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Impact of extreme weather on critical infrastructure

Deliverable D4.1

Report on SOTA of Modelling and Simulation Approaches, used currently to assess CI vulnerability

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Contents

Tables and figures

Glossary

BN	Bayesian Network
CI	Critical Infrastructure
DCST	Dynamica control system theory
EC	European Commission
EW	Extreme Weather
EWE	Extreme Weather Events
EWI	Extreme Weather Indicators
FP7	Seventh Framework Programme
HHM	Hierarchical Holographic Modelling
HLA	High Level Architecture
IRG	INTACT Reference Guide
PN	Petri-Net
RAMS-I	Reliability, Availability, Maintainability, Safety and Inspectability
TRV	Threat, Risk and Vulnerability

Executive summary

The INTACT project addresses the resilience of Critical Infrastructure (CI) to Extreme Weather Events (EWE) challenges and bring together innovative and cutting edge knowledge and experience in Europe in order to develop and demonstrate best practices in engineering, materials, construction, planning and designing protective measures as well as crisis response and recovery capabilities. All this will culminate in the INTACT Reference Guide, the decision support system that facilitates cross-disciplinary and cross-border data sharing and provides for a forum for evidence based policy formulation.

This deliverable (D4.1) is the first from WP4 on 'Risk and Risk Analysis'. The overall focus of activity in WP4 is to develop a risk assessment and simulation structure, which is complementary to the CI vulnerability assessment of WP3, and which overall, supports the improved understanding and derivation of mitigation options for testing in the case studies. The risk simulation structure will combine a range of appropriate tools, models, data protocols etc. in an overall decision framework, to enable CI owners and operators to better assess their risk from EWEs and to plan and assess a range of interventions. The work of WP4 is centred on the derivation of the risk structure in T4.2. In turn, the derivation of the structure is informed by a SOTA review (this deliverable), the case study requirements for assessment, and a gap analysis (T4.3) to provide tools that are not readily available for use in the structure. Having derived the risk structure, this will then be applied in each of the case studies, with the full involvement of the relevant stakeholders (T4.4). The final part of WP4 will be to reflect on the success of the application of the modelling framework, in terms of suitability of the models for testing mitigation options and for the decision-making process, feedback from stakeholders, and remaining gaps and recommendations for future development. This critical assessment will be reported under T4.5.

This report has reviewed a wide range of models and other assessment tools for understanding the impacts of EWE on critical infrastructures. Any review can always be added to, and this report is no exception as there is clearly a very large body of information available. A key summary outcome of this work should be the answer to the question: to what extent are models and other simulation approaches currently used for the assessment of impacts to CI, and how can the INTACT project deliver an improved risk assessment framework based on these existing SOTA approaches? The project team has found that there are a large number of methods that could be used to assess the vulnerability of CI to EWE and the approaches used may need vary with the type of system, the objective of the analysis, the analysis steps, and the available information. However, it is difficult to assign one analysis step/objective to each method as several of the methods could be used for more steps/objectives. The methods may also be used in combination e.g. agent-based modelling in combination with Monte Carlo Simulation. The methods that have been described and analysed in this deliverable are summarized in the table below and for each group of methods it is indicated which step/purpose it could be applied for.

Group of method	Step in CI analysis/purpose of analysis		
	Vulnerability of single objects; direct loss	Vulnerability of systems; identification of critical elements	Interdependencies between systems or estimation of indirect loss
Susceptibility functions (single- and multi-parameter)	X		
Economic theory based approaches (e.g. IO analysis, Computable General Equilibrium, Econometric approaches for tangible losses and e.g. Revealed and stated preferences methods for intangible losses)	X		X (estimation of indirect losses)
Probabilistic modelling (Markov/petri nets, prob. Modelling, Bayesian networks)		X	X
Statistical analyses of past events, empirical approaches	x	X	
Risk analysis of technological systems (Event tree analysis, Fault modes and effects analysis and FMECA, Fault tree analysis, HAZOP, Human reliability analysis, Preliminary hazard analysis, Reliability block diagram, tabular methods, expert judgment)		X	(X - mainly for parts of a CI)
Network based approaches (e.g. typology-based method and flow-based method)		X	X
Agent based approaches		X	X
System dynamics based approaches		(X)	X
Rating matrices (could also be included under "risk analysis of technological systems")		X	(X)
Relational databases		X	X

The methods we have analysed are being used to assess CI, although the spread of methods is not uniform across each sector, although generally each type of tool or method is used as part of the overall existing assessment framework. This finding is borne out by another SOTA review which is summarised in Section 5.

Finally, a key issue for the development of the risk framework under Task 4.2 is to what extent are tools and models being used in the five case studies within the INTACT project. This will also inform what should be considered in the Gap Analysis (Task 4.3). Unfortunately, due to the timing of activity in the case studies, it has not been possible to obtain this information and include it in this report. The case study needs will obviously play a key role in deciding what functionality is required in the framework, but at this stage it seems reasonable to assume that components, representing the elements summarized in the above table, should be included.

1 Introduction

1.1 The INTACT project

Resilience of Critical Infrastructure (CI) to Extreme Weather Events (EWE), such as heavy rainfall, drought or icing, is one of the most demanding challenges for both government and society. Extreme Weather (EW) is a phenomenon that causes severe threats to the well-functioning of CI. The effects of various levels of EW on CI will vary throughout Europe. These effects are witnessed through changes in seasons and extreme temperatures (high and low), humidity (high and low), extreme or prolonged precipitation (for example rain, fog, snow, and ice) or prolonged lack thereof (drought), extreme wind or lack of wind, and thunderstorms. The increased frequency and intensity of EWE can cause events such as flooding, drought, ice formation and wild fires which present a range of complex challenges to the operational resilience of CI.

The economic and societal relevance of the dependability and resilience of CI is obvious: infrastructure malfunctioning and outages can have far reaching consequences and impacts on economy and society. The cost of developing and maintaining CI is high if they are expected to have a realistic functional and economic life (50+ years). Hence, future EWE has to be taken into account when considering protection measures, mitigation measures and adaption measures to reflect actual and predicted instances of CI failures.

The INTACT project will address these challenges and bring together innovative and cutting edge knowledge and experience in Europe in order to develop and demonstrate best practices in engineering, materials, construction, planning and designing protective measures as well as crisis response and recovery capabilities. All this will culminate in the INTACT Reference Guide, the decision support system that facilitates cross-disciplinary and cross-border data sharing and provides for a forum for evidence based policy formulation.

The objectives of the INTACT project are to:

- Assess regionally differentiated risk throughout Europe associated with extreme weather;
- Identify and classify, on a Europe wide basis, CI and to assess the resilience of such CI to the impact of EWE;
- Raise awareness of decision-makers and CI operators about the challenges (current and future) EW conditions may pose to their CI; and,
- Indicate a set of potential measures and technologies to consider and implement, be it for planning, designing and protecting CI or for effectively preparing for crisis response and recovery.

1.2 The aim and the structure of the deliverable

Impacts on CI infrastructure can have many outcomes, affecting both loss of service, economic damage, indirect physical and economic impacts, and other social effects such as deterioration in human health. Therefore a range of assessment and modelling approaches will need to be considered, to cover risk assessment, cost-benefit analysis, impact assessment, testing of mitigation measures, and other assessment criteria.

This report is a deliverable (D4.1) as part of work package four (WP4), Risk and Risk Analysis, which ultimately provides and test a modelling and simulation structure to support the analysis of CI from adverse weather in each of the case studies. The deliverable reviews SOTA approaches for vulnerability assessment of CI and identifies models and simulations to assess impacts on CI of EW. The report also seeks to answer the question: to what extent are models and other simulation approaches currently used for the assessment of impacts to CI, and how can the INTACT project deliver an improved risk assessment framework based on existing SOTA approaches. To derive this SOTA assessment, a template was created in which to summarize the key findings from each document or study reviewed. This provided a consistent approach amongst the WP team, and formed the basis of the deliverable text. The completed assessment templates are contained in an Appendix, so that readers can investigate particular methods in more detail. In relation to other Tasks and WPs within the INTACT project, D4.1 lays the groundwork for development of a modelling and simulation framework and the INTACT Reference Guide.

The Deliverable 4.1 is divided into three main sections and is structured as follows:

- In Section 2 the basics of the concept of vulnerability and risk in relation to natural hazards are discussed and a generic framework for vulnerability is introduced;
- Section 3 focuses on the CI vulnerability and risk assessment, starting with a categorization of impacts on CI caused by EWEs, then considers the different approaches and models to assess CI vulnerability and risk;
- Section 4 is dedicated to specific application examples of assessment tools;
- Section 5 provides a summary of the main findings, plus conclusions and recommendations for further work;
- The Appendix collates the completed assessment templates for each reviewed information source.

2 CI vulnerability and risk in relation to natural hazards (NGI and HRW)

The resilience of critical infrastructures (CI) to Extreme Weather Events (EWE) is one of the most salient and demanding challenges facing society. Growing scientific evidence suggests that more frequent and severe weather extremes such as heat waves, hurricanes, flooding and droughts are having an ever increasing impact, with the range and effects on society exacerbated when CI is disrupted / destroyed. EWE causing (cascaded) CI outages frequently cause major social and economic loss in disasters. The provisions and procedures to reduce their impact and consequences have often proved inadequate. The probability of exposure to EWE is expected to increase, both in frequency and intensity. Obviously, there is a need to build anticipatory adaptation and organizational resilience to these relatively unforeseen and unexpected EWE impacts on CI.

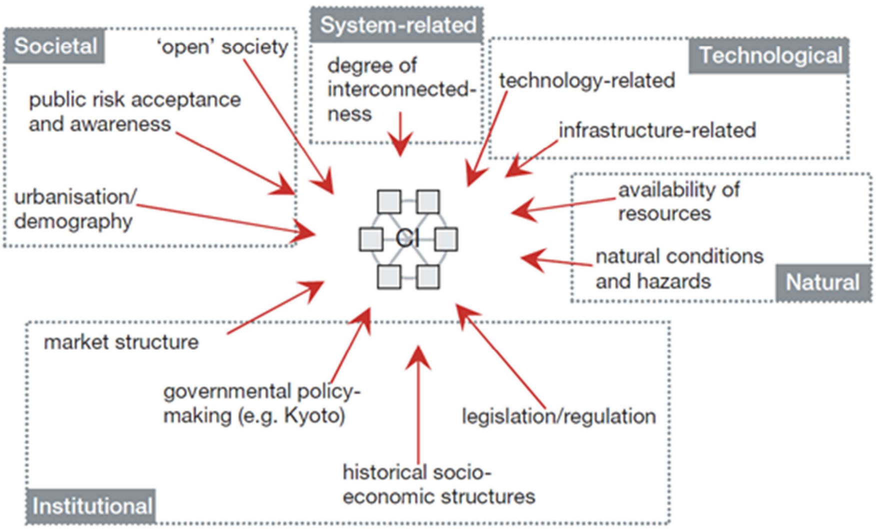
Hence, allowing for future EWE in the design and operational parameters of new and current CI is of fundamental and pressing strategic importance, to ensure cost effective fit, for purpose CI over the lifetime of the assets. There is an obligation to revisit the risk posed to new and existing CI and to develop practical (evidence based) responses by risk-based techniques and a set of validated tools and data sets tailored to practical needs reflecting the level of the risk and the severity of impact (social, economic, environmental, etc.) that would result in CI failure due to EWE. Generally, it would be expected that the standard hierarchical approach to risk would be adopted, namely ‘AVOID – SUBSTITUTE - CONTROL – MITIGATE’.

Risk management approaches are now well established in most countries and across a wide range of sectors, and form a key part of decision-making and risk reduction. The following figure (Figure 2-1) provides one example of how risk management forms a cycle, and includes risk assessment as one of the key components of such a decision process. This generic cycle allows for flexibility in the identification of a range of mitigation measures, assessment of such measures once implemented, leading to an updated risk assessment, reduction of threats/hazards, and ultimately risk.

Figure 2-1 Risk management cycle

A taxonomy of Critical Infrastructures has been defined for the INTACT project and is provided as Deliverable D1.1. Each of the CI infrastructures relies on complex physical networks, involves a combination of private and public entities, and is regulated to some degree. In addition, they are all subject to multiple and inter-linked risk-shaping factors that affect their operation (see Figure 2-2).

Figure 2-2 Factors shaping the risks faced by critical infrastructures (CI), Kröger (2008).



2.1 Frameworks for vulnerability

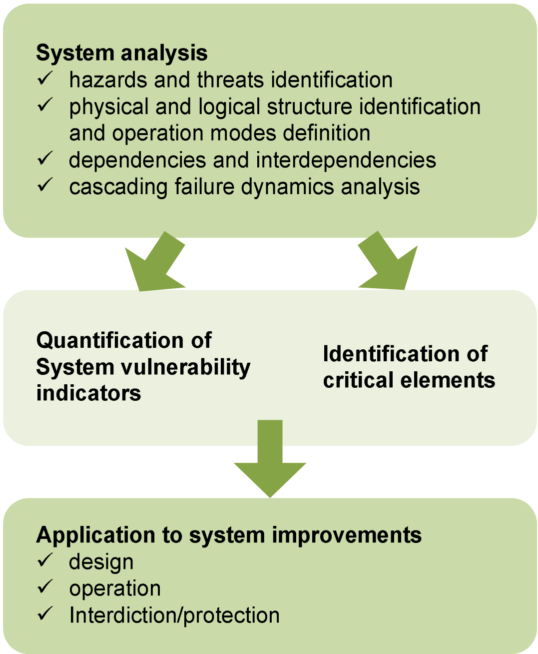
2.1.1 System vulnerability assessment

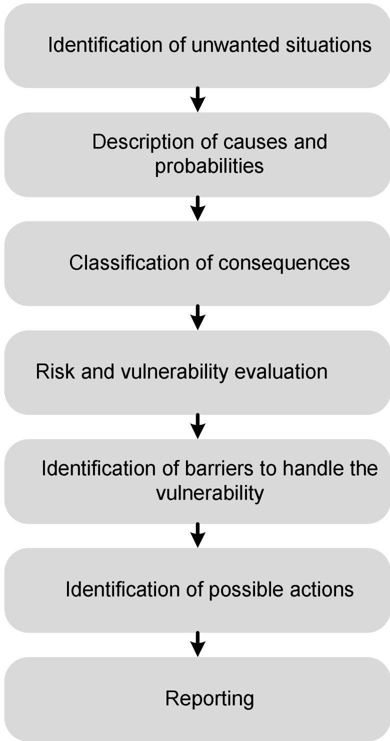
Critical infrastructures exhibit a number of complex system characteristics which call for analyzing them as a whole and make their holistic study highly challenging. A comprehensive vulnerability analysis requires not only the consideration of a large number of spatially distributed, interacting elements with nonlinear behaviour and feedback loops, but also a broad spectrum of hazards and impacts including failures and threats. (Kröger and Zio, 2011) It comprises three main activities:

- System analysis including system properties (e.g., physical and logical structures and operation modes)
- Quantification of system vulnerability indicators and identification of important elements
- Application to system improvements either technical or organizational

In the following figure two different methodological frameworks for the vulnerability analysis are described.

Figure 2-3 : Two examples of conceptualization of CI vulnerability analysis process (adapted from Kröger and Zio, 2011 and Doorman et al., 2004)





The two main outputs of a vulnerability analysis of CIs are the quantification of system vulnerability indicators and the identification of critical elements. The ultimate goal is to identify hidden vulnerabilities in infrastructure systems, to be able to act for managing and reducing them. The achievement of these goals relies on the analysis of the system, its parts and their interactions within the system; the analysis must account for the environment which the system lives in and operates, and finally for the objectives the system is expected to achieve. During the development of such basic system understanding, first vulnerabilities may have already been emerged. (Kröger and Zio, 2011).

2.1.2 SOTA framework for vulnerability

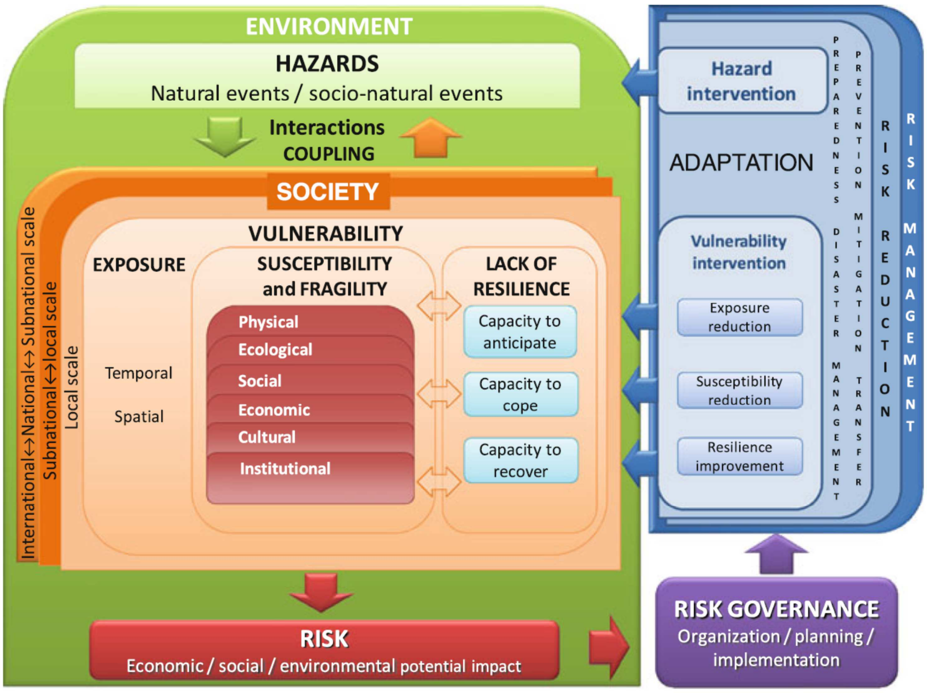
Birkmann et al. (2013) proposed a generic conceptual framework, the MOVE framework, which addresses vulnerability and risk to natural hazards from a holistic and multidimensional point of view. It is generic in order to facilitate the initial identification of elements of coupled social-ecological systems (when making a vulnerability assessment) and to guide logical and comparative development of indicators. As part of developing the MOVE framework several conceptual frameworks for vulnerability and risk assessment were reviewed and advantages and disadvantages discussed. The reviewed frameworks include: The pressure and release (PAR) framework (Wisner et al 2004), The theoretical Framework and Model for a Holistic Approach to Disaster Risk Assessment and Management (Cardona and Barbat, 2000), Turner’s et al. (2003) vulnerability framework, the BBC Conceptual framework (Bogardi and Birkmann, 2004; Cardona, 1999; Cardona, 2001).

The diagram of the generic conceptual framework, as shown in Figure 2-4 illustrates two concepts:

- Vulnerability is the result of exposure of society to hazards, in time and space, of the susceptibility (or fragility) of the society and the lack of resilience or societal response capacity. The hazards are natural or socio-natural events, which are a combination of society and environment.
- Risk management and adaptation aim to modify the initial vulnerability conditions for hazards through exposure reduction, susceptibility reduction and resilience improvement.

Exposure describes the extent to which a unit of assessment falls within the geographical range of a hazard event (e.g. infrastructure, livelihoods, economies, cultures), qualified in terms of spatial and temporal patterns. Susceptibility (or fragility) describes the predisposition (weaknesses and lack of strength) of elements at risk to suffer harm that can be expressed in physical, ecological, social, economic, cultural and institutional terms. The lack of resilience is another important vulnerability factor that reflects the capacity level of a society to anticipate (to intervene proactively the risk conditions), to adapt (to be prepared to face future hazardous events), as well to cope and recover effectively when such events occur. A lack of these capacities increases the vulnerability of the society.

Figure 2-4 MOVE conceptual framework of a holistic approach to disaster risk assessment and management, Birkmann et al. (2013).



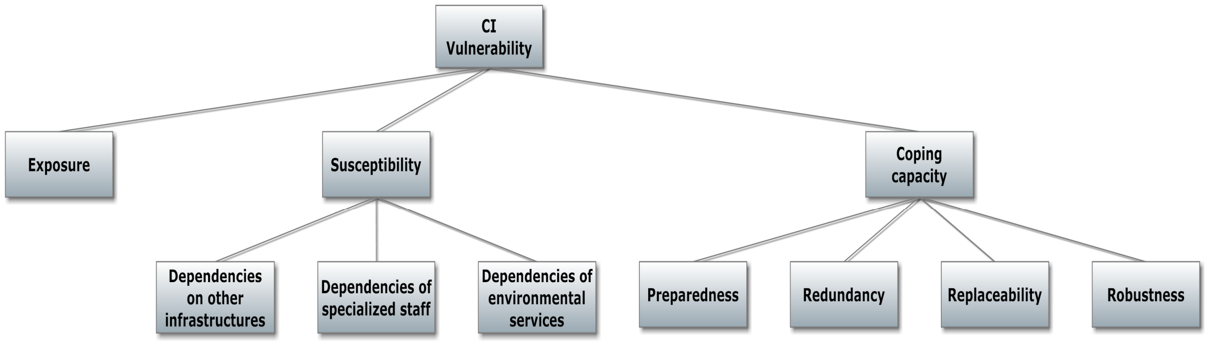
Bach et al. (2013) propose to express the vulnerability as a function of exposure, susceptibility and coping capacity.

- Exposure refers to critical infrastructures being located in the geographic range of hazardous extreme weather events
- Infrastructure susceptibility: Three main characteristics are of particular relevance:
  - Dependencies on other infrastructures. (An infrastructure is increasingly vulnerable when it needs the input of another infrastructure to function.)
  - Dependencies on specialized staff
  - Dependencies on environmental services (The more dependent an infrastructure is on staff and environmental services (e.g. the availability of water), the more vulnerable it tends to be towards hazards affecting these factors.)
- Coping capacity of a Critical Infrastructure: Basically four main general characteristics describe the system:
  - Preparedness, the level of preparation for the maintenance or rapid restoration of services affected by a hazard, e.g. emergency plans, training of employees and emergency drills and back-up systems.

- Redundancy, existences of certain components or services which are able to replace or to take over the function of another component
- Replaceability, effort needed to re-establish a service or component
- Robustness ability of a service or component to withstand the effects of one or multiple hazard(s) without losing its function.

This decomposition of CI vulnerability is shown in Figure 2-5.

Figure 2-5 Framework for CI vulnerability, Bach et al. (2013)



2.1.3 INTACT framework for CI impact

The INTACT framework illustrates the CI impacts is determined by the three main components EWE/hazard, Vulnerability and Exposure. As shown in Figure 2-4Figure 2-4 and Figure 2-5 exposure could be seen as a characteristic or physical attribute of the system at risk or as being independent of the vulnerability of a system. However, the geographic range of potential impacts of hazardous weather events on CI is essential in the INTACT project. A distinct assessment of exposure independent of the hazard vulnerability will be pertinent to the research goals. Thus it is within INTACT, in contrast to the frameworks shown in Figure 2-4 and Figure 2-5, chosen to separate exposure and vulnerability (see

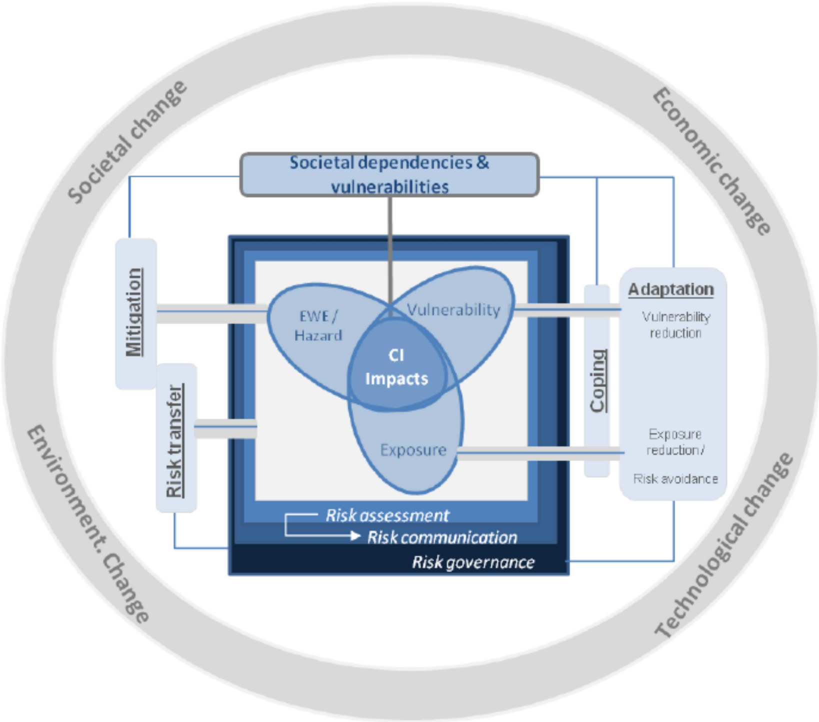
Figure 2-6). The core of the figure shows that the likelihood and magnitude of adverse CI impacts is determined by hazard, vulnerability and exposure, where vulnerability is considered as a function of susceptibility and capacities of response. The EWE/Hazard is comprised of Probability of occurrence and intensity. The impact of the CI is also influenced by environment, functions, human staff and technical structures. The Figure in the centre: relate to “risk” in describing the three elements. Risk is the result of three elements (two probabilities and one effect (exposure)) and could also be written down in the middle of the figure instead of CI impacts (potential). Risk is sort of ex ante perspective of CI impacts.

The core figure described above is surrounded by a tripartite blue frame representing risk assessment, risk communication and risk governance. Risk assessment and communication are influenced by risk governance meaning contextual factors for risk-related decision- making such as regulatory or legal frameworks, safety standards, financial arrangements, innovation management and the general socio-political culture. The light blue boxes outside the blue frame represent ways of managing the risk, which includes: adaptation, coping, mitigation and risk transfer. Adaptation refers to vulnerability and exposure reduction, the latter often also denoted as risk avoidance. Coping refers most commonly to the objective of meeting the basic needs and maintaining the functioning of the system in the short-term. Mitigation actions refer to actions taken for reducing the hazard associated with EWE, referring mainly to the reduction of greenhouse gases. Risk transfer is to manage risks, by shifting the financial consequences of particular risks from one party to another. It is most commonly used in relation to the insurance sector and particularly for risks with low probability and high consequences.

The connections with the box "social dependencies and vulnerabilities" refer to a interdependent relationship of societal dependencies and vulnerabilities with CIs at risk, meaning that society and economy increasingly depend on critical infrastructures in the course of social, technological and/or economic development. The increased dependency of society and economy on CI is one of the reasons why it is so essential to also considering the dynamics which frame CI-related risks, namely societal, economic, technological and climate/technological changes as illustrated with the surrounding grey circle in

Figure 2-6.

