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ENHANCE

Enhancing Risk Management Partnerships
for Catastrophic Natural Disasters in Europe

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Deliverable 2.1: CATALOGUE AND TOOLBOX OF RISK ASSESSMENT AND MANAGEMENT TOOLS

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SEVENTH FRAMEWORK PROGRAMME

Title	CATALOGUE AND TOOLBOX OF RISK ASSESSMENT AND MANAGEMENT TOOLS
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Contents

1 Background

The ENHANCE project is concerned with analysing and working towards improved public-private partnerships for managing risks from natural hazards. An important issue for such partnerships is the methods, tools and processes available for assessing risk and risk management options. Risk analysis has long provided useful input to decision-making (see Smith, 1996; Bedford and Cooke 2001; IPCC, 2012; Amendola et al. 2013). At the same time, the field of risk analysis is in motion and an enhanced framing of risk analysis and risk management is being embraced following an iterative cycle organized around notions of learning, innovation and transformation (see IPCC, 2012). This broadened vision on risk analysis is a key issue for the ENHANCE project as well, which takes many and different perspectives on analysing, understanding, communicating and managing risk.

Deliverable 2.1 ("Catalogue and toolbox of risk assessment and management tools") lays out the status quo at the outset of the project regarding risk analytical tools, methods and data that are currently used by project partners in ENHANCE. The task overall develops a catalogue of existing risk assessment and management tools and methods to describe the concepts of iterative risk management and further sets up a toolbox, containing individual u models and tools to be used by the case studies in their analyses.

While work in the cases study, including methodological development, is in process, we find that ENHANCE partners and cases employ a multitude of models, tools and data ranging from impact analysis, different risk modelling techniques to various decision-support methods. A number of tools that encapsulate these methods are also available with the consortium.

We suggest the tools and methods in use can be useful starting points for working towards a broader vision of iterative risk management. While the work so far, and this deliverable, have focussed on populating the technical stages of the risk analytical cycle (visually identified as the inner circle), we suggest in the next phase of ENHANCE, additional efforts should be dispensed to better understand adaptive management aspects associated with using these methods and tools, such as learning, innovation and transformation, which we exhibit visually in an outer circle.

This report proceeds as follows: We start with laying out key elements of risk analysis and management in section 2, which also describes the new framing organized around the iterative risk-management concept. Methods for assessing risk and evaluating risk management are discussed in section 3. Then we consider methods, models and datasets that are in use in the ENHANCE case studies at the moment (section 4), before section 5 concludes. Finally and importantly, the annex lists more information on cases studies, for which detailed information was received from the project partners.

2 Risk analysis and management

Traditionally, disaster management can be said to comprise the following distinct ex ante (the first four) and ex post stages (the fifth) (Smith, 1996).

1. Risk identification and analysis;
2. Risk Prevention;
3. Risk preparedness;
4. Risk sharing and financing; and
5. Disaster management (response, reconstruction and rehabilitation).

Table 1: Overview of disaster management stages and options

Type	Ex ante risk management				Ex post disaster management	
	Risk identification and analysis	**Prevention**	**Preparedness**	**Risk sharing and financing**	**Response**	**Reconstruction and rehabilitation**
Effect	Assessing risk	Reducing risk by addressing underlying factors	Reducing risk in the onset of an event	Transferring risk by reducing variability and longer term consequences	Responding to an event	Rebuilding and rehabilitating post event
Key options	Hazard assessment and monitoring	Physical and structural risk reduction works (e.g. irrigation, embankments)	Early warning systems, communication systems	Risk transfer (by means of (re-) insurance) for public infra-structure and private assets, microinsurance	Humanitarian assistance	Rehabilitation/ reconstruction of damaged critical infrastructure
	Vulnerability assessment (population and assets exposed)	Land-use planning and building codes	Emergency response	Alternative risk transfer	Clean-up, temporary repairs and restoration of services	Revitalization for affected sectors (tourism, agriculture, exports etc.)
	Risk assessment as a function of hazard, exposure and vulnerability	Economic incentives for proactive risk management	Networks of emergency responders	National and local reserve funds	Loss assessments	Macroeconomic and budget management (stabilization, protection of social expenditures)
	Mainstreaming risk into development planning	Education, training and awareness raising about risks and prevention	Shelter facilities and evacuation plans	Calamity Funds (national or local level)	Mobilization of recovery resources (public/ multilateral/insurance)	Incorporation of disaster mitigation components in reconstruction activities

(Source: Mechler et al., 2013)

It is widely understood that the impacts of disasters can be effectively tackled by employing a comprehensive disaster risk management (DRM) approach. Analysis and research supports the implementation of effective, efficient, equitable and acceptable risk management options by systematically conducting (IPCC 2012; Amendola et al. 2013):

1. Risk identification and analysis;
2. Evaluation of risk management options (in terms of meeting various criteria);
3. Supporting the implementation of options;
4. Monitoring the impacts of implemented risk management measures.

> An iterative risk-management process of monitoring, identification, analysis, evaluation, learning, and innovation can reduce disaster risk and promote adaptive management in the context of climate extremes *(high agreement, robust evidence)*. Risk-management efforts benefit from iterative risk management options because of the complexity, uncertainties, and long time frame associated with climate change (*high confidence*). Addressing knowledge gaps through enhanced observation and research can reduce uncertainty and help in designing effective risk-management and risk management options.

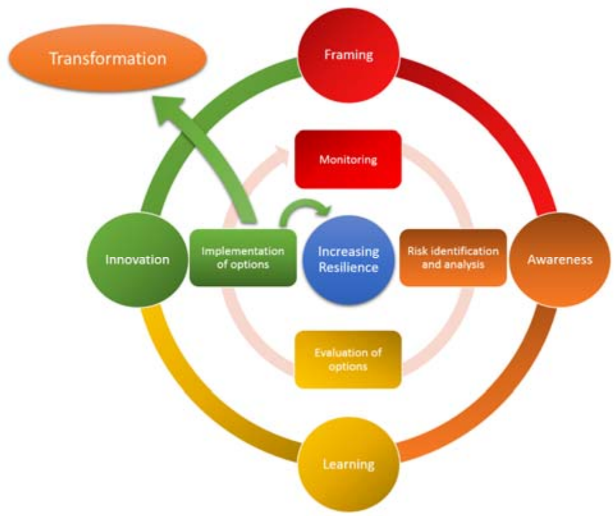

Figure 1. Framing risk management around a notion of iterative risk management. Note: Risk management takes place at multiple scales and, although not illustrated here, these cross-scale feedbacks are important (Source: Williges and Mechler 2013).

This approach to disaster risk is widely used and we exhibit this as the inner cycle in figure 1. Yet, definitions and operationalisations of risk and risk management are in motion, and given an increased understanding of the role of co-generation of information as well as decisions on risks between scientists and policymaker (Sarewitz and Pielke, 2007), as well as due to major challenges associated with data availability, operationalization and quantification, recently the concept of *iterative risk management* has been strongly promoted as, e.g., described in IPCC's Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change (IPCC, 2012).

This quotation, which is based on comprehensive review by the IPCC, suggests that risk analysis is a useful framework, yet more emphasis needs to be given to process (as compared to outcome) as well as co-generated knowledge, such as (re)framing the problem and approaches, creating enhanced awareness for risk and risk management, continuous learning of analysts and stakeholders as well as an increased role for innovation, and finally transformation. We visually exhibit this broadened understanding of the risk cycle by adding an outer circle to the inner one (Figure 1).

These aspects are described in some more detail in the conclusions (section 5), and in the following we focus on cataloguing the inner, technically oriented risk management cycle. We now first address relevant methods for assessing and managing risk in section 3, before in section 4 we summarize specific methods and tools used in the ENHANCE case studies.

3 Methods for assessing and managing risk

Following the risk management cycle, we discuss methods and tools that are associated with the distinct steps of monitoring, risk identification and analysis as well as evaluation of options risk management options. In the following, we discuss key methods that can be used for each of these steps.

