were analysed per physiographic region and administrative units at provincial and municipal levels. Another example at the local level is presented by Villagrán de León (2006), that incorporates 3 dimensions of vulnerability, the scale/level (from human being to national level), the various sectors of society, and 6 components of vulnerability. The method uses matrices to calculate a vulnerability index, which was grouped in qualitative classes (high, medium and low).

Quantitative approaches aim at expressing the risk in quantitative terms either as probabilities, or expected losses. Quantitative Risk Assessment (QRA) follows an engineering approach and focus on the evaluation of the direct physical losses resulting directly from the impact of the hazard (e.g. flooded buildings, collapsed buildings). Some also analyze indirect losses due to loss of function (e.g., disruption of transport, business losses, or clean up costs). The focus is on tangible losses that have a monetary (replacement) value. Disasters also cause a large amount of intangible losses for example, lives and injuries, cultural heritage, environmental quality, and biodiversity. For multiple sources of a particular hazard e.g. earthquakes or tsunami, some form of probabilistic modelling is needed. In other situations, "what if?" questions about particular events occurring may be more relevant - these can be addressed by modelling scenarios.

- Probabilistic Modelling: Particularly useful where the risk of damage to a region can arise from multiple sources of a hazard, e.g. earthquakes, volcanoes and tsunami. A probability distribution of hazard magnitudes and average recurrence intervals needs to be assigned to each source. Then, using a Monte Carlo approach, the impacts of many possible events can be simulated to derive the risk profile for a particular target locality.
- Scenario Modelling: The generation of specific hazard scenarios, with the same average recurrence interval, is essential to compare impacts across several hazards. Scenarios are also useful to discover the potential impacts of "what if?" scenarios, e.g. if a breach occurs in a stop bank at a critical location or if, after a volcanic eruption, the wind blows persistently in a particularly direction. Such "what if" scenarios are difficult to assign probabilities of occurrence.

The specific risks are integrated using a so-called risk curve (component F in Figure 1) in which for each specific risk scenario the losses are plotted against the probabilities, and expressing also the uncertainty as minimum and maximum loss curves. The total risk can then be calculated as the integration of all specific risks, or the area under the curve. The risk curves can be made for different basic units, e.g. administrative units such as individual slopes, road sections, census tracts, settlements, or municipalities. A similar approach can be used also for the analysis of population risk (societal risk), although the analysis depends on the spatial and temporal distribution of population and the application of specific population vulnerability curves, either for people in buildings, or in open spaces. The results are expressed as F-N curves.

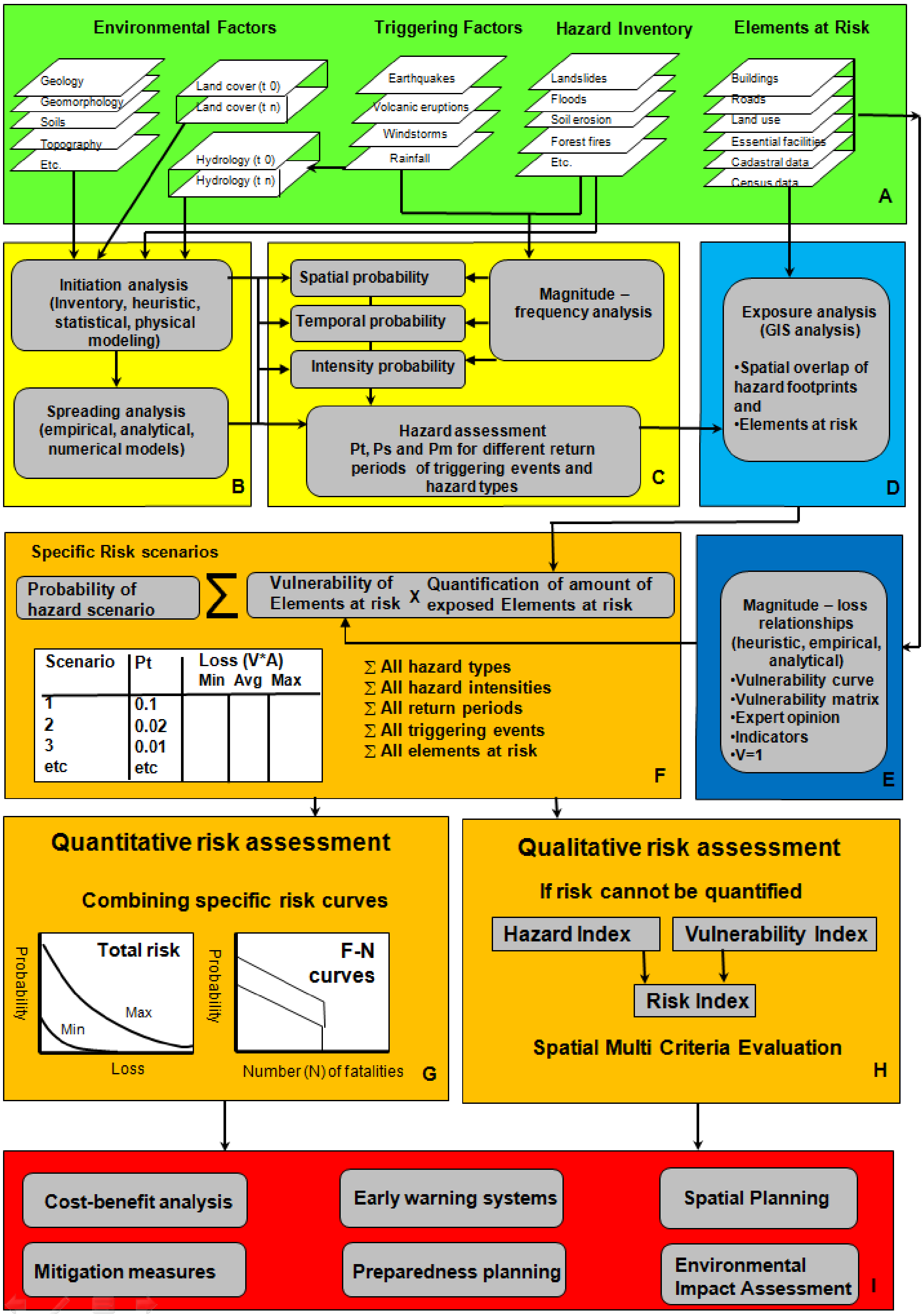

Figure 1: Framework of multi-hazard risk assessment (based on Van Westen et al. 2008. See text for explanations

3. Multi-hazards concept

A generally accepted definition of *multi-hazard* still does not exist. In practice, this term is often used to indicate all relevant hazards that are present in a specific area, while in the scientific context it frequently refers to "more than one hazard".

Likewise, the terminology that is used to indicate the relations between hazards is unclear. Many authors speak of *interactions* (Tarvainen et al. 2006, de Pippo et al. 2008, Marzocchi et al. 2009, Zuccaro and Leone 2011, European Comission 2011), while others call them *chains* (Shi 2002), *cascades* (Delmonaco et al. 2006a, Carpignano et al. 2009, Zuccaro and Leone 2011, European Comission 2011), *domino effects* (Luino 2005, Delmonaco et al. 2006a, Perles Roselló and Cantarero Prados 2010, van Westen 2010, European Comission 2011), *compound hazards* (Alexander 2001) or *coupled events* (Marzocchi et al. 2009).

There are many factors that contribute to the occurrence of hazardous phenomena, which are either related to the environmental setting (topography, geomorphology, geology, soils etc.) or to anthropogenic activities (e.g. deforestation, road construction, tourism). Although these factors contribute to the occurrence of the hazardous phenomena and therefore should be taken into account in the hazard and risk assessment, they are not directly triggering the events. For these we need triggering phenomena, which can be of meteorological or geophysical origin (earthquakes, or volcanic eruptions). Figure 2 illustrates the complex interrelationships between multi-hazards potentially affecting the same mountainous environment. This graphic indicates that a multitude of different types of interrelations exists.

The first multi-hazard relationship is therefore between different hazard types that are triggered by the same triggering event. These are what we would call *coupled events* (Marzocchi et al., 2009). The temporal probability of occurrence of such coupled events is the same as it is linked to the probability of occurrence of the triggering mechanism.

For analyzing the spatial extent of the hazard, one should take into account that when such coupled events occur in the same area and the hazard footprints overlap, the processes will interact, and therefore the hazard modeling for these events should be done simultaneously, which is still very complicated. In order to assess the risk for these multi-hazards, the consequence modeling should therefore be done using the combined hazard footprint areas, but differentiating between the intensities of the various types of hazards and using different vulnerability-intensity relationships. When the hazard analyses are carried out separately, the consequences of the modeled scenarios cannot be simply added up, as the intensity of combined hazards may be higher than the sum of both or the same areas might be affected by both hazard types, leading to overrepresentation of the losses, and double counting. Examples of such types of coupled events is the effect of an earthquake on a snow-covered building (Lee & Rosowsky, 2006) and the triggering of landslides by earthquakes occurring simultaneously with ground shaking and liquefaction (Delmonaco et al. 2006b, Marzocchi et al. 2009).

Another, frequently occurring combination are landslides, debris flows and flashfloods caused by the same extreme rainfall event. The consideration of these effects is fundamental since chains "expand the scope of affected area and exaggerate the severity of disaster" (Shi et al. 2010).

A second type of interrelations is the influence one hazard exerts on the disposition of a second peril, though without triggering it (Kappes et al. 2010). An example is the "fire-flood cycle" (Cannon & De Graff, 2009): forest fires alter the susceptibility to debris flows and flash floods due to their effect on the vegetation and soil properties.

The third type of hazard relationships consists of those that occur in chains: one hazard causes the next. These are also called domino effects, or concatenated hazards. These are the most problematic types to analyze in a multi-hazard risk assessment.

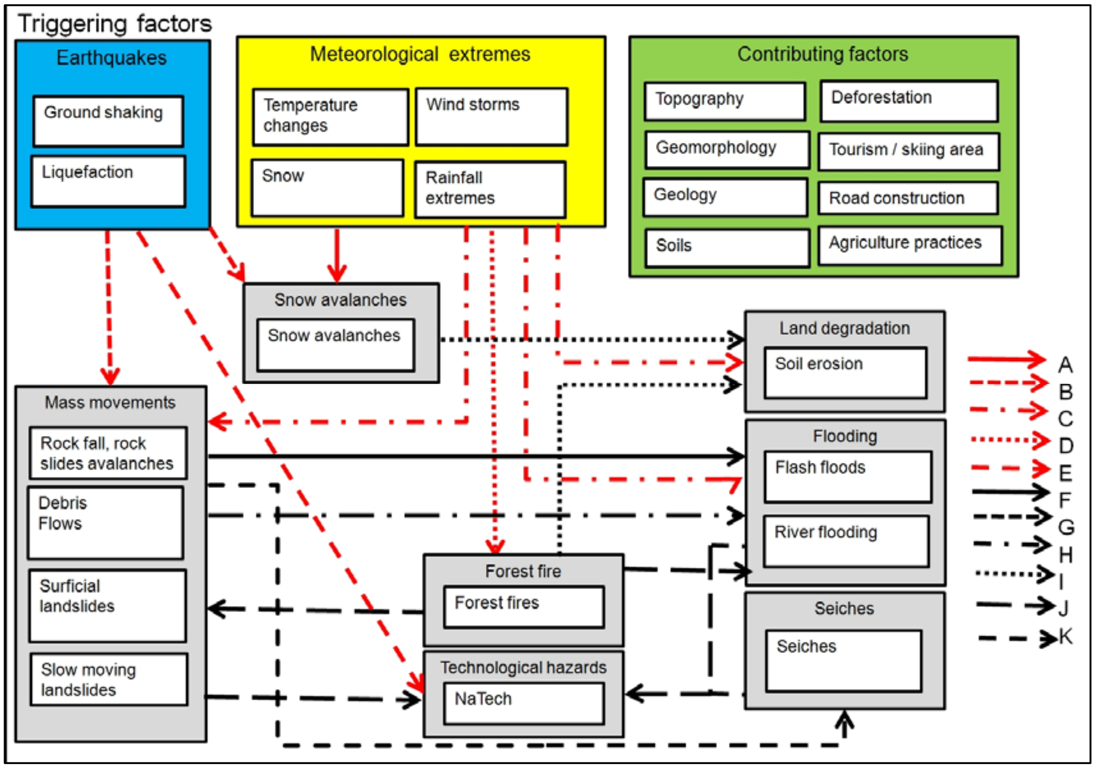

Figure 2: Multi-hazard in a mountainous environment, and their interrelationships. Above the triggering factors are indicated (earthquakes, meteorological extremes), and the contributing factors. The red arrows indicate the hazards triggered simultaneously (coupled hazards). The black arrows indicate the concatenated hazards: one hazard causing another hazard over time. (A) Snow accumulation causing snow avalanches; (B) earthquakes triggering landslides and snow avalanches simultaneously; (C) Extreme precipitation causing landslides, debris flows, flooding and soil erosion; (D) drought and/or lightning causing forest fires; (E) earthquakes causing technological hazards; (F) mass movements damming rivers causing dam break floods; (G) large rapid landslides or rockfalls in reservoirs causing seiches; (H): debris flows turning into floods in the downstream section; (I) snow avalanches or forest fires leading to soil erosion; (J) forest fires leading to surficial landslides, debris flows and flashfloods; (K) landslides, debris flows or floods leading to technological hazards.

The temporal probability of each hazard in a chain is dependent on the temporal probability of the other hazard causing it. For example a landslide might block a river, leading to the formation of a lake, which might subsequently result in a dam break flood or debris flow. The probability of the occurrence of the flood is depending on the probability of the landslide occurring in that location with a sufficiently large volume to block the valley. The occurrence of the landslide in turn is related to the temporal probability of the triggering event. The only viable solution to approach the temporal probability of these concatenated hazards is to analyze them using Event Trees (e.g. Egli 1996 or Marzocchi et al., 2009) a tool which is applied extensively in technological hazard assessment, but is still relatively new in natural hazard risk assessment. Apart from analyzing the temporal probability of concatenated events, the spatial probability is often also a challenge, as the secondary effect of one hazard (e.g. the location of damming of a river) is very site specific and difficult to predict. Therefore a number of simplified scenarios are taking into account, often using expert judgment.

4. Approaches for multi-hazard risk assessment

Loss estimation modelling science has originated from the fields of property insurance and the science of natural hazards. Loss estimation has been carried out in the insurance sector since the late 1980's using geographic information systems (Grossi, Kunreuther and Patel, 2005). Computer-based models for loss estimation were developed by combination of natural hazard studies with historical information and spatial analysis using GIS. This Chapter presents the main types of loss estimation modelling tools, which will be further described in detail later in the report.

4.1 Commercial catastrophe models

Since the end of the 1980's risk modelling has been developed by private companies, resulting in a range of proprietary software models for catastrophe modelling for different types of hazards. Nowadays a limited number of specialized risk modelling companies are dominating the market for the (re)insurance sector, such as:

- Risk Management Solutions (RMS) was formed in 1988 at Stanford University. RMS models risk in over 100 countries, allowing stakeholders to analyze the probability of losses in regions with the highest exposure. The models are built using detailed data reflecting highly localized variations in hazards, and databases capturing property and human exposures.
- EQECAT began in San Francisco in 1994 as a subsidiary of EQE International. In 2001, EQE International became a part of ABS consulting. Through its modelling platform, WORLDCATenterprise, EQECAT supports clients to model financial impact of natural hazards. The tool includes 181 natural hazard software models for 95 countries in 6 continents.
- AIR Worldwide was founded in 1987 in Boston. AIR Worldwide is active in more than 90 countries. More than 400 insurance, reinsurance, financial, corporate and government organizations work with the output of the models from AIR Worldwide. AIR is a member of the Verisk Insurance Solutions group.
- RMSI was founded in 1993 in New Delhi, India as a joint venture with RMS, USA, and become independent in 2011. RMSI develops innovative solutions that integrate geographic information with niche business applications. RMSI has over 150 active clients in 30 countries.

Apart from these there are also a number of organizations that have specialized systems for loss estimation, such as the main reinsurance companies (e.g. SwissRE, MunichRe, Willis, AON).

Complicated catastrophe modelling tools have been developed, for windstorms, earthquakes, flooding and other types of hazards. However, these models are proprietary and are not publicly available, which is a major obstacle to the development of risk assessment for many parts of the world by government organizations. The four basic components of a catastrophe model are: hazard, inventory of elements-at-risk, vulnerability, and loss. The hazard modelling is generally using a stochastic set of possible events, based on historical occurrence and modelling. The models generally provide information in the form of Loss Exceedance Curve (LEC) (See Figure 3). For a given portfolio of structures at risk, an LEC curve is a graphical representation of the probability that a certain level of loss will be surpassed in a given time period. The exceedance

probability curve enables to determine the PML or Probable Maximum Loss for a given number of elements-at-risk.
The insurance industry is currently working with the Association for Cooperative Operations Research and Development (ACORD) to develop an industry standard for collecting and sharing exposure data. To date, the industry has been operating on closed, proprietary data formats.

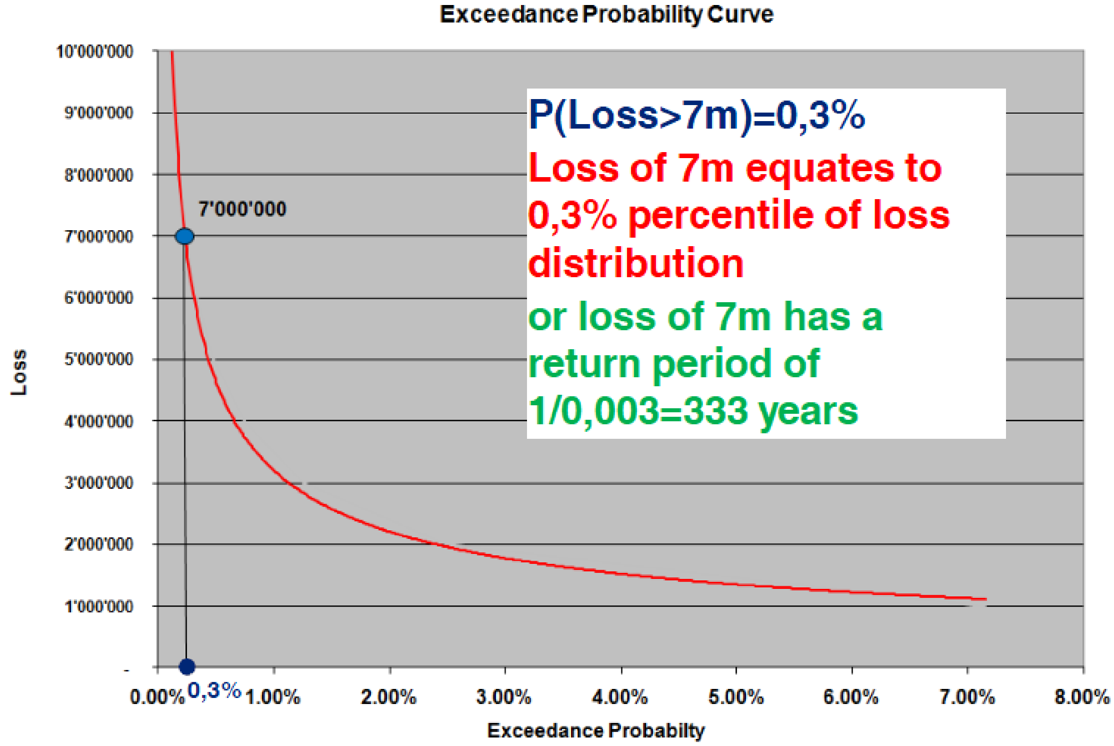

Figure 3: Example of an Loss Exceedance curve

4.2 Publicly available simple tools

One of the first loss estimation methods that was publicly available was the RADIUS method (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters), a simple tool to perform an aggregated seismic loss estimation using a simple GIS (RADIUS, 1999). The IDNDR secretariat launched the RADIUS initiative in 1996 to promote worldwide activities for the reduction of the urban seismic risk, which is growing rapidly particularly in developing countries, by helping the people understand their seismic risk and raise public awareness. The direct objectives were to develop earthquake damage scenarios and practical tools for seismic risk management, to conduct a study to understand urban seismic risk around the world and to promote information exchange for seismic risk.
As part of the Radius initiative a simply tool was developed for earthquake loss estimation which was publicly available. The goal of this tool was to aid users in understanding the seismic hazard and vulnerability of their cities and to guide them in starting preparedness programs against future earthquakes. Designed in MS Excel to provide a simple and very familiar interface, the tool is user friendly, and provides risk-mapping functionality. The area of a city and probable loss to infrastructure and life is displayed as a mesh of rectangular cells that allows the user to get a graphical view of the data. Outputs are seismic intensity, building damage, lifeline damage, and causalities, which are presented in tabular as well as map forms. (See Figure 4).
Although the damage estimations provided by this tool are rough, the results of the program can be used in various ways. Through using this tool, users can gain a better understanding of

earthquakes and the disasters associated with them. The potential extent of damage and the vulnerable points of the city are highlighted by the use of this tool. The information presented through this tool is very important and useful to manage effective seismic disaster reduction measures, including preparedness, emergency response activities, and seismic retrofit and recovery actions and policies. It can be concluded that the calculations of the damage amount should not be considered as a final goal of earthquake damage estimation, but instead as a starting point for seismic disaster reduction.

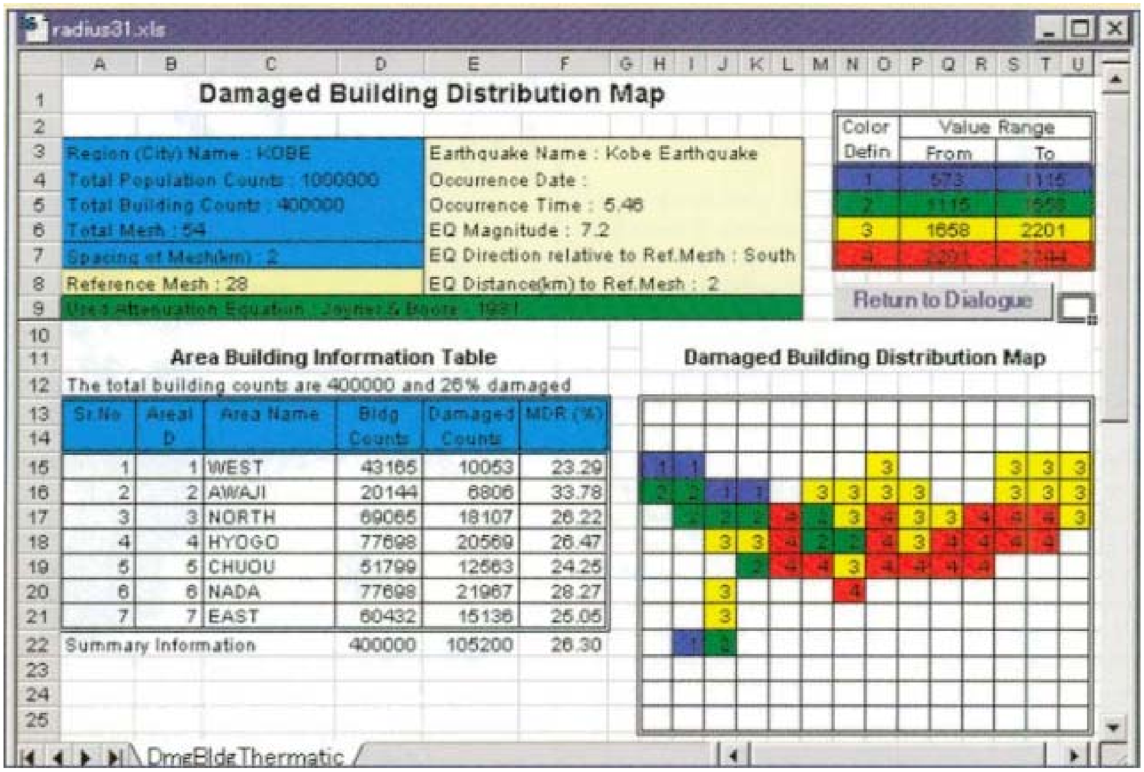

Figure 4: Example of the Radius Excel tool for earthquake loss estimation.

4.3 GIS-based tools

Another major stream within the development of loss estimation tools has been on the development of software tools that run as add-ons or plugins of existing Geographic Information Systems. The best example of such systems that provide publicly available loss estimation tools thus far has been HAZUS (which stands for "Hazards U.S.") developed by the Federal Emergency Management Agency (FEMA) together with the National Institute of Building Sciences (NIBS, Buriks et al. 2004). The first version of HAZUS was released in 1997 with a seismic loss estimation focus, and was extended to multi-hazard losses in 2004, incorporating also losses from floods and windstorms (FEMA, 2004). HAZUS was developed as a software tool under ArcGIS. HAZUS is considered a tool for multi-hazard risk assessment, but the losses for individual hazards are analyzed separately for earthquakes, windstorms and floods. Secondary hazards (e.g. earthquakes triggered landslides) are considered to some degree using a basic approach. Although the HAZUS methodology has been very well documented, the tool was primarily developed for the US, and the data formats, building types, fragility curves and empirical relationships cannot be exported easily to other countries. Several other countries have adapted the HAZUS methodology to their own situation, e.g. in Taiwan (Yeh et al., 2006) and

Bangladesh (Sarkar et al., 2010). Another successful and published international studies was performed by Bausch (2010), who developed an earthquake assessment framework on the Haiti earthquake with the major focus of aggregated inventory building data (General Building Stock) for potential damage assessment. There were no known publications about the internationally applied Hazus-MH Flood Model, until Kulmesch (Kulmesch et al. 2010) manually integrated local Austrian inventory and flood hazard datasets into the Flood Model data structure and performed a building loss estimation in a case study in Carinthia. Another study by Kaveckis (2011) successfully showed how Hazus-MH can significantly contribute to support the European Flood Directive at a national level and deliver requested assignments and outputs like flood hazard and flood risk maps.
The HAZUS methodology has also been the basis for the development of several other software tools for loss estimation. One of these is called SELENA (SEimic Loss EstimatioN using a logic tree Approach), developed by the International Centre for Geohazards (ICG), NORSAR (Norway) and the University of Alicante, Spain (Molina et al., 2010).

In the areas of industrial risk assessment also a number of methods have been developed using GIS-based decision support systems. One of these is the ARIPAR system (Analysis and Control of the Industrial and Harbour Risk in the Ravenna Area, Analisi e controllo dei Rischi Industriali e Portuali dell'Area di Ravenna, Egedi et al., 1995; Spadoni et al., 2000). The ARIPAR methodology is composed of three main parts: the databases, the risk calculation modules and the geographical user interface based on the Arc-View GIS environment. Currently the system is converted to ArcGIS, and also natural hazards are included in the analysis.

Another noteworthy example of such a plug-in has been the INASAFE initiative (Indonesian Scenario Assessment for Emergencies) which is a relatively simple tool for estimating exposure and losses from different hazards, using a Python plugin within the Open Source GIS Quantum-GIS. INSAFE is not a hazard modelling tool, as hazard scenarios have to be provided as input into the software.

4.4 Standalone tools

Another development in loss estimation tools has been the generation of tools that are standalone, and which are not dependent on a GIS system. One of the best examples of this is the CAPRA tool for Probabilistic Risk Assessment, developed by the ERN consortium for the World Bank.

Whereas most of the above mentioned GIS-based loss estimation tools focus on the analysis of risk using a deterministic approach, the CAPRA has a true probabilistic multi-hazard risk focus. The aim of CAPRA was to develop a system which catastrophe models in an open platform for disaster risk assessment, which allows users from developing countries to analyze the risk in their areas, and be able to take informed decisions on disaster risk reduction. The methodology focuses on the development of probabilistic hazard assessment modules, for earthquakes, hurricanes, extreme rainfall, and volcanic hazards, and the hazards triggered by them, such as flooding, windstorms, landslides and tsunamis. These are based on event databases with historical and simulated events. This information is combined with elements-at-risk data focusing on buildings and population. For the classes of elements-at-risk, vulnerability data can be generated using a vulnerability module. The main product of CAPRA is a software tool, called CAPRA-GIS, which combines the hazard scenarios, elements-at-risk and vulnerability data to calculate Loss Exceedance Curves.

In New Zealand a comparable effort is made by developing the RiskScape methodology for multi-hazard risk assessment (Reese et al., 2007; Schmidt et al., 2011). This approach aims at the provision of a generic software framework which is based on a set of standards for the relevant components of risk assessment. Another good example of multi-hazard risk assessment is the Cities project in Australia, which is coordinated by Geoscience Australia. Studies have been made for six cities of which the Perth study is the latest (Durham, 2003; Jones et al., 2005). Also in Europe several project have developed multi-hazard loss estimations systems and approaches, such as the ARMAGEDOM system in France (Sedan and Mirgon, 2003) and in Germany (Grünthal et al, 2006).

4.5 Open Source Web-based tools

Another recent development is towards Open Source web-based modules for multi-hazard risk assessment. A tool which is currently under development as part of the Global Earthquake Model (GEM), called OpenQuake, is most probably going to be the standard for earthquake loss estimation, and there are also plans to expand it into a multi-hazard risk assessment tool.
To manage risk from natural and technological disasters (earthquakes, hurricanes, industrial accidents, etc.) and to understand the potential impacts of new disaster science or policy, requires access to analytical and computer risk models. The models are constantly in flux as science, engineering, and disaster social science develop, but most researchers and practitioners lack risk-integration tools and methods needed for an overall understanding of risk, and must either re-develop existing integrative software or abandon potentially fruitful study. In order to exchange information on Open Source loss estimation tools the AGORA was founded. The Alliance for Global Open Risk Assessment (AGORA) is conceived as a nonprofit, international virtual organization created to promote and coordinate development of open-source risk software and methodologies to perform end-to-end risk modelling. (End-to-end refers to modelling the occurrence of hazardous events, site effects, physical damage to the built environment, and economic and human impacts.). Open-source risk software (OSR) represents an emerging solution. It is software whose source code is publicly available for review and enhancement. An example of such tools is the OpenRisk, a set of methodologies and object-oriented, open-source software for conducting multi-hazard risk analysis. It is under development and will assess risk to single sites and portfolios of facilities in terms of repair costs, casualties, and loss of use ("dollars, deaths, and downtime"). Initial applications have been collaboratively developed by Caltech , USGS , SCEC , and Kyoto University. The AGORA doesn't seem to have gained a lot of momentum as evidence by their website.
Other examples of Open Source loss estimation tools include RISIKO, RiskInABox, INASAFE, and Kalypso.