Figure 2-6 Framing of CI Impacts as a function of hazard, exposure and vulnerability and interrelations between risk, response mechanisms and impact from WP 1, Bach and Schwab (2014).



2.2 Classification of losses

Losses could be classified according to different dimensions of losses. The majority of assets and systems exposed to hazard will exhibit more than one dimension of losses.Birkmann et al. (2013) propose the following dimensions:

- Social dimension: propensity for human well-being to be damaged by disruption to individual (mental and physical health) and collective (health, education services, etc.) social systems and their characteristics (e.g. gender, marginalization of social groups).
- Economic dimension: propensity for loss of economic value from damage to physical assets and/or disruption of productive capacity.
- Physical dimension: potential for damage to physical assets including built-up areas, infrastructure and open spaces.

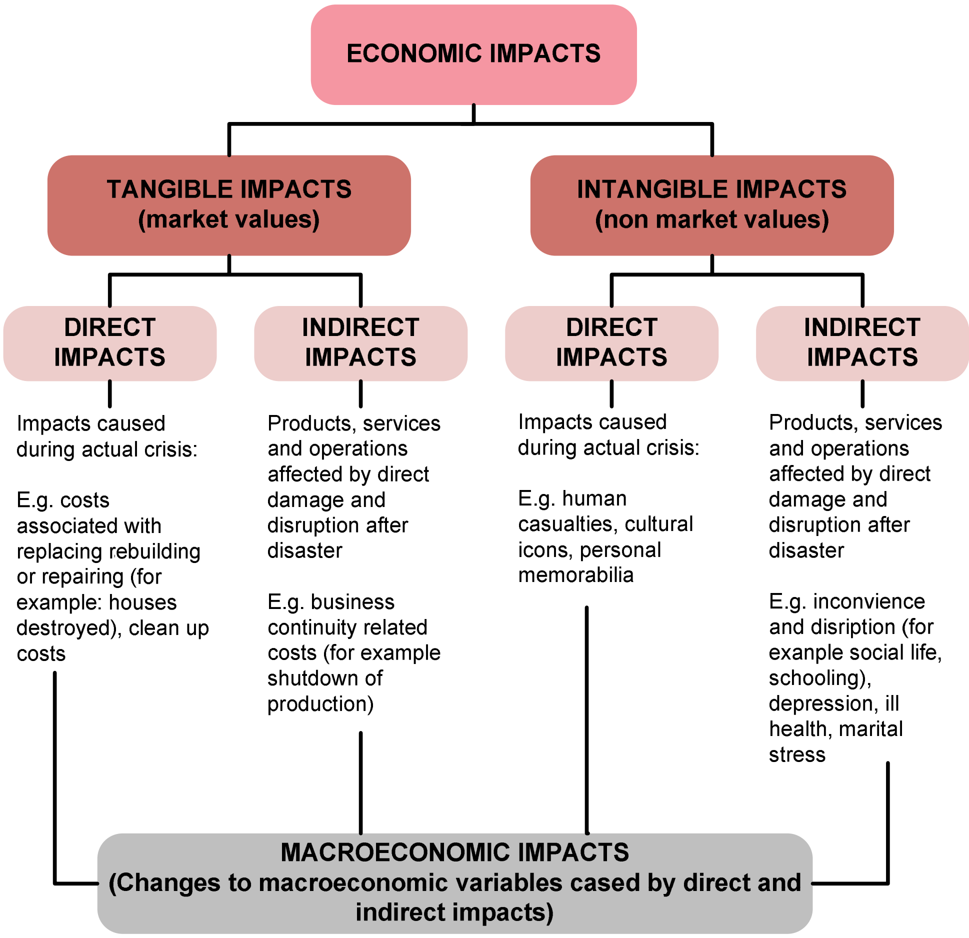
- Cultural dimension: potential for damage to intangible values including meanings placed on artefacts, customs, habitual practices and natural or urban landscapes.
- Environmental dimension: potential for damage to all ecological and bio-physical systems and their different functions. This includes particular ecosystem functions and environmental services but excludes cultural values that might be attributed.
- Institutional vulnerability: potential for damage to governance systems, organizational form and function as well as guiding formal/legal and informal/customary rules—any of which may be forced to change the following weaknesses exposed by disaster and response.

In the following, the focus will be on economic losses. Further classification of losses into direct and indirect losses and into tangible and intangible losses will be outlined. Most economic assessments of the impacts of natural hazards concentrate on direct losses i.e. the financial cost of physical damage. Equally important are indirect and secondary impacts which are, however, very difficult, or even impossible, to be expressed in monetary terms (Guha-Sapir and Hoyois, 2012; McKenzie et al., 2005; Middelmann, 2007).

An economic framework is often employed to present the economic impacts arising from natural disasters. Figure 2-7 incorporates a range of tangible and intangible impacts that can be used to describe economic effects of a crisis. Tangible impacts are relatively easy to assign to a loss: for example, houses destroyed. Intangible impacts, however, are much more complex and variable. The loss of cultural icons and personal memorabilia, for example, will affect people differently. (Guha-Sapir and Hoyois, 2012; McKenzie et al., 2005; Middelmann, 2007.)

Direct impacts are caused by a disaster during the actual event. The crisis can cause direct damages involving the complete or partial destruction of physical assets in both the public and private sectors. Examples of the physical assets that may be damaged include infrastructure, buildings, installations, machinery, final goods, raw materials, equipment, transportation and agriculture. Fatalities and injuries are also a type of direct impact if they occur during the event. (McKenzie et al., 2005; Middelmann, 2007).

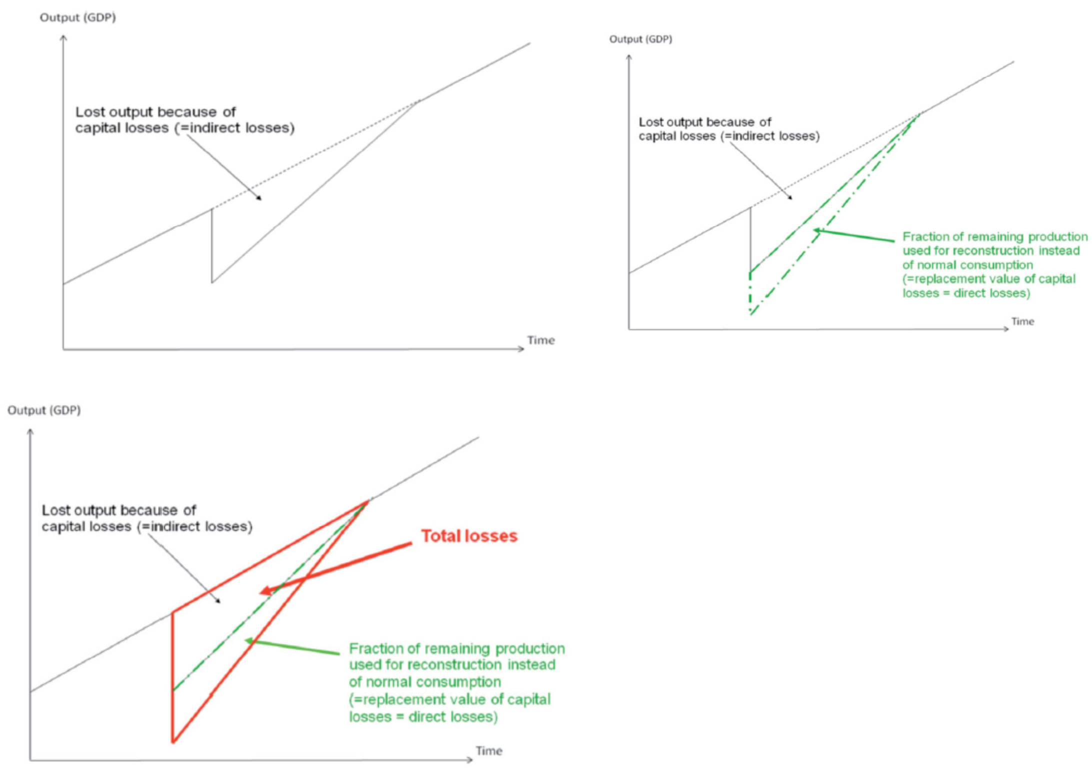
Figure 2-7 Classification of direct and indirect impacts of natural disasters (adapted from McKenzie et al., 2005 and Middelmann, 2007)



Indirect impacts are flows of impacts that occur over time after a disaster or outside the place of disaster. A direct impact can cause cascading effects. If due to a disaster a firm cannot produce, suppliers and customers of the firm are also affected. Also a breakdown of infrastructure can lead to a failure of the infrastructure elsewhere in the network or can have impacts on other infrastructures as well. For example a power breakdown of a node in the energy network, can lead to a power breakdown on other nodes as well. But it can also harm the communication network elsewhere if it is depending on this node in the energy network. Although most of the indirect impacts are negative, crisis may also generate positive indirect effects that generate benefits to society. For example, a construction boom as aid funds flow into the country for rebuilding damaged properties, which can boost production and income in the construction sector and supporting industries. Typically the indirect impacts are more difficult to express in monetary terms than the direct impacts. Indirect tangible costs may include financial elements, such as the loss of opportunity through disruption of public services. Business continuity is also a significant component of indirect costs. (McKenzie et al., 2005; Middelmann, 2007).

Hallegatte and Przyluski (2010) highlight the main difficulties in defining, measuring and predicting the total cost of disasters. It focuses on indirect (or output) losses, considered as a major component of the total loss of population welfare, see Figure 2-8

Figure 2-8 Direct losses, Indirect losses and total losses, where there are no flexibility in the production process (Hallegatte and Przyluski; 2010)



There are several methodologies to assess these indirect losses, but they are all based on questionable assumptions and modelling choices, and they can lead to very different results. It is impossible to define 'the cost' of a disaster, as the relevant cost depends largely on the purpose of the assessment. The best definition and method obviously depend on whether the assessment is supposed to inform insurers, prevention measure cost-benefit analyses, or international aid providers. Any disaster cost assessment should start by stating clearly the purpose of the assessment and the cost definition that is used. Following this recommendation would avoid misleading use of assessments, and improper comparison and aggregation of results. In addition, there are large uncertainties on indirect disaster costs, and these uncertainties arise both from insufficient data and inadequate methodologies.

Table 2-1 presents the traditional cost categorisation of natural hazards – e.g. the cost of a disaster is generally estimated by categorising the losses into tangible and intangible losses which are further subdivided into direct and indirect losses. Meyer et al. (2013) have expanded the hazard cost categorisation by presenting the business interruption costs and risk mitigation costs as own cost categories. The business interruption costs can either be included in the direct damages (as they occur due to the immediate impact of the hazard) or they can be defined as primary indirect damages (because the losses do not result from physical damage to property but from the interruption of economic processes). However, methods to evaluate losses due to business interruption differ from evaluation of those used for direct and indirect damages which makes it reasonable to consider business disruption as an own category (Mayer et al, 2013).

Table 2-1 General cost categorization (Meyer et al., 2013)

		Tangible costs	Intangible (non-market) costs
Damage costs	Direct	• Physical damage to assets: – buildings – contents – infrastructure	• Loss of life • Health effects • Loss of environmental goods
	Business interruption	• Production interruption because of destroyed machinery	• Ecosystem services interrupted
	Indirect	• Induced production losses of suppliers and customers of companies directly affected by the hazard	• Inconvenience of post-flood recovery • Increased vulnerability of survivors
Risk mitigation costs	Direct	• Set-up of infrastructure • Operation & maintenance costs	• Environmental damage - due to the development of mitigative infrastructure - or due to a change in agricultural practices
	Indirect	• Induced costs in other sectors	

Cost categories applied in this article:

Direct costs | Business interruption costs | Indirect costs | Intangible (non-market) costs | Risk mitigation costs

3 Modelling of impacts and associated losses

For CI vulnerability assessment, it is especially important to consider the different aspects of loss e.g. according to Table 2.1. Direct damages to the infrastructure itself are of minor importance compared to the indirect effects of their outage; Heilemann et al. 2013.

The following five steps should be considered in a vulnerability analysis of CI, Heilemann et al. 2013.

1. Network analysis
2. Analysis of the resistance and resilience of the network elements
3. Analysis of the effects of element failure on the network (resilience of network, redundancy)
4. Effect of failure of the network on other networks: interdependency
5. Effects of failure of the networks and the corresponding costs

These steps are considered in the following sub-chapters and steps 1 and 2 and 5 are treated with focus on impact from EWE or related hazards. Within step 5, the effect of societal response and risk management issues are included.

3.1 Impact of EWE and related hazard on CI

3.1.1 Direct losses

The most frequent applied approach for assessment of direct loss for natural hazards is the use of damage functions; Meyer et al. 2013. These functions represent the susceptibility of CI components and describe the susceptibility/fragility as a function of resistance of the component and intensity of the hazard. Intensity parameters include for example avalanche pressure, water depth or drought-induced soil subsidence. Some damage functions also take into account resistance parameters such as differences in building structures or the standard of risk mitigation measures undertaken.

There are loss models for direct losses that could either be empirical (based on empirical data) or defined from the physics of the problem, i.e. in combination with use of synthetic data.

Merz et al. (2010) summarise the advantages of empirical flood damage models:

- Real damage information possesses a greater accuracy than synthetic data.
- Effects of damage mitigation measures can be quantified and taken into account in damage modelling.

- Variability within one category and water depth is reflected by the data and uncertainty can be quantified.

Merz et al. (2010) also summarise the disadvantages of empirical flood damage models:

- Detailed damage surveys after floods are uncommon, so that models may be based on poor quality data.
- Paucity of information about floods of different magnitude and often a lack of damage records with high water depth require extrapolations.
- Transferability in time and space is difficult due to differences in warning time, flood experience, building type and contents.

Meyer et al. (2013) assessed the costs of natural hazards and undertook a review of existing cost assessment approaches for different types of natural hazards and different impacted sectors. The methods for direct loss assessment are summarised in Table 3-1.

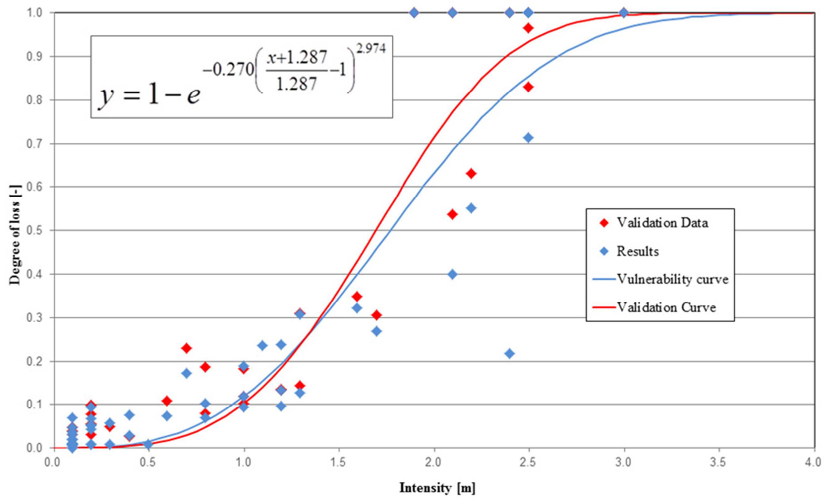
Table 3-1 Direct costs: methods, applications and examples (Meyer et al.; 2013 and Okuyama 2009)

General method	Specific method	Hazard types applied for:
Susceptibility function	Single-parameter models (based on single hazard impact parameter)	Floods, Coastal Hazards, Droughts, Alpine hazards.
	Multi-parameter models (based on several hazard impact and/or resistance parameters)	Floods, Coastal hazards, Alpine hazards.
Market valuation techniques	Market price method	Drought
Integrated Assessment Analysis	Biophysical-Agroeconomic Models	Droughts
	Hydrological-Economic Models	Droughts
Computable General Equilibrium Analysis	Computable General Equilibrium Models	Droughts

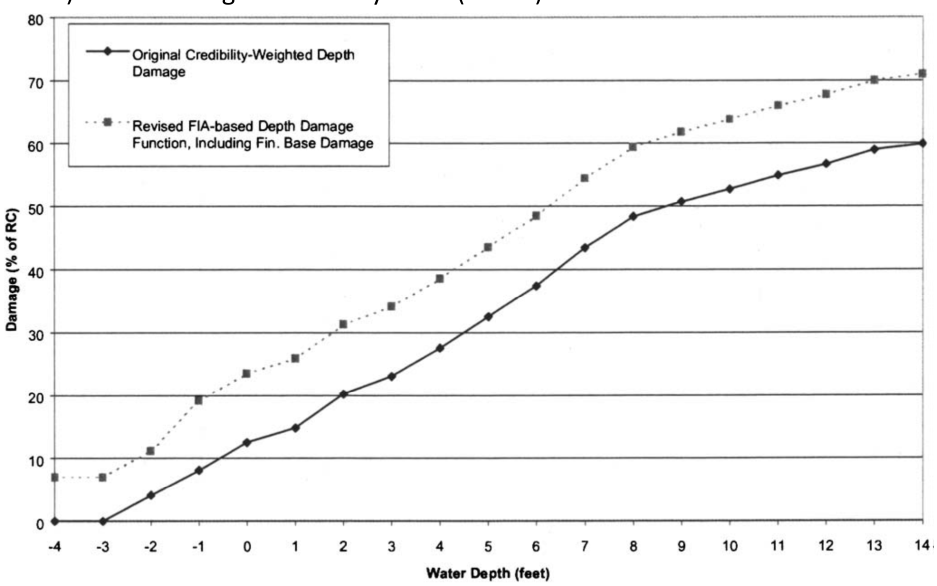
Example of direct loss assessment methods for single susceptibility functions are illustrated in **Error! Reference source not found.** a) for buildings hit by debris flows, and b) for buildings affected by flood water.

Figure 3-1 Single parameter susceptibility functions

a) For buildings hit by debris flows (Papthoma-Köhle et al. 2012)



b) For buildings affected by flood (Hazus)



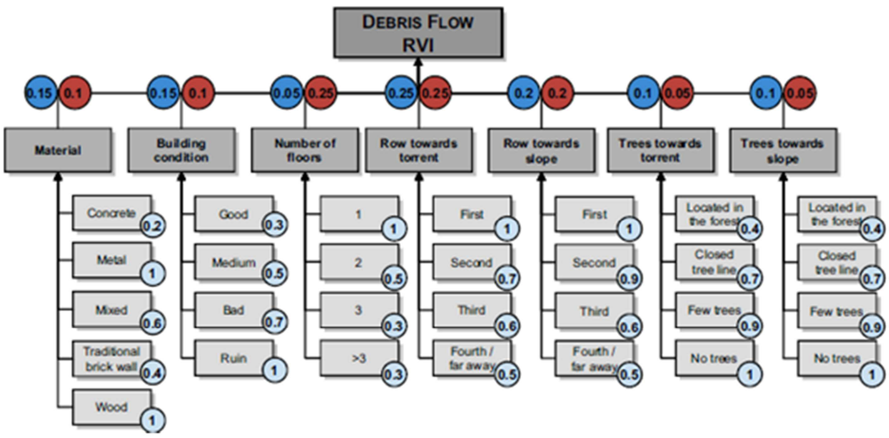
The depth-damage curves seen in Figure **3-1** b) are in widespread use around the world as an essential component of flood risk management. Often, such curves are applied in other countries to those where the data was collected, and it is possible to consider the combination of different datasets, under certain assumptions, to allow for increased 'data mining'. In Figure **3-1** a), the empirical data has been fitted to a theoretical relationship, as an alternative approach to extending the applicability of the loss function.

Kappes et al. (2012) proposed an indicator-based, semi-quantitative vulnerability approach for vulnerability of buildings to debris flows, shallow landslides and river flooding, Figure 3-2 a).

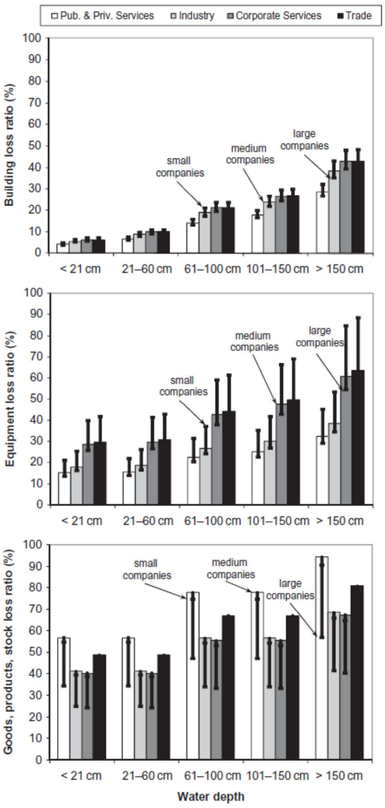
Kreiblich et al. (2010) proposed a model for the estimation of flood losses in the commercial sector based on 642 loss cases. In the first model stage, the model considers the water depth due to flood, company sizes of in terms of the number of employees, and different sectors. In the second model stage, the effects of precaution level and degree of contamination can also be evaluated. Then the estimated loss ratios of the first stage are multiplied by the respective scaling factors. The method is illustrated in Figure 3-2 b).

Figure 3-2 Multi-parameter susceptibility function

a) Relative vulnerability model for buildings hit by debris flow, Kappes et al. 2012.



b) The FLEMCO model for estimation of flood losses in the commercial sector, Kreiblich et al. (2010). Left: First stage of the model: mean loss ratios of flood losses to buildings, equipment and goods, products and stock, depending on water depth, sector and size of the company. Right: Scaling factors for the second stage of the model, accounting for effect of contamination and precaution.



	Scaling factors for loss ratios:		
	Buildings	Equipment	Goods etc.
No contamination, no precaution	1.02	1.02	0.93
No contamination, medium precaution	0.82	0.86	0.79
No contamination, very good precaution	0.67	0.72	0.75
Medium contamination, no precaution	1.28	1.03	1.08
Medium contamination, medium precaution	1.03	0.87	0.92
Medium contamination, very good precaution	0.84	0.73	0.87
High contamination, no precaution	1.28	1.33	1.22
High contamination, medium precaution	1.03	1.12	1.04
High contamination, very good precaution	0.84	0.94	0.98

3.1.2 Indirect losses caused by EWE or related hazards

Indirect losses are induced by the direct losses and transmitted through the economic system. The magnitude of indirect losses is determined by the boundaries in space and time of the damage assessment.

In economic models for losses it is often distinguished between ex-ante models and ex-post models for loss estimation. The term ex-ante is a phrase meaning "before the event" and refers to future events. The opposite of ex-ante is ex-post (actual) which is based on knowledge of the past. Ex-post means "after the fact" and uses past performance to predict the probability of a loss.

Okuyama (2009) provided an overview and a critical analysis of the methodologies used for estimating the economic impact of natural hazards. The methods for direct loss assessment as reviewed by Meyer et al. (2013) and Okuyama (2009) are summarised in Table 3-2.

Table 3-2 Indirect costs: methods, applications and examples (Meyer et al.; 2013 and Okuyama 2009)

General method	Specific method	Description
Susceptibility function	Single-parameter models (based on single hazard impact parameter)	Floods, Coastal Hazards, Droughts, Alpine hazards.
Event analysis	Surveys at firm level	Analyse a past event by surveys at firm level
	Surveys at the household level	Analyse a past event by surveys at household level
Econometric approaches	Gross regional product effect assessment	Advantages:Statistically rigorous, Stochastic estimate, Able to forecast over time Disadvantages:data requirement (time series and cross section), total impact rather than direct and higher-order impacts distinguished
	National Gross domestic product effect assessment	
Input-Output Analysis (IO analysis)	Input-Output Models	Input-output modelling can be used to estimate indirect impacts of 'shocks' to the economy, a shock being an external impact that affects the level of economic activity, such as a natural disaster. Input-output models, however, implicitly make a number of restrictive assumptions, so their use is increasingly limited to the analysis of relatively small, marginal shocks. Advantages:Simple structure,Detailed interindustry linkages, Wide range of analytical techniques available, Easily modified and integrated with other models
Computable General Equilibrium Analysis	Computable General Equilibrium Models	A CGE model is a system of equations that represents all of the agents (including households, businesses and government institutions) in an economy. The supply and demand of all goods, services and factors is explicitly modelled. The amount of direct damage from a natural disaster can be fed into the model, which will forecast the

		indirect effects that are likely to arise in different sectors. Advantages: Non-linear structure, Able to respond to price change, Able to cooperate with substitution, Able to handle supply capacity constraint
Intermediate models	Hybrid Input-Output/ Computable General Equilibrium Models	Combination of Input-Output Analysis and Computable General Equilibrium.
Public Finance Analysis	Analysis of the impact on public finance	Analysis of the impact on public finance
Idealized Models	Modeling interactions of hazard impacts with technical change or business cycles	Idealised models of interactions between hazard impacts and technical change or business cycles.
SAM social accounting matrix	SAM	The social accounting matrix (SAM) has been utilized to examine the higher-order effects across different socio-economic agents, activities, and factors. The SAM approach has rigid coefficients and it tends to provide upper bounds for the estimates. Advantages: More detailed interdependency among activities, factors and institutions, Wide range of analytical techniques available, Used widely for development studies

Przyluski and Hallegatte (2011) give a brief summary on the methodology for indirect loss assessment used or preferred for different hazard communities. Meyer et al. (2013) also give examples of application for different hazard types.

Table 3-3 Application of models for indirect costs in the different hazard communities (Przyluski and Hallegatte; 2011 and Meyer et al. 2013)

Hazard type	Applied models
Droughts	CGE and IO models

Coastal hazards	IO models
Riverine flooding	Econometric approaches, CGE and IO models
Alpine hazard	Only a few studies, based on empirical observation of important sectors rather than on macroeconomic modelling. Other studies use market valuation techniques

Ivanova et al. (2009) applied a spatial computable general equilibrium (SCGE) model with RAEM (economy represented as a circuit comprising production, labour, housing, consumption, transport, domestic trade and foreign trade) to calculate the *indirect* effects of flooding, including economic effects after the flood due to loss of production factors and adjusted behaviour of firms and households. The applied SCGE model was based on New Economic Geography developed for estimating indirect impact of transport infrastructure investment. The model was considering the following long term effects.

- demanding and supplying firms outside inundated area
- interruption of transport connections
- interruption of communication connections
- feedback effects on housing, labour and product markets in short, intermediate and long run.

Difficulties arise in placing monetary values on certain in tangible natural disaster impacts, such as environmental damage. Direct market based prices cannot be used to assess the value of these impacts, because no markets exist for these goods and services. There are, however, a variety of non-market valuation methods that can be used to assess the value people attribute to intangible natural disaster impacts. Care is needed when using these methods to estimate the value of disaster impacts, as they can be complicated and time-consuming. Methods for valuing intangible impacts are listed in Table 3-4.