3.1 Risk monitoring

One way to keep track of emerging risks is to continuously monitor risk and relevant elements contributing to the risk at hand (see the iterative risk management cycle). This can be done before the disaster arises but also emerging risks can be identified after a disaster event has occurred. One tool of relevance is impact analysis.

3.1.1 Impact analysis (IA)

Impact analysis empirically studies the consequences of natural hazards and climate change and gathers information needed to develop recovery options. Information in that regard can be taken from various sources, such as the EMDAT database, which is the most comprehensive disaster database and for a multitude of events covers disaster impacts, such as people affected, killed and monetary losses (CRED, 2013). Increasingly, and as another source of information for large-scale events requiring external assistance, Post Disaster Damage and Needs Assessments (PDNA) provide detailed information on damages (physical damages of buildings, infrastructure etc.) and indirect losses (economic losses as consequences of physical damages) after severe events based on teams sent to the countries to examine the impacts (GFDRR, 2013).

3.2 Risk identification and analysis

Risk identification and analysis is a sophisticated process that includes the study of socio-economic conditions, trends, tendencies in vulnerability and exposure etc. Methods may be broken down into qualitative and quantitative approaches.

Risk analysis in a narrow sense is a process that involves the qualitative or quantitative evaluation of hazards, socio-economic conditions, trends, tendencies in vulnerability and exposure to find solutions of risk management problems. Here, we focus on the some dimensions of disasters, e.g. socio-economic and human dimensions as well as other scenarios and risk management pre-event and post-event actions.

3.2.1 Qualitative analysis (QA)

Very often, risk can hardly be measured mathematically, or the quality of the model approximation is so low, that it is difficult to determine risk. In this case there arises the necessity to use other approaches. Risk studied through a qualitative risk assessment is descriptive and/or categorical in nature and not directly tied to a quantifiable risk measure. Qualitative risk assessments are commonly used for screening risks to determine whether they merit further investigation, and can be useful in preliminary risk management activities. However, they very well may also provide the needed information and additional analysis to answer specific risk management questions (for more details see CDCP, 2009).

Example: Monfared et al. (2013) qualitatively analysed the interactions between sub-groups of Iranian farmers during drought periods. Due to the complexity of the interactions quantitative methods were not feasible and therefore qualitative approaches were adopted. They find that heterogeneity within the society may play a more important role for recovery than expected which cannot be identified using quantitative assessments.

3.2.2 Analysis of risk perception (RP)

Risk perception is the judgment about the characteristics and severity of the natural hazards risk using mental, rather than numerical models (see IPCC 2012; for ENHANCE project details see Wadden Sea case study). Risk perception is shaped by cognitive, cultural and social factors (Slovic, 2010) and plays an essential role in judging if or if not to implement risk reduction measures. The method is partly based on perceived risk, but also on perceived coping capacity of the relevant stakeholders. Understanding how stakeholders perceive disaster risk is necessary in order to influence hazard preparedness, and can be used to explain risky behaviour such as residents of at-risk areas often have different beliefs about the hazard agent and its impacts, are unaware of available adjustments, and may have varying beliefs about the effectiveness of the adjustments of which they are aware. Risk perception plays an important part for risk analysis and the risk management cycle.

Example: Historically, the European North Sea Coast has regularly been affected by disastrous storm surges. Since 1962 – the latest fatal disaster in the area – it has been possible to prevent fatal casualties. Huge financial and technical input helped to keep damages at relatively low levels. However, the projected impacts of climate change, especially intensified storm activity and sea level rise, may lead to increased hazards and, thus, to the need to enhance resilience. The entire cultural-historical settlement area is characterized by the fight against the sea and the reclamation of land, which is closely related to issues of perception and cognition as well as the framing of spatial creation and construction of land use (see Wadden Sea case study for details).

3.2.3 Risk modelling (RM)

Modelling disaster risk is a key tool to study potential impacts using numerical approaches. Four different types are worth noting.

3.2.3.1 Extreme value theory and frequency analysis

The statistical treatment of extremes needs a theory of its own, namely extreme value theory (Embrechts et al., 1997). Extreme value theory deals with the stochastic behaviour of the maximum (or minimum) of i.i.d. random variables. The distributional properties of extremes are determined by the upper and lower tails of the underlying distribution. Conversely, the tail of the underlying distribution function may be evaluated by means of statistical procedure, e.g. to estimate accurately the tail of F given a set of independent data $X1,X2,...,Xn$ from the unknown distribution F. The greatest difficulty in estimating accurately the tail of the distribution is data scarcity: Most data is (naturally) concentrated toward the centre of the distribution and so, by definition, extreme data is scarce and therefore estimation is difficult. Further issues are: While there are very few observations in the tail, there are often estimates required beyond the largest observed data value. Additionally, while standard density estimation techniques fit well where data has greatest density, it can be severely biased in estimating tail probabilities

Extreme value theory plays an important methodological role in risk management for insurance, reinsurance, and finance. In contrast to a very large number of other statistical methods, extreme value theory pays particular attention to the tails of a distribution, i.e. the most extreme values at either the high or low end. One of the greatest challenges to a risk manager is to utilise risk management tools, which allow for modelling rare but damaging events, and permit the measurement of their consequences. As indicated, extreme value theory plays a vital role in these activities as it provides the basis to estimate rare events never observed before (Embrechts et al. 1997; Embrechts et al. 1999).

To model extreme risks it is necessary to consider the problem in the probabilistic environment with random variables, mapping unforeseen future states of the world into values representing profits and losses. These risks may be considered individually, or seen as part of a stochastic process where present risks depend on previous risks. The potential values of a risk have a probability distribution which will never be observed exactly although past losses due to similar risks, may provide partial information about that distribution that one may have estimated through statistical analysis of empirical data.

Example: Hochrainer et al. (2009) calculate flood losses associated with a 100 year event (i.e. an event, which happens on average every 100 years) for a situation where rainfall data as well as loss data are only available for a 51 year period (1960-2010).

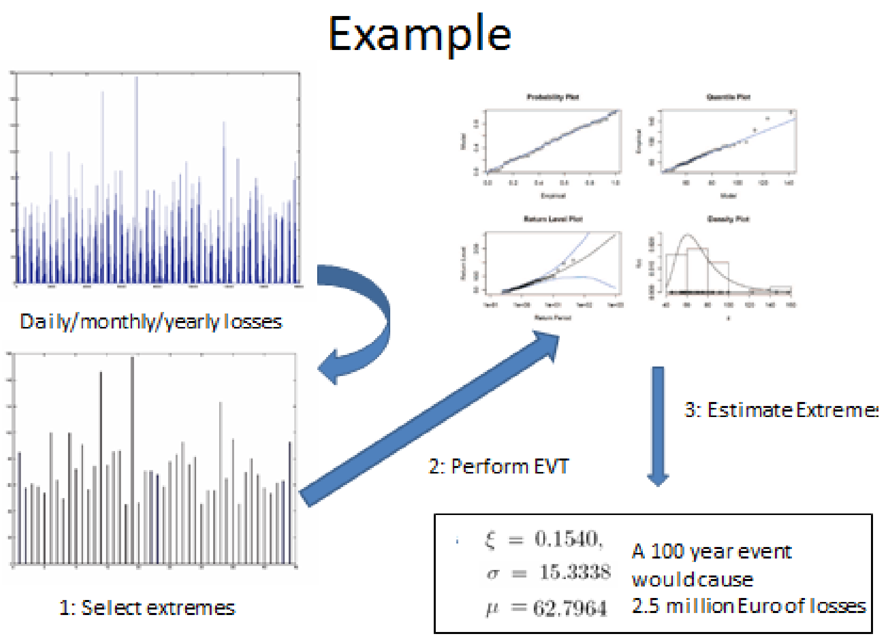

Figure 2. Extreme value theory/statistics application example.