5. Tools for specific hazards

This section will present an overview of loss estimation tools that have been developed for specific hazard types. There are several multi-hazard tools (e.g. HAZUS, CAPRA) and only the relevant component for the specific type of hazard will be described.

5.1 Earthquake hazards

By far most of the tools for loss estimation that are publicly availability (thus leaving commercial software out of the analysis) have been generated for earthquake loss estimation. Table 1 (from Silva et al., 2013) provides an overview of a number of these tools that have been developed. Daniell (2009) presents an in-depth comparative review of current Earthquake Loss Estimation (ELE) and other earthquake software packages using an "Open source Procedure for Assessment of Loss using Global Earthquake Modelling software" (OPAL-GEM1) with the view of creating a truly "Open source Program for Assessment of Loss for Global Earthquake Modelling" (OPAL-GEM2), later named as OpenQuake.
The tools may contain one of the following components:

- Scenario risk (SCN): This calculator is capable of computing losses and loss statistics due to a single, scenario earthquake, for a collection of assets, which is important, for example, for emergency management planning and for raising societal awareness of risk.
- Scenario damage assessment (SDA). This calculator is capable of estimating damage distribution due to a single, scenario earthquake, for a collection of assets, which can be used for emergency management planning or to assess which assets are more seismic vulnerable.
- Probabilistic Event-based Risk (PEB) This calculator computes the probability of losses and loss statistics for a collection of assets, based on the probabilistic hazard. The losses are calculated with an event-based approach, such that the simultaneous losses to a set (or portfolio) of assets can be calculated. The output of this calculator can be used to assess the aggregated expected losses for a collection of assets.
- Classical PSHA-based Risk (CPB) This calculator leads to the computation of the probability of losses and loss statistics for single assets, based on a probabilistic description of the hazard. The output of this calculator is useful for comparative risk assessment between assets at different locations, which can be used, for example, for the prioritisation of risk mitigation efforts.
- Benefit–cost ratio (BCR) This calculator is a decision-support tool for deciding whether the employment of retrofitting/strengthening measures to a collection of existing buildings is advantageous from an economical point of view. This output can be used to prioritize the regions in need for retrofitting/strengthening activities or to assess which seismic design is more economically adequate for a given region.

Despite the fact that some of the aforementioned software incorporates calculator philosophies are identical their implementation might vary significantly. For example, seismic hazard is not calculated by some software (thus needing other tools for its computation), and in some cases, the uncertainties in the various inputs are neglected. The HAZUS software (FEMA 2003) is also a very useful tool and a pioneering application in seismic risk assessment because the methodologies behind this software have been the basis for many of the other tools. Reviews are documented in Crowley et al. (2010) and were fundamental in order to understand the current state of the practice in seismic hazard and risk software.

The OpenQuake project (http://www.globalquakemodel.org/openquake/) was initiated as part of the Global Earthquake Model (GEM) (http://www.globalquakemodel.org) (Pinho 2012), a global collaborative effort that brings together state-of-the-art science and national/ regional/ international organizations and individuals with the aim of establishing uniform and open standards for calculating and communicating earthquake risk worldwide. OpenQuake is a web-based risk assessment platform, which will offer an integrated environment for modelling, viewing, exploring and managing earthquake risk.
The OpenQuake engine currently has the following characteristics (Silva et al 2013):

- An open-source software license with the code available on a public repository;
- Technical support and documentation;
- Users can upload their own hazard, vulnerability and exposure models (and it is thus not tied to any specific region in the world);
- Hazard and risk calculations (scenario and probabilistic) are combined within a single software, but users are able to run hazard-only and risk-only calculations;
- Site amplification is considered through the specification of Vs30 values at each site (the average shear wave velocity over the top 30 metres of soil);
- Logic trees are employed to model the epistemic uncertainty;
- Different types of assets can be modelled (e.g. buildings, population);
- Modelling of spatial correlation of ground-motion residuals is considered;
- Modelling of the correlation of uncertainty in building vulnerability is considered;
- It is scalable, with parallelized calculators, and can be used on a single processor laptop, as well as on a cluster or cloud computing infrastructure;
- A full spectrum of hazard and risk products such as stochastic event sets, ground-motion fields, uniform hazard spectra, hazard curves and maps, disaggregation plots, damage and loss curves and maps can be produced.

Despite this list of achievements, other important features were also identified during the review of the various softwares, such as the need for a user-friendly and intuitive user interface, or the capability of running the calculations on any platform (Windows, Mac, Linux, etc.), which are still part of the OpenQuake engine development roadmap.
At present, the OpenQuake engine is comprised of five main calculation workflows: two capable of computing loss and damage distribution due to single events, two with the purpose of estimating probabilistic seismic risk considering a probabilistic description of the events and associated ground motions that might occur in a given region within a certain time span, and a last one that uses loss exceedance curves to carry out retrofitting benefit–cost analysis. Several other functionalities are planned for the future development of the OpenQuake engine and its scientific libraries.
Due to its transparent, modular and test-driven development philosophy, the development of the OpenQuake engine, and in particular its two Python libraries, will continue to be a community effort where anyone can contribute with their own methods and formulae. This differs from traditional practice, where a closed “enterprise” development tends to be followed, even if the source code is eventually openly released at the end of the development process.
The OpenQuake engine is being tested by several institutions and research projects in the world for the calculation of seismic hazard and risk (such as the calculation of hazard for Europe in the European Commission-funded SHARE project, www.share-eu.org), which is helping the development team to better understand the regional requirements, and to improve and extend the development plan accordingly (Silva et al., 2013).

Software	Institution	Programming language	Applicability	Availability	GUI	Type of calculators	Web-site
SELENA	NORSAR	MATLAB/C	User-defined	OS	Yes	SCN/SDA/PEB	http://www.norsar.no/pc-35-68-SELENA.aspx
EQRM	GA	Python	User-defined	OS	No	SCN/SDA/PEB	http://www.ga.gov.au/hazards/earthquakes.html
ELER	KOERI	MATLAB	User-defined	SA	Yes	SCN/SDA	http://www.koeri.boun.edu.tr/depremmuh/eski
QLARM	WAPMERR	Java	World	SC	Yes	SCN/SDA	http://www.wapmerr.org/qlarm.asp
CEDIM	CEDIM	Visual Basic	User-defined	SC	Yes	SCN/SDA/CPB	http://www.cedim.de
CAPRA	World Bank	Visual Basic	User-Defined	SC	Yes	SCN/PEB	http://www.ecapra.org/software
RiskScape	GNS	Java	New Zealand	SA	Yes	SCN/SDA	http://www.riskscape.org.nz
LNECLoss	LNEC	Fortran	Portugal	SC	No	SCN/SDA	http://www-ext.lnec.pt/LNEC/DE/NESDE
MAEviz	MAE Center	Java	User-defined	OS	Yes	SCN/SDA/CPB	http://rcp.ncsa.uiuc.edu/maeviz/about.html
OpenRisk	SPA Risk	Java	USA	SA	Yes	CPB/BCR	http://www.risk-agora.org

Table 1: Overview of earthquake loss estimation tools (from Silva et al., 2003). Indicated are the name, the institution that developed the tool, the applicability, the availability (OS=Open Source,, code on a public repository, SA = Standard application, available upon request, SC = source code , available upon request), and the types of calculators as indicated in table 2, GUI (Graphical User Interface)

The aforementioned systems focus on the assessment of losses prior to events, while other systems aim at providing fast assessments of damage directly after the occurrence of major events. For instance the PAGER (Prompt Assessment of Global Earthquakes for Response) system, developed by the USGS is an automated system that rapidly assesses earthquake impacts by comparing the population exposed to each level of shaking intensity with models of economic and fatality losses based on past earthquakes in each country or region of the world (PAGER, 2010).

5.2 Windstorm hazards

Windstorm loss modelling is one of the main NatCat applications within the insurance industry and catastrophe modelling companies. In many countries storm damage is among the top of the list. There are much less Open Source software tools available for windstorm loss estimation. Among the one available are:

HAZUS. The Hazus-MH Hurricane Wind Model allows users to estimate the economic and social losses from hurricane winds (Vickery et al., 2006; HAZUS, Windstorm, 2013). State and local officials, can use the information provided by the hurricane model to evaluate, plan for and mitigate the effects of hurricane winds. The Hazus-MH Hurricane Wind Model makes use of an existing state-of-the-art windfield model, which has been calibrated and validated using full-scale hurricane data. The model incorporates sea surface temperature in the boundary layer analysis, and calculates wind speed as a function of central pressure, translation speed, and surface roughness. The Hazus-MH Hurricane Wind Model is an improvement over existing loss estimation models because it uses a wind hazard-load-damage-loss framework. The model addresses wind pressure, windborne debris, duration/fatigue, and rain. It includes the following features:

- A building classification system that depends on the characteristics of the building envelope and building frame.
- The capability to compute damage based on building classes and the effects of rain and progressive failure.
- The capability to compute damage to contents and building interior.
- The capability to estimate tree blow down and structure debris quantities.
- Loss estimates that include direct and indirect economic loss, shelter requirements, and casualties.
- Modules that facilitate future assessment of mitigation, benefit-cost, and building code issues.

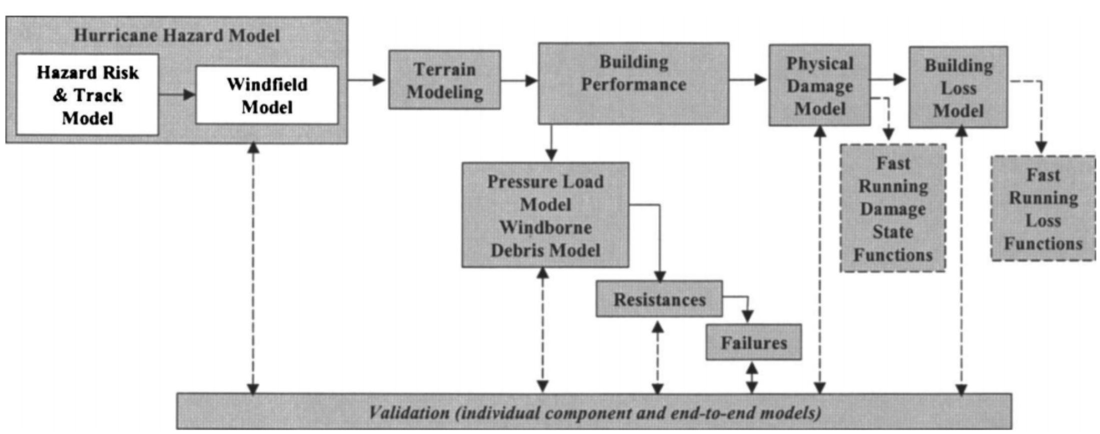

Figure 5: Overview of approach used to develop damage and loss functions for HAZUS (Source: Vickery et al., 2006)

The HAZUS physical damage model is an engineering-based load and resistance analysis of building component performance. Both wind-induced pressure and windborne debris impacts are modelled. The physical damage model estimates the damage to the building primarily in terms of failure of building envelope components, rather than failure of the structural frame, which is relatively infrequent, and occurs after failure of building enveloped components.

CAPRA. The ERN-Hurricane hazard model evaluates hazards related to strong winds, intense rain (causing floods or landslides) and storm surge. A set of stochastic hurricane path scenarios are generated using historic records and modelling techniques. Each storm is characterized with the following parameters: location through time, magnitude, and frequency. This information is used as reference to create rainfall (spatial distribution, intensity and duration); wind (spatial distribution, maximum wind speed); and storm surge (spatial distribution, wave height and velocity) scenarios. Results are to be calibrated using historic records on relevant events. These scenarios are used to generate probabilistic hazard maps for strong winds; storm surge; landslides and flood (based on rainfall scenarios) See Figure 6.

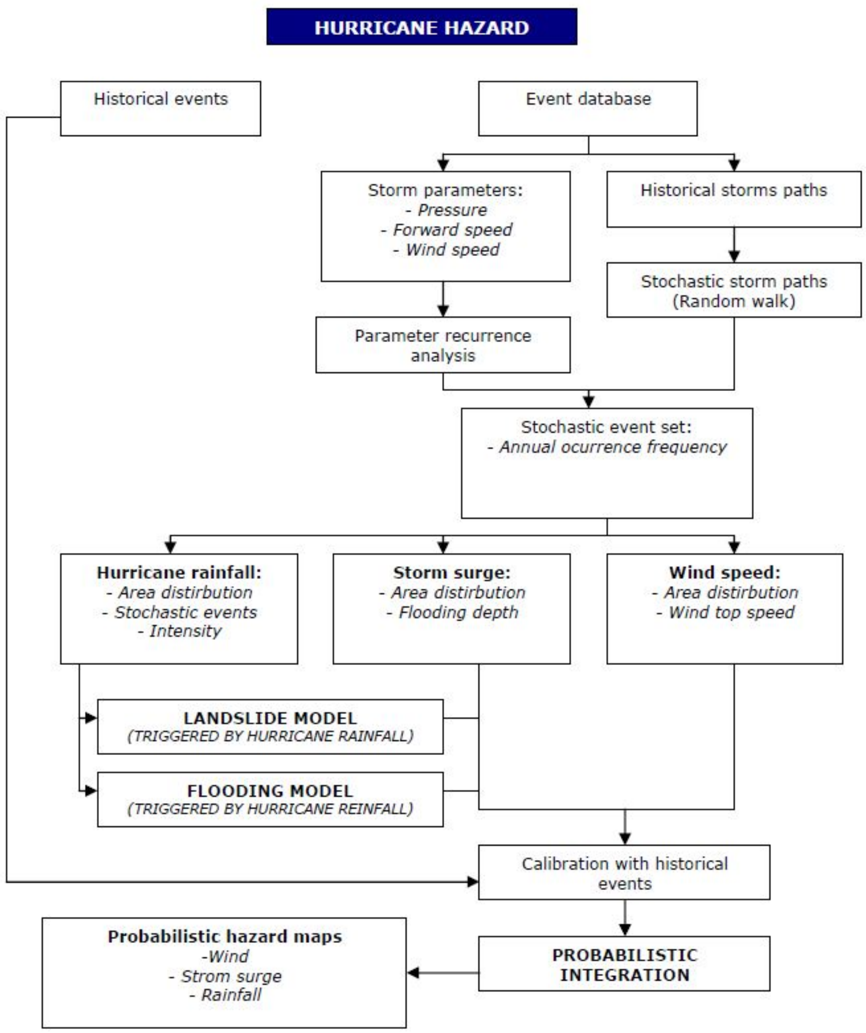

Figure 6: Example of the processing steps in the CAPRA tool ERN-Hurricane for windstorm loss estimation (Source: www.ecapra.org)

- **RiskScape.** RiskScape uses three models to develop wind gust exposures for regional pilot areas. All model outputs are calibrated for recurrence intervals from local weather-station records.
    - **RAMS:** The Regional Atmospheric Modelling System (RAMS) is a medium scale model with a maximum resolution of 1km. RAMS solves the physical equations that control the time evolution of wind and temperature fields. It is primarily a weather model but is also used to model volcanic ash transport and wind hazards (Pielke et al., 1992). RAMS has been used in Riskscape to model the variations in the region's wind field caused by local terrain during wind storms. The model was run with a 1km horizontal grid spacing and forced by background mean wind and temperature profiles forced by historical strong southerly, easterly and northwesterly wind storms.
    - **BLASIUS:** The BLASIUS (Boundary Layer above Stationary, Inhomogeneous Uneven Surfaces) is a numerical scheme for simulating turbulent flow over two- and three- dimensional hills. The model adapts a uniform wind field to underlying terrain; grid-point wind speeds are then determined for areas of interest once patterns of wind enhancement are well established (Wood et al., 2003).
    - **GERRIS:** Gerris is open source software developed by NIWA (Popinet, S., 2003 (General public license http://gfs.sf.net) for the solution of the partial differential equations describing fluid flow. The model uses a time varying, adaptive grid to solve Navier-Stokes equations.

5.3 Flood hazards

Extensive reviews on the different risk assessment methods for floading have been carried out within the European projects FLOODsite (www.floodsite.net), FloodRisk consortium (www.floodrisk.org.uk), the FloodRisk Conference of 2008 (www.floodrisk2008.net) and the Kuturisk project (www.kuturisk.eu). The last project has made an extensive overview of methods applied in flood risk assessment. Concerning the analytical approaches adopted and the main steps of each methodology some examples are Forte et al. (2005), Schmidt ‐ Thome et al. (2006), Forster et al. (2008), Meyer et al. (2009), Kubal et al. (2009) and Brundl et al. (2009). A typical risk assessment procedure consists of the following steps:

- The mathematical risk analysis, which in turn includes four steps: the hazard analysis, based on physical models; the exposure analysis, which considers the probability of exposure for person in buildings or in movement (hours/day); the consequence analysis, which combines hazard and exposure analysis by the expected loss of life equation; the risk calculation, which involved the social and individual risk equations;
- The multi-criteria evaluation of risk, which compared the risk analysis results with predefined goals (i.e. the probability of death should not be higher of 1 % of the lowest risk). This is based on the concept that risk can be reduced proportionally to the annual cost (in monetary units) of the mitigation measures;
- Planning and evaluation of mitigation measures, based on a multi-criteria approach, which evaluate the cost-effectiveness of measures using a risk-cost diagram.

With respect to specific Open Source loss estimation software tools the following can be mentioned:

HAZUS

HAZUS-MH is the principal software used to assess flood risk to affected populations, buildings, and other infrastructure in the U.S. The HAZUS flood model assesses direct damage to the buildings, facilities and aggregated building data by using flood hazard data, generates summary of debris from aggregated building data, and calculates direct/indirect economic and social losses.

However, while HAZUS is able to generate reliable assessments of flood risk, its usefulness is limited because it can only be run on a workstation by a trained operator with ESRI's ArcGIS software. In 2010, the USGS and FEMA began an effort to provide a solution to this problem by integrating HAZUS flood risk analyses with the USGS-produced flood-inundation maps and making these data available over the Web. HAZUS analyses are first run offline for each stage increment at a given site. The data from the analyses of all the stage increments are then stored in a Web-GIS compatible database (PostGIS) for posting to a Web portal through a Web Application Service (WAS). Through the WAS, users can choose from two HAZUS damage and loss categories.

Recently HAZUS has been applied successfully in other countries including European countries. However, some problems had to be solved. Originally HAZUS works with U.S. datasets. The problem in using HAZUS is the study region which should be a territory within the U.S. The U.S. administrative units (state, county, census tract, census block) do not fit into European standards. The implementation changes the study region and defines new administrative units based on NUTS (Nomenclature of Units for Territorial Statistics), but the scale of NUTS level is not enough to perform efficient aggregated data analysis in HAZUS. Even with the study region defined as Europe, the framework of HAZUS analysis for site specific data remains almost unchanged. Now HAZUS is capable of performing the flood hazard analysis in Europe if regression equations are provided (Kaveckis et al. 2012).

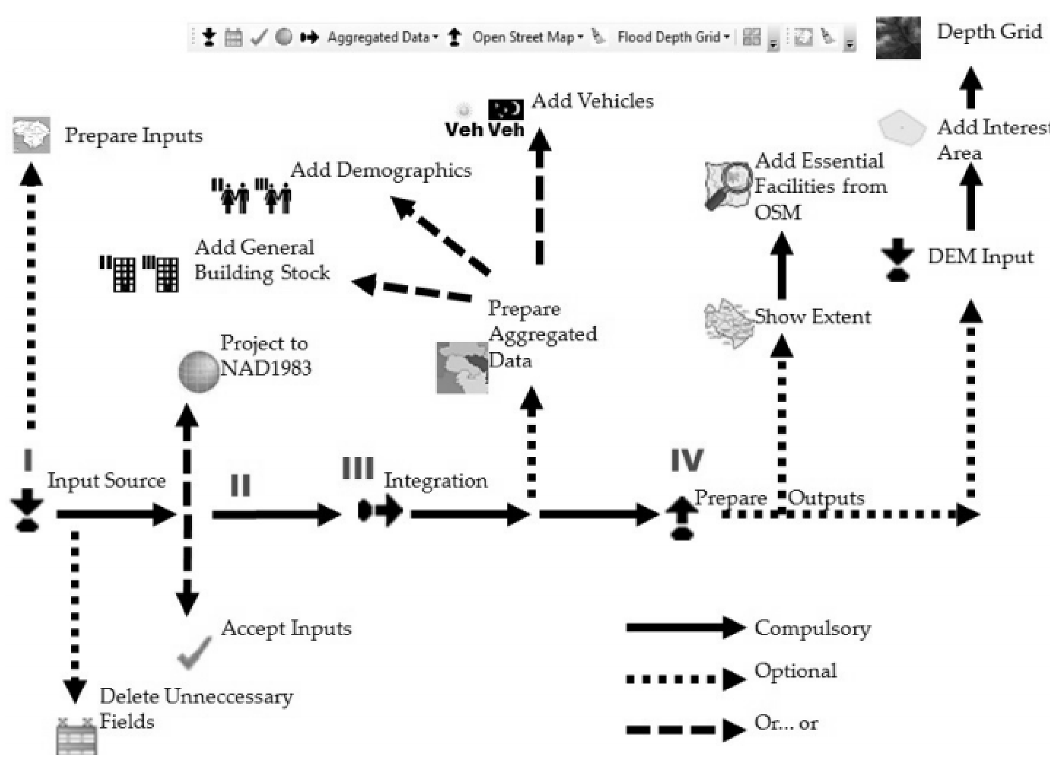

Figure 7: Framework for international application of Hazus-MH Flood Model based on HAZ-I toolset (source Kaveckis et al. 2012)

Recent research studies revealed that the European Flood Directive can be supported by Hazus-MH, which represents an extensively applied and well documented GIS-based framework for risk estimation of natural hazards in the US. However, the difficulties of non-US data integration into HazusMH Flood Model still exist. Kaveckis et al. 2012 describe the hierarchical system of Hazus data, the data types, structure and integration, and propose a newly developed automatic HAZ-I toolset (See Figure 7). This toolset works within ArcGIS framework and enables the user to create a new study region worldwide in order to perform flood risk assessment and to acquire essential assets at risk from the Volunteer Geographic Information datasets. The HAZUS -MH results show the potential how HAZ-I toolset supports HAZUS-MH in flood risk assessment together with open source or either governmental datasets.

CAPRA

ERN-Flood allows the estimation of the flood depths on any given region, based on a set of stochastic rainfall scenarios. The software is capable of simplified and in-depth methods for flood hazard analysis. The in-depth method constructs a unitary hydrogram at the mouth of the basin, based on its characteristics, for each precipitation event and analyses the evolution of the flood event, and uses HEC-RAS for the flood modelling. The simplified method obtains potential areas of flooding that take very general account of topography and land use at each point analyzed.

The proposed methodology is based on a probabilistic approach according to the documentation:

- Stochastic set of precipitation events with defined rainfall intensity (or depth) and duration.
- Calculation of effective precipitation using a simple water balance, taking into account soil permeability, slope and vegetation effects
- Spatial inundation modelling to define the extension of the flooding.
- Integration of scenarios into hazard maps.

The first of these two aspects is actually treated in the module on intense rainfall hazard assessment, and the hurricane rainfall modelling, which in our opinion should provide the input for the actual flood modelling (with rainfall maps for different return periods). See Figure 8.

Kalypso

Kalypso is an open source modeling environment. The aim was to pool their resources in order to create a joint open source modeling environment (Belger et al., 2009). For the end user, the numerical models (binary versions), the application shells (Java codes) and the graphical user interfaces (Java codes) are available as freeware or open source software. Kalypso consists of five modules:

- Kalypso Hydrology: module for rainfall-runoff modeling (conceptual, deterministic, non-linear, distributed)
- Kalypso WSPM: 1D hydraulic model for steady flow water surface profile computation
- Kalypso 1D/2D: Combined 1D/2D hydraulic module for unsteady flow
- Kalypso Flood: Module for the computation of inundated areas based on a DEM
- Kalypso Risk: Deterministic module for the computation of loss potential based on land use, monetary exposure and water depth for specific events

These modules are linked to each other in a common modeling framework. Thus, the tool can be described as an all-embracing flood hazard and risk modeling system. There are several potential end-users: hydrologists, hydraulic engineers or hazard and risk experts.

The tool can be downloaded from the project homepage: http://kalypso.bjoernsen.de/

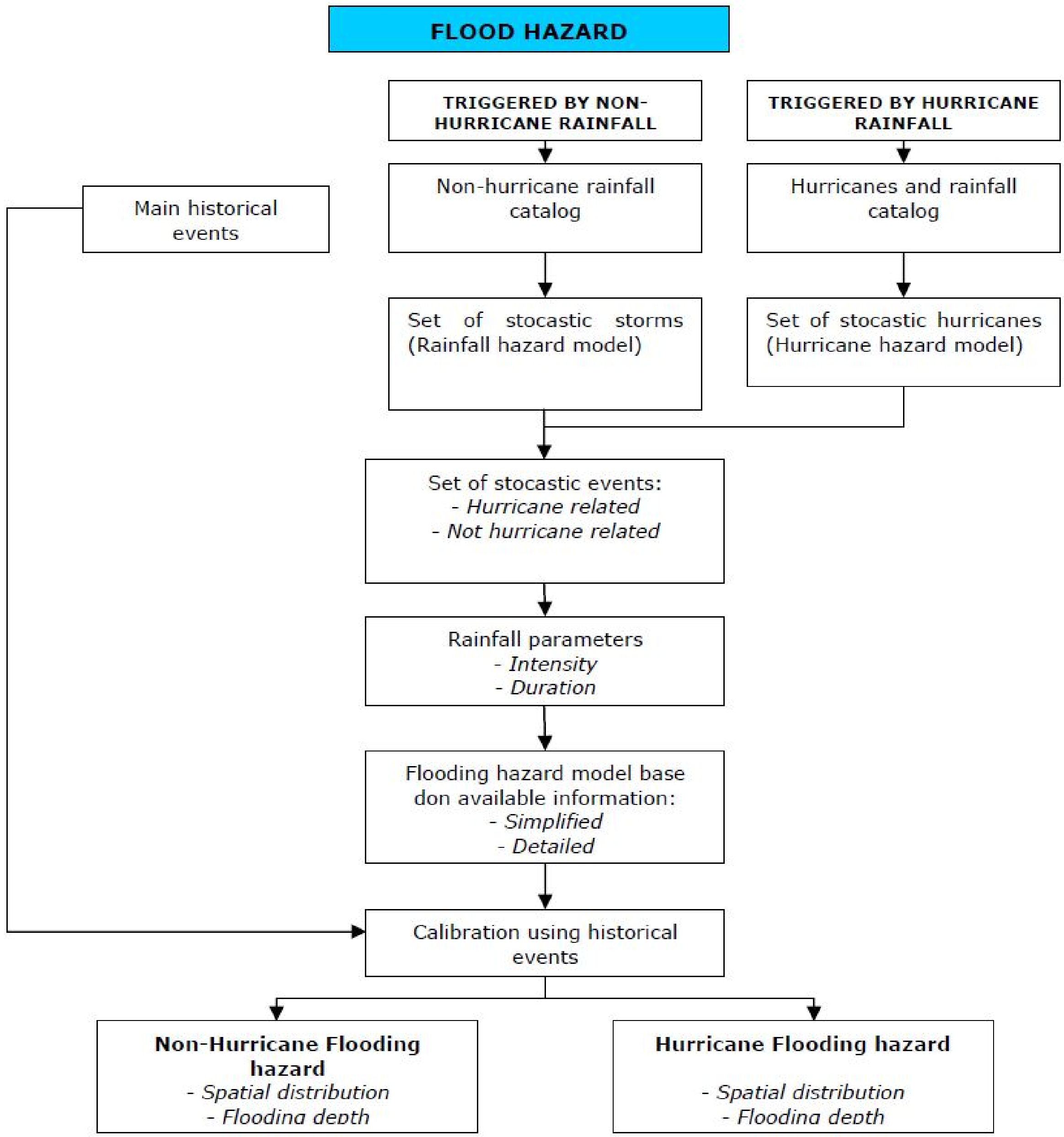

Figure 8: Example of the processing steps in the CAPRA tool ERN-Flood forflood loss estimation (Source: www.ecapra.org)

5.4 Mountain hazards

For risk assessment for mountainous areas, there are up to date no tools that analyze multi-hazard risk for combined processes, such as snow avalanches, rockfall, debris flows, floods and landslides. Studies on the assessment of landslide risk or flood risk separately have been carried out, at different scales and using different methods (e.g. Bell and Glade, 2004; Remondo et al., 2008; Alkema, 2007; Zezere et al., 2008; Cassidy et al., 2008). However, multi-hazard risk examples are still scarce. Van Westen et al. (2002) present a case study of the city of Turrialba (Costa Rica), subjected to landslide, earthquake and flood risk, and propose three different schemes to assess hazard and vulnerability and integrate the losses afterwards. Lacasse et al. (2008) carried out a multi-hazard risk assessment related to the potential collapse of the Aknes rock slide in Norway, using an event tree, for the different scenarios which include the triggering of tsunamis. Event trees were also used by Carboni et al. (2002) to analyze the probabilities of different event scenarios of a single which might lead to the partial damming of a nearby river and the followed dambreak flooding.