Table 3-4 Valuing intangible impacts (Meyer et al.; 2013)

General method	Specific method	Description/explanation
Revealed preferences Methods (analysis of actual human	Travel Cost method (time and travel cost expenses that people incur to visit a site represent the "price" of access to the site)	When a natural disaster affects the recreational and aesthetic value of an area, the economic value of the impact can be estimated on the basis of the amount that people are willing to pay to visit the area.
	Hedonic Pricing method (e.g.	This method estimates the value of intangible impacts on the

behaviour to estimate the value people place on something)	value of environmental degradation estimated from difference in house prices in areas where a natural disaster caused environmental damage as compared to house prices in unaffected areas.)	basis of the amount that people are willing to pay for marketed goods and services of varying quality. For example, the value of environmental degradation may be estimated on the basis of the difference in house prices in areas where a natural disaster caused environmental damage as compared to house prices in unaffected areas.
	Cost of Illness approach	The economic value of human health impact can be estimated using the resulting losses in earnings together with the cost of medical expenses needed for treatment. This approach, however, does not capture the economic impact of chronic health problems that do not result in losses in earnings, which may be the case for post-disaster trauma.
	Replacement Cost method (e.g. the value of coastal erosion caused by sea surge and high waves during a cyclone may be approximated as the cost of rehabilitation of the coastal area affected.)	The economic value of an intangible disaster impact can be approximated as the amount people have to pay to replace the good or service.
	Production Function Approach	Some intangible disaster impacts affect goods and services that are purchased in markets. For example, a tsunami may affect coral reefs and thereby alter the number of fish caught, or a cyclone may destroy trees and forests, thereby affecting the amount of timber available. The prices of the marketable goods (in these examples, the goods are fish and timber) can be used to estimate the economic value of the intangible impacts of natural disasters (in this case damage to the reef and forest).
Stated preferences Methods (willingness to pay for a non-marketed good	Contingent Valuation method (willing to pay for a change in the quality of an intangible good e.g. environmental quality)	In order to valuate non-market goods, people are asked in surveys about their willingness to pay to avoid a given decrement of this particular non-market good, or about their willing- ness to accept its deterioration by receiving a certain amount of compensation
	Choice Modelling method	Willingness to pay is elicited by choice experiments in which

or service)		people can choose between different bundles of goods with vary- ing characteristics. These can either be market or non-market goods.
	Life Satisfaction Analysis	Welfare estimations of public goods (health, environment) are estimated based on life satisfaction surveys
Benefit or Value Transfer methods	Benefit or Value Transfer methods	The benefit transfer method is used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and/or context.

3.2 CI system vulnerability

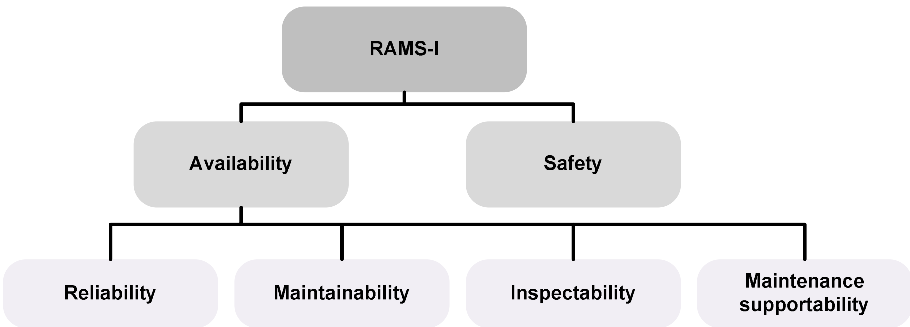
This chapter describes and focuses on the engineered physical critical infrastructures (CIs) such as the networks and associated control systems for energy supply, transportation, information and telecommunication. They can be characterized as large scale, spatially distributed, complex networks—either open or closed. These are systems and assets that function systematically to produce and distribute services vital for modern economy and social welfare.

3.2.1 System vulnerability and RAMS-I aspects

CI vulnerability can be defined as an expression of the system's lack of ability or reduced ability to withstand an unwanted situation, limit the consequences, and to recover and stabilize after the occurrence of the situation. (Doorman et al., 2004) CI vulnerability can be also be defined as a flaw or weakness (inherent characteristic, including resilience capacity) in the design, implementation, operation, and/or management of an infrastructure system, or its elements, that renders it susceptible to destruction or incapacitation when exposed to a hazard or threat, or reduces its capacity to resume new stable conditions. For example, the vulnerability of the electric power system might be specified in terms of changes in network characteristics following attacks on nodes and the scale (e.g., number of nodes/lines lost) or the duration of the associated loss. More sophistically, it can be expressed in terms of the frequency of major blackouts (number per year) and the associated severity, measured either in power lost or energy unserved. (Kröger and Zio, 2011)

In the design of critical combinations and complex integrations of large engineering systems and networks, their engineering integrity needs to be determined. Engineering integrity includes *reliability, availability, maintainability, safety* and *inspectability* (RAMS-I) of inherent systems functions and their related equipment. (Stapelberg, 2009) According to ISO 20815 reliability is the ability of a system to perform a required function under given conditions for a given time interval. The term “reliability” is also used as a measure of reliability performance and may also be expressed as a probability. (ISO 20815) Availability is the probability of a unit to be in working state at a given time t (includes maintenance) (Kröger and Zio, 2011) i.e. ability of an item to be in a state to perform a required function under given conditions at a given instant of time, or in average over a given time interval, assuming that the required external resources are provided. Maintainability is that aspect of maintenance that takes downtime of the systems into account. (ISO 20815) Safety can be classified into three categories, one relating to personal protection, another relating to equipment protection, and yet another relating to environmental protection. (ISO 20815; Stapelberg, 2009) Safety can also be defined as freedom from unacceptable risk of harm or to be the control of recognized hazards to achieve an acceptable level of risk (Tiusanen et al., 2011). Inspectability has been added to RAMS engineering especially in situations where component reliability is extremely important as it is for example. in remote operated equipment in radioactive environments. Inspectability can be seen as a characteristic of maintainability with a preventive objective. (Tiusanen et al., 2013; Tiusanen et al, 2011)

Figure 3-3 : RAMS-I concept (Tiusanen et al., 2011)



The integrity of engineering design therefore includes the design criteria of reliability, availability, maintainability and safety of systems and equipment. The overall combination of these four topics constitutes a methodology that ensures good engineering design with the desired engineering integrity. This methodology provides the means by which complex engineering designs can be properly analysed and reviewed, and is termed a RAMS analysis. The RAMS analysis model includes systems breakdown structures, process function definition, determination of failure consequences on system performance, determination of process criticality, equipment functions definition, determination of failure effects on equipment functionality, failure modes effects and criticality analysis (FMECA), and determination of equipment criticality. The management of reliability, availability, maintainability and safety issues (RAMS) becomes essential already at the system requirement specification phase continuing through the whole life cycle of a system. (IEC 60300-3-11; Stapelberg, 2009) There have been RAMS management programmes developed and standardised, for example, for safety-critical systems in railway networks (EN 50126-1, 1999; IEC 62278, 2002; Tiusanen, 2014). RAMS management in early system development phases in machinery applications has been studied among others by Lundteigen et al. (2009) and Ahonen et al. (2012).

3.2.2 System vulnerability analysis methods

A number of approaches and analysis methods can be undertaken for the vulnerability assessment of CIs depending on the type of system, the objective of the analysis and the available information. Correspondingly, the challenges to the approaches and methods used within the vulnerability analysis procedure depend on the specific objectives of the analysis and on the system characteristics; a common challenge comes from the large number of parameters needed to characterize the model of the system and the paucity of reliable data in support. Other specific challenges come from the need to capture the emergent behaviours and intricate rules of interaction, various system features like multi-layering, state changes, adaptation to new developments, ‘’system-of-systems’’ characteristics, the susceptibility to a broad spectrum of hazards and threats. All these features need to be tackled by the methods for vulnerability assessment. The most important or promising approaches and analysis methods are summarized in the following table.

Table 3-5: Summary of various methods for the vulnerability assessment of CIs (adapted from Kröger and Zio, 2011)

Approach / technique	Examples
Statistical analysis	Statistical models
Probabilistic modeling	Markov chains Markov/Petri nets Probabilistic modelling Bayesian networks
Risk analysis	Quantitative assessment, Tabular methods / expert judgment
Complex network theory	
Agent-based modelling and simulation	Monte Carlo simulation techniques

Dynamic control system theory	Transfer function

Methods of statistical analysis, probabilistic modelling techniques (e.g., Bayesian networks), and tabular methods for hazard studies and risk analysis (HAZOP, FMEA, pure expert judgment etc., see Table 3-6 below) used in isolation have been demonstrated to show limited chances of success against the challenges posed; on the contrary, integration of elements of probabilistic risk assessment (e.g., adapted logic trees), complex network theory and agent-based modelling and simulation techniques, including high-level architecture (HLA), appear most promising. (Kröger and Zio, 2011).

Table 3-6: Methods used in risk analysis of technological systems, most common methods (IEC 60300-3-9)

Method	Description and usage
Event Tree Analysis	A hazard identification and frequency analysis technique which employs inductive reasoning to translate different initiating events into possible outcomes
Fault Modes and Effects Analysis & Fault Modes, Effect and Criticality Analysis (FMECA)	A fundamental hazard identification and frequency analysis technique which analyses all the fault modes of a given equipment item for their effects both on other components and the system
Fault Tree Analysis (FTA)	A hazard identification and frequency analysis technique which starts with the undesired event and determines all the ways in which it could occur. These are displayed graphically
Hazard & Operability Study (HAZOP)	A fundamental hazard identification technique which systematically evaluates each part of the system to see how deviations from the design intent can occur and whether they can cause problems
Human Reliability Analysis	A frequency analysis technique which deals with the impact of people on system performance and evaluates the influence of human errors on reliability
Preliminary Hazard Analysis	A hazard identification and frequency analysis technique that can be used early in the design stage to identify hazards and assess their criticality
Reliability Block Diagram	A frequency analysis technique that creates a model of the system and its redundancies to evaluate the overall system reliability

During the past few years, many different schemes have been developed with the aim of supporting the process of understanding the behaviour of an infrastructure and identifying its points of weakness. Bagheri and Ghorbani (2010) discusess in their paper recently developed and influetial critical infrastructure schemes. (see Table 3-7 below)

Table 3-7 : Summary of the Selected Schemes (adapted from Bagheri and Ghorbani, 2010).

Scheme	Prominent Features
AIMS	Extendable multi-agent based architecture, pluggable visualization and analysis modules
ASPEN	Agent-based simulation, a thorough simulation of the U.S economy with the use of evolutionary learning techniques
CASCADE	Probabilistic and dynamic complex system models for cascading failure analysis
CISIA	Agent based simulation of infrastructures with three different types of interdependency (through incidence matrices)
GoRAF	Integrating engineering and business perspectives for identifying risks associated with enterprise interdependencies
HHM	Risk identification, ranking and filtering through the integration of multiple perspectives
IIM	Sector vulnerabilities assessment using inoperability and economic loss impact metrics
IRAM	Focusing on risk modelling for scarce resource allocation to improve system surety
OGC CIPI	Sharing of geospatial data for emergency management and response
UML-CI	Providing means for stakeholder and modeller communication, common understanding and knowledge transfer through a common infrastructure meta-model

In the DECRIS project, a Risk and Vulnerability Analysis (RVA) method for critical infrastructures was developed. The DECRIS project utilized experience from risk analyses within different critical infrastructures, and one of the main objectives was to develop an all-hazard generic RVA methodology suitable for cross-sector infrastructure analysis. Both safety (accidents, technological failures etc.) and security (malicious attacks) aspects are included. The DECRIS method (Risk and Decision Systems for Critical Infrastructures) supports an “all hazards” approach across sectors; i.e., electricity supply, water supply, transport (road/rail), and information and communication systems (ICT) and it emphasizes dependencies between the sectors. The method consists of the following steps (Utne et al., 2008):

1. Establish event taxonomy and risk dimensions

    a. Establish a taxonomy (hierarchy) of unwanted events. The DECRIS taxonomy has the following main event categories: Natural events, Technical/human events (error/accident), and Malicious acts.

    b. Decide on the consequence dimensions used to analyse the unwanted events. DECRIS defines the following consequence categories: Life and health, Environment, Economy, Manageability, Political Trust, and Availability of delivery/supply of infrastructure.

    c. Calibrate risk matrices. The unwanted events are described with a probability category and a consequence category for each consequence. These categories have to be established, and a discussion is needed to calibrate the resulting risk matrices.

2. Perform a simple analysis (like a standard RVA/PHA):

    a. Identify all unwanted (hazardous) events.

    b. Assess the risks related to each unwanted event. In the simple analysis, the two dimensions “Life and health” and “Availability of delivery/supply of infrastructure” are considered.

3. Select events for further detailed analyses. Potential candidates have usually high risk. In DECRIS specific information has been provided to support the selection, such as if the event has a gross accident potential, if there are relevant dependencies (in SCFs), and if there are communication challenges related to the event.

4. Perform detailed analysis of selected events. The course of events and various consequences are investigated in more detail. These analyses shall include :

    i. Evaluation of interactions and other couplings in between the infrastructures, and how this affects the consequences of the unwanted events.

    ii. Evaluation of vulnerabilities (e.g. critical junctions or weak barriers).

    iii. Suggesting and evaluating risk and vulnerability reducing measures.

The end users of the method and decision support systems are local governments, municipalities, and companies responsible for the infrastructures. (Utne et al., 2008)

Syner-G is a European Collaborative Research Project focusing on systemic seismic vulnerability and risk analysis of buildings, lifelines and infrastructures. In SYNER-G project, a general methodology to assess the seismic vulnerability of an interconnected infrastructure was developed. The main features of the methodology are (Pitilakis, 2011):

- A detailed taxonomy of the Infrastructure in a number of interconnected infrastructural systems, consisting of the description of each system and of its components.
- An object-oriented model of the Infrastructure describing the relations between all systems and components (inter- and intra-dependencies) within the taxonomy.
- Consideration of all uncertainties in the problem, and in particular: on the seismic activity of the seismo-genetic sources/faults, on the local seismic intensities at the sites for any given scenario, on the physical damageability of the components of the Infrastructure (the fragility models from WP3), on the functional consequences at component and/or system level of the physical damage at the component level, on the socio-economic consequences of physical damage, and, finally, the epistemic uncertainty in all the above models.
- The categorization of performance indicators in three groups, based on the level within the Infrastructure where they are evaluated: component, system or Infrastructure.
- An integrated evaluation of physical and socio-economic performance indicators.

In its final form the entire procedure is based on a sequence of three models: a) seismic hazard model, b) physical vulnerability model, and c) functional and socio-economic system model. (Pitilakis, 2011) The main outcome of Syner-G is an open source software tool to evaluate seismic vulnerability and losses considering both physical and socio-economic aspects.

A structured review of the existing methodologies at EU and global level is also given in the JRC report (Giannopoulos et al, 2012). In addition, it identifies gaps and prepares the ground for the proposal of a risk assessment methodology for critical infrastructure protection at European level. The report describes a selected number of these methodologies based on their citation records and their recognition in the scientific community. In order to obtain a structured review, the evaluation of these methodologies took place according to the following criteria (Giannopoulos et al, 2012):

- Scope of the methodology: Which sector is addressed, to who it is addressed (Policy makers, researchers, operators etc.).
- Objectives of the methodology.
- Applied techniques and standards.
- Interdependencies coverage.
- Is resilience addressed?
- If cross-sectorial methodology, how are risks compared across sectors?

The selected methodologies are described briefly in the separate Appendix to this deliverable.

A publication by Bagheri and Ghorbani (2010) proposes a reference model for critical infrastructure systems based on Unified Modelling Language (UML). The method is called UML-CI. The main objective is to model the infrastructure by means of structured high-level metamodels. Five metamodels are introduced in the publication, including:

- Ownership and management
- Structure and organization
- Resources
- Threat, risk and vulnerability
- Relationships

The overall objective is to define a layered architecture and interfaces so that these metamodels can be combined as larger entities. The architecture proposed in the publication is built of four layers:

- M0: Simulation instances – Very detailed models
- M1: Infrastructure design – Application level models
- M2: UML-CI – Meta-information level
- M3: MOF – Fundamental modelling layer with feature descriptions

Out of the five defined meta-models, the Threat, Risk and Vulnerability (TRV) meta-model is most relevant for the INTACT project. TRV meta-model intends to offer a structure for hazard categorization, consequence definitions and mitigation strategies. As a definition, TRV model needs to cover any hazard that could endanger the critical infrastructure.

The TRV meta-model is further divided into meta-classes: hazard, cause, consequence and mitigation strategies.

- Hazard is defined as a main class, which has a set of causes, consequences and mitigation strategies beyond it.
- The importance of finding the causes of these hazards is underlined. The classification of causes used in the publication is: natural disaster / human error / machine faulting / malicious attack.
- The relating consequences are divided into two groups: direct and indirect consequences.
- The mitigation strategies are defined by three attributes: implementation cost, time and effectiveness.

The report lists as main contributions of reference model the aspects of infrastructure ownership and management, internal organizations, system structures, asset classification and identification as well as risk profiling. In comparison to high level models, proposed UML-CI is stated to have benefits as it enables modelling of structures and interdependencies separately from simulation cases. This is said to make the models wider and more applicable for different purposes.

The report mentions two future development directions:

- Integrating system analysis methods to analyse the structures and organizations beyond infrastructures and to identify the infrastructure components, including interdependencies between them.
- Transfer methods to allow converting UML-CI models to simulation programs.

A report by Conrad et al. (2006) discusses reliability modelling. The approach is on a level higher than usual, meaning it looks at aggregate levels of hazards, restoration actions and mitigation measures across different infrastructures. Hence the equipment level is not touched. The report states such an approach is useful for investigating multiple infrastructures and their interdependencies.

The report focuses on three infrastructures; telecommunications, power system and emergency services. A special attention is set on their interdependencies and cascading of impacts. Different levels of telecommunication models are presented as functions of details and simulation time. Most of these models come from N-SMART (network simulation modelling and analysis research tools) simulation suite which covers different levels of telecommunication simulation.

Critical infrastructure modelling is performed as system dynamics consequence models utilizing Vensim simulation tools. Output of these tools is stored into a database. Database data is then used in a tailored way for providing results for different decision makers. The consequence models are not only used to simulate dynamics within infrastructures, but also their interdependencies. The process is represented as differential equations with discrete events.

The report suggests some practical needs for further improvements, like impacts of emergency call response times or costs relating to communication system loss due to power blackout. The simulation models are to be developed on the area of interactions between infrastructures. However, future needs for developing the modelling approach are not discussed in more detail.

A review of findings on vulnerability and resilience assessment has been made by Solano (2010). The research brief discusses different approaches for assessing vulnerability of critical infrastructure. For this, 12 references have been reviewed. The report does not describe the methodologies as such, but performs some clustering and comparison of methods reported.

Most of the reviewed methods apply mathematical modelling combined with network theories. In addition, some references rely on systematically using expert judgements or on qualitative assessments. In terms of finding the optimal situations, majority of the methods apply linear optimization limited to solving minimum-cost calculations. However, more sophisticated linear optimization methods are not used.

The report discusses the complexity of defining and characterizing the critical infrastructure systems. There are different approaches for modelling the networks and different types of nodes within them. Further, the report discusses analysis processes. For instance a Model-Based Vulnerability Analysis (MBVA) has been used in some of the references. MBVA seeks to list all possible event combinations and to calculate infrastructure failing probabilities for each scenario. To do this, the process uses for instanced lists of assets, network analysis and fault-tree methods.

The report gives some clear conclusions:

- Methodologies often fail to incorporate social and organizational components into the analysis of physical infrastructures.
- Relations between human and physical components are evidently strong but also very complex to model.
- For instance decision making has been included in only few references.
- Dimensions like environmental or economical ones are also lacking in existing methodology.
- Modelling techniques as such often fail to represent infrastructure-specific topologies.

Finally, the report asks whether a more holistic approach can help in understanding the risks relating to infrastructures.

It can be concluded that a universal, all-encompassing modelling approach capable of addressing by itself the assessment of vulnerable systems does not exist. Consequently, in practice, quantitative measures should be used as a guide rather than as the sole basis for the approval or rejection of specific alternatives. Decision makers should understand the key assumptions behind the analysis, how the analyses were carried out, and what the final results really mean. A major challenge in the early phases of the process is the widespread occurrence of inadequate data. It is essential that the analysis methods applied are in line with the quality and amount of data available. Used wisely, however, methods and tools are of help to risk and CI management making decisions on EWE damaging CI.

Finally, uncertainty analysis is much needed for inclusion into the picture, although still rarely an element of an overall vulnerability assessment; in this respect, computational tools for uncertainty propagation and sensitivity analysis in large scale applications, with reasonable computing times are missing. The same holds for the need of including the interactions and influences of the human operators, a cross-cutting issue into vulnerability analysis which has been addressed in other than CI sectors, mainly in the framework of PRA for nuclear power plants, but is now starting to arise also in the field of vulnerable CIs analysis. (Kröger and Zio, 2011).

3.3 Interdependencies between infrastructures

Critical infrastructure (CI) dependencies are important for understanding the cascading effects of the impact of extreme weather events (EWE). Interdependencies can improve infrastructure operational efficiency, but can increase system vulnerability (Ouyang, 2014). Cascading effects can be due to a sequence of failures leading to catastrophic proportions and serious societal impacts. An infrastructure is increasingly vulnerable when it needs the input of another infrastructure to function, but cascading effects can also occur indirectly. While modelling and simulation tools have provided insight into the behaviour of individual infrastructure networks, a far less understood area is that of the interrelationships among multiple infrastructure networks including the potential cascading effects that may result due to these interdependencies (Dudenhoeffer et al. , 2006).

3.3.1 Categorisation of CI Interdependencies

Infrastructures are composed of a collection of interconnected networks (both physical and computer based) that serve different purposes and have different owners. Indeed, even parts of the information residing on a single sub-network may have different purposes and different owners. Critical information and controls are passed between these component elements to coordinate necessary functions. The complexity and interdependency of these critical resource flows introduces nuances and potential vulnerabilities into the infrastructure. Natural disasters, deliberate attacks or accidental system failures within infrastructures may result in cascading effects that are neither readily apparent nor immediately understood (Dudenhoeffer et al., 2006). Several references use different definitions to explain the variety of ways in which critical infrastructure systems are interdependent (see e.g. Dudenhoeffer et al. (2006); Rinaldi et al. (2001); Buhne et al. (2003)). In general, the following categorization can be defined for different types of interdependencies:

- Physical, a physical reliance on material flow from one infrastructure to another;
- Cyber, a reliance on information transfer between infrastructure;
- Geographic, a local environmental event affects components across multiple infrastructure due to physical proximity;
- Other;

Infrastructure can be dependent on material flow from one to another (physical) and dependent on information transfer between infrastructure (cyber). An example of a physical interdependency between infrastructures is a rail network and a coal-fired electrical generation plant (Rinaldi et al. , 2001). Both infrastructures supply commodities that the other requires to operate. The railroad provides coal for fuel and delivers large repair and replacement parts to the electrical generator, while electricity generated by the plant powers the signals, switches, and control centres of the railroad. Also, in the case of electrified rail, the electrical generation plant directly powers the locomotives.

Advances in information technology (IT) have resulted in infrastructures that have become increasingly automated and interlinked. Cyber interdependencies have become more and more important and connect infrastructures to one another via electronic informational links. Infrastructures have computerized control systems and outputs of the information infrastructure are inputs to the other infrastructure.

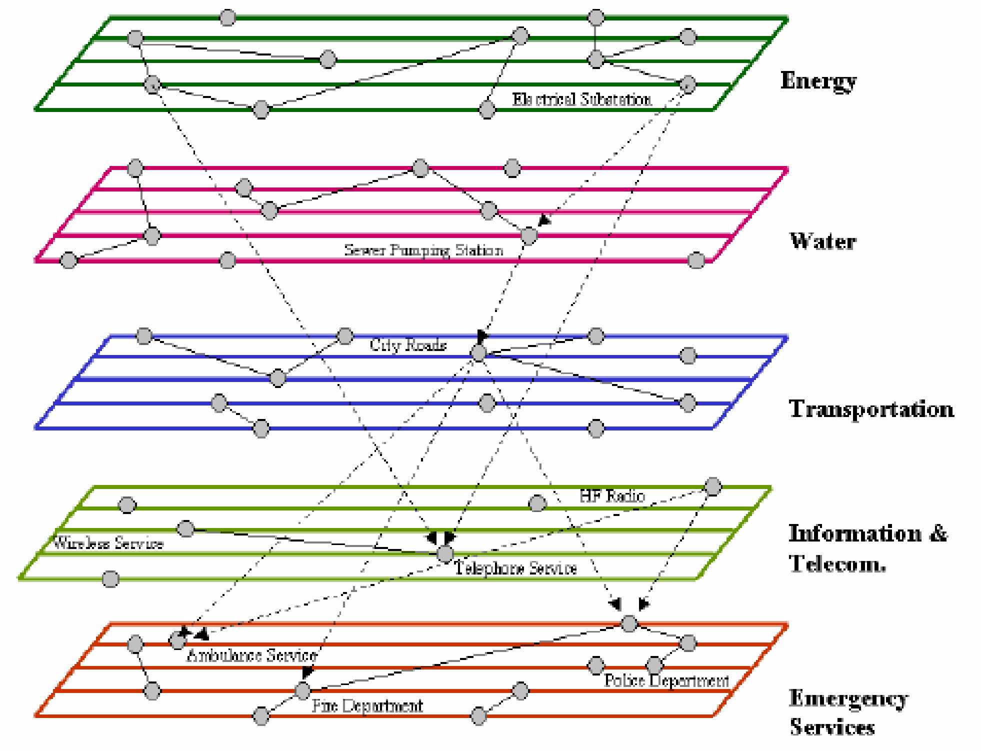
The Infrastructure can also be dependent on the local environment since it affects infrastructure components. When the infrastructure dependency does not fit within these three categories, it is in the 'other' category. The latter category can be for example due to policy or high level decisions that lead to interdependencies of infrastructures. The degree to which the infrastructures are linked, strongly influences their operational characteristics (Rinaldi et al. ,2001). Some linkages are loose and thus relatively flexible, whereas others are tight, leaving little or no flexibility for the system to respond to changing conditions or failures that can exacerbate problems or cascade from one infrastructure to another.

An alternative categorisation is that of Bühne et al. (2003) in his discussion of dependencies in feature modelling for use cases. Here he defines the following dependencies:

- Requires-dependency – a binding of one object implies the need of another object, i.e., a required following;
- Exclusive-dependency – describes that the binding of one object excludes the selection of another object;
- Hints-dependency – describes dependencies where the binding of one object has some positive influence on another object;

An illustration of interdependencies between critical infrastructures is given in the figure below. Each type of infrastructure network is represented on a single plane, where the spheres or nodes represent key infrastructure components within that sector. For example, the energy infrastructure contains the sectors of electrical generation and distribution, natural gas production and distribution, etc. Ties and dependencies exist within each infrastructure between the different sectors.