As only a 51 time horizon was available, EVT was used (step 1) to perform statistical analysis of the data (step 2) and estimate extremes outside the observation period (step 3). The analysts therefore were able to calculate the 100 year loss event, which was estimated to be Euro 2.5 million. With the estimated extreme value distribution, risk assessment for all kind of rare events became possible and could be incorporated into decision-making processes.

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3.2.3.2 Scenario generation

Extreme event risk analysis can be importantly used to generate scenarios of future risk. Generating scenarios based on the probabilistic representations of risk can be separated into random and optimal quantization methods

- **Random quantization**

  Given the historical data on losses after extreme events it is possible to estimate empirically the probability loss distribution) that will represent the current and future risks. Based on the estimated loss distribution the future scenarios for the losses can be generated randomly using Monte-Carlo or Quasi Monte-Carlo methods (for more details see Berg 2004; Caflisch 1998; Fishman 1995; Robert and Casella 2004).

- **Optimal quantization**
  Estimation of the tails of the loss probability distribution (see Extreme value theory) allows to model rare but very damaging events. In contrast to the Monte Carlo simulation that takes values randomly and mostly from the highest probable part of the distribution (near the mean value), optimal scenario generation represents the tails of the distribution much better (Hochrainer, 2006; Pflug and Roemisch, 2007; Timonina, 2013).

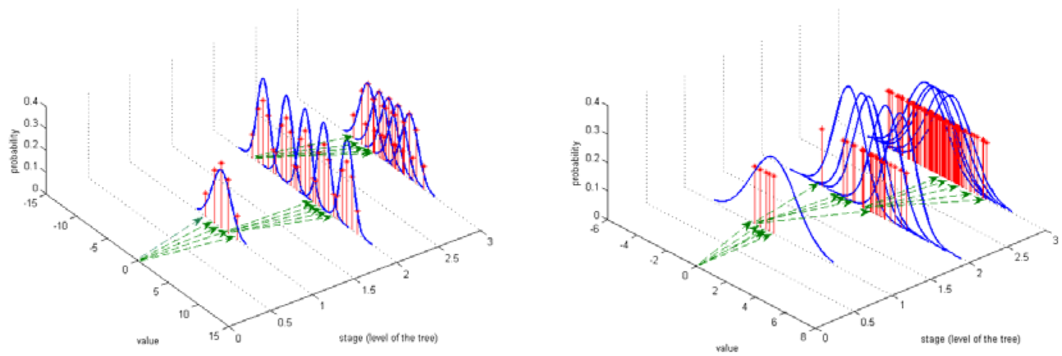

Figure 3. As one example, Timonina (2013) shows the difference between Random generation and Optimal quantization on the example of Gaussian distribution in multi-period environment. The Gaussian distribution is chosen because of the simplicity of construction of its conditional distributions.

Optimal quantization respects the probability of different events, while random quantization considers all events to be of equal probability. The fat tails are much better represented in case of optimal quantization.

3.2.3.3 Multi Risk, Dependencies and cascading effects

For correctly applying statistical and modelling techniques for the management and assessment of extreme risk it is not only necessary to model the tail behaviour of the loss distribution using extreme value theory, but also to correctly model the interdependence between losses. Traditional methods of risk assessment widely used in the insurance sector fail here. For example, natural hazards, such as floods or windstorms, often impact entire regions and thus will affect all policyholders in these regions at once. Hence, the risk in insurance portfolios, for example, is highly correlated and the law of large numbers, stating that the variance of an average decreases with the number of items, is not applicable. In contrast, in highly correlated portfolios the variance of the average may be close to the variance of an individual loss. Consequently, the probability of ruin is much higher and different diversification strategies have to be applied, e.g. re-insuring or using international financial markets (Hochrainer, 2006; Cardenas et al., 2007; Linnerooth-Bayer et al., 2011). Consequently, dependency among risks is an important matter in managing extremes and in the most general form can be dealt with the use of “copulas”. Copulas are functions that join or “couple” the one-dimensional margins to a multivariate distribution function. For a random vector X of dimension m and marginal distributions F_i, the copula $C(\cdot)$ gives the cumulative probability of not exceeding $x = (x_1,...,x_m)$ as

$$P(X \le x) = C(F_1(x_1),\ldots,F_m(x_m)).$$

As each multivariate distribution with continuous marginals has a unique copula representation the applicability of copulas is large. It can be especially useful for multi risk/hazard assessment, to include dependencies of losses from lower to larger scales as well as can be used to test cascading effects.

Example: Hochrainer et al. (2013) estimated multi risk situation with an even-based copula.

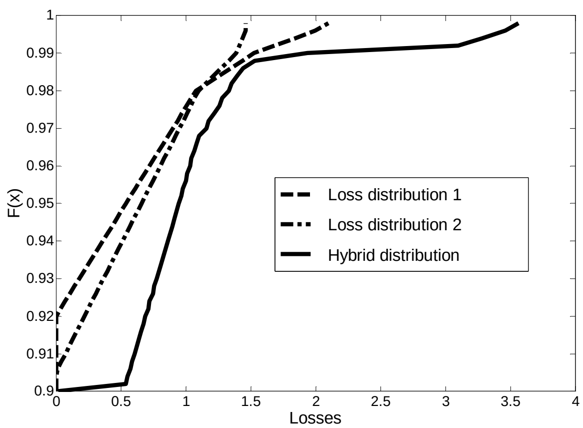

Figure 4. Deriving a copula from loss distributions.

As the figure indicates two loss distributions from two different hazards were coupled to a new single risk distribution by assuming full dependence after a 100 year event, i.e. a 100 year event of hazard one would also cause a 100 year event for hazard two. This approach can also be used to combine risk over different scales, e.g. distribution 1 and 2 are neighbouring regions. With such methods it is possible to look at multi-risk situations simultaneously.

3.2.4 Bayesian analysis (BA)

Risk modelling using extreme event statistics is based on a frequentist approach, which suggests all relevant information on assessing and generating risk is available at the time of the analysis. Bayesian analysis, in contrast, is used to update estimates as new or additional information arrives (see Behrens et al. 2006). If uncertainty is present in the loss distribution (for example, in case data is not fully reliable) one can optimize over a possible set of distributions with different distribution parameter. The set of possible distributions is dependent on the chosen parameter and has to be defined beforehand. The distribution that is received after the optimization is called posterior distribution, while the starting one is called prior distribution. Now, the posterior distribution of the parameters can be estimated based on the empirical data and on some prior distribution/information of these parameters. Generating the posterior distribution of the parameters based on the empirical data and some prior distribution of these parameters is called Bayesian analysis (Behrens et al., 2006). In this way it is possible to include new information successively within a given model.

Example: Consider a small village perched on the shores of a pristine lake, where many citizens want economic development, but development will eventually increase the pollution of the lake. The citizens know that lakes such as theirs can exhibit threshold behaviour where a small pollution increase over some level may cause a clear lake to turn suddenly and some-times irreversibly cloudy. In order to develop a plan that preserves the clarity of their lake, cognizant of their widely divergent values regarding environmental quality and growth, one should consider the divergent opinions of the citizens about the level where the pollution threshold for their lake might lie. In this case the uncertainty in distribution arises and Bayesian analysis is a useful way forward for arriving at better decisions (for details see Lempert and Collins, 2007).

3.3 Evaluation of risk management options

The evaluation of risk management options depend on many objectives, not all of them quantifiable or comparable. For example, alternatives of management options or the given strategy selected can be based in accordance with financial aspects as well as political and social realities. Dependent on the decision maker and the necessity of including results of risk management options with other investment priorities different approaches may be adopted for evaluation. The best known tool is Cost Benefit Analysis (CBA), yet there are a number of alternative approaches for economic decision-support on risk management, some of them lately receiving increasing interest, particularly in analyses pertaining to climate adaptation.