When evaluating the existing methods for multi-hazard risk assessment applicable in mountainous areas, the following aspects can be mentioned:

- As many areas are exposed to more than one type of hazard, in the hazard identification phase of the risk assessment, all hazards have to be taken into account as risk analyses are spatially oriented (Greiving et al. 2006) to enable overall risk reduction.
- The models (heuristic, statistical, physically based) required for analysis of hazard for different processes vary considerably. They depend on hazard type, scale, data typology and resolution (Delmonaco et al. 2006b) and complicate the comparison of the very different results (units of the outcome, quality, uncertainty, resolution etc.) even further. A main problem is the comparability of hazards since they vary in “nature, intensity, return periods, and […] effects they may have on exposed elements” (Carpignano et al. 2009, p. 515).
- Also for vulnerability models a very similar situation exists. For some hazards a variety of analytical methods exist while for other processes none or only very few are established and the approaches vary widely between hazards (Hollenstein, 2005).
- The way in which coupled and cascading events are evaluated. Natural hazards are not independent from each other. Instead, they are highly connected and interlinked in the natural geosystem (Kappes et al. 2010).
- The availability and quality of data are important since the model choice, the information value of the results as well as the detail of the analysis depends on these prerequisites. Each of the hazard types has different requirements with respect to the input data. The historical information on past events is crucial for most types of hazards, but the availability of historical records differs greatly among the hazard types, also depending whether these are derived from measured records (flood discharge, earthquake catalogues), archives, image interpretation, or interview (Van Westen et al., 2008).
- Uncertainty plays a major role in hazard and risk assessment. The uncertainties may be due to inherent natural variability, model uncertainties and statistical uncertainties. This leads to different uncertainty levels for the various hazards. The inclusion of uncertainty is actually a necessity in probabilistic risk assessment, and methods should still be developed to better represent these for mountain hazards and risks.
- Difficulties concerning the administrative issues as different organizations are normally involved for analyzing the hazard and risk for individual hazard types, which may make the comparison and standardization of the results difficult (Marzocchi et al. 2009). Young (2003) describes an example in the framework of environmental resources management and called this phenomenon the ‘problem of interplay’.
- The natural and the administrative system are in most cases neither sharing the same spatial nor temporal framework conditions. Hazards are not restricted to administrative boundaries (e.g. river floods or earthquakes). However, hazard and risk management is mostly operating on administrative units. Therefore, a larger coordination is required between the two affected administrative units. In these cases hazard analyses should not be limited to the administrative unit, since the cause of a damaging event might be far away from the area of impact. In the case of earthquakes, for example, the impact might be far away from the epicenter. Some hazards exhibit very long return periods, therefore

preventive measures will probably not show any effect during one or few legislative periods. Young (2002) entitled this phenomenon as 'problem of fit'.

- Not only the stakeholders involved in the elaboration of the analysis request detailed analysis and information. For example, the needs of emergency managers and civil protection are surely different from those of spatial planners.

Hazard and risk assessment requires a multitude of data, coming from different data sources. Therefore it is important to have a strategy on how to make data available for risk management. Since data is coming from different organizations it is important to look at aspects such as data quality, metadata, multi-user databases, etc. Spatial risk information requires the organization of a Spatial Data Infrastructure, where through internet basic GIS data can be shared among different technical and scientific organizations involved in hazard and risk assessment.

5.5 Technological hazards

In the field of technological risk assessment a wide range of software tools have been developed, which, although the hazard type differs substantially in its origin from natural hazards, follow more or less the same approach as far as the hazard modelling, vulnerability assessment and loss estimation are concerned. These types of software can be classified according to several criteria. One of them is the type of risk being assessed. According to this criterion the software can be classified as follows (Ristvej and Lovecek,2011):

- The overall analysis of effects, leakage, evaporation, dispersion, fire, explosion, vulnerability (ALOHA, Whazan, Phast, Safeti, Riskat, Effects(Damage, RiskCurves Socrates, IAEA – TECDOC – 727, TerEx, Rozex, Fluidyn)
- The dispersion of heavy gas (Denz/Crunch, Charm, Slab),
- The discharge in two phases (Deers. PipePhase)
- Computer programs known as the so called integrators of risk (Safeti, RiskPlot II, RiskCurves and @Risk)
- Risk calculation in designing, industry and environment (RMPlanner, Hazard-Review,Risk Radar, FaultrEase, Cegis FaultrEase, AgRisk, Site Safe, Boss, DNV Risk Management Software, EquIS –Environmental Quality Information System, RBCA, GoldSim),
- Risk calculation for the area of pipelines (Bass-Trigon Software, Boss, Pods),
- Risk calculation for the need of hydrology (Hfam, Hydron, Hydra),
- Calculation of the seismic risk (SMA, HCLPF, CDFM, IPEEE, SPRA, PSA),
- Risk calculation for the needs of healthcare and protection of employees (NPDES DMR, Human Exposure Assessment Modeling, Software Toolbox , EMS, IRAPh),
- Modelling the losses for a terrorist attack (VRA)
- Risk calculation in the area of finance and trade (Cobra, Algo Suite Solutions, QuantumSierra, Sierra Treasury, Sierra ASP, Cost-of-Risk-Analysis, Lattice Financial Software,STP, SunGard, Data).

From the point of view of the risk assessment the software can be used for the analysis of effects and impacts of individual types of risks and the probability calculation of the rise of an emergency.

The first group of software for analyzing the effects and impacts of individual types of risks will be dealt with in the next part of the text. For calculating the probability of an emergency we can mention the following types of software:

- Risk Spectrum – software for FTA, ETA, FMEA (www.riskspectrum.com), the most widespread software of the reference types of software worldwide,
- SAPHIRE – software provided by the company Lockheed martin USA for the state administration in the USA (www.saphiresoftware.com),

- Reliability Software and Safety Analysis Tools – reliability software (www.itemsoftware.com),
- UnRiskIT – used especially in the petrochemical industry (www.unriskit.com).
- @RISK. Software for Risk and Decision Analysis (http://www.palisade.com/)

Freely accessible software products were and still are being made to order for the governmental agencies (especially in the USA) or they are outputs of scientific projects funded by the European Commission or other grant agencies. They are also accessible in freeware form and accessible as open source. The most well-known freely accessible software products are developed by the US Environmental Protection Agency (EPA) EPA and the National Oceanic and Atmospheric Administration (NOAA):

- CAMEO. The CAMEO software suite is a system of software applications used widely to plan for and respond to chemical emergencies. CAMEO is used to access, store, and evaluate information critical for developing emergency plans. (http://www.epa.gov/emergencies/content/cameo/)
- ALOHA. ALOHA is an atmospheric dispersion model used for evaluating releases of hazardous chemical vapors. ALOHA allows the user to estimate the downwind dispersion of a chemical cloud based on the toxicological/physical characteristics of the released chemical, atmospheric conditions, and specific circumstances of the release. ALOHA can estimate threat zones associated with several types of hazardous chemical releases, including toxic gas clouds, fires, and explosions. (http://www.epa.gov/emergencies/content/cameo/aloha.htm)
- MARPLOT. MARPLOT is the mapping application. It allows users to "see" their data (e.g., roads, facilities, schools, response assets), display this information on computer maps, and print the information on area maps. The areas contaminated by potential or actual chemical release scenarios also can be overlaid on the maps to determine potential impacts. The maps are created from the U.S. Bureau of Census TIGER/Line files and can be manipulated quickly to show possible hazard areas.

Another interesting development in the field of industrial risk assessment is the ARIPAR software (Egedi et al., 1995). ARIPAR is a quantitative area risk assessment tool used to evaluate the risk resulting from major accidents in industrial areas where hazardous substances are stored, processed and transported. It is based on a geographical information system platform (GIS).

It was developed by the Institute for the Protection and Security of the Citizen of the Joint Research Centre of the European Commission (EC-JRC-IPSC), the Civil Protection Service of the Emilia Romagna Region (ERR), and the Chemical, Minerary and Environmental Technologies Engineering Department of the University of Bologna (DICMA). (http://ipsc.jrc.ec.europa.eu/). ARIPAR is running on ArcGIS 9.3 (Previous version 4.5 was dependent on ArcView 3.3).

6. Loss estimation for natural hazards in Europe

The loss estimation methods described above should also provide more detailed loss estimations for European countries. Maccaferri et al (2012) from the European Commission (EC) Joint Research Centre (JRC), on a request by DG Internal Market and Services (DG MARKT) investigated the publicly available information on insurance practices for Natural Catastrophes (NatCat) in place across European Member States (EU MS). The analysis should help future EC initiatives in the area of insurance for NatCat, e.g. to promote the development of an appropriate market for NatCat insurance products and/or improve the efficiency of existing markets. This research is a first step in the development of a EU

database on NatCat and of a methodology to analyze and compare NatCat risk and insurance practices across EU Member states.
The analysis focused on flood, storm, earthquake, and drought. For each of these NatCat, publicly available qualitative and quantitative information was collected and processed from a number of different sources in order to describe the size of the risks and detail existing practices of insurance systems. Interested stakeholders have been also consulted and involved in the collection of data. The research shows that that there is a need for more and better data on risk and insurance for NatCat and that common definitions should be agreed in order to make data comparable. Figure 5 presents the results of their analysis in terms of maximum expected losses as percentage of the GDP for European countries for Floods, Storms, Earthquakes and Drought. These data are only based on historical loss data for the period between 1990 and 2010, and are not based on the use of catastrophe models incorporating large events with a small frequency. They are therefore underestimation the expected losses to a large extend, as is the case for instance for flood losses in the Netherlands, which would be very high in the case of occurrence of a very rare extreme flood event. Therefore there is a great need to use this historical data in combination with catastrophe modelling to come up with better estimations and Loss Exceedance Curves.

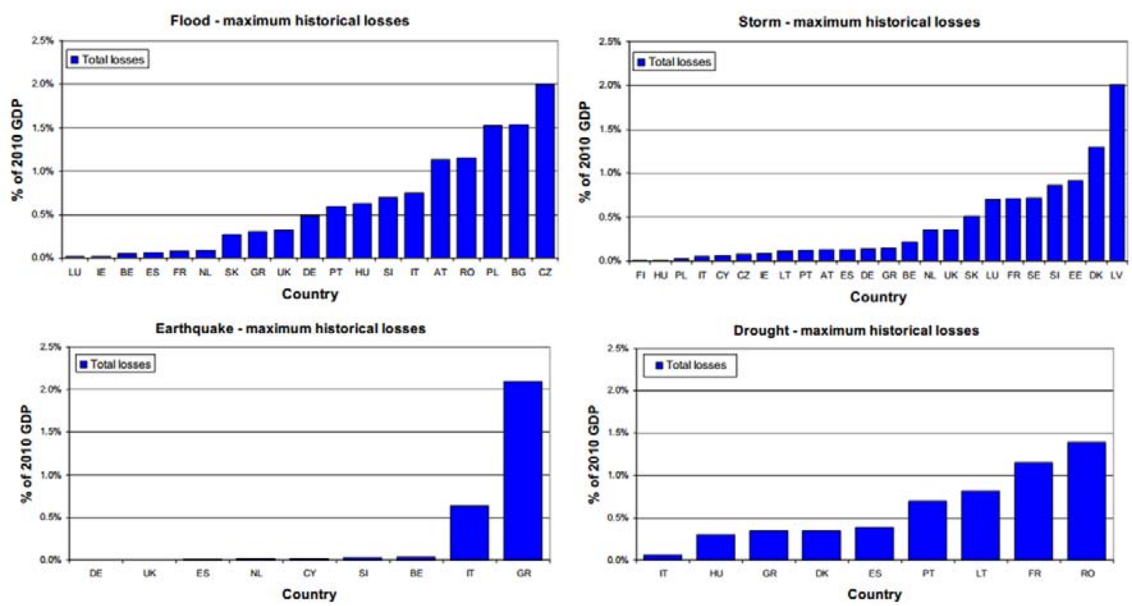

Figure 5: Overview of maximum historical losses based on available historical data for floods, storms, earthquakes and drought for European countries. Source: Maccaferri et al (2012).

For the countries that are involved in the InCREO project, Figure 6 and Table 2 provide a summary of the loss estimations based on Maccaferi et al (2012).

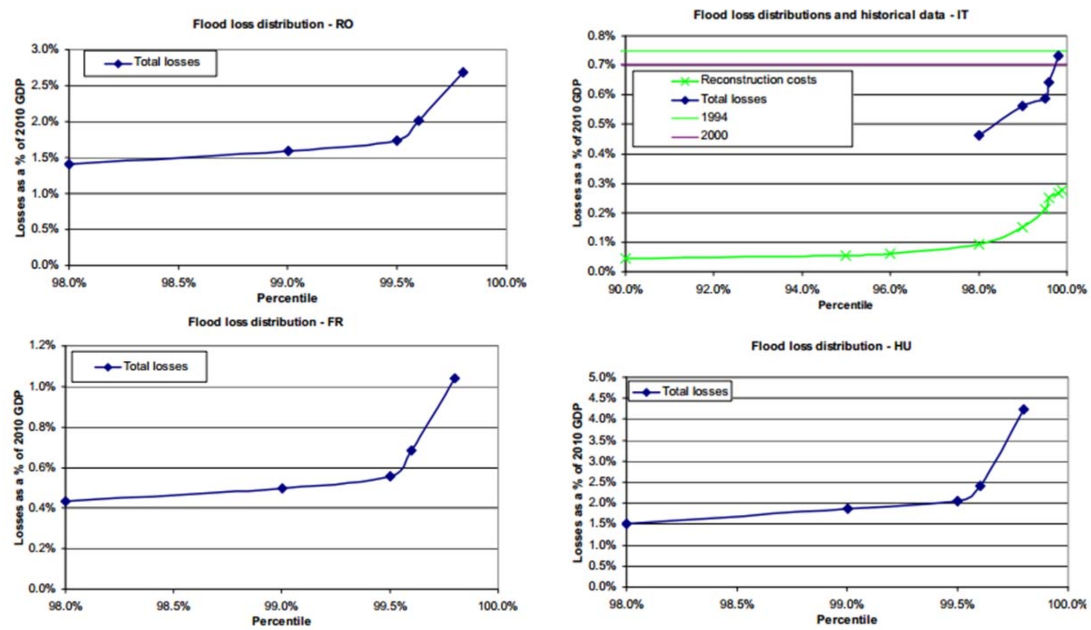

Figure 6: Simulated distribution of total losses for flooding for Romania, Italy, France and Hungary. Source: Maccaferri et al (2012). No data were available for Albania.

Country	Danger	Is the danger relevant (historical	Is danger relevant based on modelling	Is the NATCAT insured bundled?	Insurance penetration	Main Conclusions
France	Flood	<0.5%	<0.5%	Y	90%	Moderate size of the risk. Appropriate solution. The state is in charge of setting additional premiums, establishing deductibles and declaring the state of natural catastrophe. Moreover, the state owns and backs the Casse Centrale de Réassurance (CCR).
	Storm	0.7- 1.0%	-	Y		Relevant risk. Appropriate solution
	Earthquake	n.a.	-	Y		Appropriate solution
	Drought	>0.65%		Y		Relevant risk. Appropriate solutions.
Hungary	Flood	0.5 - 1.0%	1.5 - 2.0%	n.a	n.a	Relevant risk according to the loss distribution. Lack of additional information
	Storm	<0.335%	-	Y	n.a.	Moderate size of the risk. Lack of information
	Earthquake	n.a.	n.a.	n.a.	n.a.	n.a.
	Drought	0.1 0.7%	-	n.a.	n.a.	Relevant risk. Lack of additional information
Italy	Flood	0.5 - 1.0%	0.5 - 1.0%	N	5%	Moderate size of the risk. Should awareness among citizens be increased?
	Storm	<0.335%	-	N	5%	Moderate size of the risk.
	Earthquake	>=0.1%	-	N	5%	Relevant risk. Should awareness among citizens be increased?
	Drought	<0.1%	-	n.a.	n.a.	Moderate size of the risk. Lack of information.
Romania	Flood	1.0 - 1.5%	1.5 - 2.0%	N	n.a.	Relevant risk according to the loss distribution. Lack of additional information. n RO flood insurance is compulsory for dwelling but it is not bundled to any other policy
	Storm	n.a.	-.	n.a.	5%	Should awareness among citizens be increased?
	Earthquake	n.a.	-	N	5%	Should awareness among citizens be increased? In RO earthquake insurance is compulsory for dwelling but it is not bundled to any other policy
	Drought	>0.65%	-	n.a.	n.a.	Relevant risk. Lack of additional information.

Table 2: Summary of information on losses and insurance for Romania, Italy, France and Hungary. Source: Maccaferri et al (2012). No data were available for Albania.

7. Risk visualization

Risk management cannot take place without proper risk governance. Risk governance has been promoted in the ISDR, Hyogo framework for action to: “Promote and improve dialogue and cooperation among scientific communities and practitioners working on disaster-risk reduction, and encourage partnerships among stakeholders, including those working on the socio-economic dimensions of disaster-risk reduction" (UN-ISDR, 2005a). Governance depends on the level of political commitment and strong institutions. Good governance is identified in the ISDR Framework for disaster reduction as a key area for the success of effective and sustained disaster-risk reduction (IRGC, 2005). One of the important processes in risk governance is risk communication, which is the interactive exchange of information about risks among risk assessors, managers, news media, interested groups and the general public. An important component of that is the visualization of risk. Since risk is a spatially varying phenomenon, GIS technology is now the standard approach for the production and presentation of risk information. Risk can be presented in the form of statistical information per administrative unit, such as a Risk Index value resulting from qualitative risk assessment, the Probable Maximum Loss (PML) or Average Annual Loss (AAL), Loss-Exceedance curve for economic risk, or F-N curves for societal population risk. Risk can also be visualized in map form, that shows the spatial variation of risk.

The type of risk (qualitative/quantitative, direct/indirect, societal risk/individual risk etc.) and the visualization technique used depends on the stakeholder to which the risk information is communicated. Table 3 gives an overview of the relation between stakeholders and the type of risk visualization.

Internet-based GIS systems have been developed in which all the individual layers are separated (multi-tier approach) thus allowing many clients to access and visualize the geo-data at the same time. A WebGIS is a special GIS tool that uses the Internet as a means to access and transmit remote data, conduct analysis, and present GIS results. WebGIS applications for risk visualization have been developed for different purposes. At the global level, the PREVIEW Global Risk Data Platform is the result of efforts of UNEP, UNISDR, UNDP and World Bank, to share spatial data and information on global risk from natural hazards through the internet. Users can visualise, download or extract data on past hazardous events, human and economical hazard exposure, and risk from natural hazards on a platform compliant with OGC Web Services (OWS). It covers tropical cyclones and related storm surges, drought, earthquakes, biomass fires, floods, landslides, tsunamis and volcanic eruptions (see Figure 7). The collection of data is made via a wide range of partners (UNEP/DEWA/GRID, 2010).

An example of risk visualization at the international level is the multi-hazard risk atlas for the Andean region (Communidad Andina, 2009), that is available in paper atlas and Web-based versions. This atlas provides a comprehensive overview of the elements-at-risk in the region (population, production, and infrastructure), the hazard phenomena (earthquakes, tsunami, volcanic eruptions, landslides, flooding, cold waves and drought) and the risks in a very well designed manner. Examples of different approaches for visualizing flood hazard and risk maps from 19 European countries, USA and Japan are presented in EXCIMAP (2007). Many countries are also developing their own Web-based risk maps. For example the CEDIM Risk Explorer Germany is a web-based map viewer that interactively presents the results of the CEDIM project "Riskmap Germany" (Müller et al., 2006). A more complicated Web-GIS system has been developed in the Netherlands, which can be accessed by the general public as part of the national risk communication strategy. A secured section of the same system can be accessed by professionals involved in risk management, allowing them to get more detailed information required for emergency response planning. National-scale risk mapping in the Netherlands was carried out after the occurrence of major technical and flood disasters in the last decades. The Web-GIS application (see Figure 7) shows information on natural hazards (flooding, natural fires and earthquakes), technological hazards (transportation accidents, hazardous substances, nuclear) and vulnerable objects (Risicokaart, 2008). The flood-prone areas are defined by more than 1 meter flooding depth with a frequency larger than 1/4000 per year.

Stakeholder	Purpose	Type of risk visualization
General public	General information on risks over large areas	Basic WebGIS applications in which they can overlay the location of major hazard types with high-resolution imagery or topographic maps.
	Awareness raising	Animations (what if scenarios)
	Community-based DRR projects	Simple maps of the neighborhood with risk class, buildings, evacuation routes, and other features.
Businesses	Investment policies, and location planning	General information about hazards and risks in both graphical and map format.
Technical staff of (local) authorities	Land use regulation / zoning	Map with simple legend including construction restricted, construction allowed, further investigation required.
	Building codes	Maps indicating the types of building allowed (building type, number of floors).
	Spatial planning	Hazard maps, with simple legends related to probabilities and possible consequences.
	Environmental Impact Assessment	Maps and possible loss figures for future scenarios.
	Disaster preparedness	Real time simple and concise Web-based information in both map and graphical forms.
Decision makers / local authorities	Decision making on risk reduction measures	Statistical information, loss-exceedance curves, F-N curves, maps.
	Investments	Economic losses, projected economic losses for future scenarios.
	Strategic Environmental Assessment	General statistical information for administrative units.
NGO's	Influence political decisions in favor of environment and sustainable development	This can vary from simple maps to Web-based applications, depending on the objectives of the NGO.
Scientists / technical staff of hazard data producers	Hazard information exchange to public and other agencies	WebGIS applications where they can access the basic information.
	Exchange of basic information for hazard and risk assessment	Spatial Data Infrastructure / Clearinghouse for exchanging information.
Insurance industry	Development of insurance policy	Loss-Exceedance Curves of economic losses, F-N curves.
Media	Risk communication to public	Animations of hazard phenomena that clearly illustrate the problems.

Table 3: Relationship between stakeholders in risk management and risk visualization options.

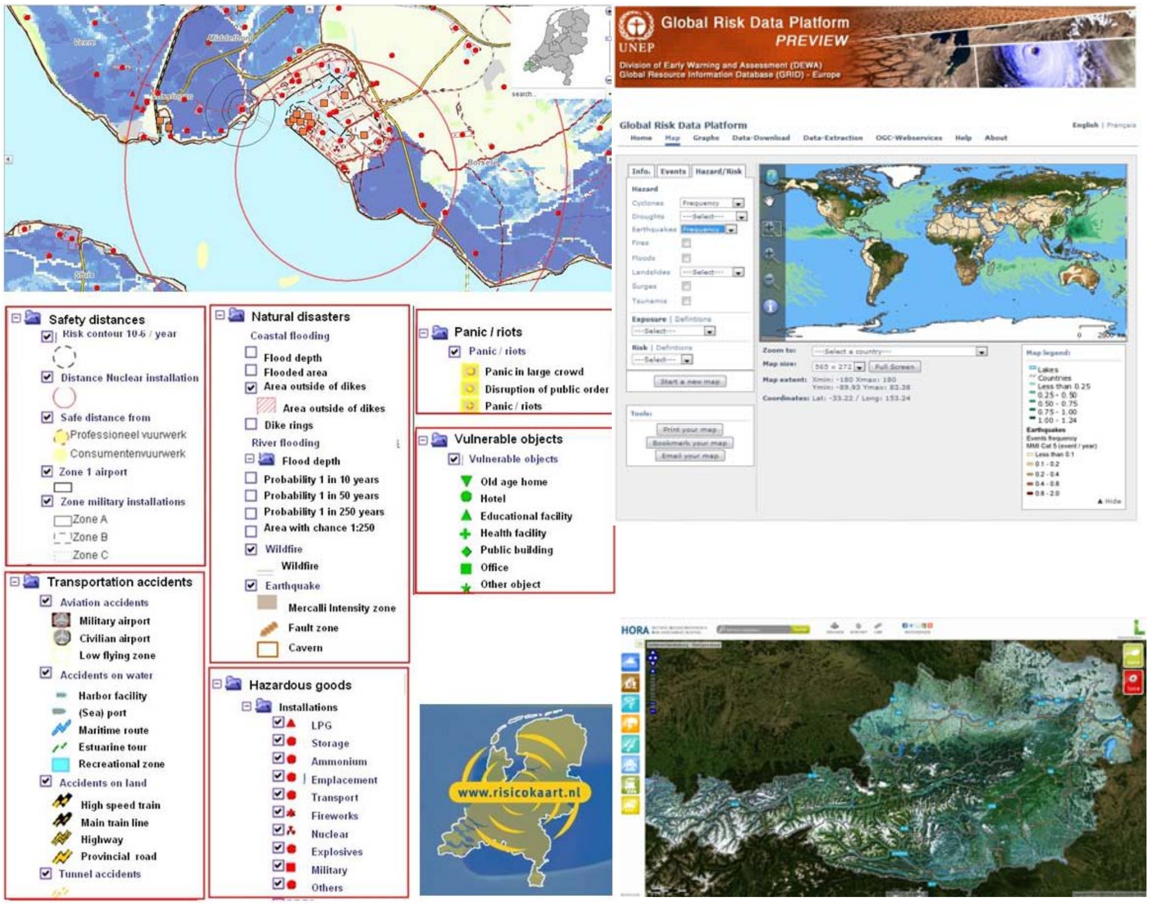

Figure 7: Three examples of Web-GIS systems for risk visualization. Upper left: National scale risk map of the Netherlands (Risicokaart.nl). Upper right: Preview portal for global risk visualization (UNEP/DEWA/GRID, 2010). Lower right: National hazard visualization system from Austria (Hora).

8. Conclusions

The aim of this deliverable is to give an overview of the available tools for loss estimation of natural hazards, focussing on the publicly available tools, and analyze their applicability in a European context.

The inventory presented in this report is probably still very incomplete as many other systems have been developed within individual countries, and which are less accessible through internet-based searches, also because they might be in different languages. As can be concluded from this inventory, there are many attempts to develop loss estimation tools, also using Open Source tools.

The standard in this field is the HAZUS software, which has been developed over a large period of time, and which is well structured and very well documented. HAZUS has been the blueprint for publicly available loss estimation tools. However, it has also a number of disadvantages which makes that others decided to develop their own software tools. The first disadvantage is that it is linked to commercial GIS software (ArcGIS) which, although this is the standard in GIS, is fairly expensive, and not Open Source. Also the regular changing version of the ArcGIS software make it in practice often cumbersome to apply HAZUS, as the version of HAZUS should match the ArcGIS version. Another disadvantage is that the HAZUS software was developed for the USA, and the administrative division and classification of building stock and other elements at risk reflects the situation in the USA. When applying HAZUS in other countries users should translate the local situation to the situation in the US, which is not always very easy. A third disadvantage is that the HAZUS software is not Open Source, eventhough the software is publicly available, for US organizations it can be downloaded, and for international users it should be ordered. This makes that the system is rigid and it is difficult or impossible to adapt the software to the particular needs of the user. Nevertheless, HAZUS has been applied in several European countries, and specific tools have been developed that make it better applicable in a European context.

Another main development has been the development of the CAPRA tool, which is strongly supported by the World Bank. The software architecture is very good, and in theory the software is adaptable to local situations. However, even though the software is Open Source, the documentation is very limited, and rather intransparent. The feedback from the developers on the Users page of the CAPRA platform is also very limited. This makes that in practice it is quite difficult to use. Also many of the individual tools use certain simplifications or use options that are more suitable for certain environments (e.g. Central America). Apart from earthquake loss estimation work in the area of Barcelona, there have been very few applications of the software in Europe.

A third major development that has taken place in the past years is the development of the OpenQuake software tool, as part of the Global Earthquake Model, in which academia collaborate with International organizations and with the (re)insurance sector. OpenQuake is developed as a web-based application, with Open Source software components. Also applications such as INASAFE, RiskinaBox, Kalypso and OpenRisk point into that direction.

In the framework of this inventory we have also tried to test a number of loss estimation tools, first by installing them, then by running the tutorial exercises (if available) and thirdly by using another dataset. The results of this testing process have been quite negative. Several of the software tools could not be installed properly, even though following exactly the installation instructions (if these were available). The ones that could be successfully installed were subsequently tested with their own datasets and tutorials. Whereas this worked very well for HAZUS (using US datasets), for RiskScape (using New Zealand data sets), and for INSAFE (using an Indonesian dataset) it was more problematic for other

tools, such as CAPRA, due to the poor documentation. If tutorials were available they were mainly directed to which button to press, without explanation on the data format, or procedures.
The application of the tools with another dataset has proven to be too difficult in the limited time which was available for this deliverable. Most of the tools had too many problems when trying to import new datasets, most often because of the poor documentation. Therefore benchmarking could not be done. This would be a good initiative in future but it would require substantially more time.

Many of the software tools are not developed enough to be able to use outside of the group that developed them. There is also a large amount of repetition and implementation of similar concepts, due to academic interests in developing such a tools themselves.

Nearly all of the tools stop at the point of the risk assessment, and very few also include tools for the evaluation of risk reduction measures. There are hardly any tools that incorporate cost-benefit analysis, cost-effective analysis or spatial multi-criteria evaluation. There are also very few tools that allow the direct comparison of a number of scenarios.

Another important point is that most of the tools focus primarily on the estimation of physical losses to buildings, lifelines, and to population loss estimations. Very few of the tools consider risk in a more holistic approach and link the loss estimation to a Spatial Multi-Criteria Evaluation of social, economic, environmental and cultural impacts.

There are also very few tools that consider risk as a dynamic process, and that take into account the analysis of future scenarios for climate change, land use change, and population change, in order to analyze the changes in risk.

One of the important developments of the past years is that the tools are developing into web-based Open Source tools. This will also be the direction in which the Risk Atlas and risk analyzer that will be developed in the framework of the INCREO project will go. The inventory of software is intended as a reference document for the software architecture to inform and guide developers about the architecture, standards, coding conventions, use cases and design constrains.