Figure 3-4 Example of interdependencies between infrastructures, Dudenhoeffer et al. (2006).



3.3.2 Modelling and simulation of interdependencies

There is a need for a clear, methodical understanding of dependencies. To better understand critical infrastructures to support planning, maintenance and emergency decision making, modelling and simulation of interdependencies of CI has recently become a key field of study. Developing a comprehensive architecture or framework for interdependency modelling and simulation is a major challenge. At the moment, there is no satisfactory set of models that articulates the risk of failures, either naturally caused or human induced, for highly interdependent infrastructures (Rinaldi et al., 2001). Many models and computer simulations exist for aspects of individual infrastructures (e.g., load flow and stability programs for electric power networks, connectivity and hydraulic analyses for pipeline systems, traffic management models for transportation networks), but simulation frameworks that allow the coupling of multiple interdependent infrastructures are limited (Rinaldi et al. (2003); Nieuwenhuijs et al. (2010)). When important aspects of CI dependencies are not modelled adequately, risk assessments conducted using these dependencies are suspect at best.

Current state of the art models and simulation approaches of CI interdependencies can be distinguished in six groups (Ouyang (2014)):

- empirical approaches;
- agent based approaches;
- system dynamics based approaches;
- economic theory based approaches;
- network based approaches;
- others.

In addition, Ouyang (2014) compares the different types of approach according to several criteria, with the resilience as the main perspective to position their applications and drive the proposal of a system-theory based integration framework. Five criteria are analyzed: quantity of input data, accessibility of input data, the types of interdependencies that can be modelled, computation complexity, and maturity of approach. Table 3-8 shows the results where labels "S", "M" and "L" rank from low to high. Types of interdependencies are into physical (P), cyber (C), geographical (G) and logical (L).

Table 3-8 Comparison of different approaches; Ouyang (2014).

Approach type	Sub-approach	Quantity of input data	Accessibility of input data	Types of interdependencies	Computation cost	Maturity
Empirical		M, L	M	P, C, G, L	S	M
Agent-based		L	S	P, C, G, L	L	L
SD based		M, L	M	P, C, L	M	L
Economic theory based	Input output	M	L	P, C	S	L
	Computable general equilibrium	L	M	P, C, G, L	M	M
Network based	Topology-based method	S, M	M	P, C, G, L	S, M	L
	Flow-based method	L	S	P, C, G,L	L	L
Others	HHM	L	S	P, C, L	S	S
	HLA based	L	L	P, C, G, L	L	S
	PN	M, L	M	P	M, L	M
	DCST	M, L	S	P, C, G, L	M	S
	BN	M, L	S	P, C, G, L	M	S

The large variety in approaches shows the complexity of modelling interdependencies. Rinaldi et al (2001) note the following requirements for a comprehensive architecture of the modelling and simulation framework:

- Leverage new or "legacy" (existing) software applications, including screening, network analysis, policy, consequence management, and impacts tools;

- Access a wide variety of data, possibly distributed over multiple sites, including threat data, dependency relationships, and repair and restoration sequences;
- Capture the dynamic interplay and coupling among models;
- Accommodate a broad range of analysis contexts, with widely varying spatial and temporal resolution and fidelity.

Empirical approaches

The empirical approaches analyse interdependencies of CI according to historical accident or disaster data and expert experience. Failures and the potential cascading effects of them can be analyzed based on real events. Often real-world dependencies and event data from CI incident databases (e.g. TNO, 2014) contain complexities that are not captured by existing dependency models; these complexities are, therefore, often ignored

Agent-based approaches

An agent-based approach is a bottom-up approach that represents the complex behaviour of many individual agents and their interactions. In the case of CI, all the CIs are regarded as complex adaptive systems where each CI component can be viewed as an agent.

Agent-based CAS approaches, which are being used to represent both the physics and finances of highly fluid, interdependent markets, have captured the interplay among economic and societal factors and the operation of multiple infrastructures. An example of an agent-based approach (ABM) is the CIMS architecture (Dudenhoeffer et al., 2006). The CIMS© architecture uses an agent-based approach (ABM) (Rocha 1999) to model infrastructure elements, the relations between elements, and individual component behaviour. The interdependency modelling framework CIMS was introduced as a tool for infrastructure analysis supporting the ability to conduct “what if” scenario analysis. It is a framework that looks into the emergent systems behaviours that develop when one or more nodes within the system are disturbed.

System dynamics based approaches

System dynamics is, in contrast to agent based approaches, a top-down holistic approach to analyse complex systems. Feedback, stock and flow are the basic concepts of this approach. An example is Nieuwenhuijs et al. (2010), that describes a model for expressing CI dependencies that is based on a system analysis approach.

Economic theory based approaches

In economic theory based approaches interactions between economic actors, such as households and producers, can be analysed at the meso or macro level. Market transactions are taken into account and show the interdependency between sectors in the economy for production and consumption. CIs are part of sectors (such as energysector, transportsector, watersector etc.) in the economy. Sectors use goods and services of other sectors for production. The intermediates of other sectors show the interdependency between sectors and are based on economic transactions. In the literature, two types of economic theories are deployed to model interdependencies and indirect effects of shocks (such as an extreme weather event): Input-Output (I-O) and computable general equilibrium (CGE).

Okoyama (2011) used Input–Output and Social Accounting Matrix methodologies to estimate higher-order effects of ten recent disaster cases. Results show that the higher-order effects of disasters are significant and complex. The estimated impact multipliers are mostly around two, and in some cases, bordering three, implying that losses of a disaster can be doubled, or sometimes tripled, via ripple effects through interdependencies within an economy (Okoyama, 2011). Another example is Ivanova et al. (2009), where a Spatial Computable General Equilibrium (SCGE) model is used to show the indirect impacts of flooding in the Netherlands in other regions and over time, partly due to interdependencies between sectors. Underlying data of the SCGE model consists also of a Social Accounting Matrix at the regional level.

Economical models and their applications are also treated in section 3.1.2.

Network based approaches

Where economic theory model take economic transaction as starting point, network based approach look at physical and relational connections. The level of analysis is more detailed, often at the level of components and nodes within a CI. Network based approaches models networks and describe interdependencies by inter-links by detailed descriptions of topologies and flow patterns. In case of failure of a component, cascading effects can be simulated within and across different CIs at the system level.

Other

Besides the approaches above, also other approaches are mentioned in the literature. Examples are the hierarchical holographic modelling (HHM) method, the high level architecture (HLA) based method, the petri-net (PN) based method, the dynamica control system theory (DCST) based method, and the Bayesian network (BN) based method.

Modelling and simulation of interdependencies of Cis is a relatively new research field. Recently, some progress has been made in integrating disparate model types and analysing multiple infrastructures. There are still many future challenges to fully understand and manage the interdependencies between critical infrastructures.

3.4 Societal response and risk management

There are many examples of risk management frameworks, and a selection is described below. A key issue in this review will be to what extent societal response is included, as often the risk management process includes technical and economic assessment, but omits the social impacts.

The RECIPE project (Klaver et al., 2011) was an EU-funded project that produced a Good Practices Manual for Critical Infrastructure Protection (CIP) Policies. The main output of the project was a summary document, which collated information from across Europe and wider afield, and included stakeholder discussions to understand existing policies and practices for improving the protection of CI. It provides a set of examples of good practice, with clear examples and references, so that policy makers in other countries can see what has already been done elsewhere. It covers all aspects related to CI, and includes major consideration of public-private interaction, CI dependencies, risk management, crisis management.

RECIPE confirmed that it is important to know where and in what ways the functioning of assets can be affected. Risk management (RM) shows which components are being addressed, show the relative significance of the impacts, and where the most benefit can be achieved. RM can be used across all levels of assessment. National Risk Assessment will also include societal impact. Providing a common risk framework and set of tools will assist in allowing organisations to carry out compatible assessments, and in turn this can ensure that societal impacts are also considered. Risk Assessment methodologies are well-established in several countries, such as UK, Germany and Denmark (e.g. Danish RVA Method). The RECIPE manual can either be used to provide guidance and tools to help organisations adopt RM, or have mandatory requirement for such an assessment, or carry out a national risk assessment, which includes all relevant risks and stakeholders in the assessment.

Crisis management (CM) requires involvement of CI operators in some form of the CM process. Governmental CM will consider roles, responsibilities and resources that are needed. CI operation may also be critical to the CM process and assist in the response, recovery etc., so it is important that the CI is kept going or recovers quickly.

One approach to the inclusion of societal responses is by the use of agent-based simulation. Kruchten, Woo, Sotoodeh and Monu (2007) developed a *Human-Centered Conceptual Model of Disasters Affecting Critical Infrastructures*, which distinguishes between the physical and social interdependencies between infrastructures. Here the social layer deals with communication and coordination among representatives (either humans or intelligent agents) from the various critical infrastructures.

The model is organized around four groups of concepts (See Figure 3-5):

1. Concepts to describe a region and the people that occupy it, and their well-being

2. Concepts to describe the various infrastructures that serve this region

3. Concepts to describe events such as a disaster and its impact on people, directly or indirectly through the infrastructures.

4. Concepts to describe communication and coordination between infrastructures, and with the regions and people.

Figure 3-5 Structure of Human-Centered Conceptual Model

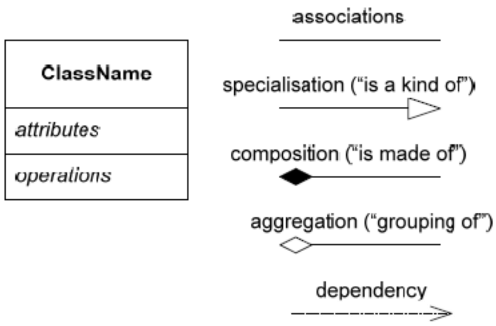
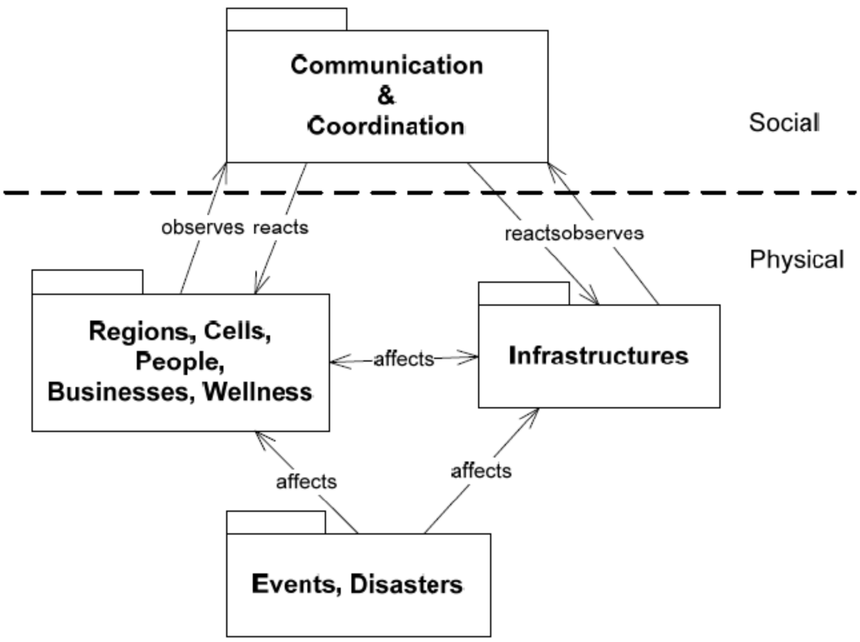


Figure 3: UML key symbols



Within the model a **Cell** is defined as an entity that has a geographic location (an area), that contains a certain number of people, and has also an attribute of Wellness, called the Collective Wellness. In the model there are several kinds of cells:

• Residential cells, containing people.

• Government cells, containing people that play a special role in the case of disasters, such as police, fire halls, government, army, etc.

• Economic cells: areas where commercial or industrial activities are conducted

A **Resource** is something that contributes significantly to wellness. An **Infrastructure** is that thing that produces and transports a given resource to the cells. Infrastructure elements have a state. Similar to the individual wellness, they define a simple scalar scale for the state of an infrastructure element, representing its current ability to handle or transport the associated resource, its health. Distribution points link a cell to a type of infrastructure.

There are several kinds of physical interdependencies between infrastructures:

• Dependent: infrastructure A is connected and dependent on infrastructure B, meaning that if B is down, A is down. This is the case of a water pump depending on electrical power.

• Dependent, with delay: A is connected with B, and a failure of B will ultimately lead to a failure of A, over time. This is the case of telephone equipment, with battery backup, depending on electrical power, but equipped with some battery backup (to hold a few hours) or with a generator (to hold for a few days).

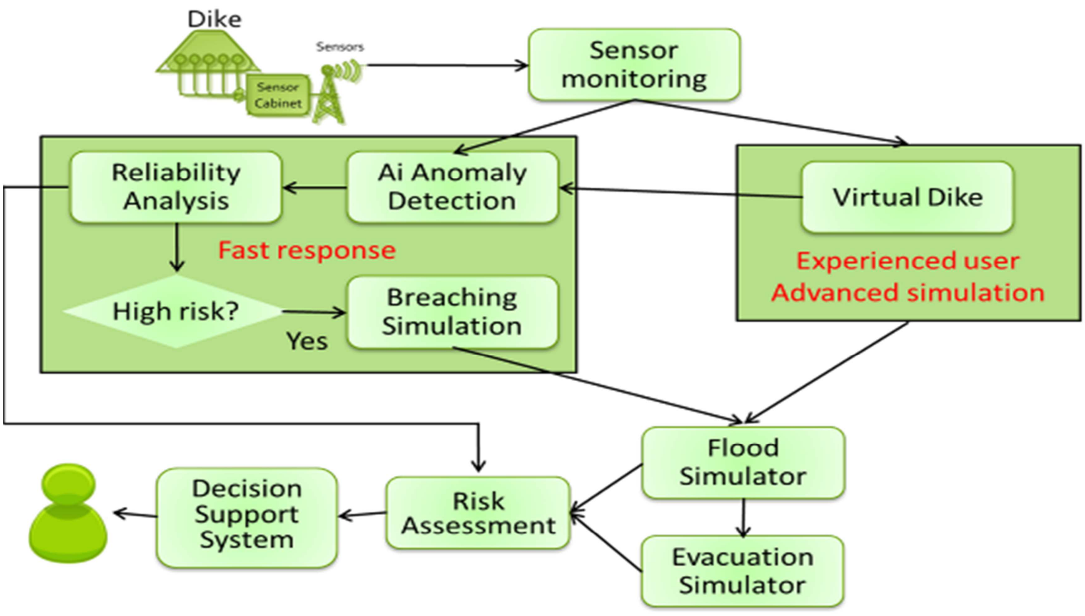
• Collocated: this is a variant of dependent: two or more infrastructures are using the same physical space in a way that makes them fail simultaneously: a road bridge that carries a gas pipeline and a fibre optic are examples of such connections.

Disaster events are external events that “happen” and affect the state of cells and infrastructure elements. A disaster event, depending on its characteristics will instantaneously or over time change the wellness of cells or the state of infrastructure elements. An earthquake will kill people in cells near the epicentre, bring the wellness to low levels in adjacent cells, and over time affect the wellness of many other cells (lack of power, lack of food). The same earthquake will also immediately destroy some infrastructures (electrical tower, water pipes), with or without some cascading effect to adjacent elements, and more effects over time.

A **conceptual agent** is an abstract entity that has goals (objective), beliefs (based on its observation of the world), and states (internal variables that can be compared with the goal). It can observe the surrounding environment, reason on how to bring it closer to its goal, and act accordingly. Some of the more sophisticated agents will also be able to learn, by observing the positive and negative effects on the discrepancy of previous attempts to satisfy their goals, and changing or adapting the strategies. The literature indicates that it was applied conceptually to the case study of a town, but it is not clear if the method has been adopted by others, and hence whether it has wider applicability and endorsement.

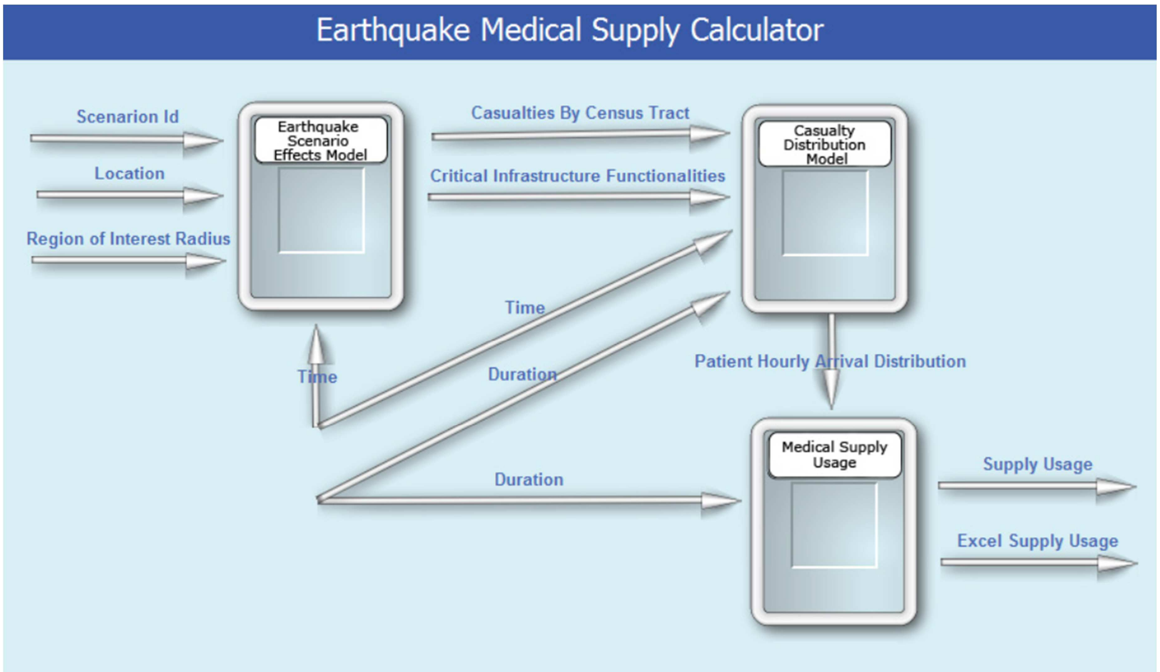
One topic area that has been debated and researched over the past 10 years or so, to provide a more holistic risk assessment framework, is that of linking together different topic/technology models or tools. The Open-MI protocol (OGC, 2014; Harpham et. al., 2014) was created to provide model developers a formal mechanism of linking their models dynamically, so that the interactions take place at run time, so there is a full, forward and backward passing of inputs and outputs between all models in the composition. A user community does exist for this technology, although it is fair to say that it is not used widely. A potentially less formal linkage was demonstrated in the UrbanFlood project (www.urbanflood.eu), where case studies were set up with a model cascade that passed results from one model to the next, to visualise potential flooding scenarios and allow decision-makers to take interventions. The cascade comprised 4 models, covering flood defence reliability, embankment failure, flood spreading and movement of people in relation to the flood wave (see Figure 3-6).

Figure 3-6 Modelling cascade used in UrbanFlood project



Another approach to the linking of models and data is SUMMIT (www.dhs-summit.us), which stands for Standard Unified Modelling, Mapping and Integration Toolkit. It was developed by the Resilient Systems Division of the US Department of Homeland Security, to create an integrated modelling capability and also to distribute SUMMIT repository data over web services to allow other tools to access and leverage the data for emergency management activities. From the information reviewed, it is not clear how the various models can be linked: use of the SUMMIT Software Development Kit (SDK) allows model and simulation developers to "wrap" their model with an interface that allows the SUMMIT server to communicate with the model. This sounds very similar to the Open-MI protocol, although one interpretation is that the data exchange and linking takes place at a more removed level. The main use of the SUMMIT system to date seems to have been in the running of emergency training exercises and in the use of advanced visualisation capabilities, which allow the linking of model results and other external data sets, together with data manipulation facilities to address 'what-if' questions. The following provides an example of the type of application that has been achieved to date with SUMMIT.

Figure 3-7 Example application composition in SUMMIT tool



Another tool developed by the US Department of Homeland Security is the Supplemental Tool, which provides a critical infrastructure risk management approach as depicted below:

Figure 3-8 Risk management framework used in Supplemental Tool.

Figure 1: Critical Infrastructure Risk Management Framework

The framework supports a common, unifying approach to risk management that enables the integration of strategies, capabilities and governance structures to achieve risk-informed decision making by CI owners or operators. The approach can be applied to all types of threats and hazards, natural or man-made.

The critical infrastructure risk management approach includes the following activities:

- Set Goals and Objectives: Define specific outcomes, conditions, end points, or performance targets that collectively describe an effective and desired risk management posture.
- Identify Infrastructure: Identify assets, systems, and networks that contribute to critical functionality and collect information pertinent to risk management, including analysis of dependencies and interdependencies.
- Assess and Analyse Risks: Evaluate the risk, taking into consideration the potential direct and indirect consequences of an incident, known vulnerabilities to various potential threats or hazards, and general or specific threat information.
- Implement Risk Management Activities: Make decisions and implement risk management approaches to control, accept, transfer, or avoid risks. Approaches can include prevention, protection, mitigation, response, and recovery activities.
- Measure Effectiveness: Use metrics and other evaluation procedures to measure progress and assess the effectiveness of efforts to secure and strengthen the resilience of critical infrastructure.

In terms of the US, there are various online resources that support the risk framework, such as details of incidents and extensive vulnerability and mitigation information. A key aspect of the framework is the use of metrics to assess effectiveness, and this approach should be considered for the INTACT risk modelling framework.

Over the past two decades there has been increased focus on the potential use of earth observation data to assist in disaster risk reduction and risk management. The RISK-EOS project, which started in 2003, is a network of European service providers delivering geo-information services to support the management of flood and fire throughout all phases of the risk cycle from prevention to post-crisis. The RISK-EOS services combine the use of satellite observation data with external data and modelling techniques; these are targeted at risk management actors across the whole of Europe at a range of administrative scales. Such services include automatic burn scar mapping during the summer fire season, and a flash flood early warning system. The latter makes use of structural basin parameters from satellite observations and real-time precipitation data from radar. Overall the flooding service produces and maintains geo-information to support decision making for flood risk areas, including production of maps of past flood events, flood hazard, and flood damage assessment. The following shows the data flows for the flood service, plus an example fire hazard map for the Iberian Peninsula.

Figure 3-9 Data flows for RISK-EOS flood service

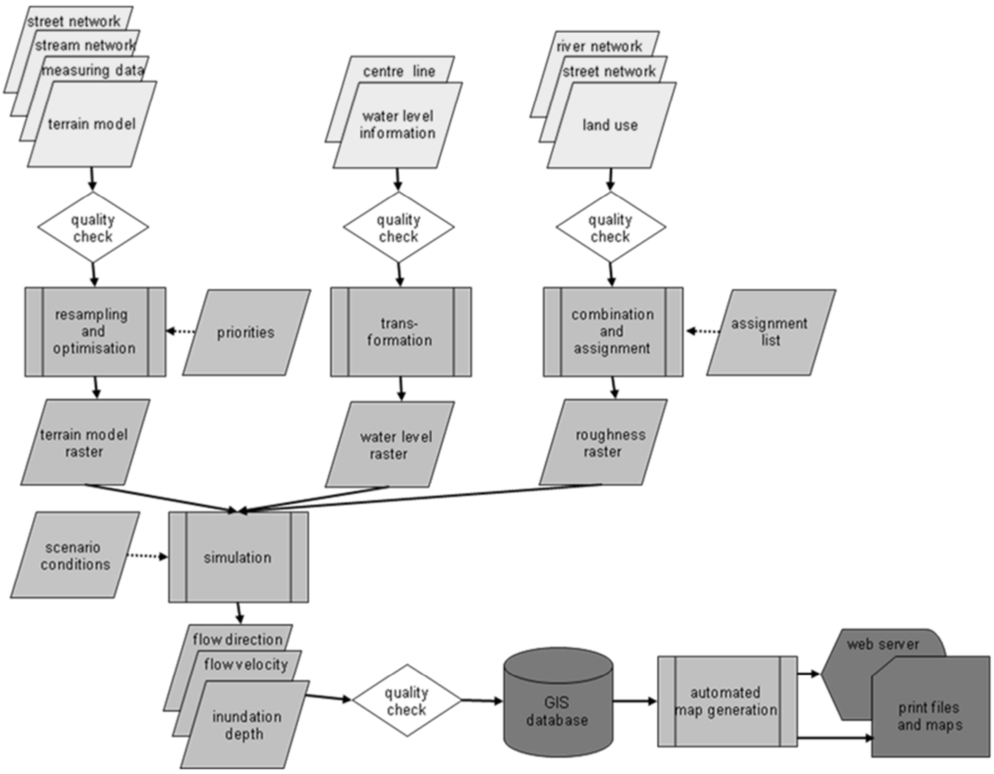
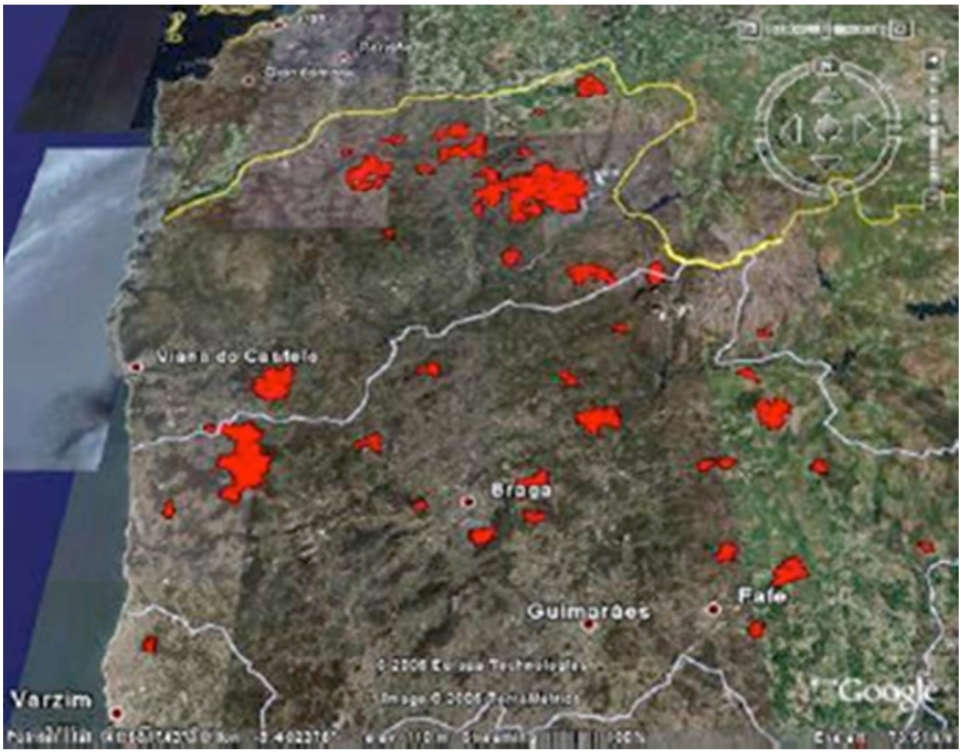


Figure 3-10 Example of fire hazard map for Iberian Peninsula from RISK-EOS project



3.5 Relevancy for Task 4.2 (Framework) and Task 4.3 (Gap analysis)

From the overview of SOTA risk tools and methods presented above, it is clear that there are many different tools, approaches and methods that can be directly integrated into the decision-making framework to be developed in Task 4.2. For hazard models, it seems that there is a large group of specific tools appropriate for each EWE type. For vulnerability models, some models are EWE specific, others are generic ones applied at present to small sets of EWEs. Impact models are mainly applied to one specific EWE. In addition, a vulnerability analysis usually entails considerable uncertainties. For example, data sources can be insufficient or highly aggregated and uncertainties related to the operational environment create confusion. Uncertainties can enter the analysis at different points (e.g. data uncertainty, parameter uncertainty and model uncertainty) which all affect the decision-maker’s perception of the usefulness of the results. These facts need to be considered also in the development of Tasks 4.2 and Task 4.3.