3.3.1 Cost benefit analysis (CBA)

Cost benefit analysis is a decision-making assistance method that identifies the economically efficient way to fulfil an objective by comparing benefits and costs of two or more courses of action. Since it is misleading to assess the benefits of prevention using deterministic models, the challenges for cost-benefit analyses in disaster risk management is to express avoided losses in probabilistic terms, evaluate and assess risk, monetize direct and indirect benefits and include dynamic drivers such as changing population, land use and climate.

For example Michel-Kerwan et al. (2013) performed cost benefit analysis for residential houses in Jakarta against flooding. They used a catastrophe modelling approach to assess costs and benefits from a risk based perspective. Table 2 below shows CB ratios for two mitigation measures.

Table 2. Cost / Benefit ratios for different mitigation measures and scenarios, from Michel-Kerwan et al. (2013).

DRR Measure	Time Horizon (years)	Masonry				Mixed Wall			
		Min Hazard		Max Hazard		Min Hazard		Max Hazard	
		Discount Rate		Discount Rate		Discount Rate		Discount Rate	
		5%	12%	5%	12%	5%	12%	5%	12%
1. Improve flood Resilience	10	0.49	0.36	0.63	0.46	0.10	0.07	0.11	0.08
	25	0.90	0.50	**1.16**	0.64	0.18	0.10	0.21	0.11
2. 1 m elevation	10	0.83	0.61	**1.18**	0.86	**2.06**	**1.51**	**3.69**	**2.70**
	25	**1.51**	0.84	**2.15**	**1.20**	**3.77**	**2.10**	**6.73**	**3.75**

Based on the need for monetizing all cost and benefit information, the results help to identify the most robust housing structures. E.g., Results show B/C ratios that are substantially higher among mixed wall structures than among masonry structures, due to a greater hazard level. Elevating the property by 1 m also has mostly favourable results, with B/C ratios ranging to up to 6.73.

3.3.2 Cost-effectiveness analysis (CEA)

Cost-effectiveness analysis (CEA) is used to identify least-cost options to meet a certain target or policy objective. As the project costs are the key variable of consideration and subjected to finding cost-minimal solutions, CEA does not require the quantification of benefits (which are fixed beforehand, such as reducing disaster fatalities and losses). One example is an assessment of the cost-effectiveness of seismic retrofit in Romania conducted by the World Bank (World Bank, 2004). Cost-effectiveness analysis was used to select possible seismic retrofitting options for a number of sub-projects under a seismic retrofitting component of a comprehensive World Bank DRM project. Among others, the selection of sub-projects was guided by their contribution to life safety while the cost of retrofitting was to be minimized below a total of 60 per cent of the cost of replacement in disaster events.

3.3.3 Multicriteria analysis (MCA)

Another decision-support approach is multi-criteria analysis (MCA). A very limited number of studies have used MCA tools in the context of managing extremes, such as Debels et al. (2009) for a quick evaluation of climate adaptation practices in terms in Latin America, and De Bruin et al. (2009), who use a hybrid approach based of qualitative and quantitative assessments of adaptation options for flood risk in the Netherlands identifying an integrated portfolio of options for nature and water management with risk based policies exhibiting particularly high potential and acceptance for stakeholders.

With an emphasis on low cost (not least cost as in CEA, and optimal cost in relation to benefits as in CBA), the methodology is organized around objectives, criteria and indicators. Criteria are attributes which can be used to compare the performance of different (policy) options in achieving one's stated objectives (economic, social, environmental and fiscal criteria). As a next methodological element, indicators are verifiable measures which can be used to monitor changes over time and space in the behaviour of the attributes mentioned above. They can be expressed in quantitative (monetary or not) or qualitative terms.

The idea is that based on the following principles (i) policies have multi-dimensional impacts on human societies and the environment; (ii) the impacts can be clustered into economic, social, environmental and governance objectives, for which criteria (such as improved economic performance or high employment) are specified, which are later on measured by way of indicators; (iii) dimensions, criteria and indicators are then weighted per subjective value given to these, and can even be aggregated to one numerical, dimensionless index, which might be used to compare the performance of different strategies and projects.

As one example, such an approach has been applied to DRM in the UNEP project *Multicriteria analysis for Climate Change* (MCA4climate), which was commissioned to provide practical assistance to governments in preparing climate change mitigation and adaptation strategies. The objective is to assist government decision-makers, particularly in developing countries to identify and examine policy options and measures for climate change that are low cost, environmentally effective and in line with national development priorities (see UNEP 2011; http://www.mca4climate.info). As one example, the MCA4C project in a case study on increasing structural resilience in Mumbai assessed the option of improved building codes in terms of “amending existing building regulations and where necessary, introducing new regulations to ensure that in 20 years’ time all floodplain buildings are on stilts, and earthquake-proof.” Achievement of this objective was measured on a scale of 100 (perfect fit) to 0 (no fit at all). Figure 5 shows the achievement across the universe of these indicators, which ranges from public sector costs over creating additional employment, reducing mortality to improving legal context and governance.

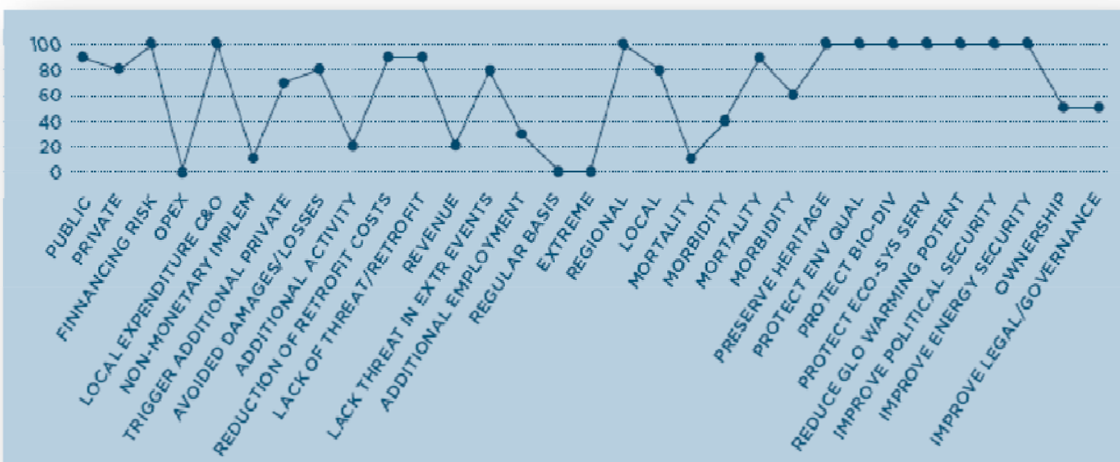

Figure 5: Using MCA to score achievement of buildings codes options against key criteria
Source: UNEP 2011

MCA in this project appeared a promising process-based tool for getting buy-in and interest of policy-advisers/makers, yet, as the figure shows, there is a high degree of subjective judgment involved. As a consequence, it is difficult to easily replicate the evaluation route taken and the choices made by an analyst. In this regard the methodology is more comprehensive, but less rigorous than CBA.

One key factor in evaluating any risk management measures is how to explicitly consider risk in decision rules. Here, two methods are worth noting.

3.3.4 Stochastic simulation (SS)

Comparing and evaluating different risk management options are based on running a large set of scenarios using different simulation techniques, e.g. Monte-Carlo simulation or optimal quantization (Pflug and Roemisch 2007; Robet and Casella 2004).

For example, for an analysis of the economic repercussions of disaster risk on Madagascar, Hochrainer et al. (2012) analysed the reduction of fiscal risk (measured in terms of a financing gap, i.e. the risk that the government is not able to finance its losses) due to cyclones based on an important sampling algorithm within an interactive user interface (figure 6).