Good risk analyses rely on modelling using spatial information ranging from hazard data to population information and administrative jurisdictions. The purpose of the INCREO tool is to support the implementation of risk assessment and to support planning organization in the selection of the optimal risk reduction measures. Some of the requirements for the software are indicated below. A risk analysis and visualization tool should be able to:

- be relatively easy to use
- allow results to be reproduced
- ensure consistency across different reporting authorities
- not be dependent on a particular platform or GIS software.
- be able to run both locally without Internet access and remotely
- use commonly available standards and technologies
- support interfaces to a variety of external systems (e.g. GeoNode)
- support flexible development of impact models using plugins
- be internationalized
- conform with international standards including WMS `http://www.opengeospatial.org/standards/wms)`_
- OGC compliant protocols (as above)
- Must be able to be completely distributed (i.e. remote geoservers) or completely local (everything running on one PC)
- Peak transaction volume even when centralizated will be relatively low (less than 1 request per second)
- Need to be able to run on a local disconnected PC via a USB interface.

- Centralized server installation must also be supported
- Windows and Linux (developed using Ubuntu) will need to be supported
- End-user characteristics : Risk Managers
- Risk Managers will not be expert in hazard modelling
- Will use the system through a web browser
- Interface must be simple and support full language internationalization.
- Input should allow local users to upload geo-data about local conditions.
- When uploading data the system should create metadata based on the respone to a survey form which is used when uploading data.
- Different stakeholders should be able to upload there data (e.g, hazard organizations, elements at risk)
- Not focus on the hazard assessment, as this is the task of specialized expers.
- Allow both simply (exposure type) of amalysis as well as more complicated quantitave (QRA)
- Allow to analyze qualitative holistic risk
- Allow flexibility in characterization of elements at risk
- Allow user defined vulnerability curves, vulnerability matrices and simply approaches
- allow to develop risk reduction measures and analyze the degree to which the risk will change
- Allow to do a cost-benefit analysis
- Allow to do a Spatial Multi Criteria Evaluation
- Output should be clear and understandable.
- An expert advanced user mode should be supported for more experienced users.
- Must be able to upload maps layers and set layer metadata
- Should be able to use the plugin API to define new risk/impact functions
- End-user characteristics: Administrators
- Should be able to setup users permissions
- Review an audit of activities
- Update local documentation
- Possible and/or probable changes in functionality
- Support for more complex impact models
- Output should lead to a full risk management plan
- Increase support for probabilistic modeling (on a hazard by hazard basis)
- Interface with other Risk based web frameworks and with science based hazard estimation tools.
- Modularity and functional separation. Ensuring that API level separation (via web services) is maintained between the functional components (Server, Web frontend and GeoServer)
- Emphasis on maintainability and robustness versus speed. Since this will be an open source project it is desired to make the code simple and well documented.

It is evident that the world undergoes rapid changes in terms of population growth, urbanization, economic development and socio-political structures. Furthermore, there is convincing evidence that greenhouse gas forcing may be causing changes in the earth's climate that are expected to lead to an increase in hazardous events due to a hydro-meteorological trigger (IPCC, 2012).

The difficulty in predicting the magnitude of these changes and the frequency of occurrence of extreme events, reiterates the need for a thorough change in our adaptation management of hydro-meteorological risks (EEA, 2004). According to recent European studies, the projected impact of flooding in Europe will increase dramatically in the coming decades. By

2080 it is estimated that between 250,000 and 400,000 people will be affected each year by flooding, and the total annual expected flood damage will range between 7.7 and 15 billion Euros. These values are more than double of those in the period 1961-1990 (Ciscar, 2009). Very limited work has been carried out up to now to include the cascading or conjoint (also called domino) effects in the analysis of future impacts of environmental changes to hydro-meteorological hazards. The exposure of elements-at-risk also increases and therefore the risk of natural hazards is constantly growing. Land-use changes will occur as a result of technological, socio-economic and political developments, as well as global environmental change. The nature and rate of change will strongly depend on policy decisions. Many environmental problems are caused by unplanned urban expansion. By 2050, approximately 70 % of all people will be living in urban areas, while in several countries the proportion will be 90 % or more. Some of the drivers of change to the urban environmental are the global economy, cross border transport networks, large scale societal, economic and demographic changes and differences in national planning laws. As the level of uncertainty of the components used in the risk equation (hazard, vulnerability, quantification of the exposed elements-at-risk) is very high, the analysis of the changes in future risk should incorporate these uncertainties in a probabilistic manner.

Impacts of natural hazards on the environment and on the society are still tackled by mono-disciplinary approaches. The focus is reflected in the domains of scientific research (single approach and tools for each type of hazard), in the existing management tools, and in the legislative basis of these activities. Management tools, models, and local-to-regional technical solutions have been proposed by numerous projects for single hazards. Only a few of them have tackled the issue of risk assessment and management, however, from a multi-hazard perspective, especially including possible combined and domino effects. Probabilistic tools for multi-hazard risk assessment are not available to stakeholders at the local level. Insurance companies and specialized risk-assessment consultants have developed models, but these are not open for public use. The implementation of risk-management measures such as disaster-preparedness programmes, land-use planning, regulatory zoning and early warning systems are considered essential. Fleischauer et al. (2006) conclude that spatial planning is only one of many aspects in risk management and that it is, in general, not properly implemented. Further, multi-risk assessment approaches are not used in planning practice: risk indicators are hardly used and vulnerability indicators are not at all used.

Therefore approaches are needed for integrating disaster-risk assessment in long-term resource allocation and land-use planning at all levels of administration. Additionally, scientific advances in hazard and risk assessment and demands of stakeholders/end-users are still not well connected. In many cases, the scientific outcomes remain rooted solely within the scientific community, or new knowledge is not fabricated enough to be implemented by stakeholders and end-users (IRGC, 2005). A key cause of the gap between the science community and stakeholders/end-users is in the complexity of human-environment interactions. This has led to the development of a diversity of approaches, often not easy to implement by the end-user community. There is a need for the development of a harmonized decision-making structure for applying hazard and risk mitigation through spatial planning in risk-prone areas. There is also a need for capacity building in the field of multi-hazard risk assessment, and the transfer of the knowledge from developed countries to developing countries using Open-source software tools and methods adapted to the data availabilities in these countries (Van Westen et al., 2009). The Hyogo framework of action 2005-2015 of the UN-ISDR indicates risk assessment and education as two of the key areas for the development of action in the coming years

Good risk analyses rely on modelling using spatial information ranging from hazard data to population information and administrative jurisdictions. The purpose of the INCREO tool is to support the implementation of risk assessment and to support planning organization in the selection of the optimal risk reduction measures (See Figure 8).

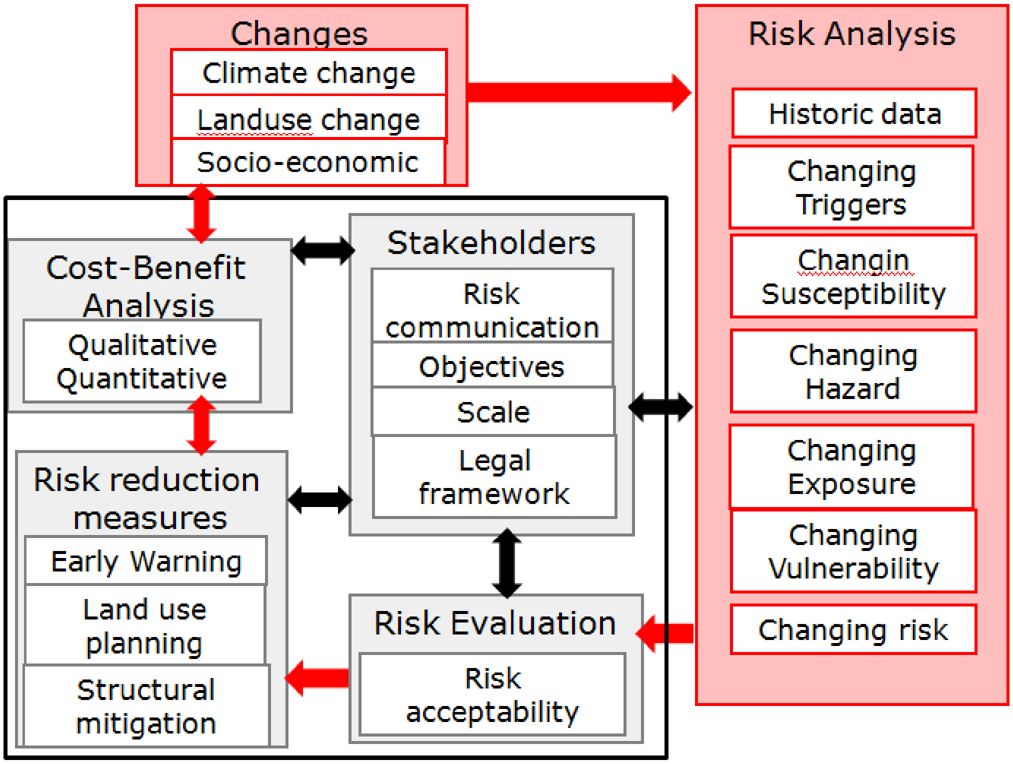

Figure 8: Risk Analysis is an important input in decision making. It is also a cyclic process as it needs to be redone for different risk reduction alternatives, as well as for future change scenarios.

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10. Annexes: description of Loss estimation software tools.

In these annexes a number of loss estimation tools are presented in more detail, than in the main text.

10.1 Multi-Hazard Risk Assessment Tools

10.1.1 HAZUS

HAZUS is a Multi-Hazard tool that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS-MH is FEMA's acronym for "Hazards U.S. Multi-Hazard" software program. HAZUS uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquake, hurricane, and floods. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modelled, a crucial function in the pre-disaster planning process.
Government planners, GIS specialists, and emergency managers use HAZUS to determine losses and the most beneficial mitigation approaches to take to minimize them. HAZUS can be used in the assessment step in the mitigation planning process, which is the foundation for a community's long-term strategy to reduce disaster losses and break the cycle of disaster damage, reconstruction, and repeated damage. Being ready will aid in recovery after a natural disaster.
The software uses C++ and Visual Basic routines to implement loss models and Microsoft SQL as a relational database, interfacing also with ArcGIS in order to express the damage states for the building stock and lifelines (as well as essential and large-potential loss facilities). HAZUS was originally developed for earthquakes. Later also modules for flooding and tropical storms were included. HAZUS was applied successfully because of the large amount of data that the U.S. has gathered on assets in digital form, the specialised nature of the program and the U.S. typology of buildings. However, most countries do not have this level of data available and may have different combinations of hazard (landslides and volcanoes) or vulnerability (building types and construction codes), which therefore render the HAZUS methodology not as effective. An example of one such adapted code is for an area in Andhra Pradesh for India, by Siddiqui *et al.* (2007).
Developed by:
Federal Emergency Management Agency (FEMA) of the US Department of Homeland Security.
For more information:
http://www.fema.gov/plan/prevent/hazus/
Data that comes with HAZUS-MH is open source and collected for the United States of America. It is regularly updated and each upgrade and it has more than 200 data layers. The inventory data is divided into the following types:

- Common to All Hazards
  - General building types and occupancies
  - Lifelines
  - Replacement costs
  - Demographics

- Hazard Specific
    - Specific building types
    - Elevation
    - Building configurations

Flood Model
The Flood Model is used to assess both riverine and coastal flooding. This model estimates potential damage to all classes of buildings (wood, concrete, unreinforced masonry, etc.), essential facilities (medical facilities, emergency operations centers, and schools), transportation and utility lifelines, vehicles, and agricultural crops. Casualties can be estimated from census information. The model addresses building debris generation and shelter requirements. Direct losses are estimated based on physical damage to structures and their contents and interiors.

Hurricane Winds Model
The Hurricane Winds Model can run analysis for 22 states including Hawaii. Loss estimations are done for commercial, residential, and industrial buildings. The analysis can take up to four hours for large study regions with Census 2000 tracts. It also estimates direct economic loss, post storm shelter needs, and building and tree debris quantities. The hurricane scenarios can now also be downloaded from the National Weather Service Web site.

Earthquake Model
HAZUS is a complex collection of components that work together to estimate casualties, loss of function and economic impacts on a region due to a scenario earthquake. With the Earthquake Model, damage and loss estimations to buildings, essential facilities, transportation and utility lifelines, and population, based on scenario or probabilistic earthquakes, can be mapped and reports can be created. It estimates the debris resulting from quake fire damage, casualties, and shelter requirements. Direct economic losses are estimated based on physical damage to structures and their contents and interiors.

Hazard
Definition of hazard (type of hazards):

- Floods
- Hurricanes
- Earthquakes

Frequency assumptions, is the tool deterministic / probabilistic:

- Temporal probability is calculated
- The time of return period is also considered to calculate the hazard

Multi-hazard assessment treated separately or real joint probabilities:

- The tool calculate the probability given by multi-hazard events (e.g. floods, hurricanes)
- Validation of the hazard:

Historical event analysis for key events (e.g. flood footprints for past events?):

- Flood event map (historical flood) are not taken in consideration

Data sources:

- Nationwide Databases

Risk/Vulnerability:
Definition of Vulnerability (monetary, risk classes etc.):

- Is defined as the probability of exceeding a limit state, given a value of displacement demand
- Vulnerability curves are used to assessing risk

Elements at risk available:

- Buildings, infrastructure, population, agriculture from a pre-existent database

Validation of the vulnerability assumptions / results:

- Vulnerability of society (shelter requirement and displaced population) is used to assess risk

Flexibility:

Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):

- study area of any size: Region, Community, Neighborhood, Individual Site

Applicability to Europe or other regions:

- It is created for US but it can be applied also in EU thanks to a specific implementation of the software

Users comment:

- **Usefulness:** The Hazus Flood Model produces loss estimates for vulnerability assessments and plans for flood risk mitigation, emergency preparedness, and response and recovery. The user can evaluate losses from a single flood event, or for a range of flood events allowing for annualized estimates of damages. Using the extensive national databases that are embedded in Hazus, users can make general loss estimates for a region. These databases contain information such as demographic aspects of the population in a study region, square footage for different occupancies. Users could be mainly from federal state to local agencies
- **Transparency:** The methods used need ArcGIS are clear and very well explained.
- **State of the art:** The inventory is very detailed. The software is complete and very well projected for a good environmental study of Multi Hazard Risk

Uncertainty Assumptions:

- Uncertainty could be assessed for losses estimation

Note:

The map and report outputs of HAZUS-MH differ for each hazard model. The Earthquake Model has the most comprehensive output list. This model estimates the damage to buildings, facilities, and systems; damage from fires following an earthquake; hazardous materials release; and lastly, debris generation. Additionally, direct losses such as repair costs, income loss, casualties, and shelter needs are included. Indirectly calculated losses are supply shortages, sales decline, opportunity costs, and economic loss.

The Flood Model estimates direct damage to buildings, essential facilities, and transportation and utility systems and induced damage estimations only for debris generation. Direct losses include the cost of repairs, income loss from crop damage, and shelter needs. Casualties are estimated by a general output. Indirect losses include supply shortages, sales decline, opportunity costs, and economic losses.

The Hurricane Winds Model estimates direct damage to buildings, essential facilities, and high-potential-loss facilities. Induced damage estimations include hazardous materials release and debris generation. Direct losses include the cost of repairs, income loss, and shelter needs. There is no output for indirect losses.

*Because of the large amount of data that the U.S. has gathered on assets in digital form, the specialised nature of the program and the U.S. typology of buildings, HAZUS can be applied successfully. However, most countries do not have this level of data available and may have different combinations of hazard (landslides and volcanoes) or vulnerability (building types and construction codes), which therefore the HAZUS methodology not as effective.

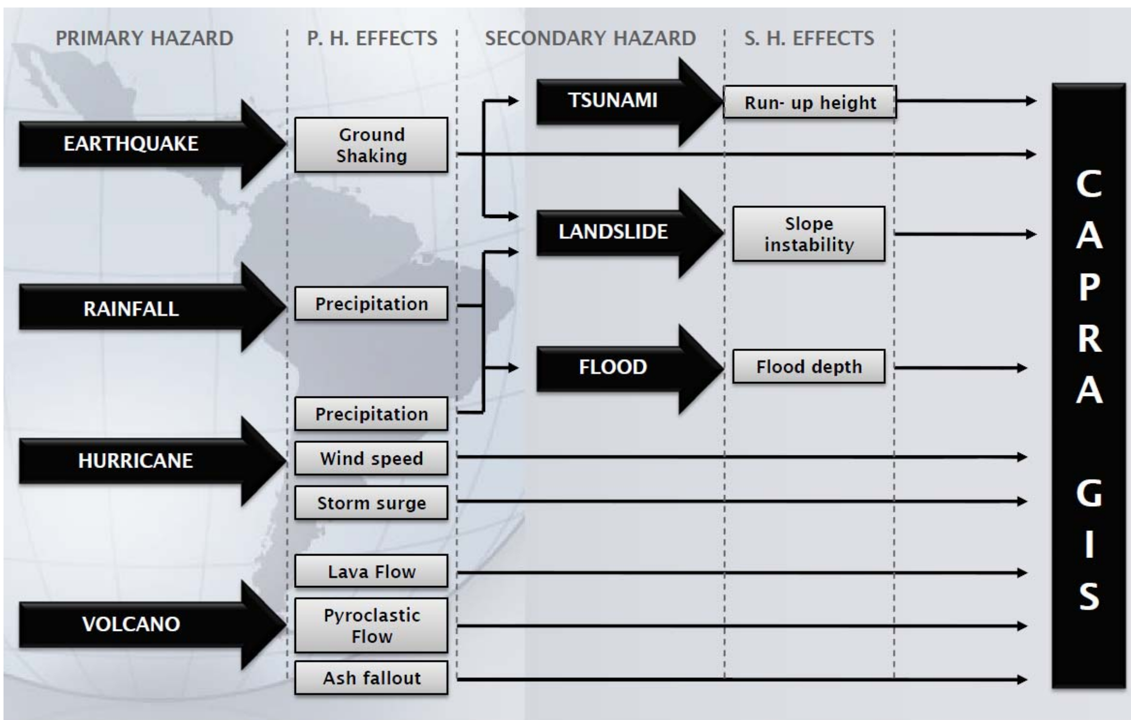
International applications of HAZUS

Recent research studies revealed that the EFD can be fully supported by Hazus-MH, which represents an extensively applied and well documented GIS-based framework for risk estimation of natural hazards in the US. However, the difficulties of non-US data integration into HazusMH Flood Model still exist. This paper describes the hierarchical system of Hazus data, the data types, structure and integration, but the main focus is a newly developed automatic HAZ-I toolset. This toolset works within ArcGIS framework and enables the user to create a new study region worldwide in order to perform flood risk assessment and to acquire essential assets at risk from the Volunteer Geographic Information datasets. The Hazus-MH results from two studies show the potential how HAZ-I toolset supports Hazus-MH in flood risk assessment together with open source or either governmental datasets.

HAZ-Taiwan is built based on HAZUS-based methodologies which have been tested for Taipei City and other cities. It uses the same type of building size discrimination as in HAZUS, which forms the database. The economic loss estimation model assumes damage based on spectral displacement (Sd) for the structural systems and drift-sensitive non-structural components; yet spectral acceleration is used for the acceleration-sensitive non-structural components. It also incorporates a probabilistic risk analysis methodology to produce exceedance probability curves based on the mean and standard deviation for regional losses on multiple event philosophies.

10.1.2 CAPRA

CAPRA (Central American Probabilistic Risk Assessment) is an open source platform for risk analysis, which applies probabilistic techniques to hazard and loss assessment. The platform was designed from the start to be modular and extensible.
CAPRA consists of a GIS-based platform for risk analysis, where probabilistic techniques are applied to the analysis of earthquakes, tsunamis, hurricanes, floods, landslides and volcanoes. Hazard information is combined with exposure and vulnerability data, allowing the user to determine risk simultaneously on an inter-related multi-hazard basis, distinguishing the platform from previous single hazard analyses. CAPRA is a Disaster Risk Information Platform for use in decision-making that is based on a unified methodology and tools for evaluating and expressing disaster risk. Building on—and strengthening—existing initiatives, CAPRA was developed by experts to consolidate hazard and risk assessment methodologies and raise risk management awareness



Developed by:
This software is developed with funding from The World Bank, by the ERN-LA consortium, formed by the following companies and institutions: ERN Ingenieros Consultores (México), ITEC (Colombia), INGENIAR (Colombia) and CIMNE (Spain).
For more information:
http://www.ecapra.org/software

Hazard Modules

- The hazard modules include a set of software tools to model hazard frequency and intensity for earthquakes, tsunamis, cyclone, floods, landslides and volcanic hazards.

Exposure Module

- The exposure module uses information to depict the inventory of assets, including tools for the localization, classification, qualification and valuation of infrastructure potentially exposed to the hazard being considered.

Physical Vulnerability Module

- The vulnerability module includes software tools for the development of physical vulnerability functions for each hazard and class of asset considered. The vulnerability module also can also be used to assign specific vulnerability functions to the exposed elements.

Loss Module

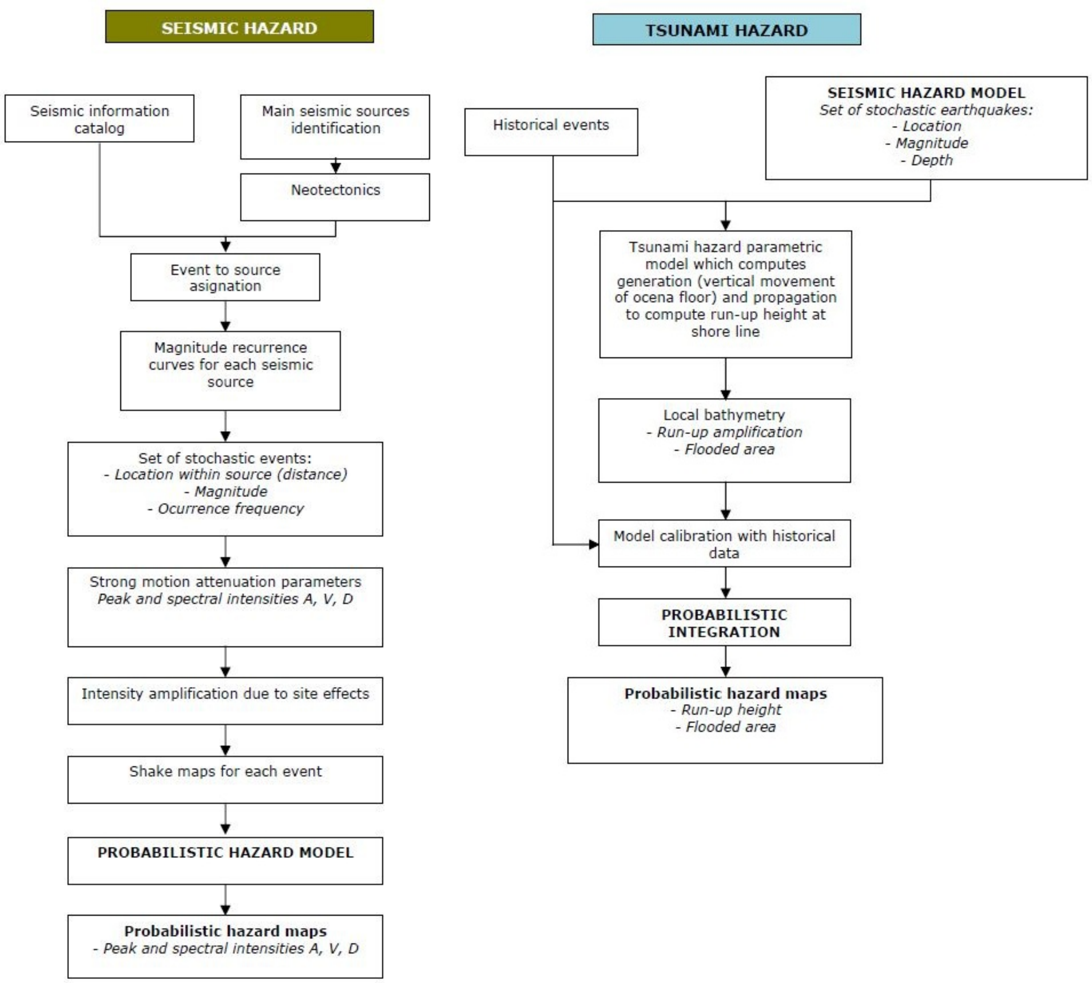
- The loss module is used to calculate the potential for losses for user-defined return periods or specific scenarios.

Additional Modules (planned but not available yet)

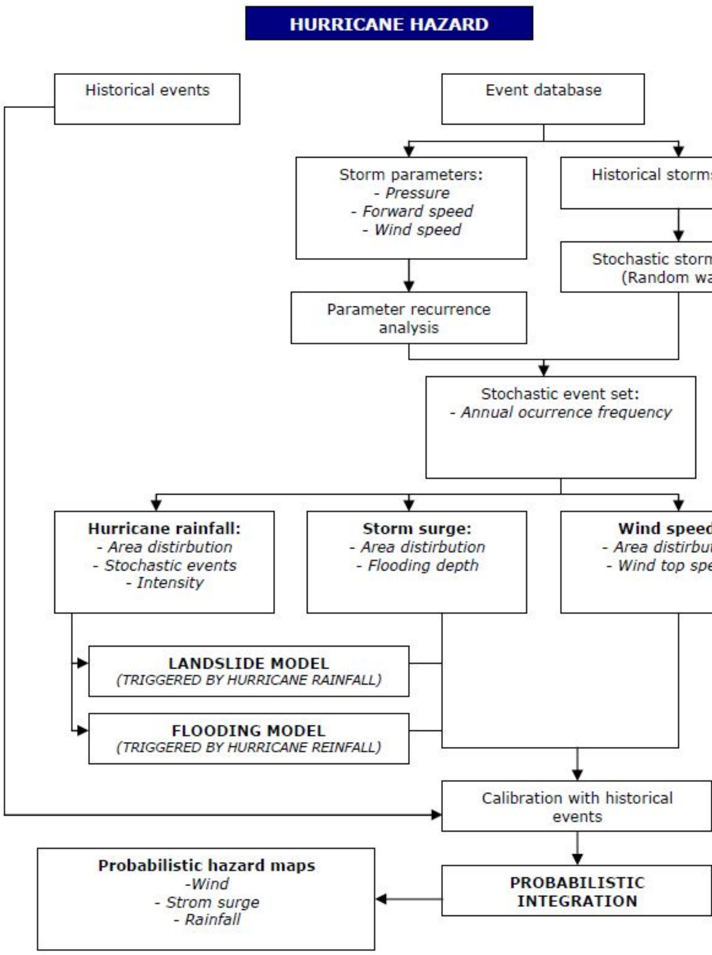
- **Climate change scenarios:** Process the extreme events and physical potential impacts based on information from climate change models.
- **Rapid on-time loss estimation:** Process probable loss estimates based on pre-defined scenario events (for cyclone or earthquake risk).
- **Holistic risk evaluation:** Process integrated interdisciplinary risk analysis to generate pre-defined risk indicators.

CAPRA has the following Hazard modules.

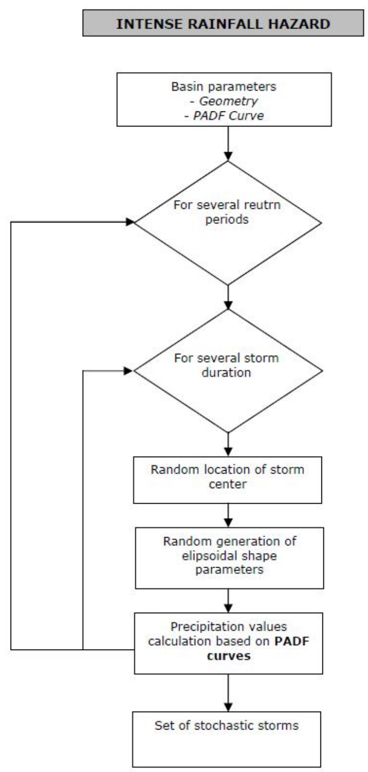
- **Crisis 2007.** CRISIS 2007 is the CAPRA seismic and tsunami hazard module. It allows the complete definition of a seismic model for probabilistic hazard assessment, and the calculation of stochastic scenarios for risk evaluation. CRISIS 2007 was developed at the Engineering Institute of the National University of Mexico (UNAM).



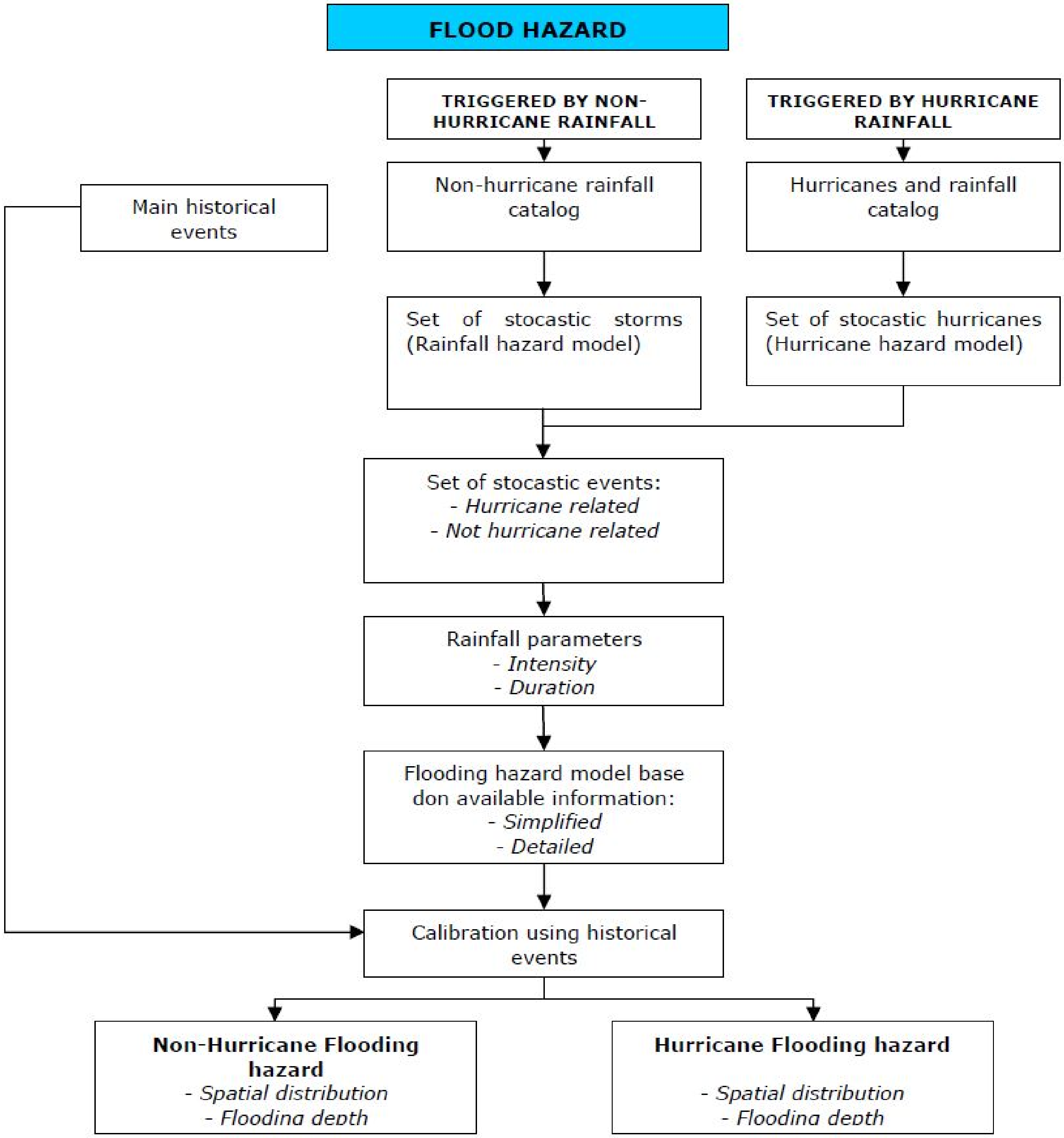
- **ERN-Hurricane.** ERN-Hurricane is a software for modelling hurricane wind, storm surge, and hurricane rainfall. It generates hazard graphs of simulated hurricanes based on historical scenario trajectories or actual historical trajectories. It also calculates the hazard of an active hurricane about to impact an area of interest.