Although some of the CI vulnerability concepts and models have been proved against statistical data (e.g., statistical data on blackouts) and benchmarked against other methods, there is still a general lack of validation, and contradictions between (limited) empirical investigations and theoretical analysis. (Kröger and Zio, 2011). In the table below, advantages and disadvantages of different CI vulnerability analysis methods are summarized.

Table 3-9: Advantages and disadvantages of different CI vulnerability analysis methods (adapted from Kröger and Zio, 2011)

Method	Advantages	Disadvantages
Complex network theory	Simple and fast analysis, which provides quantitative indicators of the topological characteristics of the network of connections underpinning a CI. Allows to identify topologically critical areas of the system	If used in isolation, it can provide only indications on the topology of the system, potentially failing to represent the other features related to the flow-driving characteristics
Risk analysis	Allows a systematic and logic analysis of vulnerability scenarios which may affect a CI, while at the same time allowing for their quantification of likelihood of occurrence and consequence, and for the identification of the critical CI components	The efforts in logic modelling and quantification are significant. The capability of providing an exhaustive analysis is limited, particularly in view of the unexpected emergent behaviours and of the many (inter) dependencies
Probabilistic modelling of cascades dynamics	The high-level of abstraction leads to a modelling which is still sufficiently slim to allow running what-if scenarios at reasonable computational expenses. The results of this add to the topological analysis by confirming or not certain network connectivity characteristics and critical points, in light of also the dynamic patterns of cascade evolution	Although dynamics is added to complement the topological analysis, it may still fail to capture physical aspects of the cascade dynamics related to the flowdriven processes actually occurring
Agent-based modelling	Close adherence to reality; capable to capture highly non-linear dynamics and emergent phenomena; integration of non-technical system elements	Usually requires a large number of model parameters and may imply long computational times
High-level architecture	As a promising approach for integrating different modelling methods, the distribution of simulation components improves the flexibility/ reusability of the simulation tool and decreases its overall complexity	It is not a ‘‘plug-and play’’ standard. Resources and time required to implement an HLA-compliant simulation tool could be significant
Human reliability and performance modelling	With a relatively simple and straightforward manner allows analysts to estimate human contribution to the risk, to calculate the possibility of the occurrence of a human error and to identify the factors that compromise human performance. In addition suggestions either to improve safety or to deal with the unpleasant consequences are provided	Lack of data and biased experts judgment can compromise the validity of the analysis. Findings may vary based on analysts experience, background and training. Complex techniques can only be used by experienced and trained analysts. The analysis can be both time-consuming and exhaustive

The main gaps of the current CI risk assessment which were identified by Giannopoulos et al. (2011) are:

- In many cases, the risk assessment methodologies for CI are an adaptation of methodologies that have been used for assessing risks within the confined environment of an organization. As a consequence, these methodologies are tailored to the particular needs of this organization and biased to consider only part of relevant threats.
- The true challenge is the upscaling of any risk assessment methodology to complex systems. Policy makers, decision makers and infrastructure operators are aware of this deficiency, and actually ask system analysts to develop effective approaches for assessment of complex infrastructures and lately system of systems.
    - The first step towards this direction has been the development of methodologies that are tailored for the assessment of critical sectors (as these are defined by the policy makers) and for a variety of hazards, e.g. terrorism, natural disasters, man-made threats, etc. The criticality is established along the dimension of interdependency, which is the main challenge for these methodologies.
- Mitigation measure evaluation
    - A complete analysis is possible if the impact is combined with the likelihood of the scenario. If this information is not available then the analysis is just an impact assessment and cannot be used for prioritization of risk mitigation measures especially for HILF (High Impact Low Probability) events.
    - A multi criteria decision analysis is qualitative and mostly useful for prioritization of mitigation measures e.g. give priority to a certain sector instead of another one because it can lead to more severe effects. However, this approach is not applicable for cost-benefit evaluation of mitigation measures.
- Operators, asset managers, policy makers tend to identify threats and vulnerabilities within their domain of responsibility. From the risk assessment point of view this approach is effective but it narrows down the possibilities for a cost-effective risk mitigation.
- In all available methodologies, resilience seems to be the missing element, or in the best option it is only implicitly addressed. If the issue would be taken from a resilience point of view, more alternatives to mitigate risks would exist. A resilience analysis requires assessing the infrastructure from a holistic point of view, enhancing coordination and timely response throughout the interdependencies.

Regarding climate information for exposure analysis of CIs, INTACT will build upon the knowledge generated in two parallel coordinated European activities focused on the development of state-of -the-art future climate scenarios and an adequate validation framework (Euro-CORDEX, http://wcrpcordex.ipsl.jussieu.fr/ and COST action VALUE, http://www.value-cost.eu/). Therefore, the reference observational databases to be used at a European scale in INTACT will be the same ones as used in these two projects.

4 Application examples from literature and from stakeholders

4.1 Exposure of CI to EWE

In the last decades a great effort has been undertaken by the scientific community to evaluate and analyse the current climate and to study the impact of climate change in the mean and extreme weather regimes. To this aim, several extreme weather indicators (EWIs) have been defined (e.g. Sillman and R. Roeckner 2008; Morán-Tejeda et al. 2013) and several projects have been developed focusing on different impact communities at a regional, national or European scale (e.g. CLIM-RUN http://www.climrun.eu/; FUME http://www.meteo.unican.es/en/projects/fume; QWeCI http://www.liv.ac.uk/qweci/; etc.). However, scientific literature addressing the impacts of EWIs on CI, and the possible effects of climate change is still scarce.

Analysing the exposure of the CI to EWEs requires the identification and definition of those climatic events affecting CIs. To this aim, we have used, on the one hand, the definition used by different meteorological services to establish the weather alerts (e.g. www.mem.ie) and, on the other hand, the indicators defined by the Expert Team on Climate Change Detection Monitoring and Indices (ETCCDMI, Sillman and Roeckner 2008). Note that these indicators require different meteorological parameters (temperature, precipitation, wind, radiation, etc.), some of them usually unavailable at a European scale in most of the climate observational datasets. To ensure their availability we have identified some reference observational databases both at national and European scales (Klein Tank et al. 2002; Haylock et al. 2008; Isotta et al.2014; Herrera, et al 2011, 2013, 2014).

After the literature review on the exposure of CI to EWEs, it becomes evident that most of the studies are related with floods and their impacts on CIs. In particular, most of these studies are based on the use of stochastic or more process-based hydrological models containing representations of terrain characteristics, land use / land cover types, channel flows... and infrastructures in order to test their behaviour under different exceptional events and exposure (see e.g. Gouldby et al. 2008).

From the climate point of view, the most important input in this type of models are precipitation series of high spatial and temporal resolution (usually daily precipitation series), corresponding to the site or sites where the model is run. The high-resolution inputs are a common need in this type of models, not just for climate but for the rest of variables involved (Wallingford 2014). Exposure assessment of CIs will require not only a high-resolution terrain, land cover and socioeconomic information, but also site-based climate information of the variables involved (e.g. solar radiation, precipitation, wind speed, temperature). The latter will be possible only in those sites for which meteorological records of sufficient length and quality are available.

4.2 Flooding of tunnels: quantifying climate change effects on infrastructure

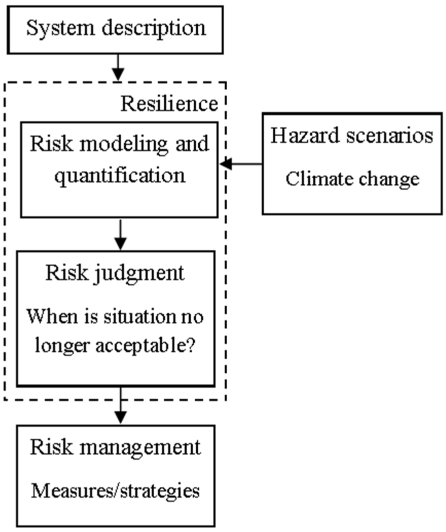
This section describes another example of application of modelling impacts of extreme weather events on critical infrastructure. To develop climate proof road infrastructure it is of importance to understand the quantitative effects of expected climate change on the performance of individual components, such as tunnels and road sections, and their contributions to the performance of the overall road network. Huibregse et al (2013) focuses on the impact of extreme weather events and long term climate change on infrastructural road networks. A methodology to perform the analysis is presented and demonstrated by studying tunnel failure as a function of a change in rain intensity. In terms of Figure 2.4, it takes into account the vulnerability of EWE due to climate change and the exposures on the road network if the tunnels fails.

Due to extreme weather and long term climate change both the intensity and frequency of extreme weather events may change significantly over time. This relates to extreme rainfall, drought, snow and storms amongst other phenomena. In Huibregtse et al. (2013) a method is developed to quantify the effects of climate change on infrastructure by performing a resilience analysis of individual objects. To illustrate this method the frequency of flooding due to (extreme) rainfall induced by climate change of a fictitious tunnel in The Netherlands, is studied as a test case. This structured method is a promising technique that might be a good basis for decision making processes. The analysis shows that several data is missing, both climatological data as well as quantified requirements on the performance of infrastructural components.

Methodology

The methodology that is proposed in this paper is based on probabilistic risk assessment as applied in civil engineering (e.g. Vrouwenvelder et al. 2000). For climate change related hazards, the risk assessment is intrinsically time-dependent. A useful indicator for decision making in time-dependent risk problems is the system resilience. This indicator reflects the amount of change the system can accommodate until an unacceptable situation arises. The assessment identifies which resilience the system has at present, how the resilience will develop or diminish over time, and at which point in time the resilience will be depleted and the situation is no longer acceptable. The system resilience can be determined from the combination of the (time dependent) risk quantification and the risk judgment (which may also vary over time), as shown in Figure 4-1.

Figure 4-1 Risk assessment approach



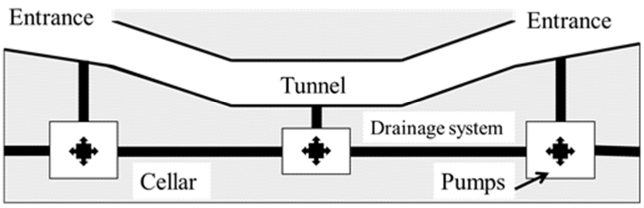
The assessment is structured in a number of steps, i.e. definition of scope and system, hazard identification, modelling and quantification of risk, risk judgement, and the identification and evaluation of risk management strategies and measures. Huibregtse et al. (2013) take the object level of road infrastructure as starting point, in this case a fictive tunnel. Considerations on the network level are translated into requirements and boundary conditions on the component level or below. Hazards are related to climate change effects in the future, such as changes in mean climatic conditions, but also shifts in the intensity and frequency of extreme weather events. In the Netherlands the uncertainties in these future changes are represented in terms of a number of climate scenarios, developed by the national meteorological institute (KNMI 2009). These scenarios provide four projections (W, W+, G and G+) of climate change in 2050 and 2100 compared to 1990. The scenarios differ in the degree of global temperature rise and the degree of change in atmospheric circulation patterns above The Netherlands. The scenarios are intended as a tool for climate impact studies and adaptation measures (KNMI 2009).

For risk modelling and quantification, risk is defined as the mathematical expectation of the consequences of failure: the probability of failure times the consequences of failure. The outcome of failure is expressed in four aspects of the performance of road infrastructure: Reliability, Availability, Maintainability and Safety (RAMS). The consequences of failure for each RAMS-aspect have impact on the particular object that fails, but also on the function of the object in the network. Risk judgement in decision making on infrastructure are based on standards and regulations with norms for an acceptable failure probability. Tunnels in the main road network in The Netherlands are designed to drain off showers with a probability of occurrence of once per 250 years. Due to climate change, the original resilience indicated by the gap between the calculated failure probability and the acceptable level gradually disappears over time. The risk assessment provides information for decision making about the time period in which appropriate measures should be considered to meet the acceptable failure probability.

Case of fictitious tunnel

Figure 4-2 gives a schematic overview of the fictive tunnel. Rain water is collected on the entrance areas and drained off via the sewer system to the pump cellars. The system pumps the water out of the tunnel system, e.g. to a river. In case one cellar is full, the system is designed such that water is pumped to other cellars, to prevent local flooding.

Figure 4-2 Schematic overview of the tunnel



The limit state of the drainage system is based on the water bearing capacity of the tunnel and the rain loading. The capacity is a function of the volume of the pump cellars and the pump capacity. In this study it is assumed that the tunnel system fails when the middle pump cellar is full and the pumps cannot drain a sufficient amount of water to the main cellars. Rain loading is based on the probabilistic modelling of the load variables, including the effects of climate change. Based on KNMI data with recorded rain amounts in mm per six minutes, measured in Rotterdam from 1974-1993, a dataset of showers was constructed with data on the total amount of rainfall (in mm) and duration of the shower (min).

To model the effect of climate change, a first step was made to compare the rainfall dataset from 1974-1993 with the dataset from 2001-2012, also from the KNMI. No differences that would conclusively indicate climate change could be found between both periods, either in the marginal or joint distributions. Based on KNMI scenarios, Huibregtse et al. (2013) assumes that the amount of rain per shower may be increased linear over time by 30% in 2050 compared to 1990, while the duration of the showers remains unchanged. Monte Carlo simulations are used to estimate the failure probability per shower over time.

Figure 4-3 Change of probability of failure over time, considering 30% increase of rain intensity between 1990 and 2050.

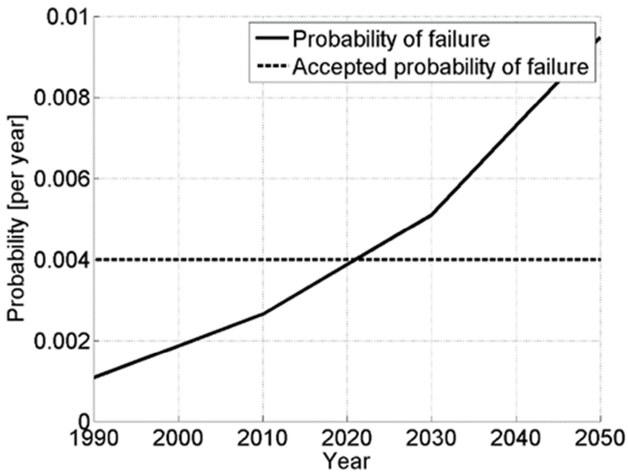


Figure 4-3 show the results and it follows that around 2020 the probability of failure is no longer acceptable. Essentially, two types of measures can be taken to improve the situation. First of all, the probability of failure could be reduced by increasing the water bearing capacity. Secondly, the acceptable probability of failure could be adapted. Measures in this category are for instance increasing the number of alternative routes, and thus reducing the dependency on the tunnel.

In the conclusion, Huibregtse et al. (2013) mention aspects that are recommended for future work. First, the investigation of climate change in relation to rainfall is far from being conclusive. Now only one parameter for rainfall modelling is taken into account, it would be worthwhile to investigate other parameters such as tail dependence and skewness in the dataset on showers. Also with respect to the effect of climate change, a more sophisticated approach is desirable. As the anticipated climate change effects are insufficiently underpinned by the available data, Structured Expert Judgment (SEJ) could be a suitable way forward. SEJ has been widely used in uncertainty analysis in nuclear and chemical and gas industries, groundwater/water pollution, dike ring barriers, aerospace sector, occupational sector, health, banking, volcanoes, dam safety and others. other fields.

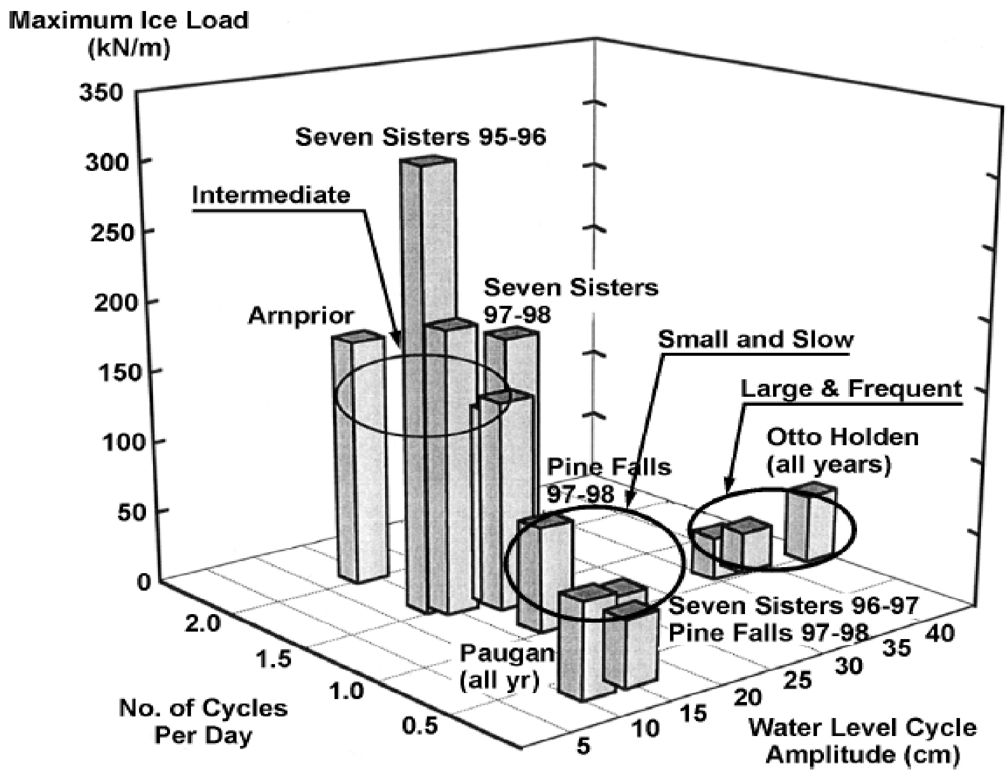
Second, the acceptable probability of failure is now fixed for all tunnels on a probability norm of 1/250 in the Netherlands and does only limited take the consequences of failure into account. But the importance of the tunnel in the total network can vary. Factors that might be incorporated are amongst others the importance of the tunnel, the number of alternative routes and the traffic intensity. A similar approach was used in the Netherlands for the flooding norms for dikes, that now differ for urban and rural areas.

4.3 Consideration of ice loading (extreme weather) on dams

The material reviewed on this topic tended to focus on the hazard (ice load) rather than the consequences. However, the literature reviewed under section 4.4 which deals with risks in reservoirs in general, including dam break and major flooding and their associated consequences, provides supporting information.

Comfort et al. (2003) reported on extensive field work undertaken in several reservoirs in Canada over nine winters in the period of 1991-2000 to measure the loads in the ice sheet near a dam, the load distribution between a gate and a pier, and to compare the loads on wooden and steel stoplogs. Parallel work was conducted to develop predictors for static ice loads. Two components of load are taken into account: thermal load (expansion of ice with a change in temperature) and load due to water level change. Based on observations they mapped the water level regime into several regions and found that the water level change in an ice-covered reservoir can produce significant loads on dams for cyclical regime with intermediate amplitudes (see Figure 4-4).

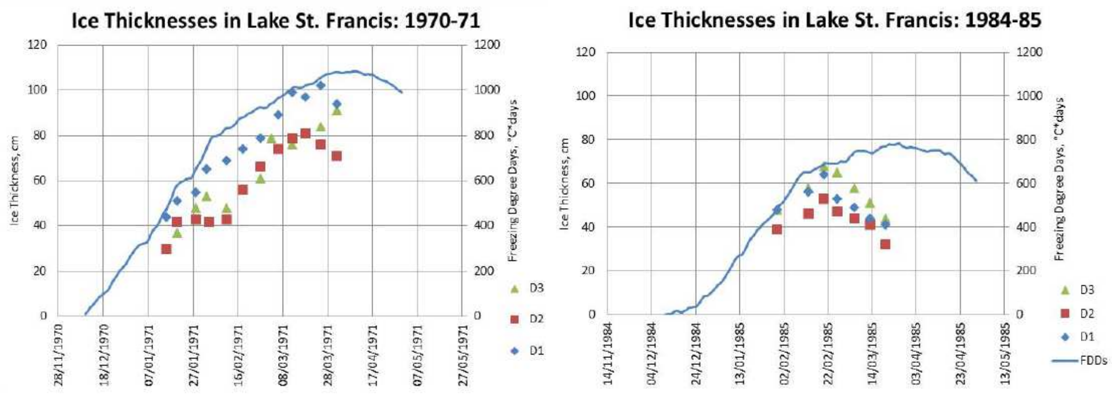
Figure 4-4 Water level oscillation map with resulting ice load on dams (Comfort et al. 2003)



Ice temperature changes were modelled with an environmental model based on air temperature and precipitation. The prediction method for ice load on dam has then been applied on several cases and verified against observed data. An analytical method was developed to extend the results to other stoplog or gate configurations (i.e., spans, flexural rigidities, etc.) and pier lengths. Based on this work, Comfort et al. (2004) produced the Ice Load Design Guide that synthesized the results and established a statistical database which allowed loads to be calculated for the long face of dam and stoplogs. Calculations are made using an Excel based computer program.

Comfort and Abdelnur (2013) compared various methods for prediction of ice thickness, which is one of the key parameters in estimating ice loads on dams. Ice thicknesses measured in Lake St Francis during the period 1970-2000 were used as a sample case for comparing the results of various ice growth predictors. The starting point was a simple method based on Freezing Degree Days (FDD). The authors found that the empirical coefficient for the simple methods varies and recommended a probabilistic approach taking into account the variability in FDD and the empirical coefficient. The authors then proceeded to more complex relations describing heat transfer and other phenomena, which required more computational effort and input data; in the described case, 10 years of field data was used. The authors found that the simplified methods underestimated the ice thickness obtained using extreme value analyses of measured ice thickness data. They believed this to be largely due to the fact that the simplified models don't account for ice surface growth, which, in some cases, is a serious limitation.

Figure 4-5 An example where FDD is a good (left) and bad (right) predictor of ice thickness.



Gebre et al. (2014) investigated how existing ice effects and problems will manifest themselves in a future changed climate. The Orkla River in central Norway, as an example of a typical high-head hydropower system, was used for the case study. The river system has been regulated with three reservoirs and five hydropower plants and a number of water transfers with secondary intakes. The current climate and several future climate scenarios were simulated. The modelling approaches included temperature derived winter indices, a one-dimensional (1D) hydrodynamic and ice cover model on three case study reservoirs, and a 1D river hydrodynamic and ice cover model for a river reach. The impacts on the following hydropower components were investigated: dams, spillways, reservoirs, trash racks, intake gates, water outlets, rivers, operational constraints. The analysis showed both positive and negative consequences for hydropower operation: reduction in ice season and reduced static ice loads contribute to positive consequences, while unstable winters that may lead to increased frequency of freeze-thaw episodes represent a future challenge.

Figure 4-6 Ice cover duration computed from- a) ICD*: 0°C isotherms (AI_0 – autumn, SI_0 – spring) and b) ICD: ice freeze-up (FU) and break-up (BU) periods (Gebre et al. 2014)

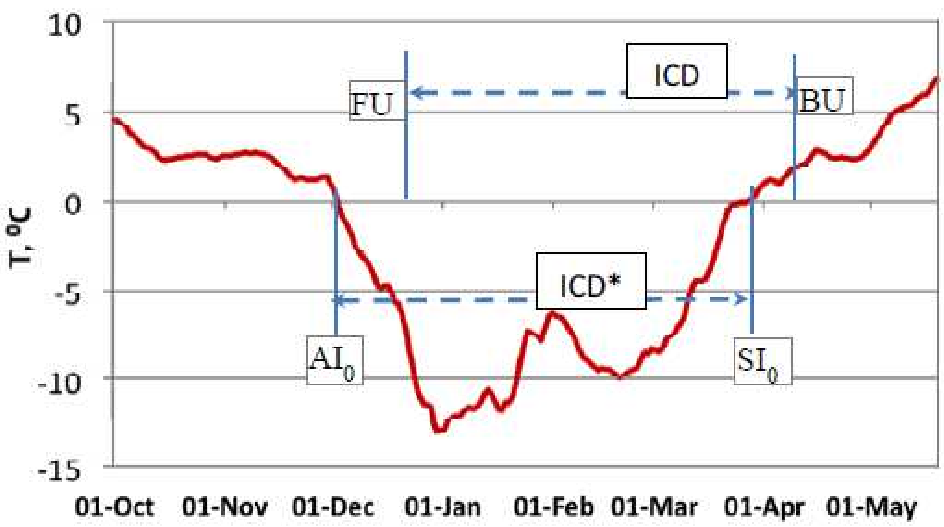
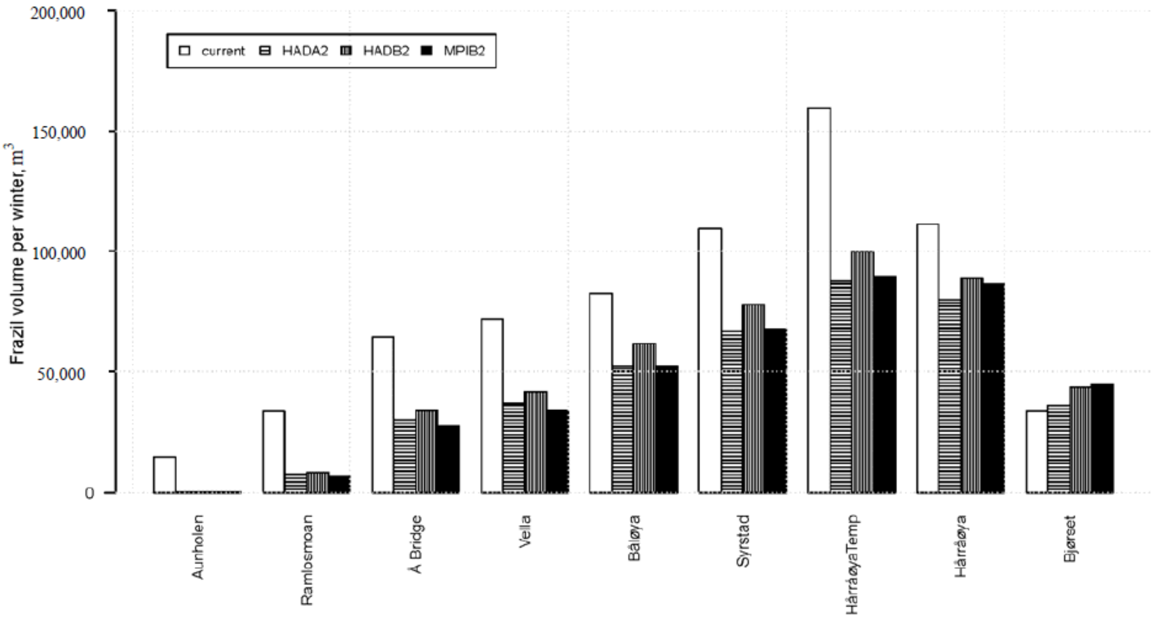


Figure 4-7 Modelled change in frazil production in the 2080s (Gebre et al. 2014)



4.4 Floods and reservoirs safety, water safety

Reservoirs have been built since antiquity to store water for various uses. Today there are more than 45,000 large dams (taller than 15 m or taller than 5 m with a volume of more than 3 million m^3) around the world. The volume of water kept is also impressive: the combined storage in US only is over 10^{12} m^3, which, if hypothetically spread over the area of that country, would reach the depth of 12.8 cm (Gebregiorgis & Hossein 2012). The reservoirs store water that provides valuable services. However, they can also cause catastrophic damage to life and property in the case of failure.