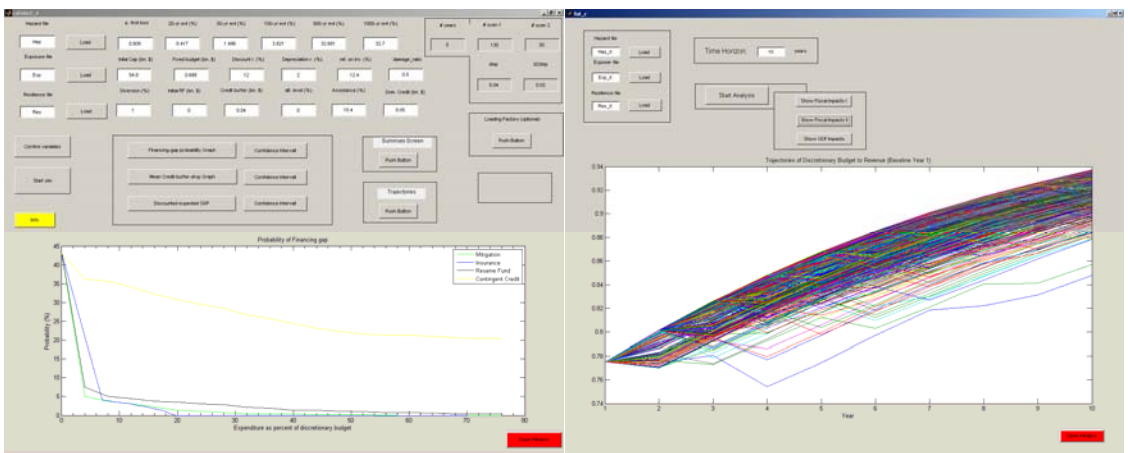

Figure 6: Decrease of the financing gap probability (left) and potential fiscal risks (right)

The analysis of the risk management options was based on simulation of hazard events up to 10 years into the future (figure 6, right hand side). As one can see, many different possible futures can be observed and have to be incorporated to arrive and compare different robust solutions.

3.3.5 Stochastic optimization (SO)

Stochastic optimization is a decision-making technique to maximize or to minimize objective functions in a stochastic context. In this case, the optimal decision can be derived using stochastic optimization methods (single-stage stochastic programming, multi-stage stochastic programming) using generated samples from the empirically estimated loss distribution. Also multi-stage optimization techniques may be of interest here (Pflug and Roemisch, 2007), e.g. first optimal solutions in the pre disaster stage are calculated and based on them, optimal solutions after the event (second stage) are calculated.

Example: As one example, using stochastic optimization techniques it is possible to find optimal insurance or investment strategies for governments of exposed countries in the multi-period environment that allows to reduce the disaster risk and to maximize the objective of a given or assumed policy-maker (for details see Timonina, 2013).

One of the main goals of following a systematic approach as described here is to provide guidance and, ideally, policy recommendations for the eventual implementation of options. Yet, while the researchers working in the project are concerned with implementation issues in a wider sense, implementation of options is undertaken by practitioners and stakeholders, and we do not further dwell on this here.

4 Discussion of methods and tools used in ENHANCE

4.1 The Case studies

The ENHANCE project considers 10 case studies with close engagement of stakeholders. The aim is to develop policy relevant knowledge for the improvements in social resilience to catastrophic natural disasters at the local, national, and European policy levels. The case studies are chosen according to the diversity of natural hazards, of locations in Europe, of geographical scales, and according to the variety of Multi-Stakeholder-Partnership types, including those with a primary focus on emergency response, risk reduction options, or financial partnerships. All cases include a high level of stakeholder engagement and policy relevance and are mutually beneficial for the transfer of knowledge between science and policy.

Table 3. Overview of ENHANCE case studies, geographical region, and specific case focus.

Name	Region	Focus
Drought management in Jucar River Basin	**Jucar River Basin**	The case study explores the usefulness of economic instruments that so far have not been applied in the Jucar Basin District, private-public partnerships, and regulatory instruments to improve the resilience to droughts of water resources systems.
Health preparedness and heat wave response plans	**Europe, Bonn and Denmark**	This case study assesses the health systems' preparedness and response plans. Developing the methods exploit past research and existing knowledge.
Flood risk management for Rotterdam Port infrastructure	**Rotterdam Port**	The case study aims "to set-up a general guidance for water related risk management for unembanked areas in the port of Rotterdam, which (i) consists of a quantitative method that enables companies and government to assess water related risk at differences scales (from individual to societal risk), (ii) offers handles to control and limit water related risk and, hence, (iii) enhances societal resilience through multi-sector partnerships".
Building railway transport resilience to alpine hazards	**Austria**	This case study develops vulnerability/damage functions for key infrastructure elements and performs a quantitative risk analysis at selected railway tracks as a basis for improved risk management procedures.
Insurance & forest fire resilience	**Chamusca**	This case study provides a hindsight analysis of the events of 2003, revisiting major drivers leading to catastrophic fires in Chamusca, and an assessment of the measures and policies implemented.

Testing the Solidarity Fund for Romania and Eastern Europe	**Romania and Eastern Europe**	This case study will test this perspective for Eastern Europe/Romania, and focus on pre-disaster measures for reducing flood and seismic risk. Two scenarios will be created: a scenario in which a set of disaster risk and vulnerability reducing measures and policies will be taken into consideration (pre-disaster risk management); and a scenario in which the EUSF and/or Europe Re intervenes in the same conditions as those existing now.
Air industry response to volcanic eruptions	**Iceland**	A volcanic eruption that produces ash can, in addition to direct risk for aircraft, have widespread, multi-national negative impacts on air transport of people and goods, which can lead to catastrophic economic consequences for individuals, and public and private entities. National economies are increasingly vulnerable to the negative impacts of such a disruption in air travel. This case study evaluates the policy measures and communication channels surrounding a major volcanic eruption affecting air travel.
Risk culture, perception & management	**Wadden Sea coast**	This case study intends to analyse the regional culturally embedded perception of nature, natural events, resources and resource interests as well as to analyse the recent historic handling of the two storm surges on 1953 and 1962 and its influence on current coastal protection measures. The research goal is to compare the different regional cultures of risk in the Netherlands and in Germany as well as to test, assess and proof the transferability of culturally embedded social resilience approaches for the future.
Climate variability & technological risk in the Po basin	**Po river basin**	The case study considers multi hazard risk situations ('hazard chains') based on: (1) review of historical disasters; (2) up-to-date climate projections for the case study region; (3) cutting edge modelling framework for simulation of drought and flood events; (4) state-of-the art research on direct/indirect economic costs and social hardship of the extreme events. The aim is to analyse risk and vulnerability of rural and urban communities and key economic sectors in the largest and most important Italian river basin (ca. 40% of GDP and national agricultural production).

Flood risk and climate change implications for MSPs	**London, UK**	Future flood risk for London (UK) is expected to increase due to urbanization and population increase, increasing household contents, climate change and deterioration of the flood defense system. This case study includes a review of existing risk analyses on London flood, vulnerability to flood and on the impacts of historical flood events to develop a disaster risk profile for London flood. Next to that, it will evaluate existing and potential new risk management partnerships for London floods.

4.2 Overview of methods used in the case studies

We now discuss quantitative and qualitative risk analytical methods that are in use in the specific case studies. The following table, based on a review with the cases studies in the summer of 2013, provides an overview of the methods being used organised around the different stages of the iterative risk-management cycle.