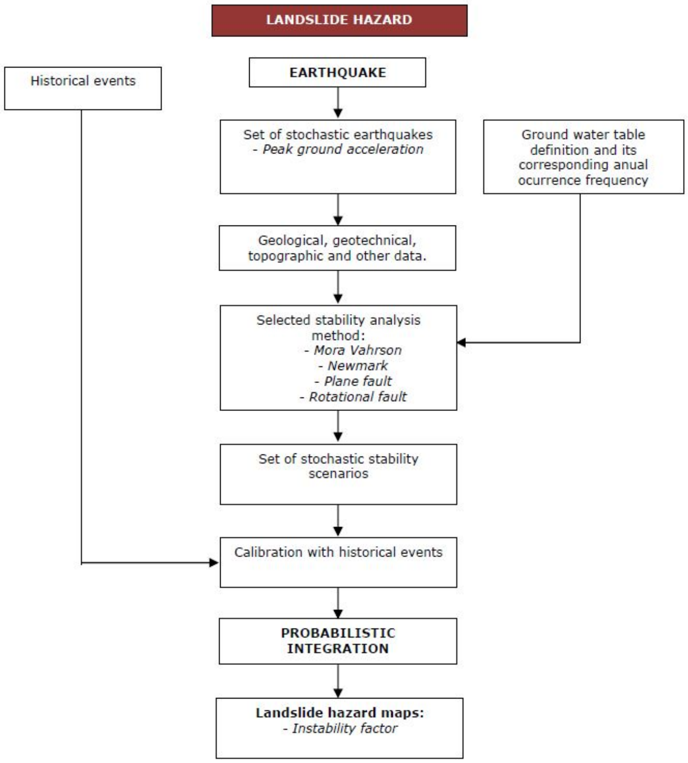
- **ERN-NH rainfall.** ERN-NH rainfall is a program for calculating intense non-hurricane rainfall hazard. The software is capable of modeling of storms based on PADF curves.

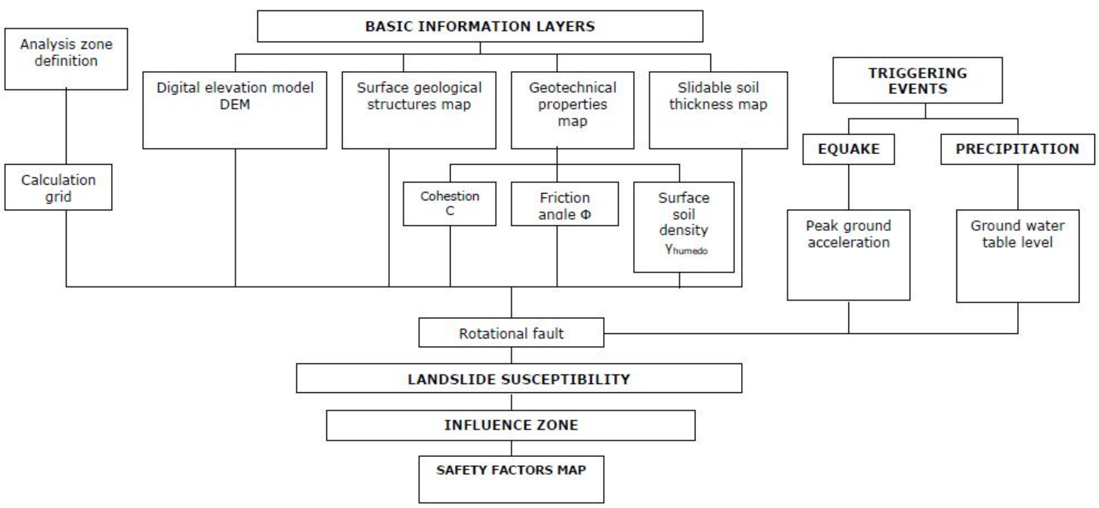


- **ERN-Flood**. ERN-Flood allows the estimation of the flood depths on any given region, based on a set of stochastic rainfall scenarios. The software is capable of simplified and inn-depth methods for flood hazard analysis. The in-depth method constructs a unitary hydrogram at the mouth of the basin, based on its characteristics, for each precipitation event and analyses the evolution of the flood event. The simplified method obtains potential areas of flooding that take very general account of topography and land use at each point analyzed.

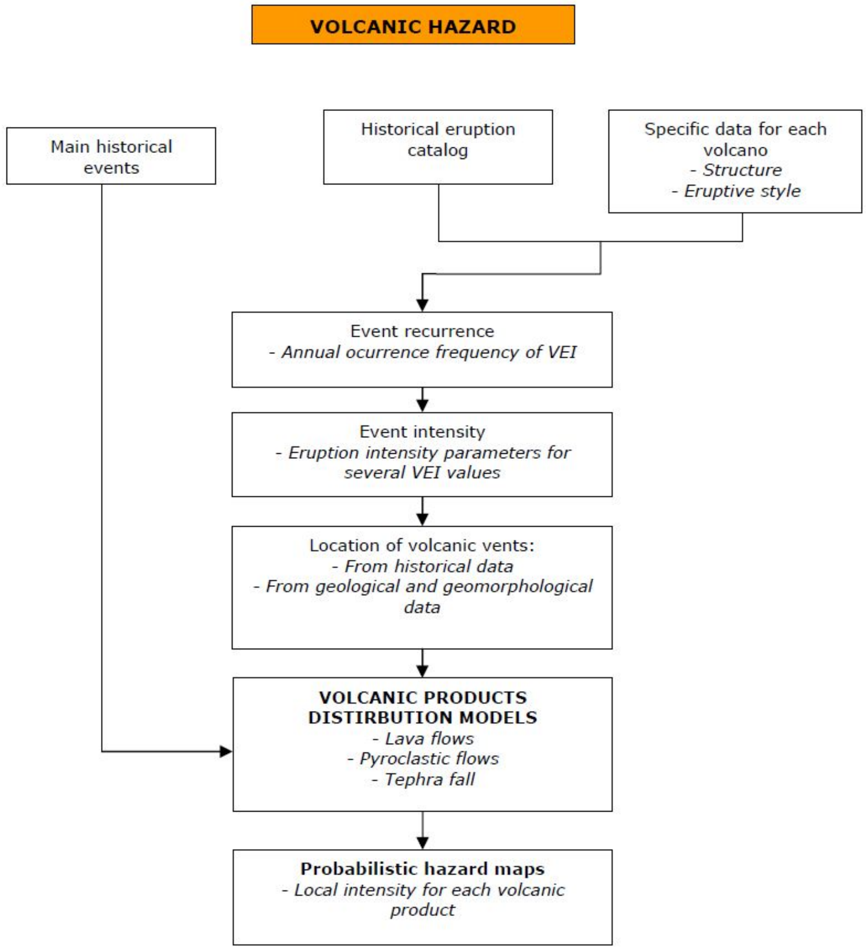


- **ERN-Landslide**. Is a software for landslide hazard modeling developed by ERN. Based on the quantity and quality of the available information, users may select between these hazard evaluation methodologies. The methods utilize seismic action and rainfall as trigger factor, but do not incorporate probabilistic aspects. The module is currently not available thorugh the website:
    - Mora-Varhson's method
    - Infinite slope method
    - Newmark's method
    - Spherical failure method


LANDSLIDE HAZARD
Historical events
EARTHQUAKE
Set of stochastic earthquakes
- Peak ground acceleration
Ground water table definition and its corresponding anual ocurrence frequency
Geological, geotechnical, topographic and other data.
Selected stability analysis method:
- Mora Vahrson
- Newmark
- Plane fault
- Rotational fault
Set of stochastic stability scenarios
Calibration with historical events
PROBABILISTIC INTEGRATION
Landslide hazard maps:
- Instability factor


Analysis zone definition
BASIC INFORMATION LAYERS
Digital elevation model DEM
Surface geological structures map
Geotechnical properties map
Slidable soil thickness map
TRIGGERING EVENTS
EQUAKE
PRECIPITATION
Calculation grid
Cohestion C
Friction angle Φ
Surface soil density
Peak ground acceleration
Ground water table level
Rotational fault
LANDSLIDE SUSCEPTIBILITY
INFLUENCE ZONE
SAFETY FACTORS MAP

- **VHAST**. VHAST is the volcanic hazard analysis and simulation tool and is capable of modelling of ash fall, lava flow, and pyroclastic flow events. It is capable of making probabilistic modeling of the hazard by stochastic eruption simulation.



- **ERN-Vulnerability.** ERN-Vulnerability is the program for calculating vulnerability curves. It generates seismic vulnerability functions based on capacity curves. Vulnerability functions can be defined for different types of hazards with a wide array of behaviours and two control points. Quantitative vulnerability using intensity-damage curves. The vulnerability is described in a curve of damage (0 to 100%) versus the hazard intensity. Elements at risk are imported as shape files, with each element part of an attribute table. The values of the elements are used to calculate the monetary loss estimation.
-
- **CAPRA**-GIS. This is the central tool for integrating the hazard, exposure and vulnerability. It is a new GIS system specifically focusing on calculating Exceedance Probability Curves, and displayed loss information.

Multi-hazard assessment treated separately or real joint probabilities:

- Hazards probabilities are calculated separately except for cascading events:
- Hurricane → rainfall → floods and landslides
- Intense rainfall → floods and landslides

Applicability to Europe or other regions:

CAPRA is being applied by ERN (MOVE, FP7 project of European Community) to estimate seismic risk for the city of Barcelona, Spain. So in theory it is possible to apply the tool on European sites. However there are 3 main points that must be addressed:

- A catalog of historic events needs to be created specifically for each European site. This is needed in order to calculate the temporal probability or to create magnitude-frequency curves for a specific hazard based on the past events in the European sites of interest.
- The actual modeling of the hazard, whether statistically or deterministic (or combination), needs to be compatible with the type of hazard being assessed in the European sites. E.g. a model used for rainfall in South-America (CAPRA) is not necessarily representative for European rainfall events.
- Vulnerability curves used in the risk and loss estimation need to be consistent with the interaction between the hazards and building types being assessed in the European test sites.

Users comment:

- **Usefulness:** If specific hazard and vulnerability modules could be built for CAPRA for the European sites, its applicability could be very useful to assess loss estimation for the multi-hazard approach.
- **Transparency:** The hazard modules within CAPRA are basically black boxes where the intensity or return period of the hazard can be specified within a specific range but cannot be accessed to assess or modify the actual models. The vulnerability curves are visible and can be chosen from files within the vulnerability module. But just like the hazard modules, one needs to be able to add their own vulnerability curves into a module.
- **State of the art:** The visualization within the GIS environment is simple but effective.
- The stochastic modeling of for example earthquake sources/intensity is time consuming but could be very useful for a probabilistic approach. The hazard models need to be assessed for their usefulness, especially in the case of landslides, which are based on susceptibility and slope stability models.
- **Uncertainty Assumptions:** CAPRA takes into account the uncertainties of the probabilistic hazard and vulnerability outputs used for the loss estimation. For example, with the vulnerability to seismic hazard, the damage ratio is given as a probability distribution and the measure of the uncertainty is given in terms of its standard deviation.

10.1.3 RiskScape

RiskScape is such a multi-hazard loss modelling tool for analyzing risks and impacts from multiple hazards. RiskScape is a joint venture between GNS Science & NIWA to develop an easy-to-use multi-hazard impact model for New Zealand
The RiskScape model's primary purpose is to provide a framework for quantifying the possible impact or risk to assets from different natural hazards. The model outputs will assist central and local government, regional civil defence emergency management groups, private organizations and the public in making risk-based decisions on natural hazard management issues.

For more information
http://www.riskscape.org.nz/

First, the assets that are to be impacted are identified. This includes the determination of the physical area that is being modelled. Second, a hazard model is run for the area. The nature of the hazard model is undefined (as it can come from any source, as described above), but it must produce an output that complies with the RiskScape plugin specification.Third, the impact model is run. The impact model takes the attributes of the chosen assets, along with the exposures calculated by the hazard model, and computes the impact of the hazard on each asset using fragility functions. This step is the core of RiskScape. Last, the results are aggregated to a set of chosen spatial units (e.g. meshblocks).

Hazard Module. RiskScape currently covers five natural hazard types:
- Earthquakes
- Flooding (River)
- Tsunami
- Volcanic Ashfall
- Windstorm

* While using the software it was found that **Storm Surge hazard** is also covered

- **In future will include extending the list of hazards:**
- Landslides (both earthquake and rainfall triggered)
- Coastal storm-tide inundation
- Proximal volcanic hazards (pyroclastic flows and lahars)
- Snow storms
- Climate change effects

Asset Module
These are databases of assets that can be impacted by a RiskScape model. Each asset module may contain only one type of asset, but multiple modules can be combined into a single analysis. The types of assets and the attributes that each type must specify are described in the next section.A number of 'default' asset databases are supplied with RiskScape, but a toolbox is also supplied to allow users to import their own asset datasets. The only caveat is that the user dataset must comply to the RiskScape standards for the attributes that it specifies.
Regional Asset databases supported by RiskScape

- **Business Sector (**Commercial, Industrial, Farming & Horticulture , Forestry , Tourism)
- **Built Environment (**Critical facilities (Medical/Fire/Police/Local Authorities/Civil Defence), Buildings (Residential /Commercial/Industrial), Utilities (Gas/Power/Telecom/Fuel/Water & Wastewater, etc.) , Transport (Road/Rail/Air/Sea)
- **Human Environment .** Demographics (e.g. age, gender, ethnicity, income distribution), Deprivation Index, Seasonal/Diurnal variations, Aggregation Module

The aggregation module specifies the aggregation units that are to be used to collate the results of the analysis. Applying fragility curves to individual assets yields the average expected loss (for that particular asset type), not the actual damage of that individual asset. Hazards can be however quite localized, like flood and wind hazards.

Input and Output:
Inputs:

- The tool works with Modules that are Assets (Agriculture under development, Buildings, Electricity Cables, Network Junction Points, Open Space, Pipelines, Roads, Telecommunication Cables, Waterways). You have the choice of analyzing the entire dataset or choosing a subset of the data creating filter.
- Hazards (type of hazard that you want to calculate)
- Impact (type of damage that you want to calculate as human losses, reinstatement costs, etc…).

Outputs and visualizations:

- Hazard visualization:
- Earthquake Ground Shaking Intensity
- Flood Inundation Depth, Inundation Duration, Inundation Velocity, Ponding
- Tsunami Inundation Depth, Inundation Duration, Inundation Velocity, Ponding
- Storm Wind Velocity
- Landslide Ground Displacement
- Volcanic Ash fall Ash fall, Ash Thickness
- Impact and Fragility Types:
- Human Losses (A measure of the detrimental effect on humans who are present in or at this asset of the asset's exposure to the hazard. Measured in number of people and displayed as a number or proportion)

- o Damage State (A measure of the extent to which the asset is Damaged)
- o Human Displacement (A measure of the extent to which humans and human activities are displaced by exposure of the asset to the hazard)
- o Human Susceptibility (A measure of the susceptibility to injury (damage) of a hypothetical human present in or at this asset.
- o Reinstatement Cost (Encompasses all direct costs caused by exposure of the asset to the hazard Measured in $ and displayed as number).
- o Functional Downtime (Productive time lost due to the impact of the hazard on the asset, measured in person-days.)
- o The output of the analysis must be aggregated to an aggregation unit mesh blocks, suburbs and a 1km grid in each area.
- o Visualization of the results:
- o Final Hazard results on pdf, ArcGIS shape-file, Google Earth.

Multi-hazard assessment treated separately or real joint probabilities:
Its real joint probabilities but this section is under development. Now each asset dataset is assessed separately, but the results are displayed as the sum of damages to all the selected assets.

Validation of the hazard:
Historical event analysis for key events (e.g. flood footprints for past events?):
The default earthquake model allows to configure the model based on a historic event, a typical earthquake on a given fault, by entering the earthquake parameters yourself, or by selecting a recent event from the Geo-net recent events list (internet access required)

Risk/Vulnerability:
Definition of Vulnerability (monetary, risk classes etc.):
The impact model takes the attributes of the chosen assets, along with the exposures calculated by the hazard model and computes the impact of the hazard on each asset using fragility functions.

Elements at risk available:
A number of 'default' asset databases are supplied with RiskScape, (Agriculture, Buildings, Electricity Cables, Pipelines, Roads, and Telecommunication Cables Waterways etc…) but a toolbox is also supplied to allow users to import their own asset datasets. Each asset module may contain only one type of asset, but multiple modules can be combined into a single analysis.

Validation of the vulnerability assumptions / results:
Reinstatement Cost encompasses all direct costs caused by exposure of the asset to the hazard Measured in $. Displayed as number

Flexibility:
Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):
The tool work with regional scale

Applicability to Europe or other regions:
From a theoretical point of view it could be used in every region or country, but the value of the element at risk must be expressed in NZ$

Users comment:

- **Usefulness:** Can be used for a wide range of applications, from planning to hazard management to asset management
- **Transparency:** In theory it is very user friendly and easy to use, but in practice is very difficult to upload you own data for your personal risk assessment. It works well with the default assets. In addiction the forum is scarce of information and the contact center doesn't answer.
- **State of the art:**The modules (default) are very easy to assemble. The hazard analysis is very detailed . The database of the elements at risk is very complete and detailed but only for NZ
- The probabilistic section in still under construction (is possible to run only simple scenarios)
- **Uncertainty Assumptions:** It doesn't take in consideration the uncertainty

Note:

Result are easy to export and the exported files can easily be used by other software like ArcGIS, Microsoft Excel or google earth.

The software works well for New Zealand. The special supported file system requires for this software. It's not clear how to convert the data into that file system.

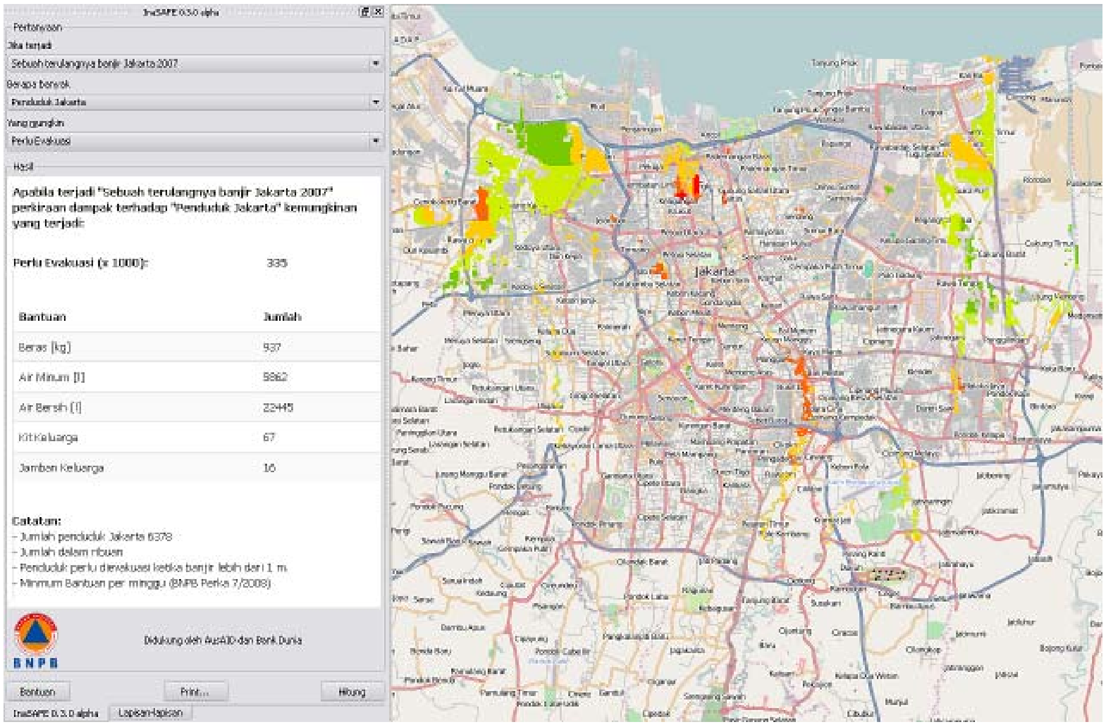
10.1.4 INASAFE

InaSAFE provides a simple but rigorous way to combine data from scientists, local governments and communities to provide insights into the likely impacts of future disaster events. The software is focused on examining, in detail, the impacts by a single hazard would have on specific sectors. e.g. location of primary schools and estimated number of students affected by a possible tsunami in Maumere (when it happened during the school hours).
InaSAFE is a plugin for QGIS software. It aims to produce realistic natural hazard impact scenarios for better planning, preparedness and response activities, using hazard and exposure geographic data

Risk in a Box is the name of a concept aimed at producing realistic natural disaster scenarios for better planning and preparedness (riskinabox.org)
Normally, information on the location of people and important assets are provided by local communities and government departments responsible for each sector, often through a facilitated part of a disaster preparedness and planning exercise. Where appropriate spatial data doesn't yet exist, external tools such as OpenStreetMap (www.LearnOSM.org) can allow governments and communities to quickly and easily map their assets that are important to them. It is important to note that InaSAFE is not a hazard modeling tool. Information on hazards needs to be provided either by technical experts, often from Government agencies, universities or technical consultants, or from communities themselves based on their previous experiences
The InaSAFE website (www.inasafe.org) has more information and instructions for installing InaSAFE.
A hazard (in the event of) may be represented as a raster layer or as an area (polygon). For example:

- Raster: where each pixel in the raster represents the current flood depth following an inundation event.
- Polygon: where it has been identified that flood has existed in that area (this will not have depth related information)

An exposure (How many) layer could be represented, for example, as vector polygon data representing building outlines, or a raster outline where each pixel represents the number of people resident in that cell.
The impact function (Might) will spatially combine the hazard and exposure input layers in order to postulate what the impacts of the hazard will be on the exposure infrastructure or people. By selecting a combination from the "In the event of" and "How many" combo boxes, an appropriate set of impact functions will be listed in the "Might" combo box.
Impact scenarios are predefined depending on what the decision-maker is looking for. For our flood analysis in Jakarta, we only have on predefined impact function which asks: In case of flood event, how many buildings might be temporarily closed? As we see on the previous step, this is filled automatically by default in the InaSAFE panel dock as soon as the hazard [flood] and exposure [buildings] layers are entered correctly.
InaSAFE was conceived and initially developed by the Indonesia's National Disaster Management Agency (BNPB), the Australian Agency for International Development (AusAID) and the World Bank.



The latest source code is available at https://github.com/AIFDR/inasafe which contains modules for risk calculations, gis functionality and functions for impact modelling.
InaSAFE is still a new project. The current code development started in earnest in March 2011 and there is still much to be done. However, we work on the philosophy that stakeholders should have access to the development and source code from the very beginning and invite comments, suggestions and contributions.
As such, InaSAFE currently has some limitations, including

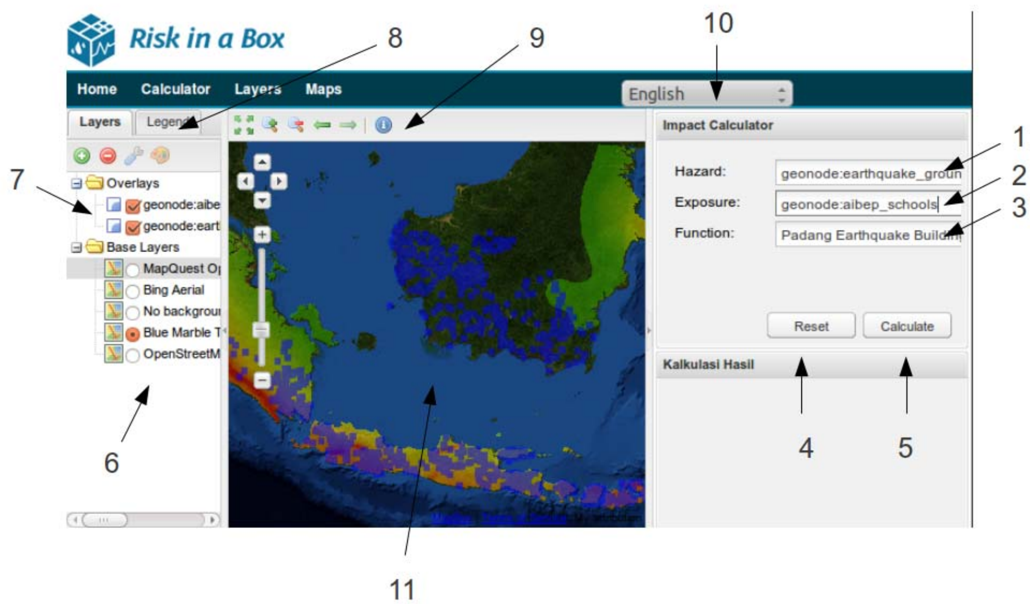
- Exposure data in the form of roads (or any other line feature) is not supported.
- Polygon area analysis (such as land use) is not supported.
- Population density data must be provided in WGS84 geographic coordinates

10.1.5 RISIKO

Risiko is a web based tool that models impacts of different hazard events on population or infrastructure. It is part of a set of Open Source Software tools called Risk in a Box. The documentation is still very basic and focusing more on the technical implementation than on the actual contents. Therefore it is a bit difficult to make the evaluation similar to the other systems. Nevertheless it is a good example of an Open-Source development of such a system.

Available from
http://risiko.readthedocs.org/en/latest/
http://risiko_dev.readthedocs.org
https://github.com/AIFDR/riab/ tree/master/impact
http://riab.readthedocs.org/en/latest/development/architecture.html

Risiko is based on geonode (http://geonode.org/).



Risiko screenshot of main calculation area

- The selected Hazard layer
- The selected Exposure layer
- The function to use to determine the Impact from the Hazard and Exposure
- Button to reset the layers and any calculation
- Button to start the calculation
- The list of the base map layers
- The list of the Hazard and Impact layers
- The Legend for the map
- The info button - allows the selection of point of calculation impact points (e.g. houses) and shows details for that point.
- Language Selection
- The main calculation map

10.1.6 MultiRISK

MultiRISK is a tool using empirical and deterministic methods to model flood extent and landslide susceptibility and run-out. It further visualizes multiple hazards at local and regional scale in a web-based environment.

The calculation of multi-hazard risk requires a large number of calculation steps which could be integrated in a spatial decision support system. In the framework of the Mountain Risks project a prototype software for multi-hazard risk analyses has been developed. This software is designed to offer a user-friendly, fast and combined examination of multiple mountain hazards (i.e. debris flows, rock falls, shallow landslides, avalanches and river floods). Since multi-hazard studies suffer from high data requirements a top-down approach is recommendable within which, by means of a regional study, areas of potential risk and hazard interactions are identified to be subsequently analyzed in detail in local studies. The MultiRISK Modeling Tool is designed according to a top-down concept. It consists of at least two scales at which analyses are carried out - first an overview analysis and secondly detailed studies (possible extension by a third even more detailed scale for e.g. specific engineering purposes). In its current version MultiRISK consists still exclusively of the regional overview analysis (~1:10.000-1:50.000) but will be extended in the future by local models and methods. In this section, the regional analysis scheme behind the analysis software as well as the structure of the software itself is presented shortly (for a more detailed presentation refer to Kappes et al. 2011, 2012).

For the regional analysis simple empirical models with low data-requirements were chosen. For the identification of potential rock fall sources a method was used which employs a threshold slope angle and the exclusion of certain rock types as for example outcropping clays. For the flood analysis a method was selected which extrapolates the inundation over a DSM based on a fixed inundation depth (Using the FloodArea model developed by Geomer). Shallow landslide source areas are modeled with Shalstab, avalanche source areas are modeled according to the methodology proposed by (Maggioni, 2004) and debris flow sources with Flow-R after. The run out of rock falls, shallow landslides, avalanches and debris flows is computed with Flow-R as described in Horton et al. (2008). The spatial input data needed for all these models is composed of a DEM and derivatives, land use/cover and lithological information. Figure gives an indication of the decision rules used in the multi-hazard analysis (format changes etc. are not considered).