Extreme weather conditions (rainfall or snowmelt) generate floods. Reservoir flooding occurs as a result of a failure of a dam to release the incoming water in a controlled manner, i.e. below a certain limit. This can be either due to exceeding the reservoir storage volume (water is spilled over the dam crest) – a performance failure; or a mechanical fault (e.g. in operation of gates) or embankment breach – a structural failure. A number of recent papers and reports have been reviewed that deal with this topic and present application examples. Some focus on hydrological risk (hazard) only, using improved modelling and statistical approaches and uncertainty analyses (Jan Tai et al. 2007; Gebregiorgis & Hossain 2012; Goodarzi et al. 2013), while others also examine the vulnerability of the structure and impact in terms of population at risk, economic damage etc. (Fridolf 2004; Mason 2010; Morison & King

2010; Environment agency 2013; Smith et al. 2014). A summary of reviewed application examples is shown below.

Table 4-1 Reviewed application examples for floods and reservoirs safety

Reference	Name (year) Location	Dam height Reservoir volume	Analyses
Jan Tai et al. (2007)	Feitsui Dam (1986) Taiwan	H= 122.5 m V= 406 hm3	Overtopping risk Uncertainty: seven parameters
Gebregiorgis and Hossain (2012)	Wilson Dam (1927) Tennessee, USA	H= 42 m V= 66 hm3	Overtopping risk in lifetime Considers sedimentation and adapted for regulated flows
Goodarzi et al. (2013)	Meijaran Dam (2003) Iran	H= 55 m V= 8 hm3	Overtopping risk including wind waves Uncertainty: three parameters
Fridolf (2004)	Sala silver mine dams (from 16th century) Sweden	H= a few m V= 16 hm3	Hydrological model of the system Simplified dam break analysis Assessment of risk and review of risk reduction alternatives
Mason (2010)	Loyne dam (1956) United Kingdom	H ~ 20 m V= N/A	QRA : Failure probability vs Life loss estimate
Morison and King (2010)	Dunalastair Dam (1933) United Kingdom	H= 11 m V= N/A	Dam break modelling, loss of life estimates for two probabilities and three emergency response cases
Smith et al. (2014)	Ulley Dam (1874) United Kingdom	H ~ 15 m V= 2 hm3	Dam break modelling Spatio-temporal population modelling to assess the risk to the population
Environment Agency (2014)	11 dams United Kingdom	H= 6-72 m V= 0.02-50 hm3	Three tier approach according to UK guidelines; Tier 1 (qualitative) and Tier 2 (simplified quantitative) were used

Jan Tai et al. (2007) present the procedure and application of risk and uncertainty analysis by various mathematical and statistical methods for Feitsui Reservoir in northern Taiwan. The safety of the dam is a major concern as millions of people live downstream in metropolitan Taipei. The double-curvature arch dam is 122.5 m tall, with an upstream catchment area of 303 km^2 and the total storage volume of 406 million m^3. The main functions of the reservoir are domestic water supply, hydropower generation, and flood control. Seven factors subject to uncertainty were studied: (1) dam crest height – thermal expansion of dam body, (2) initial water level, (3) reservoir release, (4) reservoir routing – numerical error, (5) reservoir geometry, (6) peak flow magnitude at given return period, (7) time of concentration. The overtopping risk was assessed by five uncertainty analysis methods: Rosenblueth's point estimation method (RPEM), Harr's point estimation method (HPEM), Monte Carlo simulation (MCS), Latin hypercube sampling (LHS), and the mean-value first-order second-moment (MFOSM) method. The authors concluded that for sampling methods (SMs), MCS is the most widely used method, but convergence is only achieved when the sample size reaches a large number. LHS is more complicated in programming terms than MCS, but it is also more computationally efficient. As for point estimation methods (PEMs), HPEM becomes more computationally attractive than RPEM as the number of random variables increases. The authors suggest applying computationally less expensive PEMs at moderate peak values, as their results are comparable to the "true" overtopping risk obtained by the large sample size of SMs.

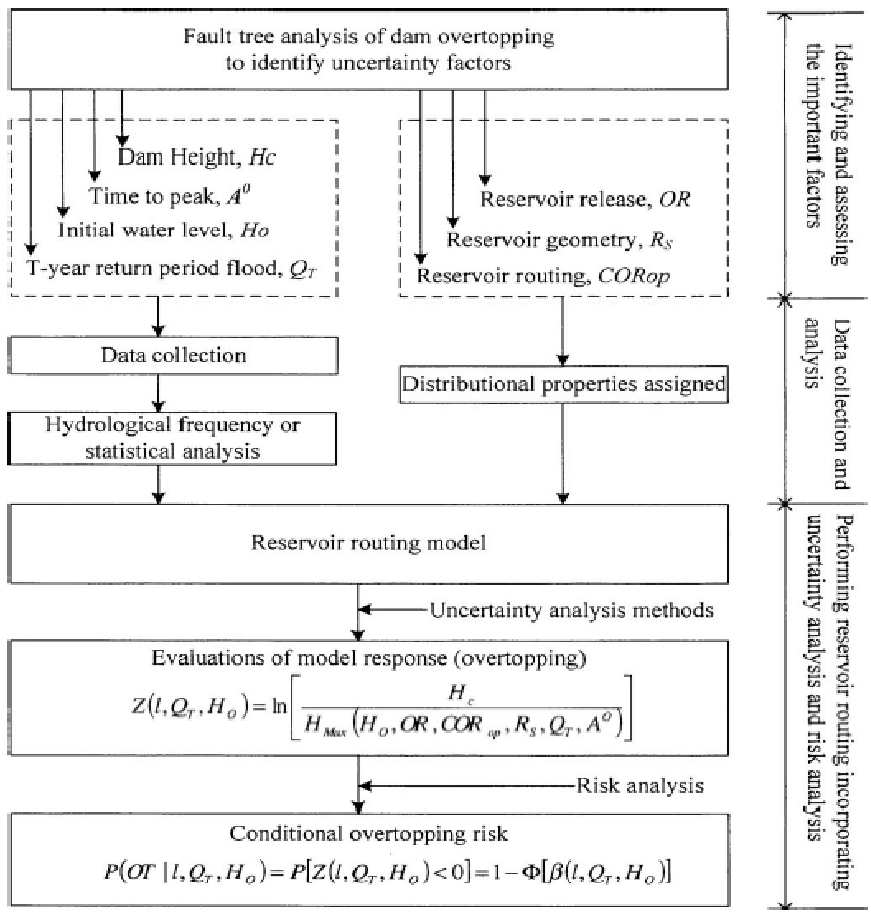
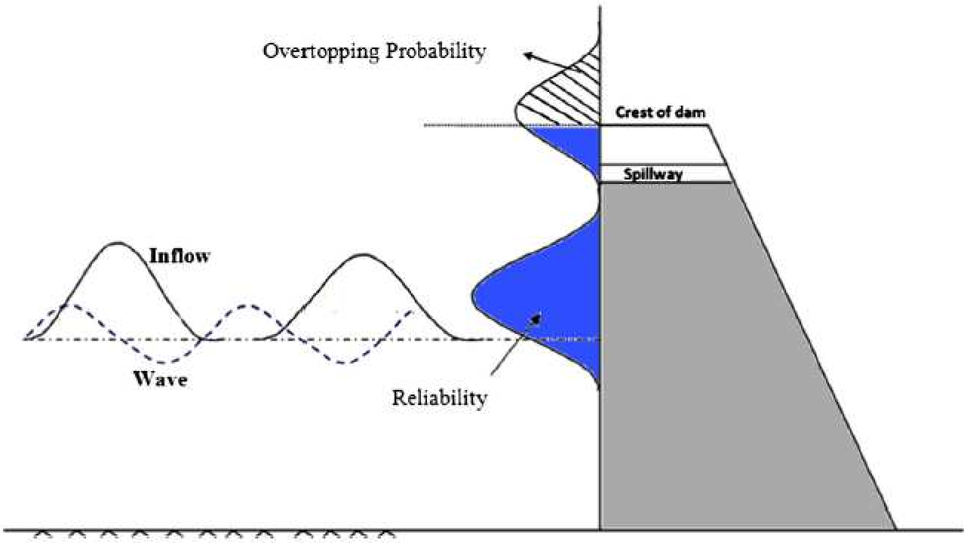


Figure 4-8 A sample flow chart for overtopping risk analysis (Jan Tai et al. 2007).

Figure 4-9 Overtopping risk concept based on probabilistic approach (Goodarzi et al. 2013)



A similar study of Gebregiorgis and Hossain (2012) assessed the hydrological risk of the hydropower Wilson Dam in Tennessee, USA, by analysing peak flows. The dam is 42 m high, 1,384 m wide and has a power generating capacity of 675 megawatts (MW) of electricity. They assessed the risk over the whole lifetime of the dam, i.e. as probability of failure in a lifetime, and also considered the loss of storage volume due to sedimentation. The authors pointed out that the frequency models are not designed for analysing regulated flows (e.g. peaks regulated by reservoirs). The regulated peak flow was split into two components: the deterministic component (taken as minimum flow/release from the reservoir) and the stochastic component (above minimum flow). The frequency distribution model was then fitted to the stochastic component using L-Moment Method. Three theoretical distributions were tested and GEV was selected as the most appropriate for both flow peak and volume.

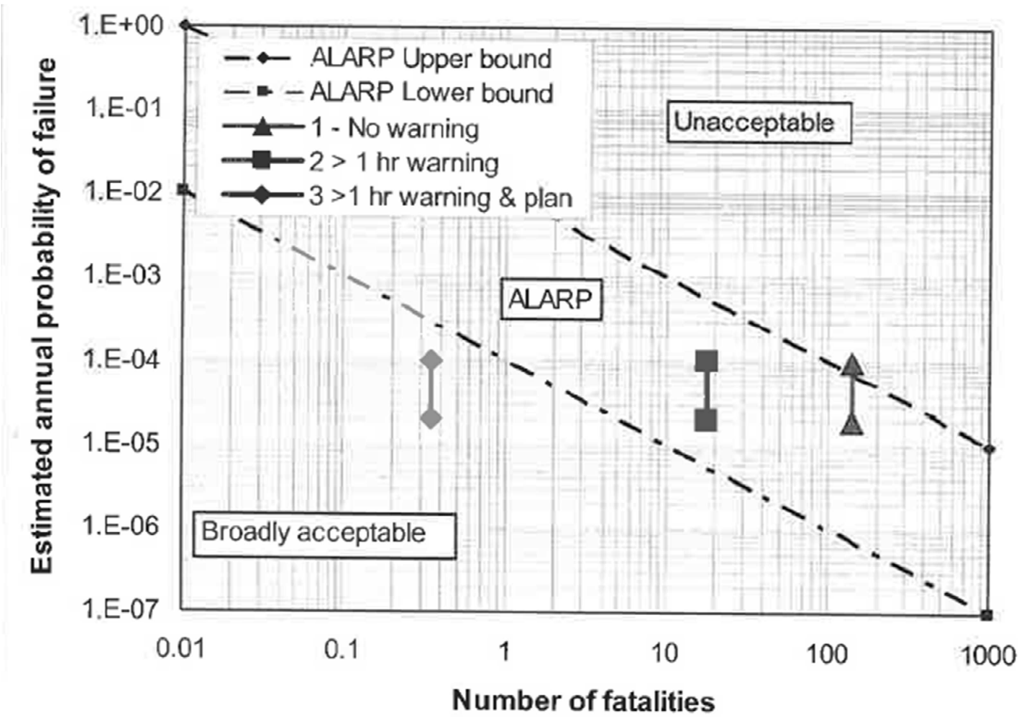
Goodarzi et al. (2013) present the application of risk and uncertainty analysis to dam overtopping not only due to inflow but due to wind speed as well for the Meijaran Dam in the north of Iran. The dam is 186 m wide and 55 m high and provides agricultural and domestic water, as well as flood protection and tourism development. The risk was assessed by applying two uncertainty analysis methods (Monte Carlo simulation and Latin hypercube sampling), and considering the flood peak discharge, initial depth of water in the reservoir and spillway discharge coefficient as uncertain variables. The authors found that while the initial water level has the largest impact on the probability of overtopping, the presence of wind also increases the risk by more than 50%.

Fridolf (2004) analysed a complex system of channels and reservoirs near the city of Sala, Sweden. The dams were constructed centuries ago to supply hydropower for silver mining. The dams consist of long earth walls just a few metres high and often covered with trees. Today the water system has a great value as a recreational area and as an historical monument. The area contributing to the runoff is approximately 84 km^2 and the total available storage volume of the water system has been estimated to about 16 million m^3. A hydrological model of the system was set-up in HEC-HMS to simulate flows based on rainfall events with different return periods. Dam break analysis for two dams was carried out according to the Dam safety guidelines of Washington State Department of Ecology (1992). Potential risk sources for dam safety evaluation were determined, an event tree constructed and probabilities assigned to each of its items. The author then took the following consequences into account: loss of life and injuries; environmental damage; economic damage; and bad publicity. Several risk reduction alternatives are discussed: flood diversion, rise of dam crest, warning system, emergency and evacuation plan; relocation of summer houses; increased spillway capacity; and flood mitigation; of which the first one seems to be the most practicable and efficient.

Mason (2010) performed a quantitative risk assessment for the concrete gravity Loyne dam (UK). The author adapted the approach used in the recent USBR Unified method for erosion of fill dams. The failure modes and the associated events which would have to take place for failure to occur and their likelihood factors were determined based on collective experience. Eight events were identified and presented in the form of an event tree. Outflow from the reservoir was calculated and compared to previous flooding studies to assess the number of persons at risk in the concerned reach. The values of annual probability of failure and persons at risk were compared to ranges of acceptability according to Interim guide to Quantitative Risk assessment (QRA) for UK Reservoirs (2004) and Guidelines for Achieving Public Protection in Dam Safety Decision Making (US, 2003).

Morison and King (2010) performed dam safety analysis for Dunalastair Dam in Scotland, UK, and assessed risk to the downstream village of Tummel Bridge. The catchment area of the reservoir is 679 km^2 of mountain terrain and is extensively developed for hydropower. No clearly effective engineering solutions to improve dam safety are available and proactive preparation of emergency plans for the downstream community was considered. A number of hydrological assessments of the complex catchment were reviewed, taking into account snowmelt and gate operation. The assessment was based on winter PMF. Flood modelling for instantaneous dam break was conducted with a 1D model. Three emergency response scenarios for expected loss of life from dambreak incident are presented: 1) no warning; 2) more than one hour warning, but no evacuation plan; and 3) more than one hour warning and an effective evacuation plan. A comparison to acceptability levels showed that scenario 1 is marginally inacceptable, scenario 2 is within the ALARP (as low as practically possible) and scenario 3 is within acceptable region. Authors also discuss the potential difficulties with implementing an emergency response plan, such as: no primary responders (e.g. police) are present in the village; road access; locating the place of safety for evacuation; and evacuation hazards.

Figure 4-10 Risk assessment as probability of failure vs number of fatalities with acceptability ranges for Dunalastair dam (Morison and King 2010).



Smith et al. (2014) proposed and applied an enhanced flood risk assessment in three stages: 1) probabilistic modelling of a failure scenario using embankment breach models; 2) hydrodynamic inundation modelling for assessment of flood water spreading, depths and velocities; 3) spatio-temporal population modelling to assess the risk to the population likely to be present. The proposed method was applied to the Ulley reservoir risk assessment (a narrowly averted flood event in 2007), assuming no emergency preventive action had been taken. The authors used an appropriate model to simulate each stage. The integration with spatio-temporal population outputs demonstrated the enhancements achievable in evaluating the population at risk for different areas and (day) times of dam failure. The results suggested that the closure of the motorway and evacuation of the residents was necessary and proportionate. The model also showed that the worst time for this dam to fail is likely to be the morning peak hours, with potentially over 100 fatalities if prevention measures are not taken.

An Environment Agency (2013) pilot study assessed eleven dams of height between 6 and 72 m and volume of 20,000 – 50,000,000 m^3 and between 40 to 200 years old using the new methodologies and guidance of UK Environment Agency. They were tested with Tier 1 (qualitative) and Tier 2 (simplified quantitative) approach, while the detailed Tier 3 approach was not used in this study. Eight embankment dams, two concrete dams and one composite dam were analysed.

4.5 EWE threatening road transport (Approaches applied by stakeholders)

4.5.1 Impact on transport infrastructures (roads and highways)

Transport systems could potentially be affected by a multitude of changes in the future climate, including hotter summer conditions, extreme precipitation events, increased storminess and sea level rise. This could accentuate infrastructure deterioration processes, risk of infrastructure failure and collapse, traffic disruption and, in the most severe cases, fatalities. Weather-induced traffic disruptions can also result in important consequences in supply chains and on the whole economy.

For road transport infrastructures, weather stresses represent from 30% to 50% of current road maintenance costs in Europe (8 to 13 billon €/yr). About 10% of these costs (~0.9 billion €/yr) are associated with extreme weather events alone, in which extreme heavy rainfall and floods events represent the major contribution.

Traditionally, the structural design of transport infrastructures is based on weather patterns of the past, where extreme events are considered, but without considering possible changes beyond the patterns considered "normal". Also it is considered necessary to limit the predictions, because if the design parameters considered are very high the result is a much more expensive infrastructure.

Climate change is causing these extraordinary events to occur with increasing frequency and reach levels very close to or even exceed the design parameters of structures.

Higher temperatures can cause pavements to soften and expand. This can create rutting and potholes, particularly in high-traffic areas and can place stress on bridge joints. Heat waves can also limit construction activities, particularly in areas with high humidity. With these changes, it could become more costly to build and maintain roads and highways. On the other hand, certain areas may experience cost savings and improved mobility from reduced snowfall and less-frequent winter storms, since warmer winters may lead to reductions in snow and ice removal, as well as salting requirements.

Another factor to consider is that infrastructures are designed for a very long life span due to their high cost, therefore they have to be designed to resist the impact that weather may cause on them over a long time period.

Exposure to flooding and extreme snow events also shortens the life expectancy of highways and roads. The stress of water and snow may cause damage, requiring more frequent maintenance, repairs, and rebuilding. Road infrastructure in coastal areas is particularly sensitive to more frequent and permanent flooding from sea level rise and storm surges.

Climate change has affected many infrastructures in recent years, because they weren't designed with appropriate safety coefficients to resist the increased loads generated.

The assessment of the impacts of climate change on critical infrastructure should be made both at the stage of planning a transport infrastructure and during its design, construction, operation and maintenance to maintain their integrity and serviceability. Nevertheless, complete avoidance of weather-induced infrastructure deterioration and failures is not economically feasible.

The probability of the impact and its consequences have to be taken into account to differentiate the levels of impact in terms of cost for those responsible for the infrastructure and service level and safety for the final users of the infrastructure.

4.5.2 Impacts during the planning phase

The impact that climate change may have during the planning of an infrastructure is limited when compared to the potential impact on their design and operation. The two facets of planning that could be more compromised a priori by climate change are the studies for the demand of the infrastructure and the evaluation of alternative locations for the construction of a new infrastructure.

In the analysis of alternative locations, changes in coastal areas (sea level rise) and the risk of disruption of local climatic conditions that may reduce the efficiency or regularity to operations in nodal infrastructure must be taken into account. The effects on the demand for transport and the behaviour of the passengers and goods mobility are difficult to predict.

4.5.3 Impacts affecting the design of new infrastructures

The major impacts on the design of new roads affect slopes and pavements. In the case of the slopes, the main problem will be associated with the increased intensity of extreme rainfall of short duration. This can affect the stability of the slopes by runoff water. The increased intensity of extreme rainfall, combined with increased aridity, can also affect the erosion of the slopes. Also to be considered are the effects of extraordinary floods in the rivers caused by an increase in the intensity of the rainfall that can cause slope instability of the embankments along the banks of the rivers.

In the case of pavements, increased temperatures can cause an increase in the risk of rutting due to premature oxidation of the binder, while a decrease of precipitation may advise against the use of porous asphalt mixes. In regions experiencing cold winter conditions the two main effects in the pavement are deep or moderate frost depth and freeze-thaw cycles that could cause non-structural cracking appearance due to the stiffening of the mixture.

Other parts of the infrastructure that may be affected by climate change are plantations, bridges and structures for protection, the geometry of the road, signalling and protection.

River bridges represent essential components of a transport network. In the case of bridges, extraordinary floods may affect the stability of slopes in the abutments and undermine the foundations of the piles and protection works (inducing bridge scour). It has been estimated that 60% of all bridge failures result from scour and other hydraulic related causes. Higher temperatures could induce stress on bridge joints.

Regarding the geometry of the road an increase in the intensity of extreme precipitation could increase the number of locations where the drainage capacity of the road surface is insufficient and a new design of the drainage conditions of the platform and drainage systems will be needed.

The increase of maximum temperatures and heat waves supposes an increase in the sunlight conditions, which can affect the durability of the signalling elements by the action of the ultraviolet rays. It can also affect the ageing of the road markings or cause the breakage of the connecting elements by excessive thermal expansion in very long lengths of metal safety barriers.

4.5.4 Impacts during the construction phase

Climate change may affect some aspects of health and safety and risk prevention during the construction phase of the infrastructures. The increase in maximum temperatures and heat waves may affect conditions and / or working periods and the performance and comfort requirements of the construction workforce and machinery. It may also increase the risk of accidental fires during the execution of the works. The increased intensity of extreme rainfall may require an occasional increase of the capacity of the drainage system and protection.

4.5.5 Impacts during the exploitation phase

The components most affected during the exploitation phase are road earthworks and drainage.

The increased intensity of extreme precipitation may increase the number of locations where the drainage capacity of the road surface or drains in bridges is insufficient and cause aqua-planing problems or sweep along stones off the slopes falling onto the road.

The level of affect to other components of the road will be lower. Extreme rainfall and extraordinary avenues are the main risk in bridges, masonry works and protection works. Increased intensity of rainfall episodes may increase localized erosion in piers, abutments and retaining walls, and impact on the piers due to materials swept along. The combination of heavy rain and strong gusts of wind may reduce the stability of the signposts. The increased intensity of storms may increase the risk of damage to lighting, ventilation and traffic management installations in tunnels, and to other management facilities. Also the temperature increase, heat waves and droughts will increase the risk of fire in the margins of the road and the requirements of irrigation and plant replanting in the road environment.

4.5.6 Conclusions

The incidents caused by climatic effects to the infrastructures pose a high economic cost both social and environmental. The economic cost for the situation of no service caused by various causes on the one hand will affect the users of the infrastructure and secondly to the infrastructure operator.

Affected users by each collapse not only will the inhabitants of the neighbouring towns, but will cover all users who use or rely somehow the route in which the collapsed section is integrated.

Losses for infrastructure concessionaires will come firstly by the non-recovery of toll revenues during the time when the road is closed to traffic and secondly by the cost of repairing the infrastructure, which lies at the concessionaire or the insurance if one exists.

The next table shows the impacts caused by EWE in roads and highways during the different phases of the life cycle.

Table 4-2 Impacts caused by EW in roads/ highways during different phases of the life cycle

EWE	Part of the road affected	Life cycle phase	Impacts
Temperature increase	Pavement	Design / Exploitation	- Rutting and potholes
	Bridges	Exploitation	- Stress on bridge joints
	Road	Construction /Exploitation	- Health and Safety problems - Risk of accidental fires increased
	Signalling elements	Design / Exploitation	- Durability reduced
	Road markings	Design / Exploitation	- Premature aging
	Metal safety barriers	Design / Exploitation	- Breakage due to excessive thermal expansion
Freeze-thaw cycles increase	Pavements	Design / Exploitation	- Non-structural cracking due to the stiffening of the mixture
Sea level rise	Roads in coastal areas	Operation/Maintenance	- Flooding of the road surface

	Road	Planning	- Studies for demand of the infrastructure poorly performed
	Road	Planning	- Wrong evaluation of the location for the construction of a new infrastructure
Increased intensity of extreme rainfall of short duration	Slopes	Design / Exploitation	- Slopes instability - Slopes erosion (jointly to aridity increase)
	Embankments	Design / Exploitation	- Embankments instability (due to extraordinary floods in the rivers)
	Bridges	Design /Exploitation	- Slopes instability in the abutments - Foundations of the piles undermined - Bridge scour - Erosion in piers, abutments and retaining walls
	Road geometry	Design /Exploitation	- Insufficient road surface drainage capacity
	Drainage systems	Design / Construction / Exploitation	- Insufficient drainage system capacity (including drains in bridges)
	Road	Exploitation	- Aqua-planing problems in the road surface - Stones in the road swept along the slopes

4.6 EWE threatening electricity networks (Approaches applied by stakeholders)

4.6.1 Development of the Risk Analysis and Management Methods in Major Disturbances in the Supply of Electric Power

The objective of this project was to develop information technology methods for major disturbance management for the supply of electric power. In addition to the DSOs (Distribution System Operators), key actors to be studied were the actors responsible for the critical infrastructure of the society, such as fire and rescue services, municipalities and the consumers of electric power. The target of the research was to improve the actions under the disturbances and on the other hand preparedness for the major disturbances especially by means of the information technology. The first part of the project was to make a present state analysis to collect and extend former knowledge. The topic proved to be very extensive, which made the whole project quite challenging. (Verho et al., 2012)

The need for the project was proved in the questionnaire study made among DSOs but also in real major disturbances during the project in the summer 2010 and in the winter 2011. These major disturbances verified the problems and the need for exchange of information which the project aimed to solve.