Table 4. Summary of current usage of methods in ENHANCE case studies

	Risk monitoring	Risk identification and analysis				Evaluation of risk-management options				
	IA	QA	RP	RM	BA	CEA	MCA	CBA	SS	SO
Drought management in Jucar river basin district	x	x		x		x	x	x	x	x
Flood risk management for Rotterdam Port infrastructure	x	x		x						
Health preparedness and heat wave response plans	x	x		x		x				
Air industry response to volcanic eruptions	x	x								
Risk culture, perception & storm surge management (Wadden Sea)	x	x	x				x			
Climate variability & technological risk in the Po basin	x	x		x			x		x	
Flood risk and climate change implications for MSPs, London	x	x		x		x		x	x	
Building railway transport resilience to alpine hazards	x	x		x		x		x	x	
Insurance & forest fire resilience, Chamusca	x	x		x				x	x	
Testing the Solidarity Fund for Romania and Eastern Europe	x	x		x		x		x	x	x

Note: IA: Impact Analysis, QA: Qualitative analysis, RP: Risk Perception, RM: Risk modelling; BA: Bayesian analysis; CEA: Cost-effective analysis; MCA; Multi-criteria analysis; CBA; Cost Benefit Analysis; SS: Stochastic Simulation; SO: Stochastic Optimization

Based on the assessment of the current status quo of the usage of methods (which will be subject to change over the course of the project), we find that ENHANCE partners and cases employ a multitude of methods. All case studies base their analyses on empirical impact data, which if used continuously over time allows for monitoring risk. In terms of risk identification and analysis, qualitative approaches are as well decisive for identifying the risks as well as dominant drivers of risk. In terms of assessing risk, interestingly, analysis focussing on risk perception was only mentioned once. Risk modelling, employing among others, extreme value statistics would be used in most cases. Again of interest, according to this quick survey, these methods currently would employ frequentist approaches only, and Bayesian techniques were not mentioned yet. What concerns decision-tools for evaluating risk management, all three key techniques (CEA, MCA and CBA) receive application. A number of cases currently plan to use stochastic simulation, and two stochastic optimization techniques.

4.3 Tools for assessing and managing risk

Based on the described methods, we also reviewed specific tools that have been developed to assess and manage risk by using, among others, the methods described in the previous section. To provide perspective, the overview provides a general summary of selected tools, classification within the IRM framework, and links for further information. The table is not (an not meant to be) exhaustive, but shows the wide variety of operationalisations of the methods discussed above (for more detail, see UNFCCC, 2012; Williges et al., 2011; Williges et al., 2013; Guha-Sapir and Hoyois, 2012). A number of tools (EM-DAT, CATSIM, AquaCrop, AQUATOOL and the IWRM toolbox; entries in table marked in grey) listed are currently run or available with the ENHANCE project consortium. It is envisaged, that more and other tools will be employed in the course of the project.

Table 5. Selected tools for the assessment and management of disaster risk, providing summaries of selected tools, classification within the IRM framework, and links for further information.

Name (jncl. Weblink)	Type	Institution	Purpose	Description
EM-DAT	IA	Centre for Research on the Epidemiology of Disasters	Disaster impact database: The main objective of the database is to serve the purposes of humanitarian action at national and international levels.	Extraction and consolidation of historical data on heat wave mortality from global EMDAT database and other sources (e.g. national and European mortality monitoring projects such as Be-MOMO and EUROMOMO).
Natural Disaster HotSpots	IA	World Bank	To present a global view of major natural disaster risk hotspots – areas at relatively high risk of loss from one or more natural hazards.	Data on six hazards are combined with state-of-the-art data on the subnational distribution of population and economic output and past disaster losses.
Desinventar	IA	Corporacion	Desinventar is a conceptual and	The Disaster Information

		OSSO, La Red, UNISDR	methodological tool for the construction of databases of loss, damage, or effects caused by emergencies or disasters.	Management System is a sustainable arrangement within an institution for the systematic collection, documentation and analysis of data about losses caused by disasters associated to natural hazards.
WorldRiskIndex	IA	UNU-EHS	The WorldRiskIndex presents a global view on risk, exposure and vulnerability.	The index is based on 28 indicators that are available worldwide. The selected indicators represent four components of risk, namely, exposure and vulnerability, whereas vulnerability is composed of susceptibility, coping capacities and adaptive capacities.
Disaster Loss Assessment Guidelines	IA	Emergency Management Australia	To provide an explanation of the process of loss assessment, and lead the reader through the steps required to carry out an economic assessment of disaster losses.	Disaster Loss Assessment Guidelines assist in the management and delivery of support services in a disaster context.
Handbook for Estimating the Socioeconomic and Environmental Effects of Disasters	IA	Economic Commission for Latin America and the Caribbean	To describe the methods required to assess the social, economic and environmental effects of disasters, breaking them down into direct damage and indirect losses and into overall and macroeconomic effects.	The handbook incorporates new and significant developments while refining and improving the methodology for damage assessment contained in several sections included in the first version published in 1991.
HAZUS-MH (Hazards U.S. Multi-Hazard)	IA	Federal Emergency Management Agency	To analyse losses from floods, hurricanes and earthquakes.	HAZUS-MH applies geographic information systems (GIS) technology to produce estimates of hazard-related damage before or after a disaster occurs.
CATSIM	IA, RM, SG, SS, CEA	International Institute for Applied Systems Analysis	To help policymakers, particularly in developing countries, devise public financing options to be implemented in both the pre- and post-disaster context.	CATSIM uses Monte Carlo simulation of disaster risks in a country or region, and examines fiscal and economic risk based on an assessment of the ability of governments to finance relief and recovery.

CAPRA (Central American Probabilistic Risk Assessment)	RM, SG, SS	Consortium in Latin America	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.	The model is based on a GIS platform for risk assessment linked to selected hazards. The approach is to use probabilistic methods to analyse different natural hazards, including hurricanes and floods. For the risk assessment, hazard information is combined with exposure and vulnerability data. The GIS information system allows focusing on a single hazard risk and multi-hazard risks.
Vulnerability and capacity assessment (VCA)	QA	International Federation of Red Cross and Red Crescent Societies; CARE	To identify the strengths and weaknesses of households, communities, institutions such as national societies and nations.	Vulnerability and Capacity Assessment (VCA) uses various participatory tools to gauge people's exposure to and capacity to resist natural hazards. It is an integral part of disaster preparedness and contributes to the creation of community-based disaster preparedness programmes at the rural and urban grass-roots level.
Community based disaster risk management	QA	Asian Disaster Preparedness Center	To denote the application of measures in risk analysis, disaster prevention and mitigation and disaster preparedness by local actors as part of a national disaster risk management system. A key feature is multi-sectoral and multi-disciplinary cooperation with special responsibility borne by the municipal authority.	Community based disaster risk management (CBDRM) is a process, which leads to a locally appropriate and locally 'owned' strategy for disaster preparedness and risk reduction.
AquaCrop	IA	Food and Agriculture Organization (FAO) of the United Nations	The model estimates crop growth, given a set of climate and soil parameters, together with crop management. As the model was designed to assess crop response to water, it allows for the evaluation of climate impacts (reduced water availability) or environmental	AquaCrop is a crop-model to simulate yield response to water of several herbaceous crops. It is designed to balance simplicity, accuracy and robustness, and is particularly suited to address conditions where

			regulations (reduced water quotas) on crop yields.	water is a key limiting factor in crop production. AquaCrop is a companion tool for a wide range of users and applications including yield prediction under climate change scenarios.
DIVA	IA, QA, SS		DIVA produces quantitative information on a range of ecological, social and economic coastal vulnerability indicators from sub-national to global scales, covering all coastal nations.	DIVA (Dynamic and Interactive Vulnerability Assessment) is an integrated model of coastal systems that was developed, together with its proper coastal database, within the EU-funded project DINAS-COAST.
AQUATOOL	IA, QA, SG, SS	David Haro, Joaquín Andreu, Manuel Pulido	AQUATOOL includes several utilities focused in water resources systems analysis, namely, quantitative simulation of water management and water quality (SIMGES and GESCAL), optimal water allocation (OPTIGES), definition of environmental flows (CAUDECO), stream flow series analysis and modeling (MASHWIN), drought risk assessment (SIMRISK methodology), and rainfall-runoff modeling for stream flow series generation (EVALHID).	AQUATOOL is a Decision Support System (DSS) for the management of the water resources in a river basin which integrates in a comprehensive way all relevant water elements and its interactions, in order to provide different scenarios that incorporate water offers and demands.
IWRM toolbox	IA, RM	Global Water Partnership	Adapting to climate change implies improving and adapting water management. IWRM is offering a base for climate change risk-management and has been recognized by both IPCC and UNFCCC as a way forward.	GWP developed tools to approach IWRM that deal with access to water and protecting the integrity of the ecosystem, thus safeguarding water quality for future generations. In this way IWRM can assist communities to adapt to changing climatic conditions that limit water availability or may lead to excessive floods and droughts.