The complexity of the analysis scheme indicates the effort necessary and the time-consumption for the step-by-step performance of the whole procedure in GIS software. Hence, an automation was undertaken to relief the modelers of the intermediate steps, simplify the structure to the important decisions and facilitate a fast and reproducible computation and re-computation of a multi-hazard analysis.

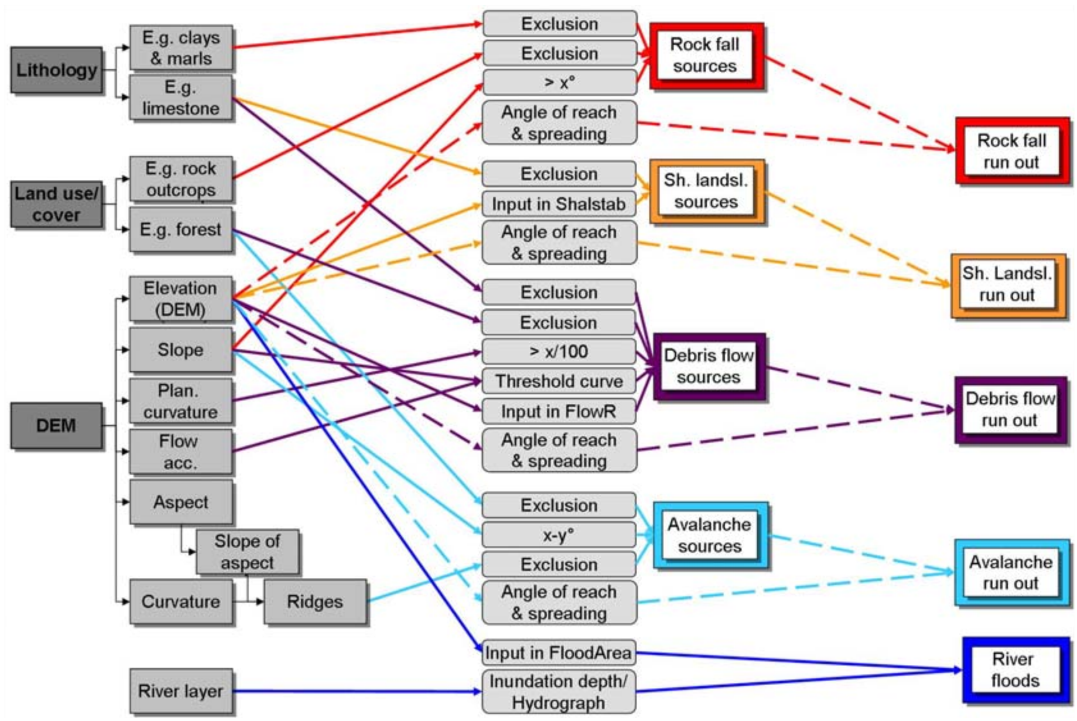


Figure: Analysis scheme for the MULTIRISK software (Kappes et al., 2012)

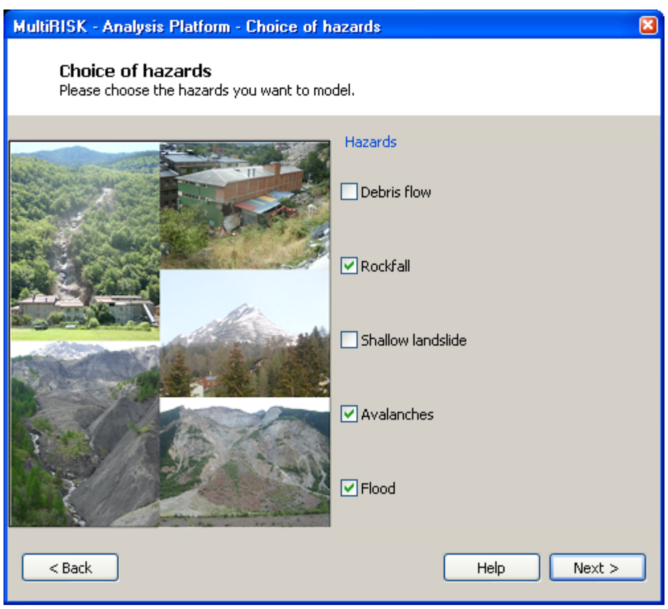


Figure: Interface of the MultiRISK Modeling Tool

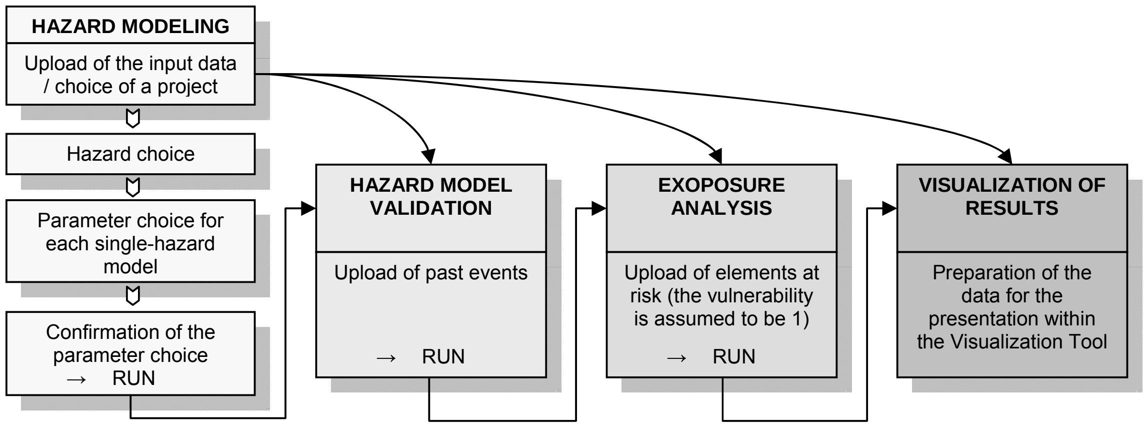


Figure: Flow chart of the MultiRISK Modeling Tool (c.f. Kappes et al. 2012)

The exposure analysis offered in MultiRISK is carried out by means of an overlay of the elements at risk and the single-hazard zones. The number of buildings, length of infrastructure or proportion of settled area exposed is calculated.
The effect of interactions is not yet implemented in the structure of the software tool but conceptual considerations how to account for them do already exist. This refers first to the alteration of the disposition one hazard by another. Within the analysis procedure this refers to the alteration of factors which serve as input data as e.g. the impact of avalanche events on the land use (the destruction of forest) and subsequently the modification of future rock fall, debris flow and avalanche hazard this entails. By means of feedback-loops this phenomenon can be included.

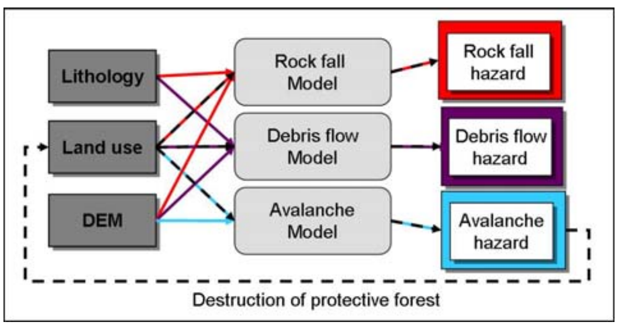


Figure: Feedback loop after Kappes et al. (2010) and Kappes and Glade (2011)

The tool does not incorporate temporal probability or quantitatively calculates the risk to elements exposed to the hazards; therefore it can be described as a partial hazard or susceptibility assessment tool with visualization capabilities.
End-users are hazard experts or planners wishing to view the extent of possible areas susceptible to multi-hazards. The tool is web-based, but not accessible at the moment.

Developed by:

- Melanie S. Kappes, Klemens Gruber, Simone Frigerio, Margreth Keiler, Rainer Bell & Thomas Glade. In the framework of the project Mountain Risks: from prediction to management and governance, 2007-2010 a Marie Curie Research Training Network financed by the European Union (http://mountain-risks.eu, contract MCRTN03598).

For more info:
http://changes-itn.eu/Portals/0/Content/2011/Poland/KappesEtAl-MultiRISK_110923.pdf

Input and Output:

Inputs:
- DEM
- Land use/Land cover
- Lithology
- Source Parameters (soil thickness, rainfall, source angle)
- Run-out Parameters (friction)
- Rainfall duration and hydrographs for flood modeling
- Polygons of past events and elements at risk

Outputs and visualizations:
- Hazard visualization (0 – 1)
- The number of overlapping hazards
- Past events (one hazard at a time)
- Elements at risk exposed to hazards (indicated in yellow)

Definition of hazard (type of hazard):
- Rock falls
- Shallow landslides
- Debris flows
- Snow avalanches
- Floods

Frequency assumption / Probabilistic (deterministic or probabilistic tool):
- Temporal probabilities are not calculated
- Probabilities for susceptibility is used for the hazard
- Susceptibility is determined by empirical and deterministic landslide run-out and flood modelling

Multi-hazard assessment treated separately or real joint probabilities:
- Hazards are calculated separately and are only joined in the visualization process

Definition of Vulnerability (monetary, risk classes etc.):
- Qualitative (low, medium, high), not used for assessing risk but only for visual purposes

Elements at risk available:
- They are used to visualize their overlap with the susceptible areas (run-out, flood)

Validation of the vulnerability assumptions / results:
- No vulnerability curves or monetary damage values are used to assess the risk

Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):
- The susceptibility assessment can be used at local and basin/regional scale

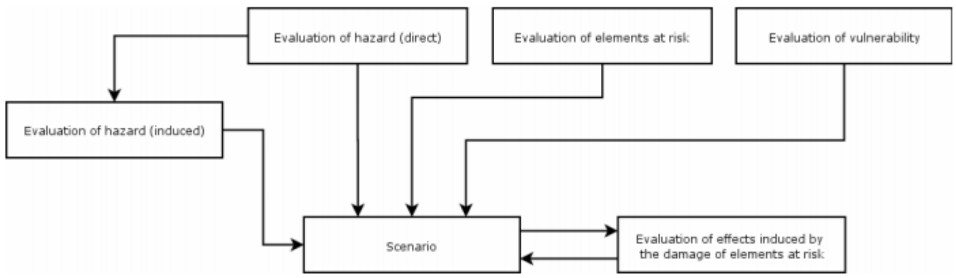
Applicability to Europe or other regions:
- In principle can be applied to any catchment or region in Europe. However one must assess the applicability of the empirical/deterministic susceptibility and run-out models for different test sites

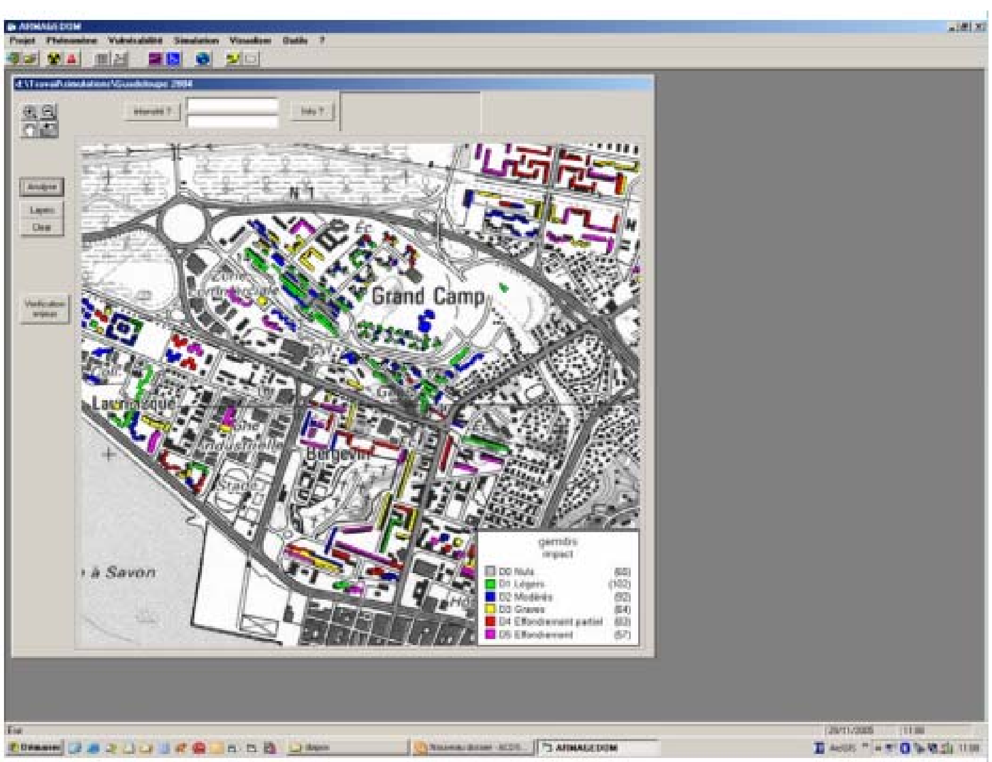
Users comment:

- **Usefulness:** Possibly useful to generally assess which areas in a catchment are susceptible to multi-hazards. However, it is not a tool for determining the actual hazard (qualitatively or quantitatively) or the risk. Temporal probabilities are not assessed. One must assess whether the hazard models can be modified or imported to suit the test site of interest.
- **Transparency:** The methods and data used are known and transparent. The actual susceptibility and run-out models can be retrieved from the developers and the visualization process is straight forward.
- **State of the art:** The visualization used in the web-based environment looks very clean and professional. The susceptibility analysis is a bit too general (more parameters could be added).
- The hazard models need to be assessed for their usefulness.
- **Uncertainty Assumptions:** Uncertainty can only be assessed for the susceptibility and run-out modeling. The models and their assumptions need to be validated.

10.1.7 ARMAGEDOM

A wide variety of software is available under this platform which has been developed by the BRGM (France): they are more or less flexible and use different levels of precision to model ground motion and vulnerability of the built environment. All are based on risk calculation through the convolution of hazard and vulnerability.
Unfortunately there is very little published information available on this platform. Below is an flowchart of the methodology and a screenshot of the User Interface.





10.1.8 EmerGeo (previously NHEMATIS)

NHEMATIS (Natural Hazards Electronic Map and Assessment Tools Information System) was originally developed for the EPC (Emergency Preparedness Canada) but has since been updated by a completely privatised company, EmerGeo which uses up-to-date ESRI ArcGIS software and an obviously updated version of the original routines of NHEMATIS but still with the same principles.

It is a multi-hazard tool for Canada, similar to HAZUS and it includes many national databases. The model produces maps of MMI and PGA, and needs at least one soil map to operate. It also takes into account secondary effects of earthquakes, as well as damage and injury maps based on lifeline, building and facility types. It includes a GPS-based setup which can be used to locate an expert on the damage map and transfer damage information straight to the expert, which allows for on-the ground emergency task forcing to occur quickly and with real-time information. It is also starting to be used in Australia, UAE and other locations around the world but is a completely closed source.

For more information

http://www.emergeo.com/

SIS EmerGeo, a subsidiary of Sai Infosystems Ltd, develops emergency management software solutions and provides consulting services and support to government and industry around the world. In response to growing demands for multi-agency interoperability and real-time situational awareness, EmerGeo has developed two integrated products: Fusionpoint and EmerGeo Mapping.

EmerGeo's Fusionpoint and emergency mapping applications are used to log, track and communicate critical information required by emergency and security personnel. By leveraging open web standards and a data fusion engine, EmerGeo's software allows customers to configure a relevant common operating picture tailored to each emergency role. Dispatch, crisis management, mapping, surveillance cameras and other system data come together in a configurable web dashboard for decision-makers.

EmerGeo's technology and people have been at the forefront of some of the world's largest disasters and are proven effective in helping government and industry to mitigate against, prepare for, respond to and recover from potential or actual incidents, natural disasters, acts of terrorism, or pre-planned events.

Due to the limited information available it is not possible to make a more in-depth review.

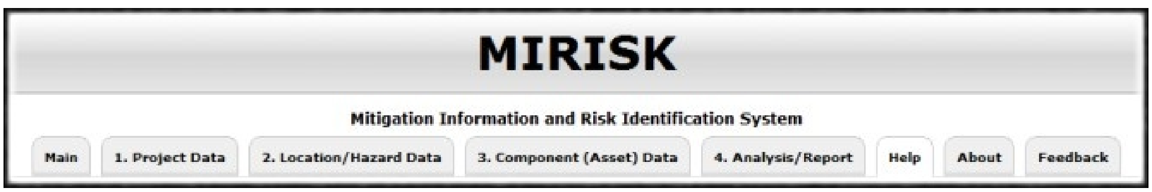
10.1.9 MIRISK

MIRISK (Mitigation Information and Risk Identification System) is a tool to help Development Managers consider natural hazards risk, and ways to reduce that risk, by:

- **identifying** natural hazards affecting a region
- **defining** the kinds of infrastructure ("assets") that make up typical Development projects
- **describing** the vulnerability of these assets to natural hazards, and how vulnerability can be reduced
- **analyzing** the natural hazards and vulnerability data, to assess whether Projects should follow normal design practices, or whether the cost of some enhanced design for natural hazards is justified by the benefits (of avoided losses).

MIRISK's basic purpose is to allow a Development Manager to quickly learn if natural hazards are very significant in a region where the Manager is considering development. If so, MIRISK provides information on what can be done, and permits estimation of the added cost for a moderately enhanced level of construction for natural hazards. An 'optimum' level of enhanced construction is estimated, based on the degree of hazard, the type of facility, and the Project's benefit cost ratio (BCR, used to account for indirect costs of damage).

For more information
http://psa2.kuciv.kyoto-u.ac.jp/lab/ja/education/program/308-mirisk-overview.html



A MIRISK user accesses four basic tabs or screens:

- **Project Data.** This screen is for administrative purposes - the user enters data for a new project, or resumes a previously saved project. Information recorded here are project identifier data, users names, and related information needed for administrative purposes.
- **Location/Hazard Data**. The first step in risk analysis is to learn if a project component is located in a high hazard region. When the region is located, the degree of Earthquake, Wind, Flood or Volcano risk for a region can be seen via color codes
- **Component (Asset) Data**. Define the component, and input asset value data (e.g. anticipated component cost, for construction and including overhead) and component benefit cost ratio (BCR). The component cost and BCR are used for a benefit-cost assessment. BCR is the estimate of the total component benefit (including some monetized estimate of future social benefits), divided by the total component cost.
- **Analysis/Report**. Estimate: potential losses due to a natural hazard for the identified site and the cost of enhanced design for that hazard, to identify if enhanced design may be warranted, given the regional hazards for the project location and the value of the project. When the Category Class (e.g. Low Rise Reinforced Masonry or Reinforced Concrete) is selected, the description, damage and design information on assets pane changes, to provide photographs and a description of the class, its Vulnerability to various hazards and how to reduce (mitigate) the vulnerability. By reading these descriptions, a Development Manager can quickly gain some familiarity with what these various Classes are, how they are damaged by natural hazards and, in

general, what are some of the techniques used to reduce their vulnerability to natural hazards. This information provides a good background for users not expert in natural hazards mitigation.

Analysis/Report

The Results are provided for the various hazards, and consist of the expected cost of construction for minimum code, and for some moderately enhanced level of construction (for natural hazards). The enhanced level is shown as a factor (eg, 1.02) which represents designing the component (asset) for "2%" more than the minimum code requirement for the component for that site. Enhancing the level of construction increases the cost of construction, and an estimate of that increased cost is shown in the table on this tab.

When a natural hazard occurs, such as an earthquake or tropical cyclone, damage is likely to occur, especially if the component was designed only per the minimum building code requirements. This is because the purpose of normal building design codes is not to eliminate all damage given a major earthquake, flood or tropical cyclone. Rather, the code's purpose is to prevent major loss of life - significant damage is acceptable per modern building codes, if not many people die.

Therefore, the cost of damage and associated losses are estimated for minimal code level design. The technical details of this estimation are discussed further below, but basically the MIRISK estimates the cost of damage from a database of such costs for various hazards and types of facilities. It includes in this loss estimate not only the direct cost of repairs to the facility, but also the associated costs of loss of use of the facility (eg, renting another facility while the first is repaired). These associated costs are estimated using the BCR input by the User.

In return for the increased expenditure for natural hazards, the enhanced level of construction should have less damage when a natural hazard occurs. Therefore, the cost of damage and associated losses are estimated for not only for minimal code level design, but also for each level of design, from 1.0 (minimum code requirement) to 1.4 (40% greater than minimum code). These are tabulated in the Results Table.

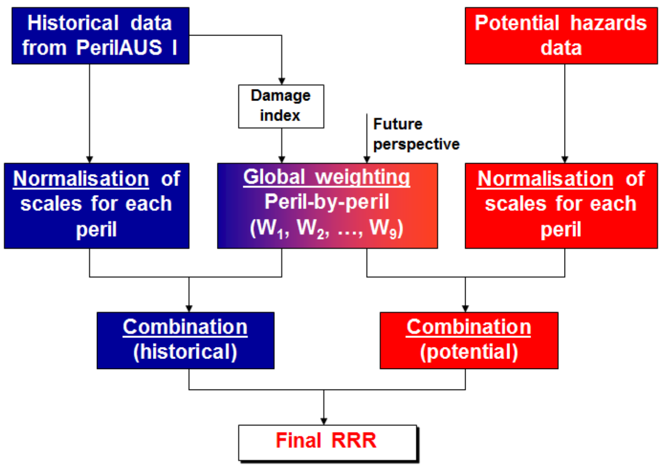
Lastly, the Total Cost of the component, which is the sum of the cost of construction (increasing with enhanced level of design) plus the cost of damage and associated losses (decreasing with enhanced level of design), are tabulated.

The minimum Total Cost is the 'optimum' enhanced level of construction design for the component.

The results are presented in tabular form, and graphically, for each hazard.

10.1.10 PerilAUS

PerilAus is a unique database on the incidence and consequences of Australian natural hazards. It combines a searchable database of natural hazards in Australia and maps them in a user interface. It qualitatively estimates the risk based on past events and historic damage and fatalities down to the postal code level.
Hazards covered in PerilAus include bushfires, landslides, earthquakes, floods, tropical cyclones, hail storms, wind storms, tornados and tsunamis. The focus has been on historic and recent information on natural hazard incidence, consequences and insurance losses, including event analyses, damage indices, insurable tangible damage, risk assessments and maps.
PerilAus captures data on natural hazard impacts on buildings, infrastructure and human populations. It is distinguished from other such databases by the wealth of descriptive detail contained therein concerning the hazard impact and the inclusion of data about any fatalities caused by that hazard. The damage information, especially the unique "housing equivalent" calculator, has been utilized in comparisons of particular hazard types, locations or years of record by a variety of insurance and specialist hazard-related organizations.



Developed by:
Risk Frontiers, an independent research center based at Macquarie University, Sydney, Australia.

For more information:
http://www.riskfrontiers.com/perilaus.htm

Definition of hazard (type of hazard):
- Bushfires
- Tropical Cyclones
- Floods, Earthquakes
- Landslides
- Gusts
- Hail
- Tornadoes
- Tsunamis

Frequency assumption / Probabilistic (deterministic or probabilistic tool):
- Based on past events and catalogs. Mainly qualitative assessment.

Multi-hazard assessment treated separately or real joint probabilities:

- There are no real quantitative probabilities. However, the hazards can be visualized simultaneously.

Historical event analysis for key events (e.g. flood footprints for past events?):

- This is PerilAUS's strongest point. It has an extensive historic catalog of events and is being updated continuously. Its assessment of risk in an area is solely based on the past events.

Definition of Vulnerability (monetary, risk classes etc.):

- Not included in the tool

Elements at risk available:

- They are related to the postal codes and regional areas (counties, provinces).

Validation of the vulnerability assumptions / results:

- Not included in the tool

Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):

- Historic events and qualitative risk based on local to regional levels of counties and their postal codes

Applicability to Europe or other regions:

- The tool cannot be applied to Europe. The historic events are only located in Australia. The maps and visualization are for elements at Risk in Australia.

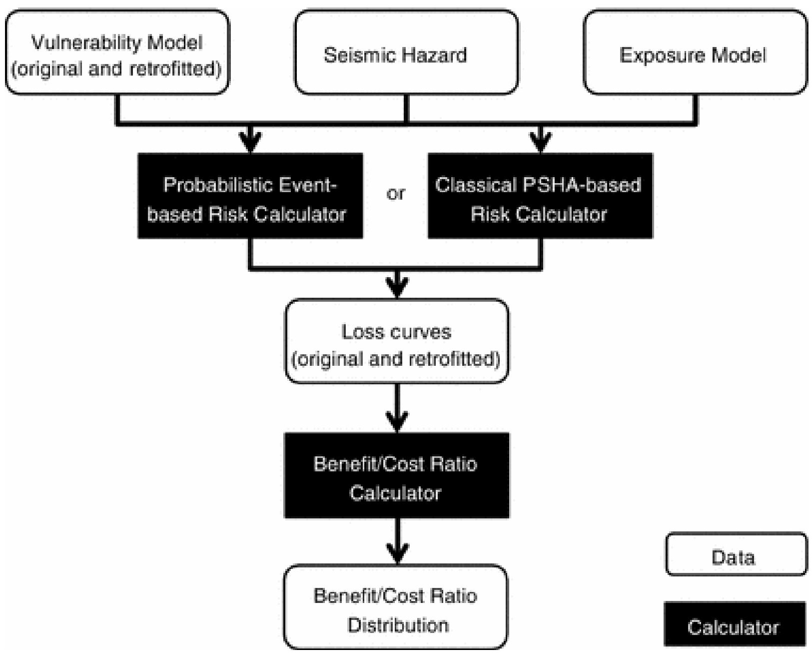
Users comment:

- **Usefulness:** Gives an indication for planners and experts on the distribution of the most probable hazardous events in a qualitative manner. Is not useful for a full scale probabilistic risk assessment. However, the amount of historic data and the extensive catalog can be very useful to assess the temporal probability of several types of hazards in Australia.
- **Transparency:** The access to the temporal catalog and historic events is straight forward, and so is the visualization.
- **State of the art:** For a catalog of historic events and its visualization, this tool is very complete and will be continuously updated in the future.
- **Uncertainty Assumptions:** The question is how accurate is the historic data. Assuming the collection has been carried out by an expert, the historic data should be accurate (temporally and geographically) and well documented.

10.2 Earthquake loss estimation tools

10.2.1 OpenQuake

The OpenQuake project (http://www.globalquakemodel.org/openquake/) was initiated as part of the Global Earthquake Model (GEM) (http://www.globalquakemodel.org) (Pinho *2012*), a global collaborative effort that brings together state-of-the-art science and national/regional/international organizations and individuals with the aim of establishing uniform and open standards for calculating and communicating earthquake risk worldwide. OpenQuake is a web-based risk assessment platform, which will offer an integrated environment for modelling, viewing, exploring and managing earthquake risk. The engine behind the platform currently has five main calculators, each one contributing uniquely in the area of seismic risk assessment and mitigation.



OpenQuake refers to all tools, apps and IT-infrastructure being developed to support in assessing risk. The core of OpenQuake is the web-based risk assessment platform, which will offer an integrated environment for modeling, viewing, exploring, and managing earthquake risk.
The OpenQuake engine is open-source software written in the Python programming language for calculating seismic hazard and risk at variable scales (from single sites to large regions). The OpenQuake engine is a web-based hosting service for open-source software development projects.

A beta version is now available online, and a first version of OpenQuake will come available in 2014.
The scientific libraries of the OpenQuake engine rely on a data model to represent the objects used in hazard and risk calculations; the latter is being developed in parallel to the engine, and a transparent and standard markup language is utilized to transfer different types of information within and out of the software. This language, which has been named
the Natural hazards Risk Markup Language (NRML), is XML-based.

NRML is being hosted on a repository at GitHub (https://github.com/gem/nrml), and information regarding how to create and edit these files can be found within the Open-Quake Engine User Manual. Although the present scope of NRML is for seismic risk, it is planned to extend this markup language to cover other natural hazards such as hurricanes, floods or tsunamis.

Input/output

- Currently, NRML is being used to represent input data such as hazard source zone models, logic trees, finite ruptures, vulnerability models, fragility models, exposure models, all of which are described in the following sections.
- The Natural hazards Risk Markup Language (NRML) is also used for the OpenQuake engine output data, which currently include hazard curves, hazard maps, ground-motion fields, loss curves and loss maps, and damage distributions
- OpenQuake is one of the few tools that includes Cost-Benefit analysis

Further information:

http://meetingorganizer.copernicus.org/EGU2013/EGU2013-10547.pdf
http://www.globalquakemodel.org/search/41/openquake/
http://www.globalquakemodel.org/resources/publications/technical-reports-gem1/gem1-opengem-system-design-document/

10.2.2 DBELA

DBELA (Displacement-Based Earthquake Loss Assessment) is an earthquake loss estimation prediction method of the degree of structural and non-structural damage to building classes under both ground shaking and liquefaction-induced ground failure. Earthquake actions and structural reactions are represented in DBELA by displacements following the evident correlation between building damage and lateral displacements. The main concept of DBELA is to compare the displacement capacity of the building stock and the imposed displacement demand from the earthquake.

DBELA has been applied using the Turkish building stock following the collection of a large database of structural characteristics of buildings from the northern Marmara region. The methodology has then been applied to predict preliminary damage distributions and social losses for the Istanbul Metropolitan Municipality for a Mw 7.5 scenario earthquake (Bal *et al.,* 2008).

DBELA uses mechanical-based formulae in order to determine the displacement capacity for reinforced concrete and masonry buildings grouped by failure mechanism and also the building class. It is a fully probabilistically-based method and uses statistical exposure data to formulate a probability density function for each parameter, and then uses Monte Carlo simulation to produce the building database on which the vulnerability methodology (displacement demand and capacity produced for all periods) is applied for a given hazard or group of hazards. The damage distribution for three limit states is then directly applied to the original building set (the exposure data). It takes into account the uncertainties associated through the process for demand and capacity.

Developed by

DBELA has been developed at the ROSE School/EUCENTRE in Pavia, Italy. The software has been written in Matlab as well as Fortran.