The focal result of the project is a sketch of an information system for major disturbance management. The idea of this system is to extend DSOs' existing web services so that graphical information is provided for authorities like fire and rescue services and municipalities. The information contains not only the interruption data but also information about customers' location and criticality. A requirement for building the foregoing system is to have criticality information about customers in the system. In the sketch of the system, this is realized with a web service where the actors responsible for critical sites maintain the information themselves. The system could also be used as a tool of planning by comparing the estimated criticalities of critical sites with realized interruption statistics or with calculated probabilities. For a critical customers' point of view this makes it possible to focus the preparation on the most critical sites. The DSOs could take the criticality as initial data for the network development. The sketched system could also be used as a simulator in major disturbance exercises. A small scale demonstration made in the project verifies the viability of the system.

4.6.2 Using weather modelling for assessing electricity network hazards

An article by Yates et al. (2014) reviews the impacts of superstorm Sandy on electrical infrastructure in Long Island, US. The article focuses mainly on power plants and substations which were flooded during the storm. In addition, a major part of electricity distribution infrastructure was damaged by the storm. The analysis performed relies mainly on simulating the extent of flooding and comparing it geographically with substation locations.

The article discusses different weather modelling methods and refers to regional weather research and forecasting (WRF) models. One objective has been taking WRF based results further to storm and flooding models. The studies conducted applied two different scenarios; the first one was the superstorm Sandy as it was experienced, while the second scenario assumes future climatic conditions as the initial state and the impacts of superstorm in that case.

The article highlights some key findings. First of all, mutual understanding and efficient information exchange between involved stakeholders is very essential. Also the contribution of power system engineers for directing the climate analysis properly was considered important. Obviously, accurate local-level climate models have a very central role. Interfacing the climate, hazard and impact models was considered important as well.

Although the article describes a very practical approach in which the flooding probabilities of substations have been assessed based on weather modelling, no ideas for taking these developments towards daily planning actions are expressed. The ideas and result presented could be integrated in electricity network planning and management systems and processes.

4.7 Other application examples from stakeholders

Four Finnish water and sewage works, a Finnish software company and VTT (Technical Research Centre of Finland) co-operated in research with the aim to develop new methods and tools for the asset management of water and sewer systems. The research identified the most essential technical parameters of water and sewer systems from a reliability point of view. Tacit knowledge in the form of expert data was being used to complement the data acquired from the information systems. The main results of the research project included procedures and tools for assessing reliability and criticality of water and sewer systems; utilisation methods of expert data and data analyses for estimation of different variables of water and sewer systems; procedures for developing asset management strategies for water and sewage works and a tool for benchmarking technical performance of water and sewage works. (Hanski et al., 2013)

5 Discussion and conclusion

The report has reviewed a wide range of models and other assessment tools for understanding the impacts of EWE on critical infrastructures. Any review can always be added to, and this report is no exception as there is clearly a very large body of information available. A key summary outcome of this work is the answer to the question: to what extent are models and other simulation approaches currently used for the assessment of impacts to CI, and how can the INTACT project deliver an improved risk assessment framework based on these existing SOTA approaches.

There is a variety of methods that could be used to assess the vulnerability of CI to EWE and the approaches used may vary with the type of system, the objective of the analysis, the analysis steps, and the available information. However, it is difficult to assign one analysis step/objective to each method as several of the methods could be used for more steps/objectives. The methods may also be used in combination e.g. agent-based modelling in combination with Monte Carlo Simulation. The methods are summarized in the table below and for each group of methods it is indicated which step/purpose it could be applied for.

Table 5-1 Steps in assessment of impacts on CI and the availability of methods

Group of method	Step in CI analysis/purpose of analysis		
	Vulnerability of single objects; direct loss	Vulnerability of systems; identification of critical elements	Interdependencies between systems or estimation of indirect loss
Susceptibility functions (single- and multi-parameter)	X		
Economic theory based approaches (e.g. IO analysis, Computable General Equilibrium, Econometric approaches for tangible losses and e.g. Revealed and stated preferences methods for intangible losses)	X		X (estimation of indirect losses)
Probabilistic modeling (Markov/petri nets, prob. Modelling, Bayesian networks)		X	X
Statistical analyses of past events, empirical approaches	X	X	

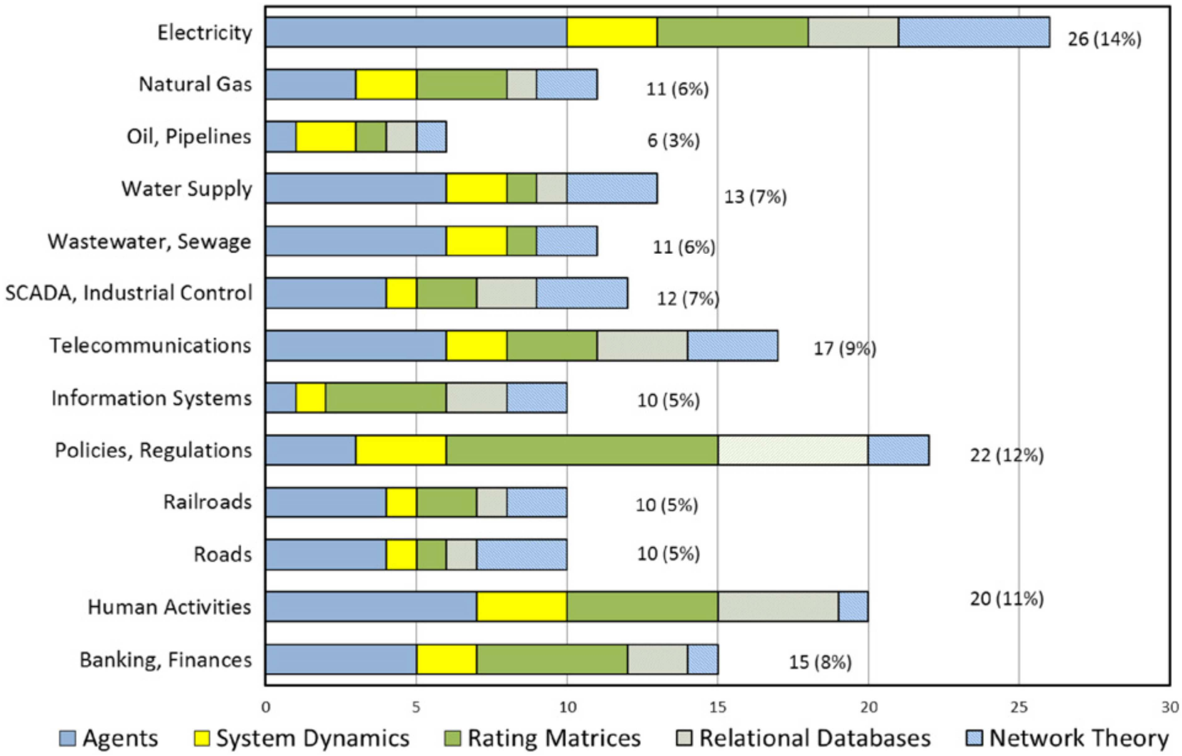
Risk analysis of technological systems (Event tree analysis, Fault modes and effects analysis and FMECA, Fault tree analysis, HAZOP, Human reliability analysis, Preliminary hazard analysis, Reliability block diagram, tabular methods, expert judgment)		X	(X - mainly for parts of a CI)
Network based approaches (e.g. typology-based method and flow-based method)		X	X
Agent based approaches		X	X
System dynamics based approaches		(X)	X
Rating matrices (could also be included under "risk analysis of technological systems")		X	(X)
Relational databases		X	X

To what extent are the different simulation approaches used? One potential summary can be derived from another SOTA review by Yusta, J. M., Correa, G. J., & Lacal-Arántegui, R. (2011). They surveyed the methodologies, applications and tools to conduct studies in critical infrastructure protection, through a literature review and classification of the international journal articles, reports and standards that appeared during the period from 1999 to 2010.

References to the methodologies employed in each of the strategic sectors of critical infrastructure can be seen in the figure below. Nearly, 23% of applications are involved with energy infrastructure (electricity, natural gas, oil and pipelines). Such applications are mainly based on rating matrices as well as simulation through system dynamics or multi-agent systems.

Other infrastructures receiving attention are those related to information technologies and communication and control sys- tems (21%), water (13%), transportation (10%) and banking (8%). About 11% of methodologies are related to human activities queries and responses checking into critical infrastructure, which establishes responses to human users system under emergencies, industrial security, policy recommendations on assets protection (and/or) human life protection.

Figure 5-1 Modelling techniques in the study of each critical infrastructure sector, (Yusta et al. (2011)



A key issue for the development of the risk framework under Task 4.2 is to what extent are tools and models being used in the five case studies within the INTACT project. This will also inform what should be considered in the Gap Analysis (Task 4.3). Unfortunately, due to the timing of activity in the case studies, it has not been possible to obtain this information and include it in this report. The case study needs will obviously play a key role in deciding what functionality is required in the framework, but at this stage it seems reasonable to assume that components, representing the elements summarized in the above table, should be included.

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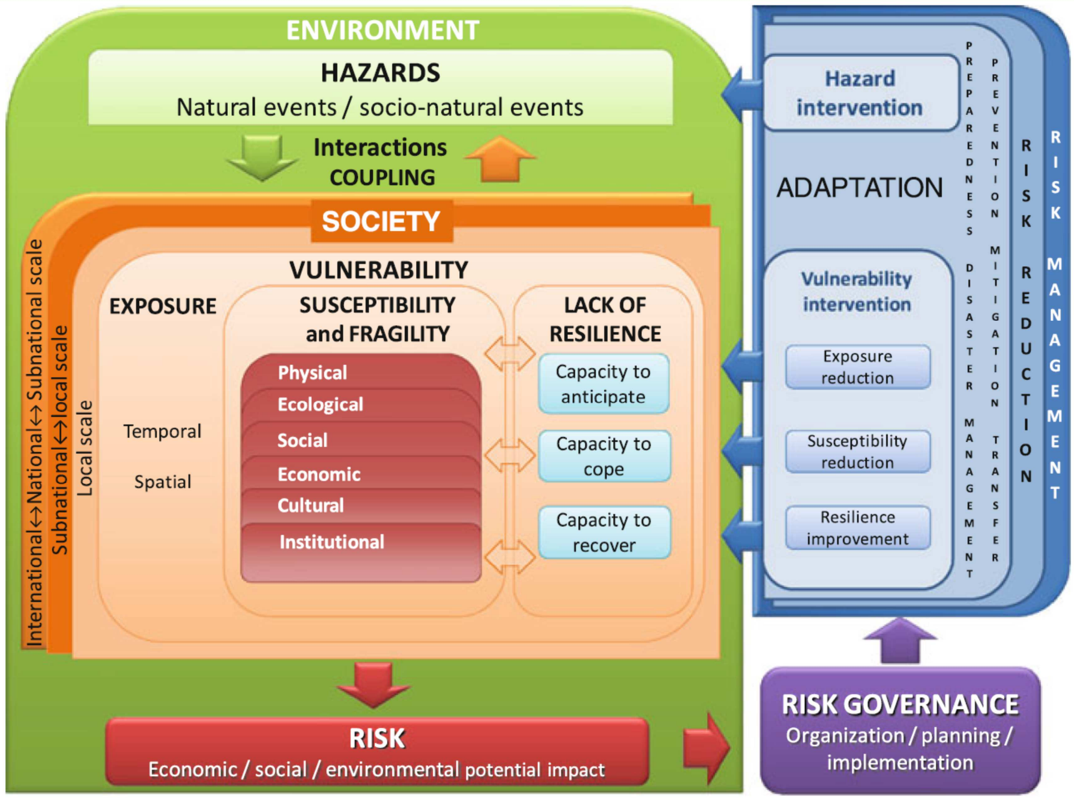
Annex 1: Summary of selected references

This annex contains a summary of selected literature reviewed in Task 4.1.

This template below is a generic form created to guide the literature review on modelling approaches used currently to assess CI vulnerability.

Literature to section 2:

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Unni Eidsvig, NGI
Complete reference of the reviewed document (include Internet links, if available):
Birkmann et al. (2013): Framing vulnerability, risk and societal responses: the MOVE framework, Nat. Hazards 67: 193-211.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
The paper deals with the development of a general as well as integrative and holistic framework to systematize and assess vulnerability, risk and adaptation. The framework is a thinking tool meant as a heuristic that outlines key factors and Different dimensions that need to be addressed when assessing vulnerability in the context of natural hazard and climate change.



1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

For all geographical scales.

Different dimensions of vulnerability considered: physical, ecological, social, economic, cultural, and institutional.

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

The framework is developed for natural events/socio-natural events

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Vulnerability

1.5 Parameters and data: Which are the input data/the data required by the method?

The framework can be applied as a basis for developing and differentiating indicators and criteria for vulnerability assessment.

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

The framework is not developed for a special methodology, but is e.g. suitable for indicator-based methods and rating matrices.

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Methodology
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Could be applied for qualitative, semi-quantitative and quantitative analyses.
1.9 Advantages and disadvantages with the methodology
The MOVE framework is a thinking tool and is general, integrative and holistic. However, the framework does not provide a specific assessment method or a pre-defined list of indicators.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Relevant as thinking tool also for CI vulnerability assessment.
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Assessment criteria and indicators for different case studies are outlined: Social dimension of vulnerability to floods on city district level for Cologne. Hazard, exposure and several dimensions of vulnerability to earthquake in a urban area case study in Barcelona.
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**

Name(s), and partner acronym:
HRW
Complete reference of the reviewed document (include Internet links, if available):
V. Przyluski, S. Hallegatte, R. Tomozeiu, C.Cacciamani, V. Pavan, C. Doll (2011). Weather trends and economy-wide impacts . Deliverable 1 within the research project WEATHER (Weather Extremes: Impacts on Transport Systems and Hazards for European Regions) European Commission, 7th framework programme.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Report
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
WEATHER Project aims at adding to the current state of knowledge on the impacts of extreme weather events on economy and society in total and on European transport systems in particular. The project uses • **climate scenarios** • **Economic growth models are applied to study the impacts on economy and society and the inter-relations between transport and other sectors** • **The vulnerability of transport is assessed mode by mode including infrastructures, operations and intermodal issues.** **The project focuses on quantification of expected damage, emergency and adaptation costs and the benefits of improved emergency management and adaptation.** **This report focuses on three topics:** • **Development of Weather Extremes until 2050** • **Economy-wide impacts** • **Transport sector assessment framework**
1.1 Methodological approach description
Development of weather extremes is based on climate change scenarios for temperature and precipitation over Europe, both at regional (Europe) and local (N Italy) scale. Extreme events of **temperature and precipitation defined based on percentile thresholds (10th and 90th percentile). The emission scenario analysed is the IPCC scenario A1B.** **Economy-wide impacts are assessed. Both direct and indirect costs, i.e. "the downstream consequences of transport interruption on the economy" are taken into account. The following process is followed based around ARIO-T model. Direct losses and transport disruption are input of the models, which provides as output an estimate of indirect losses output, for each type of disaster. Transport related indirect losses are obtained by subtracting indirect losses obtained without transport disruption. The framework of understanding is a macroeconomic framework with disruption understood as an economic shock.**

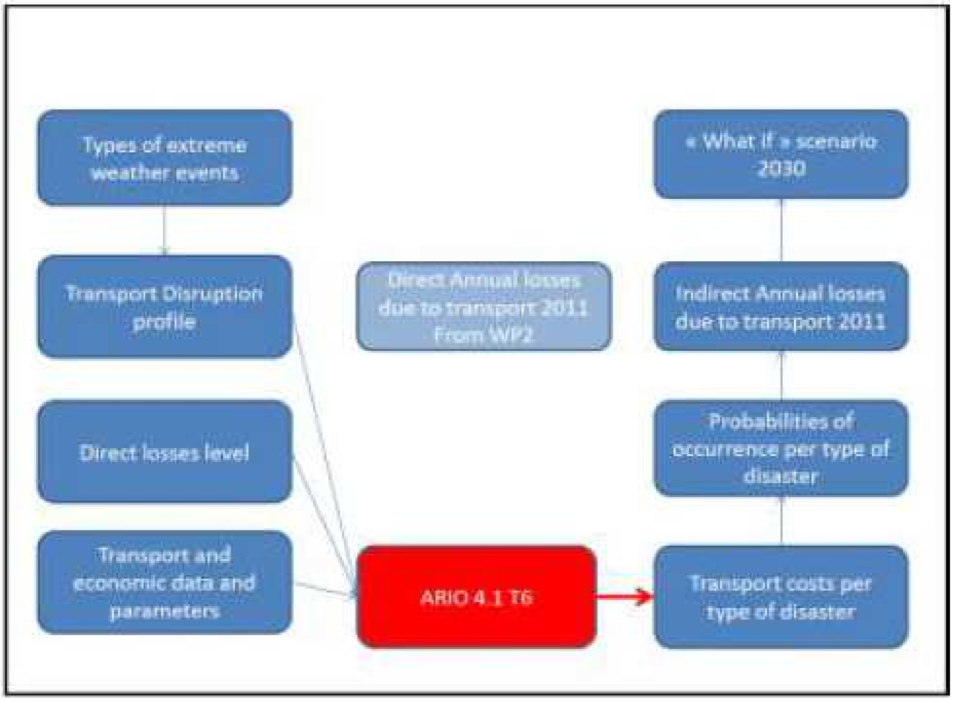


Figure 0-1: Methodology of indirect costs assessment

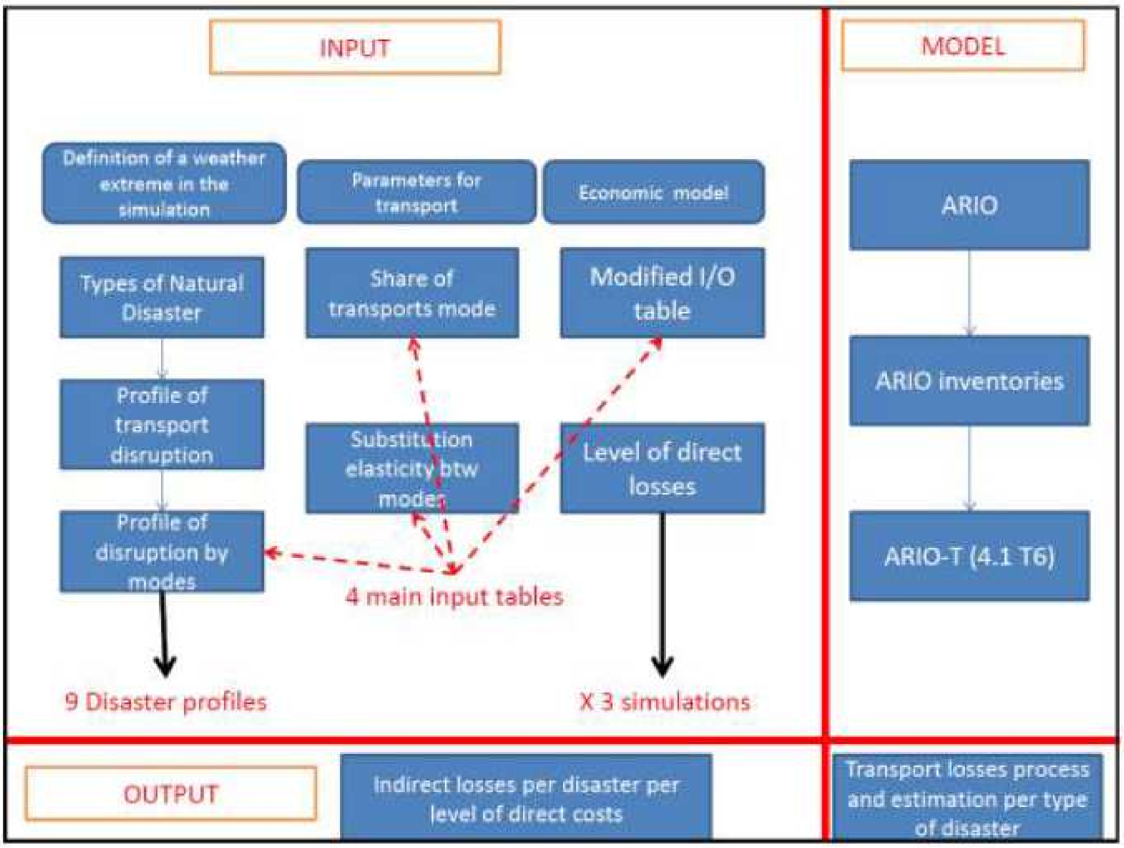


Figure 5-1: Sum-up scheme of work for simulating economic losses due to extreme weather events with ARIO 4.1 T6.

The adaptations of the model include:

- **Shorter time step (1 day)**
- **Inventories as additional flexibility in production process, distinguishing between: (i) essential supplies that cannot be stocked (e.g., electricity, water) and whose scarcity can paralyze all economic activity; (ii) essential supplies that can be stocked at least temporarily (e.g., steel, chemicals), whose scarcity creates problems only over the medium term; and (iii) supplies that are not essential in the production process (e.g., pens, some business services) and whose scarcity is problematic only over the long run and are therefore easy to replace with imports**

Transport has then be introduced as a constraint on inventories

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Regional / local

Cascading effects included

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Heat, winter, flood, storm, landslide

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling,

more general on risk, risk management etc.)

Focus is on impact

1.5 Parameters and data: Which are the input data/the data required by the method?

Precipitation and temperature – disaster profile, probabilities
Direct losses
Input-Output tables of inter-industrial transmission of economic perturbations

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Climate model
Economic model

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Method/Software

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.9 Advantages and disadvantages with the methodology

Innovative, not thoroughly tested, requires expert knowledge

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

Economic model for assessment of indirect impacts

2 Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

No

3 Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

Applied to a stereotypical EU region. Data came from Eurostat for Belgium. Seven economic sectors and four transport sectors (air, road, rail, water) were analysed.

Three different simulations were run with respect to capital losses (0-0.1%).

The costs per event type are presented for nine event types:

- **Heatwave light**
- **Heatwave heavy**
- **Winter light**
- **Winter heavy**
- **Windstorm/Alpine/Landslide Light**
- **Windstorm/Alpine/Landslide Heavy**
- **Floods light**
- **Floods heavy**
- **Storms**

4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

ARIO is a macroeconomic model, upgraded here for transport (ARIO-T)

ARIO-T provides an understanding of the process of indirect losses due to transport disruption by providing an insight on transport and

natural disaster economics. The results give transport losses.

Limitations:

- Sensitivity to transport tables, which are (at best) informed guesses
- No assumption on structural modification of the economy
- Model - highly simplified view of the reality
- not coupled with a weather model – it uses "disruption profiles"

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

HRW

Complete reference of the reviewed document (include Internet links, if available):

A. Papanikolaou, V. Mitsakis, K. Chrysostomou, C. Trinks, I. Partzsch (2011). Innovative emergency management strategies. Deliverable 3, WEATHER, 7th FP of the EC

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Report

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

WEATHER Project aims at adding to the current state of knowledge on the impacts of extreme weather events on economy and society in total and on European transport systems in particular. The project uses

- climate scenarios
- Economic growth models are applied to study the impacts on economy and society and the inter-relations between transport and other sectors
- The vulnerability of transport is assessed mode by mode including infrastructures, operations and intermodal issues.

The project focuses on quantification of expected damage, emergency and adaptation costs and the benefits of improved emergency management and adaptation.

This report provides guidelines on how the negative impacts of extreme weather events can be eased by installing suitable crisis and emergency management systems and system recovery mechanisms. This is achieved in three steps:

1) top down description of emergency management and its organization, aiming at linking emergency management operations and procedures with the role of transport networks in the case of extreme weather events
2) detailed analysis of the key issues identified for the provision of Emergency Transport Management (ETM): the organisational and technological aspects
3) summary of the key policy issues as drawn from the literature review and the analysis of the previous parts

1.1 Methodological approach description

As regards (1), the project integrates concepts for emergency management with transport sector and develops the framework for ETM operation.