Note: IA: Impact Analysis, QA: Qualitative analysis, RP: Risk Perception, RM: Risk modelling; CEA: Cost-effective analysis; SS: Stochastic Simulation; SO: Stochastic Optimization, Note: tools marked in grey are owned or run by ENHANCE project partners,

5 Conclusions and recommendations: Towards an iterative risk-management cycle

This report has laid out the multitude of models, tools and data that ENHANCE partners and cases employ, ranging from impact analysis and different risk modelling techniques to various decision-support methods. A number of tools that encapsulate these methods are also available with the consortium. Work in the case studies, including further methodological development, is in progress, and it is very likely that more methods and tools will find application in the project.

We suggest these tools and methods, as they are useful to identify, assess and monitor risk and risk management, can similarly be useful starting points for working towards a broader vision of risk analysis using an iterative and adaptive cycle. The work so far and in this deliverable has focused on populating the technical stages of the risk analytical cycle (visually identified as the inner circle of figure 1), and we suggest in the next phases of ENHANCE, additional efforts should be dispensed to better understand adaptive management aspects associated with using these methods and tools, such as (re)framing, learning, innovation and transformation, which we exhibit visually in an outer circle of the figure.

Framing and reframing the analysis is essential to work towards risk management that contributes widely to reducing risk and building resilience. Research has focussed on finding solutions to managing risk, often successfully so, yet with limitations; the focus of attention has been largely on reducing risk through engineering-based (hard) solutions or top-down systems (such as planning and insurance). There is much less scientifically-grounded understanding regarding measures for enhancing resilience through soft and smart options shaping and affecting individual and community behaviour (Moench et al., 2009). While there would much more to say to this point, one issue worth noting here is the need for critically considering how risk analysis and management approaches are framed and whether they are able to well integrate with the debate.

What is more, it is widely understood that business-as-usual may not suffice for dealing with the growing burdens imposed by disasters, which directly leads to notions of innovation and transformation. Innovative options and process for identifying, communicating and implementing risk management are required for working towards building resilience holistically. Innovative actions may comprise incremental and more radical steps, the most radical being transformation. O'Brien et al. (2012) suggest that incremental change increases efficiency in existing technological, governance, and value systems, while transformation describes changing fundamental attributes of those systems (see figure 7).

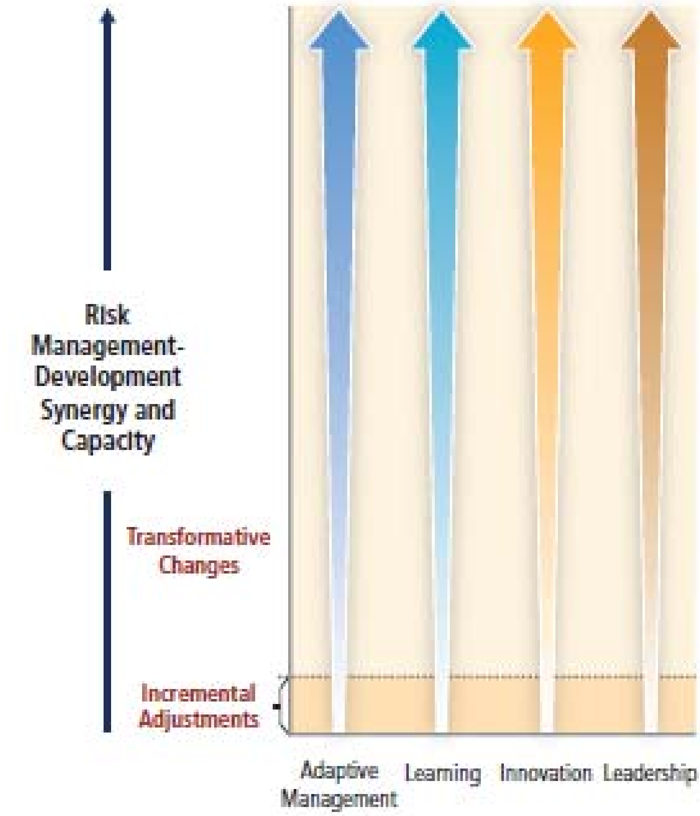

Figure 7: Incremental and transformational change associated in risk management
Source: O'Brien et al. 2012

Learning is fundamental for all these notions, and single-loop (comparing models to reality), double-loop (studying whether actors are behaving as they should) to triple-loop learning (working towards paradigmatic insight and change) can be distinguished (Kolb and Fry 1975).

Generally, the iterative cycle may enable case study partners to think more holistically and outside the box throughout the project. Overall, it appears that better understanding how risk analytical techniques contribute to these broader outcomes of an iterative and reflexive process seems highly desirable generally and specifically for the ENHANCE project. To this end, it may be useful to formalize this focus by considering as part of the case study protocols to study the interrelationship between the, on the one hand, technical risk analytical methods and tools used and, on the other hand, the broader iterative management aspects.

In this spirit, the catalogue, which has been put together with input from all project partners, will be posted online and accessible for all involved in the analyses, thus serving as a repository for methods and tools for the project duration and beyond. As methodological development is on-going, this report should be seen as a living document, which project partners can update over time. It is envisaged that the catalogue and toolbox will improve the understanding and utilization of the iterative management methodology and individual tools in ENHANCE and beyond, provide improved access to tools, increase consistency and cohesion between tools where possible, and finally lead to mutual learning among project partners and stakeholders.

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7 Annex I: Detail on usage of tools and methods in case studies

Case Study "Drought management in Jucar River Basin district"

Contributor: UPVLC

	Category	Detail	Application of in the context of the case study?	Tools
Risk monitoring	**Impact Analysis**	Empirical assessment of events and consequences	Study of drought episodes consequences after the episode is considered to be finished. Evaluation of the real effectiveness of the taken measures.	EM-DAT
Risk identification and risk analysis	**Risk modelling**	Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	Use of climate change scenarios to assess future drought hazard analysis. Use of future demand projections for vulnerability and exposure. Definitions of drought scenarios according to the indicators values.	IWRM, AQUATOOL, WEAP
	Qualitative analysis	Qualitative assessment of events and consequences	Analysis of time series (precipitations, stream flow, aquifers and reservoirs storage), calculation of standardized indexes for comparison, threshold analysis, definition of drought indices.	
Evaluation of risk management options	**Cost effectiveness Analysis**	Minimizing costs under a fixed (risk-based) threshold	Use of AQUATOOL to support decision making by simulation of different measures and analyze the obtained results under the scope of the different analysis techniques.	WARSYP, SEDEMED, SEDEMED 2, AQUAMONEY, GENESIS, DROUGHT R&SPI
	Multi-Criteria Analysis	Consideration of multiple objectives and plural values in a context of risk		
	Cost-benefit analysis	Framework for comparing costs with benefits in a context of risk		

	Stochastic simulation	Comparing and evaluating different risk management options based on running a large set of scenarios using different techniques (Monte-Carlo simulation).	Simulation of the water resources system with AQUATOOL-SIMGES. Comparison of different mitigation measures. Generation of synthetic series with ARMA models calibrated with measured time series. Realisation of multiple simulations.	IWRM, AQUATOOL, WEAP

Case Study "Health preparedness and heat wave response plans"

Contributor: Centre for Research on the Epidemiology of Disasters

	Category	Detail	Application of in the context of the case study?	Tools
Risk monitoring	**Impact Analysis**	Empirical assessment of events and consequences	Extraction and consolidation of historical data on heat wave mortality from global EMDAT database and other sources (e.g. national and European mortality monitoring projects such as Be-MOMO and EUROMOMO).	EMDAT, CEDAT
Risk identification and risk analysis	**Scenario generation**	Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	Scenarios will include possible changes in climate (general increase in temperature and higher frequency of extreme temperature events); demographic changes (ageing societies); change in epidemiological pattern (particularly regarding risk factors associated with heat wave mortality such as cardiovascular diseases and diabetes) Also, other factors such as the quality of the urban infrastructure and socio-economic status may be considered influential in shaping resilience. (e.g. Rey et al 2009)	MICRODIS