Daniell *et al.*, 2009 mentioned that DBELA was found more accurate than HAZUS, but was more time consuming for some Istanbul datasets.

More information:

https://github.com/VSilva/DBELA

http://www.quakeschool.org/files/EQPAPRES/Crowley.pdf

10.2.3 ELER

ELER-Earthquake Loss Estimation Routine is a software for rapid estimation of earthquake shaking and losses throughout the Euro-Mediterranean region.

Developed by:
The software was developed under the Joint Research Activity-3 (JRA3) of the EC FP6 Project entitled "Network of Research Infrastructures for European Seismology-NERIES" http://www.neries-eu.org/

Platform Dependency
The software package coded and compiled in MATLAB environment and easy to install and to use in different operating systems such as Windows (x64), Linux (x86-64), Mac OS X, Solaris 64. All the analyses and calculations are performed by the computational and statistical toolboxes of MATLAB. However, the user does not need to have a MATLAB license to execute the analysis since the program works as a stand-alone tool.

Background
The methodology encompasses the following general steps:

- For a given earthquake magnitude and epicentre information, estimation of the spatial distribution of selected ground motion parameters through region specific ground motion prediction equations and using shear wave velocity distributions or other site descriptors.
- If available, incorporation of strong ground motion data for the improvement and bias adjustment of theoretical estimations.
- Estimation of the building damage and human casualty at different levels of sophistication that commensurate with the availability of inventory of human built environment.
- Estimation of direct economic losses stemming from building damages.
- Estimation of damages for urban pipeline systems

Modules
ELER consists of four modules, for earthquake hazard and loss assessments, namely:

- **HAZARD:** In Hazard module, for a given earthquake magnitude and epicenter information, spatially
- distributed intensity and ground motion parameters PGA, PGV, Sa, Sd were estimated through region specific ground motion prediction equations and gridded shear wave velocity information.
- **LEVEL 0:** In Level 0 module, the casualty estimation is done utilizing regionally adjusted intensity casualty or magnitude-casualty correlations based on the Landscan population distribution inventory.
- **Level 1**: In Level 1 module calculates number of damaged buildings and associated casualty. The intensity based empirical vulnerability relationship is employed to find number of damaged buildings. The casualty estimation is done through number of damaged buildings.
- **Level 2:** In Level 2 module also calculates number of damaged buildings and associated casualty. The spectral acceleration-displacement-based vulnerability assessment methodology is utilized for the building damage estimation. The casualty

estimation is done through number of damaged buildings using HAZUS99 (FEMA, 1999) and HAZUS-MH (FEMA, 2003) methodologies.

Output

ELER has the option of user defined ground motion prediction equations (GMPEs).
The Gtopo30 (30 arc second resolution) elevation data files for the whole world have been included in the data folder of ELER v3. This enables the user to plot the distribution of ground motions on tohic maps for any given region.

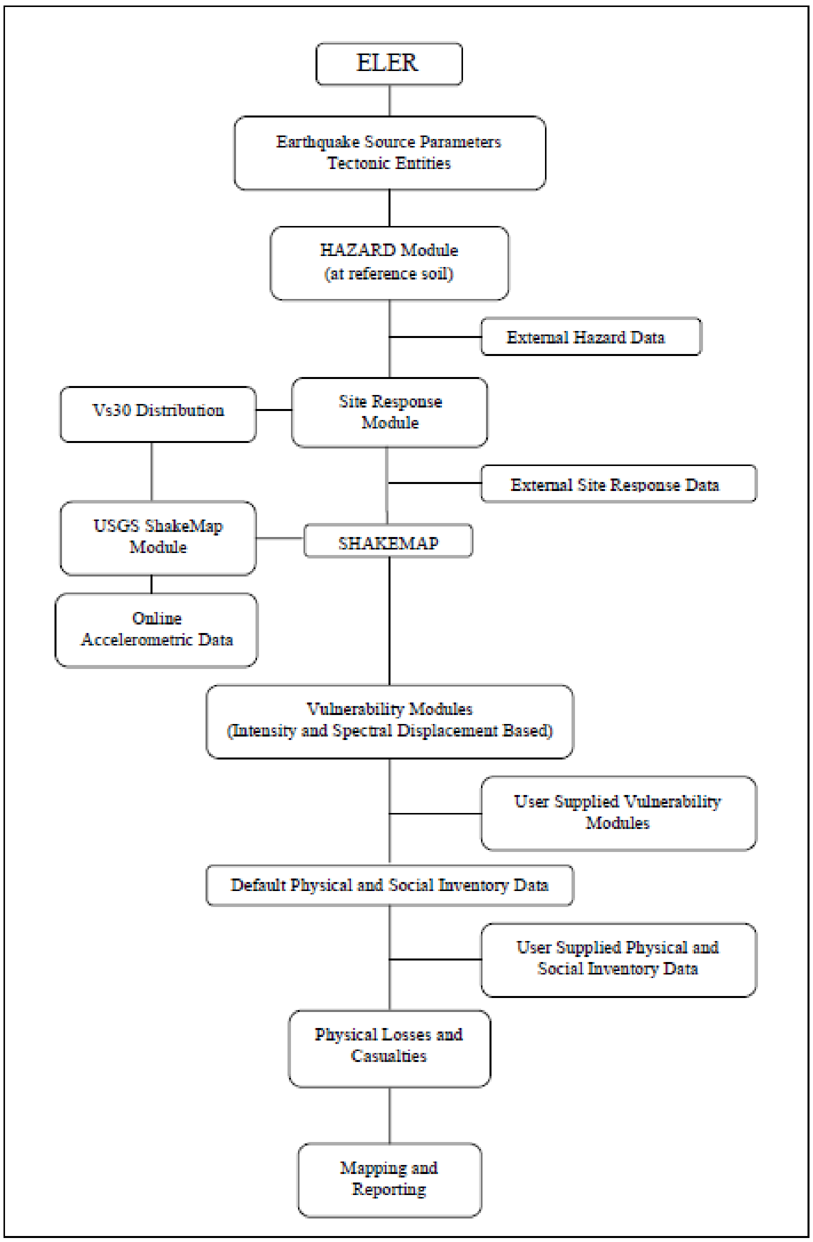


Figure: Overview of ELER software components

10.2.4 EPEDAT

EPEDAT (Early Post Earthquake Damage Assessment Tool) was produced for California OES by EQE International Inc to give a real-time information system in Southern California to assist the local and state governments to produce not only response plans and organise resources by simulating, but also by real-time infrastructure damage and casualty estimates. The method uses observed post-earthquake information from satellite and aerial survey to update model-based predictions of damage via loss estimation after an earthquake. It is particularly useful with respect to significant ground deformation, as seen via liquefaction. The methodology consists of 5 models which include an earthquake scenario generator, building inventory models, building and lifeline damage models, casualty estimation models and displaced individuals modelling. The real time information works in conjunction with data through CUBE (Caltech – USGS Broadcast of Earthquakes System) and REDI (Rapid Earthquake Data Integration). It uses Modified Mercalli Intensity, and links can be seen between it and the current PAGER system. It is Windows-based; however, not much data can be found from 1997 onwards on it except that it is being used for building data in a current NASA QuakeSim project.

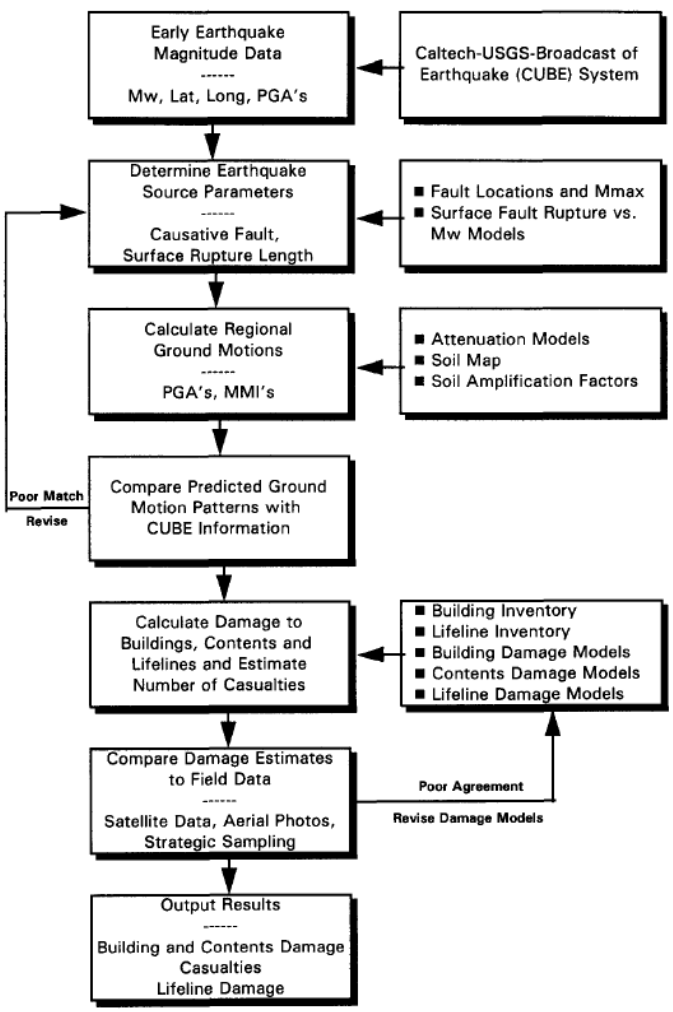


Figure: Methodology of EPEDAT (after Eguchi et al., 1997)

10.2.5 EQRM

EarthQuake Risk Management (EQRM) is a model for regional earthquake risk assessment that has been developed by Geoscience Australia (GA) for application to Australian cities. The model is utilised in the form of a Python or Matlab-based program founded on the HAZUS (Hazards United States) model that is widely used for risk assessment purposes around the world. It has been adapted to Australian conditions with the building types and other changes, especially the geological conditions within the Hazard section. It is a reasonably straightforward program to use and the current version is that of February, 2009. It does not require any GIS software and is based on the convolution of the four key areas that make up seismic risk, i.e. Hazard (including a regional seismicity model, attenuation model and regolith site response model), Elements at Risk (Social demographics, building inventory), Vulnerability of those elements at risk (Building vulnerability model (capacity), casualty and injury model and economic loss model) and Risk (the final earthquake loss assessment). Significant studies have been undertaken in order to look at uncertainties of the EQRM model as EQRM can be thought to be a proxy of the HAZUS procedure.

For more information:
http://www.ga.gov.au/hazards/our-techniques/modelling/our-models/what-is-eqrm.html

Strong ground-shaking from earthquakes can result in severe damage to the built environment. To model impacts on communities from earthquakes, Geoscience Australia have developed the Earthquake Risk Model (EQRM) which can simulate the estimated ground-shaking from an earthquake of a given magnitude and location, and subsequently calculate the impact to a portfolio of buildings.

Modelling of earthquake risk involves estimating the probability of a building portfolio experiencing a range of earthquake induced losses. Losses to the built environment incurred from earthquakes are dependent on the vulnerability of a structure to strong ground-shaking. For any number of synthetic earthquakes, the EQRM application can be used to estimate:

- the ground motion and its likelihood of occurrence
- the direct financial loss and its likelihood of occurrence.

10.2.6 EQSIM

Another methodology that is heavily based on HAZUS is EQSIM, an EarthQuake damage SIMulation tool (including the integrated Disaster Management Tool, DMT) which has been developed by the University of Karlsruhe. However, this is not open source. The tool has been used for a test location in Bucharest, Romania, with some adaptations to European conditions (14 HAZUS classes were added). It uses up-to-date reconnaissance techniques (damage detection using airborne laser scanning data and response tools for coordination, communication and information after an earthquake as part of the DMT). In the same way as EPEDAT, there is a detection support system that analyses data after the earthquake to combine with pre-earthquake data. This includes an 'augmented reality' system which enables individual buildings to be viewed in terms of their structural weaknesses post-earthquake. This is an extremely detailed method proposed by Markus *et al.* (2004) and unfortunately is closed to the public, despite an attempt to contact the authors. Many papers, nevertheless, have been sourced to provide an insight into the system tools used.

The Disaster Management Tool has three main functional parts. The first part comprises components for fast damage and casualty estimation, simulation of future progression of the disaster like fire propagation and consequences of decisions during exercises. It is named "simulation part". The damage and casualty estimation based on seismic data is performed by the component EQSIM, which is in the most advanced stage of development within DMT.

The second part encloses elements for decision support. Main components are a system for damage analysis based on airborne laser scanning, damage and casualty estimation based on building stock and residential data as well as the results of the damage analysis. An expert and information system supports rescue activities at collapsed buildings with case relevant advice and information from central database. A decision support tool for emergency operation centre members helps to assign the response resources in order to maximize the efficiency of response activities.

To integrate the operations on the different executive levels, the third functional part of the DMT provides means for the tasks of communication and information. The management information system conducts the aggregation, selection and distribution of information relevant for the specific actors of disaster response.

10.2.7 Extremum

The Extremum software tool is a combination of many different tools developed at Extreme Situations Research Center Ltd., including Emercom and SIGE, Russian Academy of Sciences. The system is extremely closed source. However, a partnership with ETH Zurich has spawned QUAKELOSS which is a version of Extremum. Extremum uses an updateable model of settlements throughout the world based on various scales, population distribution via mathematical models combined with hazard and exposure data, and lifeline and hazardous system information, in order to produce damage distributions for infrastructure and human loss, as well as rapid assessment methodologies. Past event impact is required for calibration of the tool, and uncertainties need to be taken into account. By combining it with the knowledge of QUAKELOSS, an extremely accurate tool has been produced. It is Windows-based and incorporates GIS data. The integrated risk tool also takes into account tsunami and other such secondary effects of earthquakes.

10.2.8 SELENA-RISe

The SELENA–*RISe* Open Risk Package consists of the two separate software tools SELENA (Seismic Loss Estimation using a Logic Tree Approach) and *RISe* (Risk Illustrator for SELENA). While SELENA is the computational platform for earthquake damage and loss assessment for any given study area, *RISe* can be used in order to illustrate all geo-referenced input, inventory and output files on Google Earth. *RISe* thereby translates SELENA's ASCII files into KML files that can be read by Google Earth.

SELENA relies on the principles of capacity spectrum methods (CSM) and follows the same approach as the loss estimation tool for the United States HAZUS-MH (FEMA, 2004). Unlike HAZUS, which is connected to the ArcGIS software (ESRI, Inc.), SELENA works independently of any Geographic Information System.

Development

The development of SELENA and *RISe* was enabled through funding from the International Centre of Geohazards (ICG), NORSAR, the University of Alicante, as well as the SAFER and RESIS-II projects. Further support was received from INETER (Managua, Nicaragua) and the Technical University of Madrid (Spain).

For more information
http://selena.sourceforge.net/

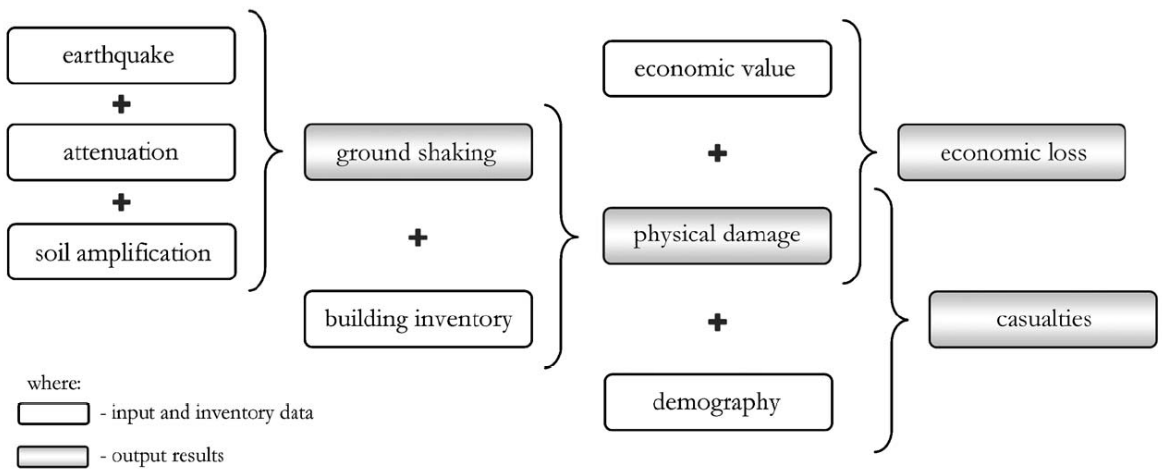


Figure . Principle flowchart of a deterministic analysis using the SELENA-tool.

10.2.9 MAEvis

MAEviz is an open-source project that helps reduce the time-from-discovery gap that exists between researchers, practitioners, and decision makers by integrating the latest research findings, most accurate data, and new methodologies into a single software product. It was developed as a platform to perform seismic risk assessment based on the Mid-America Earthquake (MAE) (MAE) Center research in the Consequence-based Risk Management (CRM) framework.

MAEviz provides an extensible software platform and helps bridge the time-from-discovery gap among researchers, practitioners and decision makers . The MAEviz project has an intuitive graphical user interface that allows users to visually interact with workflows providing a better understanding of the inputs, outputs and readiness of the system for execution. This interface is built upon an open, extensible, and non-domain specific set of projects: Bard and the Analysis Framework.

Bard is a base application that provides data management, GIS functionality, visualization tools (2D & 3D), charting and reporting Bard also includes a data catalog that gives the user the ability to import, export, explore, and share data.

The Analysis Framework facilitates the definition and connection of analyses to create workflows and explore new scientific possibilities by creating new workflows from the existing components. Also, the framework reports any problems to the user that would prevent the execution of the workflow and attempts to give some insight into what the problem might be so the user can correct it, thus saving time and reducing frustration.

Developed by

Department of Civil Engineering, University of Illinois, Urbana-Champaign campus the MAE Center collaborated with the Automated Learning Group at the National Center for Supercomputing Applications (NCSA) worked for the development of MAEviz.

For more information

https://wiki.ncsa.illinois.edu/display/MAE/Home

10.2.10 NECloss

LNECloss is an automatic seismic scenario evaluation tool, integrated on a Geographic Information System (GIS), which comprises modules to compute seismic scenario bedrock input, local soil effects, vulnerability and fragility analysis, human and economic losses.

Input/Output
Following results from LNECloss is possible

- **Modeling scenario earthquake:** Peak ground acceleration for bedrock and considering the dynamic effect of soils.
- **Modeling building damages and losses:** LNECloss uses HAZUS loss estimation methodology to evaluate the peak response for each type of building. Besides physical damage LNECloss computes economic and human losses.
- **Modeling strengthening interventions:** In general terms, any structural system can be improved to resist seismic actions by increasing its force horizontal capacity (improvement of force capacity), its stiffness, or its ability to undergo higher seismic displacement demands without collapsing (improvement of ductile capacity). In practical terms, in LNECloss code those improvement assumptions can be reflected by introducing higher over strength factors in parameters that define the capacity curve (λ and γ) and/or by introducing higher median values of spectral displacements at which the structural system reaches the threshold of damage states, that are a function of drift ratio, δ_d.

10.2.11 OPENRisk

OPENRisk is a suite of programs which has been produced by Porter et al. (2007) and Porter (2008c) in building an open source Earthquake Loss Estimation software program that combines the vulnerability of CUREE-Caltech vulnerability functions and HAZUS fragility functions with OpenSHA Hazard and user-defined exposure data with up-to-date HAZUS social and economic loss functions. It has been produced as part of the AGORA (Alliance for Global Open Risk Analysis) project and is entirely in Java, UML format; it also uses the USGS ELE Software ResRisk. It consists of a Hazard Loss Exceedance Frequency Curve program, Fragility Function Calculator and a Benefit/Cost Ratio application, allowing users to analyse whether it is better to retrofit and have less losses or not retrofit and have higher losses. These decision making machines take into account HAZUS mathematical functions for deaths and repair costs and allow for open-source viewing of the financial loss models (EAL, LE, BCF) of types of commercial software in a single-site risk calculation or portfolio risk calculation algorithm.

Due to the limited information available it is not possible to make a more in-depth review.

10.3 Flood loss estimation tools

10.3.1 Hora

HORA is a countrywide river flood zonation system for Austria in which 30, 100 and 200 year return period floodplains were estimated for 26,000 km of Austrian streams, corresponding to more than 10,000 nodes. The flood zones for the three return periods do not include flood defense information. They are based on extreme value statistics of river gauge stations, regionalization approaches and hydraulic modeling to "translate" the discharge volume into flooded areas. The HORA zonation has been integrated into a countrywide web GIS covering not only river flood risk but also other perils such as lightning or earthquake hazard.

End-users are government officials, insurance companies as well as risk managers in general wishing to conduct hazard and risk assessment for any location in Austria potentially being prone to river flooding.
Developed by:
After the widespread and severe flood event 2002 in Europe, HORA was initiated by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management and the Austrian insurance industry. The tool was developed by Technical University of Vienna and an Austrian engineering office (Ing.-Büro Hummer).

For more information:
http://www.hora.gv.at/
http://www.lebensministerium.at/en/fields/water/Protection-against-natural-hazards/Hora.html

Input and Output:

- They cannot be altered / implemented during development.

Inputs (amongst others):

- River discharge time series
- DEM
- Topographic maps
- Land use/Land cover (Corine)
- Channel geometries

Outputs and visualizations:

- Countrywide river flood maps for three return periods: 30, 100, 200 yrs

Definition of hazard (type of hazard):

- River flooding

Frequency assumption / Probabilistic (deterministic or probabilistic tool):

- Flood zonation based on gauge station probabilistic

Multi-hazard: perils treated separately or real joint probabilities:

- n/a

Validation of the hazard:
Historical event analysis for key events (e.g. flood footprints for past events?):

Incorporation of several local authorities such as hydrological offices etc. during the scientific parts of the project for verification of time series, extreme events, historical floods etc.

Data sources:
Local hydrological offices of Austria

Definition of Vulnerability (monetary, risk classes etc.):
Quantitative (monetary) based on stage-damage curves

Elements at risk available:
Exposure assumptions provided by developer

Validation of the vulnerability assumptions / results:
No source for vulnerability assumptions or validation mentioned

Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):
Floodplains are limited to Austria
No import or export functionalities (e.g. import of location data or export of floodplains as pictures or GIS layers not possible)

Applicability to Europe or other regions:
Not possible

Users comment:

- **Usefulness:** Useful to generally assess the river flood hazard for any location in Austria. There is no interface for any data exchange in the web GIS application which is why the user has to make a rough estimate for the location of the property of interest
- **Transparency:**There is some documentation on the methods used available. Raw data and methods are not accessible. Final product (floodplains) can only be used in the WebGIS and cannot be obtained in GIS format or similar
- **State of the art:** Floodplains are modeled in 1D – currently state of the art is a combined 1D/2D hydraulic modeling approach for river reaches; DEM is 10x10m which is state-of-the-art for countrywide flood modeling; Statistical methods are state-of-the-art in science and engineering
- **Uncertainty Assumptions:**Uncertainties have been taken into account in every step of the analyses. Information on the data quality and uncertainties of the discharge values have been provided by local authorities. This was not only to limit the uncertainties in the final floodplains but also to reach a wider acceptance of the product, especially acceptance by local stakeholders.

10.3.2 Kalypso

Kalypso is an open source modeling environment. The aim was to pool their resources in order to create a joint open source modeling environment. For the end user, the numerical models (binary versions), the application shells (Java codes) and the graphical user interfaces (Java codes) are available as freeware or open source software.

Kalypso consists of five modules:

- **Kalypso Hydrology**: module for rainfall-runoff modeling (conceptual, deterministic, non-linear, distributed)
- **Kalypso WSPM**: 1D hydraulic model for steady flow water surface profile computation
- **Kalypso 1D/2D**: Combined 1D/2D hydraulic module for unsteady flow
- **Kalypso Flood**: Module for the computation of inundated areas based on a DEM
- **Kalypso Risk**: Deterministic module for the computation of loss potential based on land use, monetary exposure and water depth for specific events

These modules are linked to each other in a common modeling framework. Thus, the tool can be described as an all-embracing flood hazard and risk modeling system. There are several potential end-users: hydrologists, hydraulic engineers or hazard and risk experts.
The tool can be downloaded from the project homepage.

Developed by:
Björnsen Consulting Engineers and the Institute of Hydraulic Engineering at the Technical University of Hamburg.

For more information:
http://sourceforge.net/projects/kalypso/
http://kalypso.bjoernsen.de/

Description of the modules are listed below:
Kalypso Hydrology

- Kalypso Hydrology is a software package for carrying out precipitation-runoff simulations. The standard version of Kalypso Hydrology contains the computation module from the Institute of Hydraulic Engineering at the Technical University of Hamburg-Harburg. This model allows for simulating the entire land-based part of the water balance on the basis of given precipitation time series. In this context the processes of snow storage, evapotranspiration, soil water storage, groundwater recharge, surface runoff, interflow, groundwater flow and wave translation in open channels are modeled.

Kalypso WSPM

- Kalypso WSPM is a module for computing one-dimensional water surface profiles. The standard version contains the computation module from the Institute of Hydraulic Engineering at the Technical University of Hamburg-Harburg - also referred to as PASCHE computation module. This module supports the newest methods and approaches which have been standardized in Germany for carrying out hydraulic computations for near-natural creaks and rivers and are summarized in the Technical Bulletins 1/1999 of BWK and 220/1991 of DVWK.

Kalypso 1D/2D

- Kalypso 1D/2D is a module for computing unsteady coupled 1D/2D flows for surface waters. Coupling in this context refers to a serial coupling of models, thus enabling to connect a one-dimensionally modeled river section with another section which has been modeled using the 2D model. Both models will be simulated integrally, boundary conditions will be automatically shared between the two models. The standard version supports the computation module from the Institute of Hydraulic Engineering at the Technical University of Hamburg-Harburg. The program nucleus is based on RMA 10s by Dr. Ian King and has been further enhanced by the Technical University of Hamburg-Harburg since 2005. This computation module is currently not by default distributed with the Kalypso modules. The mathematical basis of the computation module is formed by the St. Venant equations and the depth-averaged shallow water equations, respectively. The computation module is based on the finite element method. A modified Crank-Nicolson time-stepping scheme is used to advance the solution in time; the nonlinear equations are solved using the iterative Newton-Raphson method.

Kalypso Flood

- Kalypso Flood is a post-processing module for determining and displaying inundated areas and flow depths on the basis of digital terrain model data and water surface profiles. Kalypso Flood works with ESRI ASCII grid formatted data with arbitrary spatial resolution. During data processing every cell of the digital terrain model data is assigned a water surface profile value from the water surface profile data and by determining the difference of these values flow depths for every grid cell are calculated. This results in a flow depth grid inheriting the cell size and spatial resolution from the digital terrain model being applied. Water profile data are directly imported from Kalypso WSPM and Kalypso 1D/2D. Water profile data from other sources may be imported with BCE HMO and ESRI ASCII Grid formats. Kalypso Flood allows for merging different model and intersection results into a single result set thus providing means for combining separately computed model segments for further processing. This result set also serves as input for Kalypso Risk for determining damage potentials and risk maps. Further, Kalypso Flood provides means for data editing to the user. For example, clip and extrapolation areas may be defined in order to exclude areas from intersection processes or to assign water level data to areas with no water level data for determining overall inundated areas. The result sets may be exported in ESRI ASCII Grid format for further processing with other software.

Kalypso Risk

- complements the post-processing palette of Kalypso with a module for determining flood risks along the course of rivers. On the basis of land use data and flow depths the module provides means for determining damage potentials for predefined flood events and yearly expected damage values as well as allocating risk zones. In particular for determining annually expected damage values, flow depth data from a variety of flood events corresponding to different return intervals are required. Land use data are imported as Shape data into Kalypso Risk. Flow depths are imported as raster data in ESRI ASCII Grid format; the user interface of Kalypso Risk provides efficient management tools for carrying out these tasks. Annual expected damage values are computed based upon a mesoscale approach for monetary values (specific asset allocations to land use categories) and user selected stage-damage functions which determine the relationship between water depth and structure damage.The user of Kalypso Risk can choose between working with specific asset values and stage-damage functions defined by himself or applying existing material from e.g. the International Commission for the Protection of the Rhine (IKSR) or the International

Commission for the Protection of the Elbe River (IKSE). Flood risk categories are derived from the annually expected damage values. By defining limiting values on this scale the user can identify six risk categories which are depicted on a map of the study area.

Definition of hazard (type of hazards):
Flooding

Frequency assumptions, is the tool deterministic / probabilistic:
Deterministic tool for specific events
No probabilistic functionality (loop algorithm) implemented

Multi-hazard assessment treated separately or real joint probabilities:
Not a multi-hazard tool but a single hazard too for calculating flood risk

Historical event analysis for key events (e.g. flood footprints for past events?):
The tool is flexible and validation must be conducted by the user themselves, e.g. externally in a GIS application

Data sources:
Are provided by the user

Definition of Vulnerability (monetary, risk classes etc.):
Quantitative (monetary) based on stage land-use class and corresponding stage-damage curves
Individual stage-damage curves can be imported

Elements at risk available:
Default: exposure provided for Rhine and Elbe
Individual exposure can be imported by user

Validation of the vulnerability assumptions / results:
Default stage-damage curves are based on studies by the BWK (*Bund* der *Ingenieure* für *Wasserwirtschaft*, Abfallwirtschaft und Kulturbau), a governmental organization
BWK: Hochwasserschadenspotenziale. Bericht 1/2001, Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau e.V., Sindelfingen, 2001.

Flexibility:
Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):
The tool is very flexible – studies can be conducted at every scale and location and are certainly only limited by computation power

Applicability to Europe or other regions:
In principle can be applied to any catchment or region in Europe.

Users comment:

- **Usefulness:** Possibly very useful to generally assess monetary damage caused by river flooding for individual catchments. The tool is designed for deterministic analyses. The tool is capable of modeling the whole risk assessment chain starting with the hazard assessment and finally providing information on the (monetary) losses. Probabilistic analyses cannot be applied, though.