Case Study “Flood risk management for Rotterdam Port infrastructure”

Contributor: HKV

	Category	Detail	Application of in the context of the case study?	Tools
Risk monitoring	Impact Analysis	Empirical assessment of events and consequences	The impact is analyzed in terms of economic losses due to business interruption, material damage and societal disruption. Interviews are held with several industry firms in the port of Rotterdam.	IAPH, EMDAT
Risk identification and analysis	Qualitative analysis	Qualitative assessment of events and consequences	Some factors that influence societal disruption (earnestness) are quite difficult to quantify. Moreover, quantitative methods may require too many data to be applicable. Hence qualitative and quantitative expert judgment is applied.	IAPH
	Risk modelling	Finding of probabilistic representations of risk based on empirical data, Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	Extreme value analysis of water levels and hydraulic conditions Is applied to set-up water related hazard scenarios. Flood scenarios for 2015, 2050 and 2100, The consequences of a flood event with a certain horizon (2100) are computed in a deterministic way. Risk management policies are incorporated in damage functions.	

Evaluation of risk management options	**Cost - benefit analysis**	Framework for comparing costs with benefits in a context of risk	Material damage, losses due to business interruption and societal disruption are quantified for several scenarios, with and without measures / policies. The costs incurred are compared.	

Case Study “Air industry response to volcanic eruptions”

Contributor: HI

	Category	Detail	Application of in the context of the case study?	Tools
Risk Monitoring	**Impact Analysis**	Empirical assessment of events and consequences	Volcano: Will gather data on air traffic in Europe before, during, and after the EVE to assess air traffic impacts and consequences.	EMDAT
Risk identification and analysis	**Qualitative analysis**	Qualitative assessment of events and consequences	Volcano: Will interview stakeholders about the decision processes related to a volcanic ash eruption and the impacts of the Eyjafjallajökull volcanic eruption 2010 (EVE) on air traffic in Europe.	
	Scenario generation	Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	Volcano: Develop scenario of volcanic eruptions affecting air traffic.	

Case Study "Risk culture, perception, and storm surge management (North Sea coast)

Contributor: HZG

	Category	Detail	Application of in the context of the case study?	Tools
Risk monitoring	**Scenario generation**	Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	In cooperation with scientist from public BSH and HZG simulation and scenarios of sea level rise and storm development in the German Bight. We intend to elaborate scenarios together with our stakeholder collaboration partner Wadden Sea Forum.	
Risk identification and analysis	**Qualitative analysis**	Qualitative assessment of events and consequences	Qualitative assessment via literature review, interviews and a population survey – regional culture and historical events are decisive in storm surge risk-management on the North Sea coast. We have two population survey already existing and two research projects were undertaken about the role of the media, public perception and regional culture. More about this in Venice.	?

Evaluation of risk management options	**Decision-making in a context of risk**	Awareness and perception study – population survey	It is crucial to know the perception on natural hazards, and personally perceived threats and the preparedness and understanding for risk-management measures.

Case Study "Climate variability & technological risk in the Po basin"

Contributor: FEEM

	Category	Detail	Application of in the context of the case study?	Tools
Risk monitoring	**Impact Analysis**	Empirical assessment of events and consequences	Economic impacts of drought/floods, based on micro- and macroeconomic assessment tools	EM-DAT, Desinventar
Risk identification and analysis	**Qualitative analysis**	Qualitative assessment of events and consequences	Assessment of risk governance and amplifying/attenuating factors; vulnerability and resilience	
	Extreme value theory and frequency analysis	Finding of probabilistic representations of risk based on empirical data	Estimation of the return period of extreme events, based on the available time series (flood stage since 1900)	
	Scenario generation	Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	Societal driver of risk – water use and land development, based on the demographics and environmental policies in place (water and agriculture)	

Evaluation of risk management options	**Stochastic simulation**	Comparing and evaluating different risk management options based on running a large set of scenarios using different techniques (Monte-Carlo simulation).	Climate risk analysis, Propagation of flood.	

Case Study "Flood risk and climate change implications for MSPs"

Contributor: LSE & UOXF

	Category	Detail	Application of in the context of the case study?	Tools
Risk monitoring	**Impact Analysis**	Empirical assessment of events and consequences	A review of existing risk and vulnerability to London flood events, and the impacts of flood events to develop a disaster risk profile. Role of insurance-based mechanisms in enhancing resilience to economic and social impacts of floods - through the development of an ABM.	
Risk identification and risk analysis	**Qualitative analysis**	Qualitative assessment of events and consequences	Assessment via literature review of flood risk, vulnerability, and resilience. Stakeholder mapping of existing and proposed flood insurance schemes, risk reduction measures, proposed flood insurance scheme, and scope for new risk sharing partnerships – including	

			surveys and interviews.	
	Scenario generation	Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	Develop scenarios of climate change and flood risk in London, UK, including the role of insurance based mechanisms. Scenarios will incorporate different levels of flood risk for the present day and using projections of climate change. Scenarios will also incorporate demographic and socio-economic change, varying roles of stakeholders/insurance based mechanisms, and agent behaviour for risk reduction.	UKCP09 compliant Urban Spatial Weather Generator MCM Depth Damage Functions
Evaluation of risk-management risk management options	**Stochastic simulation**	Comparing and evaluating different risk management options based on running a large set of scenarios using different techniques (Monte-Carlo simulation).	Climate and flood risk analysis. Simulation of flood risk and comparison of different risk sharing agreements and partnerships to reduce risk and enhance resilience. Generation of multiple series based on outputs from a spatial weather generator. Realisation of multiple simulations.	London surface water flood risk maps (From GLA)
	Cost effectiveness Analysis	Minimizing costs under a fixed (risk-based) threshold	Development and use of an ABM to evaluate risk of different stakeholders using insurance-related instruments. Economic losses from flooding and social impacts will be compared for a variety of risk-sharing scenarios. This will be used to identify risk sharing arrangements that encourage efficient overall risk reduction, and the ways in which risk management for dealing with these events may be incentivised.	Agent Based Model
	Cost -benefit analysis	Framework for comparing costs with benefits in a context of risk		

Case Study: "Testing the Solidarity Fund for Romania and Eastern Europe"

Contributor: IIASA, ASE, PCC

	Category	Detail	Application of in the context of the case study?	Tools
Risk monitoring	**Impact Analysis**	Empirical assessment of events and consequences	Extraction and consolidation of historical data on flood and earthquake risk from EMDAT and other database	EMDAT
Risk identification and risk analysis	**Scenario generation**	Creating scenarios of future risk including changes in drivers of hazard, exposure and vulnerability	Scenarios will include possible changes in climate (general increase in temperature and higher frequency of extreme temperature events); demographic changes (ageing societies); change in epidemiological pattern (particularly regarding risk factors associated with heat wave mortality such as cardiovascular diseases and diabetes) Also, other factors such as the quality of the urban infrastructure and socio-economic status may be considered influential in shaping resilience. (e.g. Rey et al 2009)	CATSIM
Evaluation of risk-management risk management	**Cost effectiveness Analysis**	Minimizing costs under a fixed (risk-based) threshold	Minimize occurrence probability of impacts	CATSIM
	Cost-benefit analysis	Framework for comparing costs with benefits in a context of risk	Minimize fiscal and aggregate costs of risk bearing	CATSIM

[Note: detail on the following cases will be added as information becomes available from the cases]

		Risk monitoring	Risk identification Risk analysis	Evaluation of risk-management options
Forest fire resilience and Insurance	**Chamusca**	FIREPARADOX, EUFIRELAB, WUI, PHOENIX		
Transport resilience	**Austrian Railways**	PARAmount project		