- **Transparency:** Apparently, there still is a lack of documentation. The tool can be downloaded and for Kalypso Hydrology a documentation is provided. For other tools there is no detailed documentation available yet. It must be said, though, that source codes are available
- **State of the art:** Methods seem to be state-of-the art in each component (RR-modeling, hydraulics etc.)
- The risk component ought to be assessed for its usefulness
- **Uncertainty Assumptions:** For the hazard component, uncertainty must be taken into account by the user as there is nothing implemented. For the risk component, there is no uncertainty assumption implemented (such as confidence intervals etc.)

10.4 Technological risk assessment tools

10.4.1 ARIPAR

ARIPAR is a quantitative area risk assessment tool used to evaluate the risk resulting from major accidents in industrial areas where hazardous substances are stored, processed and transported. It is based on a geographical information system platform (GIS).

Developed by:
The Institute for the Protection and Security of the Citizen of the Joint Research Centre of the European Commission (**EC-JRC-IPSC**), the Civil Protection Service of the Emilia Romagna Region (**ERR**), and the Chemical, Minerary and Environmental Technologies Engineering Department of the University of Bologna (**DICMA**).
The software code was developed by **THS** Informatica

For more information
http://ipsc.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

Platform Dependency
ARIPAR 5.0 is dependent on ArcGIS 9.3 (Previous version 4.5 was dependent on ArcView 3.3)

Background
The Italian *Department for Civil Protection*, together with *Regione Emilia Romagna*, started the ARIPAR project (*Analisi e controllo dei Rischi Industriali e Portuali dell'Area di Ravenna*,i.e. Analysis and Control of the Industrial and Harbour Risk in the Ravenna Area). The main outcome of the ARIPAR project was the development of a methodology and the related software tool for area risk assessment. The ARIPAR methodology and the first software prototype was developed by the Company Consortium that was charged of the technical development of the project, i.e. *Snamprogetti*, *NIER Ingegneria*, and *DAM*, and subsequently optimised by the *Chemical, Minerary and Environmental Technologies Engineering Department* (DICMA) of the University of Bologna. This prototype was solely applicable to the area of Ravenna, since all the input data for risk assessment, which are problem-specific, were incorporated within the software.

Input
- Population distribution (in %)
- Vulnerability centres (number of people) [Vulnerability centres i.e. hospital, churches, schools, railway stations, stadiums, etc.]
- Plants
- Road network
- Risk sources fixed (for plants)
- Risk sources linear (for roads)
- Meteorological data (wind speed, wind direction)
- Population category (permanent/temporary, Indoor/outdoor presence in %)
- Land use class
- Population density (inhabitants/ha)
- Cell dimension (m)

*Each input with a dialog box required detailed input

Output

- **Local risk: .**
    - Individual Risk contours from 1 to 10^{-10}
    - Coloured risk areas (grid representation)
    - Point risk contribution (as histogram)
- **Individual risk:**
    - Risk contours from 1 to 10^{-10}
    - Coloured risk areas (grid representation)
    - Point risk contribution (as histogram)
    - (Places of particular vulnerability (e.g., schools, hospitals, supermarkets, etc.) in risk contour plot)
- **Societal risk:**
    - F-N curve
    - I-N histogram
    - (The number of people might be affected in hazardous incidents. An F-N curve is a plot of inverse cumulative frequency (F) of accidents to a number people greater than or equal to N. I-N histogram, where N number of people exposed to an individual risk within the range I.)
    - Capable to give the following outputs:
        - Risk source importance vs. number of causalities (N)
        - Risk source ranking for a given value of number of causalities (N)
        - different risk source types
        - different substances
        - scenarios for one or more selected risk source types
        - outcomes for one or more selected scenarios

10.4.2 CATS

CATS (Consequence Assessment Tool Set) assesses the consequences of technological and natural disasters to population, resources, and infrastructure. It takes into account from natural disasters such as hurricanes and earthquakes, to technological disasters such as industrial accidents, terrorism, and acts of war. It uses ESRI ArcView as the GIS platform, as well as demographic and infrastructure data. It was created out of cold war technology and is Windows-based. It provides the facility to create realistic scenarios and assess the effects on the infrastructure and population to allow for emergency management, resource deployment and to assess the requirements for a sustained disaster response. CATS is owned by FEMA and also DTRA. Science Applications International Corporation (SAIC) correlated a wealth of data on structural damage from atmospheric nuclear tests with hurricane gust characteristics to create a robust damage assessment methodology.

Developed by
The software is developed under the guidance of the U.S. Defense Threat Reduction Agency (DTRA).For more information
https://www.saic.com/products/security/cats/
CATS has been tested for the earthquakes of Northridge, U.S., Kobe, Japan, and Izmit and Duezce, Turkey.
CATS takes into account ground failure, tsunami, fire and ground shaking. It is extremely detailed and even takes roadblock information into account for the U.S. version. It is likely that these options are not as readily available for users outside the U.S.. It is available as part of the ESRI CATS Bundle and work is continuing on various versions (CATS 6 is currently used).

CATS has been used to identify:

- Roadblock distributions and editing
- Population and infrastructure at risk
- Atmospheric plume foot prints
- Locations and resources for disaster recovery
- Blast effects
- Road network building and routing
- Addresses and locations
- Best and regional weather

CATS is capable

- to import natural hazard (earthquakes, hurricanes, floods) damage files from the Federal Emergency Management Agency (FEMA) HAZUS model
- to import hazard plume data from the DTRA HPAC atmospheric dispersion model and the Joint Effect Model (JEM)
- to use specified damage areas and assets.

10.5 Other Tools, various applications

10.5.1 GoldSim

GoldSim is a user-friendly, highly graphical program for carrying out dynamic, probabilistic simulations for support, management and decision-making in business, engineering and science. Although GoldSim can be run in a deterministic manner (i.e., with no uncertainty specified in the input parameters), one of the key features of the program is its ability to explicitly represent such uncertainty through the use of probability distributions.

Developed by:
GoldSim Technology Group LLC**.** GoldSim Technology Group 22500 SE 64th Place, Suite 240 Issaquah, Washington 98027 USA.

For more information:
http://www.goldsim.com/Home/

Input and Output:
The mathematical model identifies specific inputs (e.g., the flow rate for a river, the financial discount rate) which are required in order to simulate the system. These must be quantified by specifying their values or probability distributions. GoldSim has an extensive internal database of units and conversion factors. You can enter data and display results in any units.

Inputs:
- *Three types of inputs:* Data, Time Series and Stochastics. A single scalar datum, or vectors and matrices of data can be specified
- *Functions* which operate on one or more inputs and produce one or more outputs
- Stock and Delay Elements are specialized function elements with the unique property that their outputs are influenced by what has happened in the past

Outputs and visualizations:
- Probabilistic models where graphics, explanatory text, notes and hyperlinks can be added and organized in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audience.

Hazard:
Definition of hazard (type of hazards):
- The tool is not hazard specific

Frequency assumptions, is the tool deterministic / probabilistic:
- Temporal probabilities are calculated in the dynamic simulation you could also run a static simulation (deterministic) without taking in consideration the time.

Multi-hazard assessment, perils treated separately or real joint probabilities:
- The hazardous events are considered together for a multivariate analysis

Validation of the hazard:
Historical event analysis for key events (e.g. flood footprints for past events?):
- Outputs are computed based on the historical values of their inputs.

Data sources:

- A source of data external to GoldSim model can be automatically imported into GoldSim elements. External data sources are either spreadsheets, text files, databases or DLLs

Risk/Vulnerability:

Definition of Vulnerability (monetary, risk classes etc.):

- Quantitative and used for assessing risk

Elements at risk available:

- Element at risk are not available in the software, doesn't exist any inventory about them

Validation of the vulnerability assumptions / results:

- Probabilistic curves on vulnerability is calculated and used to assess risk

Flexibility:

Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):

- All the parameter are dimensionally aware, is possible to use every dimension system. The program has an extensive database of units and conversion factors. You can enter data and display results in any units. You can even define your own custom units.
- Possible to construct a very small model and then add details in a hierarchical manner as warranted. Very large models can be supported

Applicability to Europe or other regions:

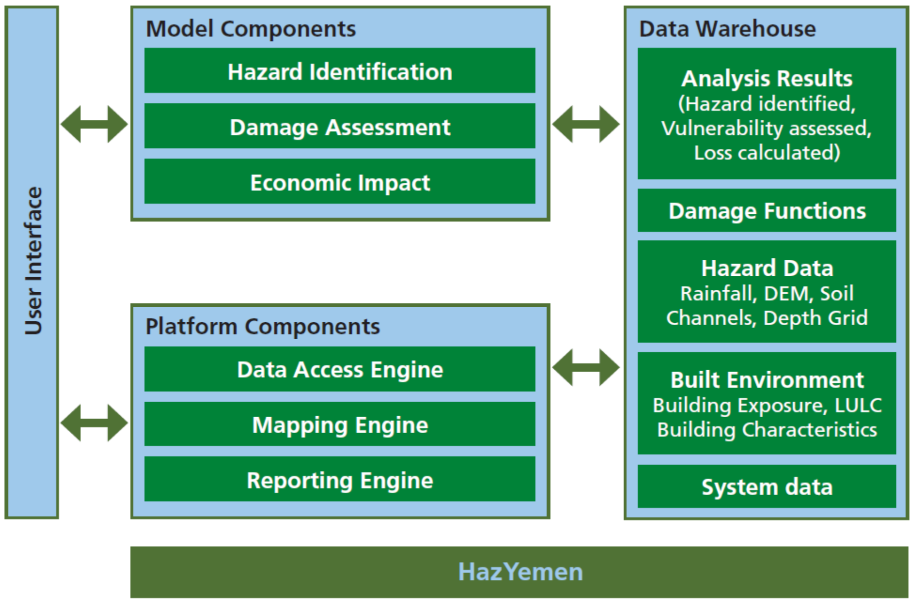
- It is not a specific environmental PRA software, it can be used in many field and in every cases study.

Users comment:

- **Usefulness: I**s useful to calculate the probability to predict future behaviour, taking in consideration also the uncertainties that are represented using probability distribution (Uncertainty is propagated using Monte Carlo Simulation). The program is not specific so could be used for many application in different fields.
- **Transparency:**The methods and data used are known and transparent. The methods are also well explained in a good user manual and a lot of information could be found in the web site.
- **State of the art:** The visualization used is very simple and user friendly. Probably for an advanced use it need a good knowledge of probabilistic study and models
- **Uncertainty Assumptions:** GoldSim was specifically designed to quantitatively address the inherent uncertainty which is present in real-world systems

10.5.2 HazYemen / HazSana'a

HazSana'a and HazYemen are two open source GIS-based multi-hazard risk platform being developed for Sana'a city, two governorates (Hadramout and Al Mahra) and Yemen country, respectively.



Three following risk assessment studies are being conducted in Yemen:

1. Flood and landslide risk assessment for Sana'a city
2. Flood and landslide risk assessment in Hadramout and Al Mahra governorates
3. Earthquake, flash flood, flood (storm surge and tsunami), volcano, and landslide risk assessment for the whole country

End-users are government officials, insurance companies as well as risk managers in general wishing to conduct long-term disaster risk reduction planning and mitigation measures at local (Sana'a city), regional (governorates) and countrywide scale (Yemen).

Developed by:
The software applications HazSana'a and HazYemen has been developed by the Worldbank and the GFDRR (Global Facility for Diaster Reduction and Recovery) respectively, in the framework of a major study called "Probabilistic Risk Assessment Studies in Yemen" that was initiated following a storm in 2008 that caused severe flooding in eastern Yemen. They Yemeni technical counterparts have been the Yemen Geological Survey and Mineral Resources Board (YGSMRB), Ministry of Oil and Minerals, and the Saylah Implementation Unit of the Municipality of Sana'a.

For more information:
http://gfdrr.org/gfdrr/sites/gfdrr.org/files/publication/GFDRR_Probabilistic_Risk_Studies_Yemen.pdf

Input and Output:
They cannot be altered / implemented during development.

Inputs (HazSana'a study):
- Historical flood records, reports, manuals
- Historical landslide records, reports, manuals
- Predicted flood records (assuming certain urbanization processes etc.)
- Exposure information
- Vulnerability assumptions (stage-damage curves)

Inputs (Hadramout and Al Mahra studies):
- Historical flood records, reports, manuals
- Historical landslide records, reports, manuals
- Predicted flood records (assuming certain urbanization processes etc.)
- Exposure information
- Vulnerability assumptions (stage-damage curves)

Inputs (Yemen national study):
- Historical records, reports, manuals of earthquakes, flash floods, floods (coastal storm surge and tsunami), volcanoes, and landslides
- Exposure information
- Vulnerability assumptions (stage-damage curves)

Outputs and visualizations (HazSana'a):
- Risk maps for probabilistic flood events
- Risk maps for deterministic landslide events
- Loss exceedance curves, split by occupancy types (residential, commercial, industrial, squatters)

Outputs and visualizations (Hadramout and Al Mahra studies):
- Hadramout and Al Mahra Risk Atlas, including a printed atlas of probabilistic losses under different scenarios of climate change etc.
- Maps for exposure, hazard (river flooding), risk (Annual Average Loss)

Outputs and visualizations (Yemen national study):
- Loss exceedance curves

Hazard

Definition of hazard (type of hazard):
- Earthquakes, flash flood, floods (river floods, coastal storm surge and tsunami), volcano, and landslides (assessed at different scales: city level, regional level, national level)

Frequency assumption / Probabilistic (deterministic or probabilistic tool):
- Deterministic modeling for landsliding
- Probabilistic modeling for river flooding
- All other perils and underlying frequency assumptions are not further explained in the reports available yet – detailed information has been requested from Worldbank

Multi-hazard assessment treated separately or real joint probabilities:

- Treated separately

Validation of the hazard:

Historical event analysis for key events (e.g. flood footprints for past events?):

- Validation has been carried out for the LE curves considering event based loss experience

Data sources:

- Loss information from the government for key events

Risk/Vulnerability:

Definition of Vulnerability (monetary, risk classes etc.):

- Quantitative (monetary) based on stage-damage curves

Elements at risk available:

- Exposure assumptions provided by developer

Validation of the vulnerability assumptions / results:

- No source for vulnerability assumptions or validation mentioned

Flexibility:

Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):

- The three studies and two software products are designed for their specific study areas and scales – apparently there is no option for scaling or to import user specific data (such as altered vulnerability assumptions etc.)

Applicability to Europe or other regions:

- Tools cannot be applied to Europe but only to Yemen

Users comment:

- **Usefulness:** Possibly useful to generally assess monetary damage caused by natural perils specifically for Yemen. The tool is designed for deterministic (landsliding) and probabilistic (flooding) analyses
- **Transparency:** Apparently, there still is a lack of documentation. This might be due to the fact some parts are still under development. The tools can only be judged when there is a proper and most importantly detailed documentation of the methods applied.
- **State of the art:** No judgment possible yet due to missing documentation of methods applied
- **Uncertainty Assumptions:** No judgment possible yet due to missing documentation of uncertainty assumptions potentially applied

10.5.3 InLET

InLET (Internet-based Loss Estimation Tool) has been developed by the University of California and ImageCat Inc and is a complete web-based real-time earthquake loss estimation tool. It is part of the RESCUE project funded by the NSF, encompassing several California universities. Data, model updates and results are completely stored online in order to provide availability to users at all times. USGS ShakeCast notifications provide loss estimates within a minute of building damage and casualties using simplified HAZUS damage functions and GIS databases. This method also provides traffic information and is easily changeable for federal and local scenarios (ImageCat Inc., 2008). As stated, just the internet is required (Web 2.0), which is a problem if the internet in the area of interest has been cut off by the earthquake (but they will possibly be able to get help from outside), and also uses high resolution imagery, including street view from Mcrosoft Virtual Earth. The internet-based methodology is also a large advantage due to the fact that updates to the software can be simultaneously shown to customers rather than having to send out DVD updates. The program claims differences with HAZUS of less than 5%, which for emergency purposes is extremely useful. Unfortunately, it is rather specialised in location at present, with only California data. It is essentially EPEDAT in internet form.

10.5.4 Lumina-Analytica

Lumina is used to develop a probabilistic model thought influence diagram. Its Intelligent Arrays permit to create and manage multidimensional tables with an ease and reliability unknown in spread sheets. Its efficient Monte Carlo evaluates risk and uncertainty, and finds out what variables really matter and why. It generates dynamic simulations that take in consideration the temporal probability.

Developed by:
Lumina Decision Systems, Inc. Los Gatos, CA
For more information:
http://www.lumina.com/

Input and Output:
Inputs:

- Because it is a very generic probabilistic tool it not need maps or other specifically geological input, but it needs numbers and nodes, that are necessary to construct the model

Outputs and visualizations:

- Different type of graphic for probability distribution
- Risk with associated uncertainties

Definition of hazard (type of hazards):

- No specific Hazard type

Frequency assumptions, is the tool deterministic / probabilistic:

- Temporal probabilities are calculated

Multi-hazard assessment treated separately or real joint probabilities:

- The tool calculate as all the factors interact and influence each other

Validation of the hazard:

- Historical event analysis for key events (e.g. flood footprints for past events?):
- Historical data are used to construct regression coefficient, to make projections of the future. Could be used as a starting point for building a predictive model

Data sources:

- External. Every type of data could be added in text and numerical format

Risk/Vulnerability:

- Definition of Vulnerability (monetary, risk classes etc.):
- No vulnerability curves or monetary damage values are expressed as results

Elements at risk available:

- Element at risk are not available, doesn't exist any inventory about them

Validation of the vulnerability assumptions / results:

- No vulnerability curves or monetary damage values are used

Flexibility:

- Scale of the tool (up- and downscaling ability, e.g. village vs. catchment):
- The system is not based on maps, and the input value could be only numerical and dimension free.

Applicability to Europe or other regions:

- Is not a specific environmental PRA software, it can be used in many fields and in every cases study.

Users comment:

- **Usefulness:** Reading, analyzing and communicating quantitative decision models. Analytica includes hierarchical influence diagrams for visual creation and view of models, intelligent arrays for working with multidimensional data, and Monte Carlo simulation for analyzing risk and uncertainty. The design of Analytica, especially its influence diagrams and treatment of uncertainty, is based on ideas from the field of decision analysis. Analytica includes a computer language, which is notable in being declarative (non-procedural) for referential transparency, supporting array abstraction, and providing automatic dependency maintenance for efficient sequencing of computation.
- **Transparency:** The methods used are clear and well known. The construction of the model is easy for a middle expert modelers, not for a new user.
- **State of the art:** The tool is user friendly and very simple for the command. It is accompanied to a very useful and complete user manual
- **Uncertainty Assumptions:** The uncertainties is calculated by the Monte Carlo Simulation

10.6 Relevant project related to multi-hazard risk assessment

10.6.1 MATRIX

MATRIX is a collaborative research project, coordinated by the German National Research Centre for Geosciences, that aims to develop multi-type hazard and risk assessment and mitigation tools suited to the European context. MATRIX is supported by the European Union's Seventh Framework Program (FP7), and is an international consortium of 12 institutions from 10 countries, including one from outside of Europe.
MATRIX will develop methods and tools to tackle multi-type natural hazards within a common framework, focusing on methodologies that are suited to the European context.
Main goals of MATRIX

- Determine and demonstrate under what conditions multi-type risk assessment provides better (or not) results compared with considering only single-type hazards.
- Provide tools for analysing multi-type risk problems within a European context.
- Establish a European knowledge base on multi-type risk in Europe.
- Disseminate multi-type risk concepts to potential end-users and other relevant members of the broader community.
- Provide support for the decision making necessary by civil protection and disaster management authorities on the basis of probabilistic information.
- Expected results and outcomes of MATRIX
- Multi-type risk assessment tools, tuned to the European context that may be exploited by researchers, disaster management and civil protection authorities.
- Characteristic multi-type risk scenarios for Europe for research and planning purposes.
- A knowledge base of the multi-risk situation in Europe that is accessible to researchers, disaster managers and other interested parties.
- Reports outlining guidelines and recommended best practices for multi-type risk and its assessment in Europe.

Training for potential end users.
The MATRIX Consortium has the following partners:

- Helmholtz Zentrum Potsdam Deutsches GeoForschungsZentrum, Germany
- AMRA - Analisi e Monitoraggio del Rischo Ambientale, Italy
- Bureau de Recherches Geologiques et Minieres, France
- Stiftelsen Norges Geotekniskeinstitutt, Norway
- Internationales Institut für Angewandte Systemanalyse, Austria
- Aspinall William Phillip – Aspinall & Associates, United Kingdom
- Karlsruher Institut für Technologie, Germany
- Technische Universiteit Delft , Netherlands
- Eidgenössische Technische Hochschule Zürich, Switzerland
- Instituto Superior de Agronomia, Portugal
- Deutsches Komitee Katastrophenvorsorge e.V., Germany
- University of British Columbia, Canada

For more information
http://matrix.gpi.kit.edu/

10.6.2 Syner-G

Syner-G is a European Collaborative Research Project focusing on systemic seismic vulnerability and risk analysis of buildings, lifelines and infrastructures.
Main Goals of Syner-G are:

- to elaborate appropriate, in the European context, fragility relationships for the vulnerability analysis and loss estimation of all elements at risk
- to develop social and economic vulnerability relationships for quantifying the impact of earthquakes
- to develop a unified methodology, and tools for systemic vulnerability assessment accounting for all components exposed to seismic hazard, considering interdependencies within a system unit and between systems
- to validate the methodology and the proposed fragility functions in selected sites (urban scale) and systems and to implement in an appropriate open source and unrestricted access software tool

The main outcome of Syner-G will be an open source software tool to evaluate seismic vulnerability and losses considering both physical and socio-economic aspects.
For more information
http://www.vce.at/SYNER-G/

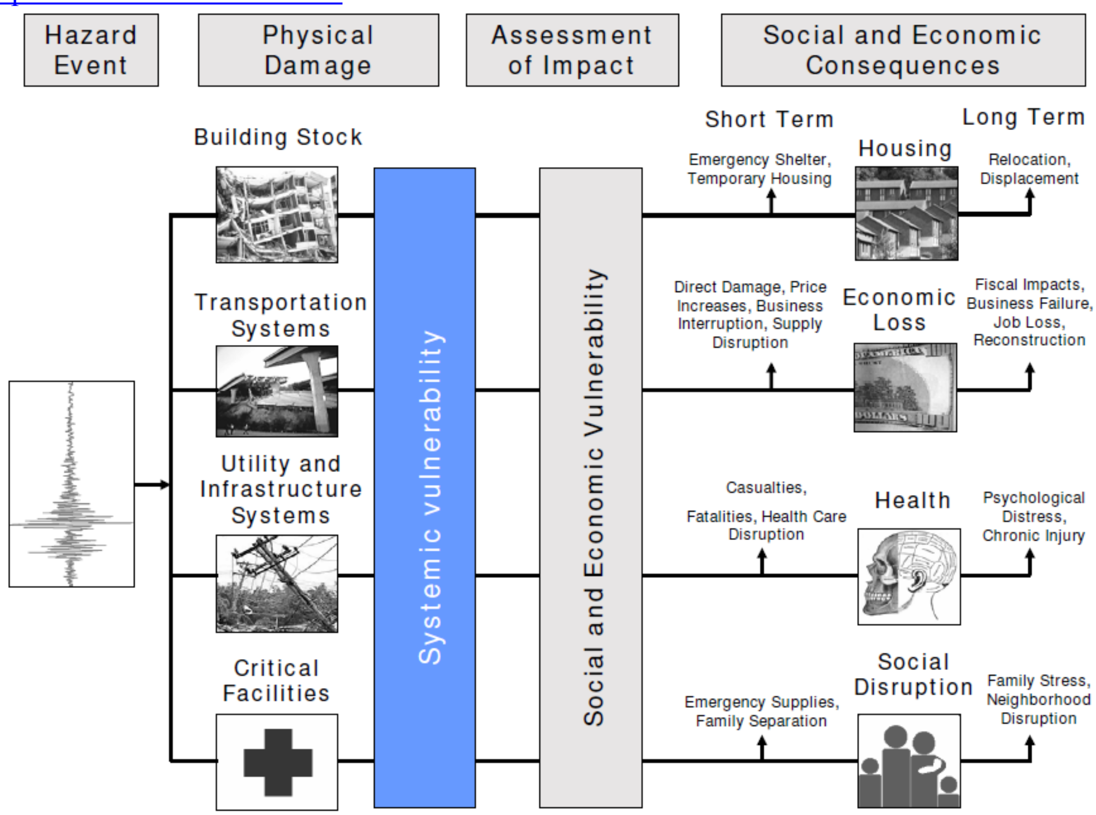


Figure . General graphical layout of the concept and goals of SYNER-G

10.7 Summary table

Comparison of open source software or related projects

Name of software/project	Developed by	Applicability	Open/ Closed source	Comment
Multi Hazard Risk Assessment Tools				
HAZUS	Federal Emergency Management Agency (FEMA) of the US Department of Homeland Security	USA, User Defined, but is rather a	Open/On request	Hazus is open source for US and for other countries with some modifications.
CAPRA-GIS	ERN-LA consortium, formed by ERN Ingenieros Consultores (México), ITEC (Colombia), INGENIAR (Colombia) and CIMNE (Spain)	User Defined	Open	
RiskScape	A joint venture between GNS Science & National Institute of Water and Atmospheric Research (NIWA)	New Zealand	Open/On request	Works for New Zealand
InaSAFE	Indonesia's National Disaster Management Agency (BNPB), the Australian Agency for International Development (AusAID) and the World Bank	User Defined	Open	Plugin for QGIS
RISIKO		User Defined	Open	Part of Risk in a Box, Web based
MultiRISK	Melanie S. Kappes, Klemens Gruber, Simone Frigerio, Margreth Keiler, Rainer Bell & Thomas Glade. In the framework of the project Mountain Risks: from prediction to management and governance, 2007-2010	User Defined	Open	Web based
ARMAGEDOM	BRGM, France			very little published information available
EmerGeo	For Canada, Sai Infosystems Ltd	Canada	Closed	Applied other part of world like Australia , UAE
MIRISK	Department of Urban management, Graduate school of Engineering, Kyoto University	User Defined		Tool for managers for decision making
PerilAUS	Risk Frontiers, an independent research center based at Macquarie University, Sydney, Australia	Australia		
Earthquake Loss Estimation Tools				
OpenQuake	GitHub	User Defined	Open	Web based engine
DBELA	DBELA has been developed at the ROSE School/EUCENTRE in Pavia, Italy	User Defined	Closed	
ELER	Joint Research Activity-3 (JRA3) of the EC FP6	Europe	On request	earthquake shaking and losses throughout the Euro-Mediterranean region
EPEDAT	For California OES by EQE International Inc	USA		
EQRM	Geoscience Australia (GA)	Australia	Open	Can simulate the estimated ground-shaking from an earthquake
EQSIM	University of Karlsruhe	User Defined	Closed	Earthquake including Disaster management tool
Extremum	Extreme Situations Research Center Ltd., including Emercom and SIGE, Russian Academy of Sciences	World wide	Closed	The integrated risk tool also takes into account tsunami and other such secondary effects of earthquakes
SELENA-*RISe*	The development of SELENA and *RISe* was enabled through funding from the International Centre of Geohazards (ICG),	User Defined	Open	

	NORSAR, the University of Alicante, as well as the SAFER and RESIS-II projects. Further support was received from INETER (Managua, Nicaragua) and the Technical University of Madrid (Spain)			
MAEvis	Department of Civil Engineering, University of Illinois, Urbana-Champaign campus the MAE Center collaborated with the Automated Learning Group at the National Center for Supercomputing Applications (NCSA)	User Defined	Open	
LNECLOSS	In the framework of various projects of National laboratory for Civil Engineering (LNEC), Lisbon, Portugal	Europe	Open	
OPENRisk		World wide	Open	
Flood Loss Estimation Tools				
Hora	Technical University of Vienna and an Austrian engineering office (Ing.-Büro Hummer)	Austria	Open	
Kalypso	Björnsen Consulting Engineers and the Institute of Hydraulic Engineering at the Technical University of Hamburg	User Defined	Open	
Technological Risk Estimation Tools				
ARIPAR	The Institute for the Protection and Security of the Citizen of the Joint Research Centre of the European Commission (EC-JRC-IPSC), the Civil Protection Service of the Emilia Romagna Region (ERR), and the Chemical, Minerary and Environmental Technologies Engineering Department of the University of Bologna (DICMA)	User defined	Open	ARIPAR (5.0) is dependent on ArcGIS 9.3
CATS	U.S. Defense Threat Reduction Agency (DTRA)	User defined	Closed	
Other Risk Estimation Tools				
GoldSim	GoldSim Technology Group LLC, USA			Dynamic, probabilistic simulations for support, management and decision-making in business, engineering and science. The tool is not hazard specific
HazYemen/HazSana'a	Worldbank and the GFDRR (Global Facility for Disaster Reduction and Recovery)	Yemen		Flood, landslide, earthquake, flash flood, tsunami, volcano
InLET	University of California and ImageCat Inc	USA (California)	Closed	Earthquake, Internet based
Lumina-Analytica	Lumina Decision Systems, Inc. Los Gatos, CA			Generic probabilistic tool uses Monte Carlo Simulation
Relevant Project related to multi-hazard risk assessment				
MATRIX	In coordination of German National Research Centre for Geosciences; supported by the European Union's Seventh Framework Program (FP7), and is an international consortium of 12 institutions from 10 countries, including one from outside of Europe	User defined	Open	
Syner-G	European Collaborative Research Project	User defined	Open	
Additional software				
Buncombe County Multi-Hazard Risk tool	The County Emergency Operations Center with RENCI and UNC-Asheville			Flooding, wildfire, Landslide
ByMuR	Italian Ministry of Education (MIUR), University and Research			Seismic, volcanic, tsunami
QLARM	WAPMERR and the Swiss Seismological Service and with the support of the Swiss Agency for Development and Cooperation	User defined		To trigger rapid humanitarian response and to analyse the risk in scenario or probabilistic mode

ROVER-SAT	University of Boulder, Colorado	USA	Open	