Table 1: The framework of ETM operation

<table>
<tr><th>Extreme weather event</th><th>Impact to transport network</th><th colspan="2">Emergency strategies</th><th>Actions</th><th>Implementation tools</th><th>Strategic Emergency Management</th></tr>
<tr><td>Before the event</td><td>Surpass predefined vulnerability thresholds</td><td colspan="2">Activation of alarming systems</td><td>Provide real time information to authorities</td><td>Weather and traffic sensors, RWIS</td><td rowspan="2">Technological issues</td></tr>
<tr><td rowspan="4">During and after the event</td><td>Overload of transport network</td><td rowspan="2">Network management</td><td>Traffic management, control, provision of information</td><td>Provide real time information for alternative solutions /paths</td><td>ITS, GPS, GIS, VMS, Car2X, ATIS, DTA models</td></tr>
<tr><td>Overload + infrastructure failures</td><td>Infrastructure repair</td><td rowspan="3">Building efficient and innovative mechanisms and structures, information flow</td><td rowspan="3">Standards for cooperation and coordination between authorities</td><td rowspan="3">Organizational issues</td></tr>
<tr><td rowspan="2">Assign Emergency (transport) actions</td><td>Network restoration</td><td rowspan="2">Evacuation, first aid, search and rescue etc</td></tr>
<tr><td>Set up and execute EM plans</td></tr>
</table>

As regards (2), meteorological risk is integrated into ETM as follows:

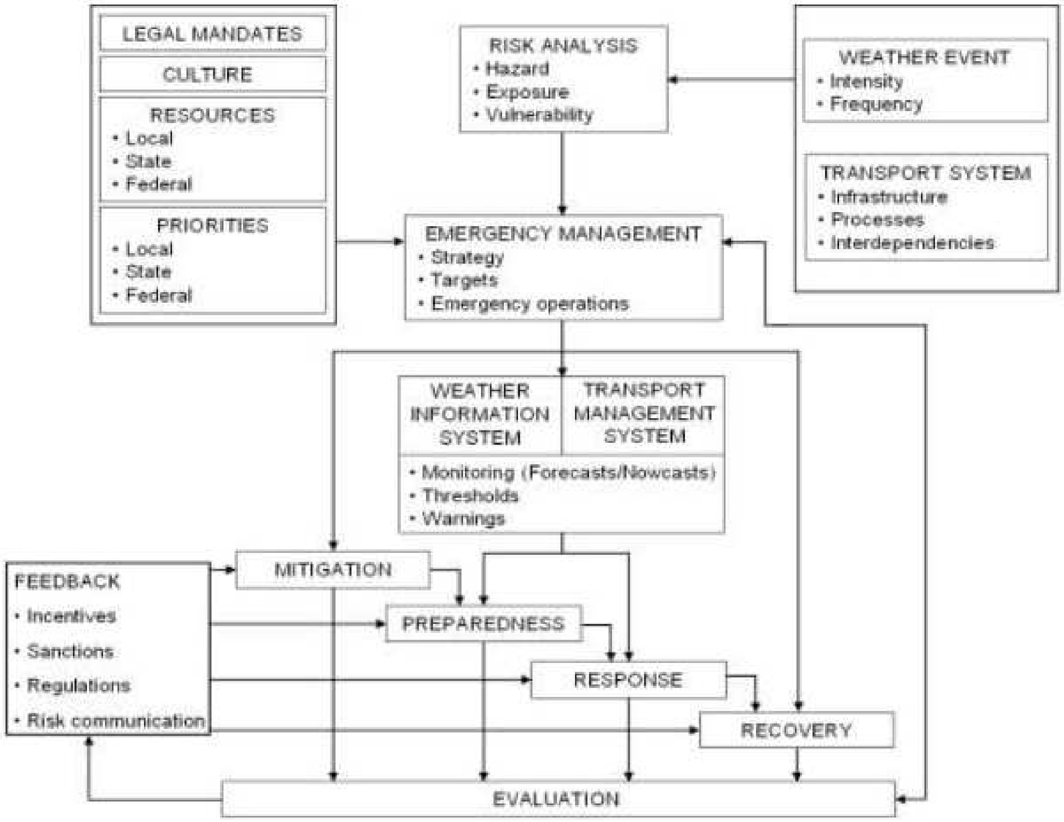


Figure 5: *ETM framework for meteorological risk*

Two examples of good practice that illustrate how natural hazards are integrated into the emergency management of transport operators are presented: Austrian and Swiss railways. Common safety method (CSM) on risk evaluation and assessment is also discussed.
As far as the meteorological information is concerned, the reports analyses mode-specific weather information systems for suitable ETM.
The Intelligent transport systems and their role in ETM is also investigated.

Table 18: Classification method of ITS

A: Automatic process M: Manual Process A/M: Can be executed either automatically or manually	Processes								
	Data collection			Data processing			Data transmission		
	Traffic	Weather	Environment Surveillance	Data Mining	Modeling	Decision-Making	General communication media	Alarming	Information
Informing systems	A/M	A/M	A/M	A	A		A/M		A/M
Systems that propose solutions	A	A/M	A/M	A	A	A/M	A		A
Systems that manage conditions	A	A/M	A/M	A	A	A	A	A	A

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Continental

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

General meteorological

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Focus is on risk management

1.5 Parameters and data: Which are the input data/the data required by the method?

Weather and traffic information, organisational parameters

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

(management system)

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

n/a

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

n/a

1.9 Advantages and disadvantages with the methodology

Overview, Innovative approach
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Provides a framework for Emergency Transport Management **Identified a number of key technologies and procedures to make transport more capable to support evacuation and supply chains in emergency cases**
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
n/a
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
n/a
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HRW
Complete reference of the reviewed document (include Internet links, if available):
Trinks, C., Papanikolaou, A., Doll, C., Klug, S., Tercero Espinoza, L.A., Mitsakis, E. (2012). The role of governance and incentives. Deliverable 5, WEATHER, 7th FP of the EC
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Report
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description

WEATHER Project aims at adding to the current state of knowledge on the impacts of extreme weather events on economy and society in total and on European transport systems in particular. The project uses

- climate scenarios
- Economic growth models are applied to study the impacts on economy and society and the inter-relations between transport and other sectors
- The vulnerability of transport is assessed mode by mode including infrastructures, operations and intermodal issues.

The project focuses on quantification of expected damage, emergency and adaptation costs and the benefits of improved emergency management and adaptation.

This report clarifies the role of relevant actors and networks, classify adaptation strategies, and discuss challenges and characteristics of different policy instruments /systems as well as the development of innovation and technology in adapting the European transport sector to changing climate and weather conditions. This is done through:

- Analysis of the roles (rights, duties, interests and options for action) of public and private actors and their inter-relations in transport infrastructure and system planning, design, operation, maintenance and financing.
- Analysis of the policy instruments and conducting a review of incentive and regulation systems dealing with long-term risk.
- Exploring the dynamics in the markets for adaptation and emergency management technologies.

The methods employed are expert interviews, comprehensive literature reviews and empirical analysis of policy instruments and patents.

1.2 Scale

- Geographic scale (site specific, local, regional, national)
- Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Continental

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Not directly considered

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Focus is on risk management

1.5 Parameters and data: Which are the input data/the data required by the method?

n/a

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

n/a

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

n/a

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

n/a

1.9 Advantages and disadvantages with the methodology

Analyses some interesting societal factors
Difficult to quantify/model

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

Provide some information on societal response (actor analysis, policy, market response)

2 Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

No

3 <u>Case studies</u> *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
n/a
4 <u>Software</u> *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
n/a
5 <u>Further comments</u> *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
HRW
Complete reference of the reviewed document (include Internet links, if available):
Maurer, H.; Rudzikaite, L., Kiel, J., et al. (2012) WEATHER Case studies – Synthesis Report. Deliverable 6, WEATHER, 7th FP of the EC.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Report
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
WEATHER Project aims at adding to the current state of knowledge on the impacts of extreme weather events on economy and society in total and on European transport systems in particular. The project uses • **climate scenarios** • **Economic growth models are applied to study the impacts on economy and society and the inter-relations between transport and other sectors** • **The vulnerability of transport is assessed mode by mode including infrastructures, operations and intermodal issues.** **The project focuses on quantification of expected damage, emergency and adaptation costs and the benefits of improved emergency management and adaptation.** **This report provides case studies which cover local specificities, lessons learned and long-term adaptation strategies. The case studies provide recommendations of better emergency management, adaptation measures and policy implementation on a local level. In total six case studies were selected for reviewing local issues of climate adaptation in Europe.** **The case studies were all analysed in the same manner, starting with a case study description which gives some basic information on the type of extreme weather event, the location, duration of the event and the recovery, as well as the damage costs. Then the specific impacts on the**

transport sector were identified, including how long it took until transport operations returned to the normal schedule. For each case study some notes were made regarding tools that were and can be used in future for support in emergency response and planning.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Regional
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Flood, heat, storm, snow
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Focus is on risk management
1.5 Parameters and data: Which are the input data/the data required by the method?
various
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
n/a
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
n/a
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
n/a
1.9 Advantages and disadvantages with the methodology
n/a
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Provides case studies and further links to methods/models for emergency response and planning
2 <u>Uncertainties</u> *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
No
3 <u>Case studies</u> *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
Flooding in Germany and Czech Republic in 2002. Analysed the event and described a set of tools that are developed to facilitate emergency response. The EU-project STAR-TRANS "will produce tools analyzing how risk propagates and affects interconnected transportation systems in Europe" [STAR-TRANS 2010]. Such analysis tools can support network planning, especially with regard to vulnerabilities and needed redundancies. Summer Heat 2007 in Southern Europe. Among others, analyses the forest fires in Greece and evacuation process and emergency routes and the resulting improvements to action plans. Flooding of the rail link Vienna – Prague in 2006 Analysed the event, alternative routes and associated costs. Describes the emergency plan that was put in force after the incident.

Hurricanes Xynthia 2010 in France
Describes the event and its consequences.

Heavy Snow on Alpine Roads
Analyses the heavy snow event in Italian Alps in 2004 and its impact on road network. A technical and administration coordination „Viabilità Italia" has been established afterwards to prevent and manage the road system emergencies caused by severe meteorological and other events.

Rhine Shipping during 2003 Summer Heat
Analyses the impact of Rhine levels during 2003 to shipping conditions. The authors state that the following adaptations are required:

- **imposing of adequate navigation restrictions, loading restrictions and deploying of reserve fleet to be able to fulfil the pending contractual obligations;**
- **structural adaptation measures**

4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

n/a

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

Literature to section 3.1:

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

Unni Eidsvig, NGI

Complete reference of the reviewed document (include Internet links, if available):

Meyer et al. (2013): Review article: Assessing the costs of natural hazards – state of the art and knowledge gaps, Nat. Hazards Earth Syst. Sci., 13, 1351-1373

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Journal paper

1 Methodological approach
Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc.

are considered; you can include figures (with respective references).
1.1 Methodological approach description
The paper provides an overview of the state-of-the-art cost assessment approaches and discusses key knowledge gaps.
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Geographical scale: cost approaches on different geographical scales reviewed in the paper. Scale of losses: Approaches for direct and indirect losses are reviewed
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Natural hazards
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Loss modelling
1.5 Parameters and data: Which are the input data/the data required by the method?
Methods with different inputs are reviewed
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Mainly economic theory-based approaches
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Summary of methods
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative methods are reviewed
1.9 Advantages and disadvantages with the methodology
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Relevant for cost estimations of indirect loss and assessment of direct loss. The relevant methods are listed in the main report.
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***

No
3 **Case studies** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
4 **Software** ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
5 **Further comments** ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Unni Eidsvig, NGI
Complete reference of the reviewed document (include Internet links, if available):
Okuyama
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
GFDRR report/paper (GFDRR= Global Facility for Disatseter Reduction and Recovery, www.gfdrr.org)
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
The paper provides an overview and a critical analysis of the **methodologies used for estimating the economic impact of disaster, e.g. input-output, social accounting, and computable general equilibrium models. The paper presents the strengths and weaknesses of the methodologies.**
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Geographical scale: regional – national

Scale of losses: indirect losses

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Natural hazards

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Loss/impact

1.5 Parameters and data: Which are the input data/the data required by the method?

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Economic theory-based approaches

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Methods

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.9 Advantages and disadvantages with the methodology

Several advantages and disadvantages are discussed in the paper:

	Strength	Weaknesses
IO	- simple structure - detailed interindustry linkages - wide range of analytical techniques available - easily modified and integrated with other models	- linear structure - rigid coefficients - no supply capacity constraint - no response to price change - overestimation of impact
SAM	- more detailed interdependency among activities, factors, and institutions - wide range of analytical techniques available - used widely for development studies	- linear structure - rigid coefficients - no supply capacity constraint - no response to price change - data requirement - overestimation of impact
CGE	- non-linear structure - able to respond to price change - able to cooperate with substitution - able to handle supply capacity constraint	- too flexible to handle changes - data requirement and calibration - optimization behavior under disaster - underestimation of impact
Econometric	- statistically rigorous - stochastic estimate - able to forecast over time	- data requirement (time series and cross section) - total impact rather than direct and higher-order impacts distinguished

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

Relevant for evaluation of methods for indirect loss assessment

2 <u>Uncertainties</u>

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment
3 Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
The paper discusses measurement issues in the context of developing countries
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Unni Eidsvig, NGI
Complete reference of the reviewed document (include Internet links, if available):
Scawthorn et al. 2006 : HAZUZ-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
Model for Damage and Loss Assessment. **The reference model contains depth damage curves for different groups of exposed elements, e.g. different building types and vehicles.** **The indirect loss is estimated through the HAZUS-MH Software tool referred to as the Indirect Economic Loss Methodology (IELM). The Flood IELM builds on the IELM in the Earthquake Model. The methodology was enhanced to encompass agriculture and tourism-based economies and also adds a capability to evaluate tax revenue losses to the government sector.**
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Geographic: Mostly site specific or local

Models for both direct and indirect losses are proposed.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Flood
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Loss modelling
1.5 Parameters and data: Which are the input data/the data required by the method?
For buildings: Occupancy class, flooding type/zone, number of stories, building material, flood depth **For indirect loss: Synthetic economic type that best represent the study area, economic data for impact analyses for planning.**
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
For direct loss: Empirical, one parameter engineering method. **For indirect loss: Indicator based approach (?)**
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Software tool
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Seems easy to use.; contains a large amount of empirical information on flood. **Could maybe be used without understanding which calculations which were actually done and thus lead to misinterpretations of the results.**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Very relevant for classification of losses
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
No
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
Yes
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

Cavallo, E. & Noy, I. 2010.

Complete reference of the reviewed document (include Internet links, if available):

The Economics of Natural Disasters.

IDB working paper WP 124. Inter-American Development Bank

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Govt inst publication

1. Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

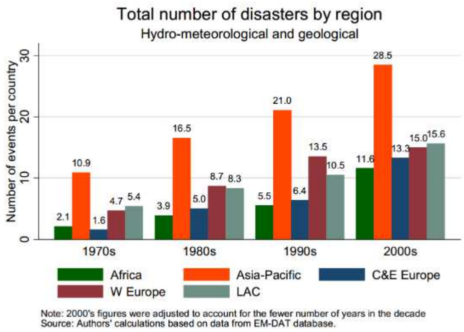
This paper starts explaining how the amount of damage reported database is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutions, and press agencies.

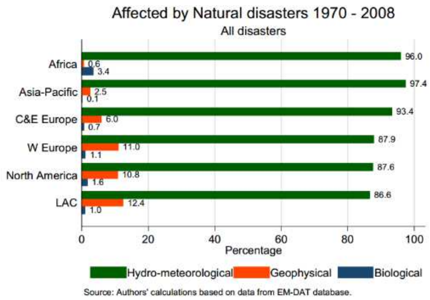
The events, and their incidence has been growing over time but the document advise that recording milder events have improved and seems to increase the frequency of occurrence, so there is no time trend for the subset of large events in any region. Therefore, natural "large" events are rarer, and the direct costs associated with these events are huge. Developing countries bear burden, in terms of both casualties and direct economic damages.

The paper continues explaining the determinants of initial disaster costs, using an usual model used on most papers to measure direct damages of a disaster: $DIS_{it} = \alpha + \beta X_{it} + \varepsilon_{it}$ **where**

- **I = country**
- **t = time**
- X_{it} **= is a vector of control variables of interest with each paper distinguishing different independent variables.**
- ε_{it} **= is an independent and identically distributed error term**

While the damage caused by disasters is naturally related to the physical intensity of the event, the literature has identified a series of economic, social, and political conditions that also affect vulnerability. Those conditions that may increase a country's susceptibility are level of economic development, Location of the countries (near to the costs and floodplains is more dangerous), size of the countries and political and institutional factors.





The paper try to define the importance of indirect impacts, starting with short-run growth effects that have a negative impact caused by natural events. Yet, the channels that are responsible for this economic slowdown have not been described methodically at all. An examination of these channels necessitates an attempt to determine whether these effects are transitory or permanent.

On long-run growth effects a new methodological approach was implemented and the conclusions demonstrate that there isn't any significant long-run effect of disasters, Only when very large events are followed by radical political revolution, the method indicate negative impact on long-run effect. Therefore, it is possible that the economic consequences that they find came from the revolutions, rather than from the disasters. The document ends this section with literature about other economic impacts

The next section of the paper, describes the studies of some real cases of natural events disaster impacts like the 1995 Kobe earthquake in Japan, the 1999 earthquake in Turkey, the Hurricane Katrina in 2005, the earthquake that struck the Caribbean country on January 12, 2010, the 1992 hurricane on the economy of a Hawaiian island, etc.

The document continues with policies and disasters, and highlight that, besides policies that can reduce initial disaster damage, policies that can reduce the longer-term economic damage that disasters can wreak should also be contemplated. There is a discussion between ex-ante insurance and ex-post disaster financing.

Finally, the paper comments the effects of the climate changes on the different natural events, taking importance the natural events related with the temperatures, because the higher temperatures affect on hurricane formation and tide level makes coastal areas, more vulnerable to the storms.

1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Geographic scale: national and regional. **Scale of losses: This document is focus on direct and indirect (Short-run, and Long-run) losses.**
1.3 Considered hazards
The hazards considered in this paper are natural large events like Tsunamis, earthquakes, coastal floods, Hurricanes, etc.
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

This document have a qualitative perspective methodology.

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

Simulation approach

1.6 Parameters and data:
- **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?**
- **Which are the input data/the data required by the method?**

The methodology is focus on vulnerability, and economic loss.

1.7 Advantages and disadvantages with the methodology

Advantages: This document clarify the effects of natural large events on the economy of a country, and the countries characteristics that produce different responses at those events. Furthermore, the document shows how the natural large events are changing with the clime.

Disadvantages: This document is based on different studies of other authors, and just their results obtained are compare to provide conclusions.

2. Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

There is a discussion between Ex-ante Insurance and Ex-post disaster financing. More ex-post assistance to damaged communities, generates a "Samaritan's dilemma," i.e., an increase in risk-taking and a reluctance to purchase insurance when taking into account the help that is likely to be provided should a disaster strike. However, apart from these ex-ante 'shrink-the target' policies, many other ex-ante and ex-post policies that can alleviate or worsen the economic impact of disasters will necessarily be weighed before and after any large event.

3. Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

There are some real examples used to explain the literature of the document. Those real cases are:

- The 1995 Kobe earthquake in Japan.

- The 1999 earthquake in Turkey, the Hurricane Katrina in 2005.

- The earthquake that struck the Caribbean country on January 12, 2010.

- The 1992 hurricane on the economy of a Hawaiian island.

- Etc.

4. Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

5. Further comments

If you have further comments about the document that you have reviewed, please include it here

Literature to section 3.2:

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
VTT
Complete reference of the reviewed document (include Internet links, if available):
Ghorbani, A. A. and Bagheri, E. (2008) The State of the Art in Critical Infrastructure Protection: a Framework for Convergence. Int. J. of Critical Infrastructures, Vol.4, No.3, pp. 215 – 244. **Available at:** **http://ebagheri.athabascau.ca/papers/CIPFramework.pdf**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper, journal publisher: Inderscience
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description

Paper describes different schemes developed with the aim of supporting the process of understanding the behavior of an infrastructure and identify its points of weakness. Summary of the selected schemes is:

Scheme	Prominent Features
AIMS	Extendable multi-agent based architecture, pluggable visualizatio and analysis modules
ASPEN	Agent-based simulation, a thorough simulation of the U.S economy with the use of evolutionary learning techniques
CASCADE	Probabilistic and dynamic complex system models for cascading failure analysis
CISIA	Agent based simulation of infrastructures with three different types of interdependency (through incidence matrices)
GoRAF	Integrating engineering and business perspectives for identifying risks associated with enterprise interdependencies
HHM	Risk identification, ranking and filtering through the integration of multiple perspectives
IIM	Sector vulnerabilities assessment using inoperability and economic loss impact metrics
IRAM	Focusing on risk modeling for scarce resource allocation to improve system surety
OGC CIPI	Sharing of geospatial data for emergency management and response
UML-CI	Providing means for stakeholder and modeler communication, common understanding and knowledge transfer through a common infrastructure metamodel

A multifaceted strategy requires an integration of many different techniques that are in most cases from a totally different background. The consolidation of these methods and schemes can be achieved through a unified framework. Based on the available schemes, a five

dimensional CIP (Critical Infrastructure Protection) framework that introduces the major research necessities in this field is introduced.

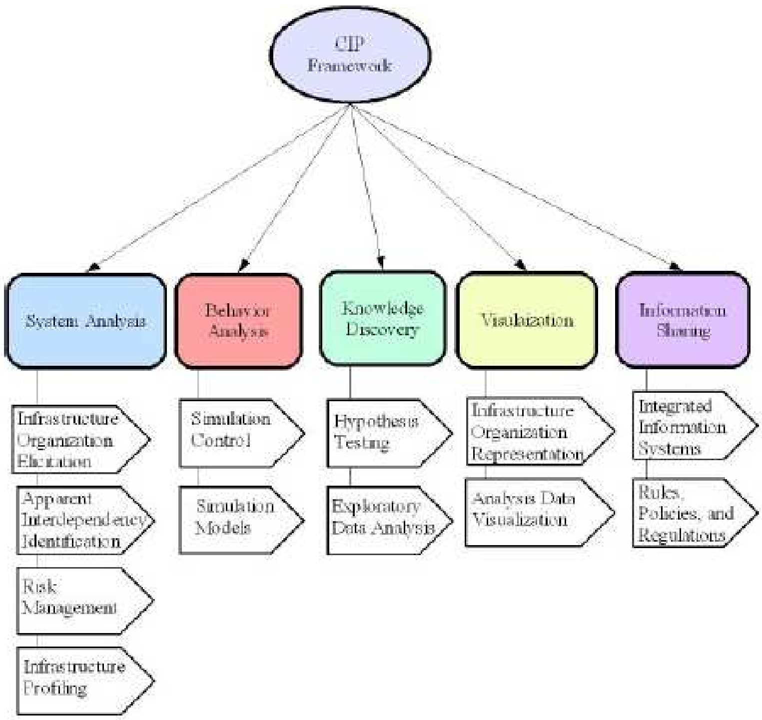


Fig. 2. The Proposed Five Dimensional CIP Framework

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

The question of geographical interdependency is discussed at the general level- Any two infrastructures or their systems that are within a geographical proximity have geographical interdependency. By analyzing the geographical coordinates of two different infrastructure systems, their geographical interdependencies can be revealed. In the route of this process two major obstacles exist. Firstly, not all infrastructures in a geographical region are known to every

body. There are usually visibility levels that are devised for security concerns.

The focus is on the possible causes of CI failure and to a great extent their consequences.

It should also be noted that although many of the possible roots for failure are detected in

the approaches and schemes described shortly in the paper, but not all of their consequences are visibly perceived and understood. However, losses – direct or indirect – are in a wider sense really not in the scope of this paper.

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Focusing on CIs, not on EWEs. Not any specific EWEs mentioned.

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

System analysis, behavior analysis, knowledge discovery, visualization and information sharing are the phases of the framework which all includes different approaches / schemes (e.d. risk analysis, statistical analysis, agent based simulation…)

1.5 Parameters and data: Which are the input data/the data required by the method?

Depends on the scheme and the approach.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Framework incorporates many different schemes (approaches).
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method (qualitative/quantitative/semi-quantitative) and methodology/theory.
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
All
1.9 Advantages and disadvantages with the methodology
No explicitly expressed advantages and disadvantages in the paper. Concerning couple of schemes, some of their advantages are mentioned. **For example, the advantage of UML-CI is that it gives initial insight for infrastructure analysis and system identification, provides sound basis for common understanding, communication, and knowledge transfer, it also allows the documentation of best practices and infrastructure metamodels. Secondly, the process of specifying the associations and making the hypotheses is a time-consuming task.**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Possibly relevant to some extent for INTACT although the framework needs further tailoring to INTACT. Possibly the schemes / approached can be further examined and used in Task 4.2 and WP6 (reference guide).
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No.
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
No. The paper is theoretical and no case studies was included. Two examles was mentioned in the context of the Graph Theory Techniques: Fig 5 A Simplified Network of the U.S. Airlines System and Fig 6 Failure Propagation in Gas and Electricity Infrastructures, but they are only examples to visualize the techniques i.e. no case studies.
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
No mentioned.
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
VTT
Complete reference of the reviewed document (include Internet links, if available):
Kröger, W. and Zio, E. (2011)Vulnerable Systems. Springer. 212 p. **Available at Springer's website:** **http://www.springer.com/engineering/production+engineering/book/978-0-85729-654-2**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Book
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
Vulnerable Systems –book reflects the current state of knowledge on the procedures which are being put forward for the risk and vulnerability analysis of critical infrastructures. Classical methods of reliability and risk analysis, as well as new paradigms based on network and systems theory, including simulation, are considered in a dynamic and holistic way.

Approach / technique	
Statistical analysis	Statistical models
Probabilistic modeling	Markov chains Markov/Petri nets Probabilistic modelling Bayesian networks
Risk analysis	Quantitative assessment, Tabular methods / expert judgment
Complex network theory	
Agent-based modelling and simulation	Monte Carlo simulation techniques
Dynamic control system theory	Transfer function

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

The book is focusing on large, geographically-distributed, physical-engineered networks, and particularly on those of undoubted importance for at least highly industrialized countries, such as:

– energy supply (electricity, gas)

– urban freshwater supply and wastewater treatment

– information and communication

– transport (rail, road)

– control systems (SCADA).

Most of these systems are coupled and mutually dependent on different degree and order, difficult to understand and emulate. Very often ‘‘the system’’ consists of a ‘‘part being under control’’ and ‘‘the control part’’ itself, using the same technology as public information and communication systems or even those directly, i.e., the Internet for transport of data and commands.

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

The book is presenting general methods for the vulnerability analysis of CI i.e. it is not focusing on any specific hazard type(s) or EWE(s). In the book, multiple hazards and threats disclosing vulnerabilities of CI are classified as it follows:

Table 1.1 Set of multiple hazards and threats disclosing vulnerabilities of CI

Natural events such as earthquakes, hurricanes/typhoons, tornados, severe flooding, landslides or other (increasingly) extreme weather conditions

Accidents or technical factors such as components' failure/rupture leading to the debilitation of plants, networks and operations

Market factors such as instability associated with major producer groups, or economic pressure trading off security factors

Policy factors such as artificial supply limitations or negative pricing outcomes or misusing "energy" for political purposes

Human factors such as unintended failures of omission or commission, e.g., of system operator, intended errors or even targeted malicious attacks, either physical or cyber

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

According to the book, a comprehensive CI vulnerability analysis comprises three main activities:

- **System analysis including system properties (e.g., physical and logical structures and operation modes)**
- **Quantification of system vulnerability indicators and identification of important elements**
- **Application to system improvements either technical or organizational**

The two main outputs of a vulnerability analysis of CIs are the quantification of system vulnerability indicators and the identification of critical elements. The ultimate goal is to identify hidden vulnerabilities in infrastructure systems, to be able to act for managing and reducing them.

1.5 Parameters and data: Which are the input data/the data required by the method?

Depends on the method.

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Methods of Analysis: Complex Network Theory, Risk Analysis of Critical Infrastructures, Probabilistic Modeling of Cascading Failures Dynamics, Agent-Based Modeling and Simulation, High Level Architecture and Human Reliability Analysis.
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Book focuses on describing the methods. It is also mentioned that there are commercial and free ready-to-use software tools available that are based on the methods. For example, for supporting the technical implementation of the agent-based modeling concept there are several software environments available, for example: • **StarLogo: www.media.mit.edu/starlogo** • **NetLog: ccl.northwestern.edu/netlogo** • **Mathematica: www.wolfram.com** • **AnyLogic: www.xjtek.com** • **Repast3.X: repast.sourceforge.net** • **Ascape: ascape.sourceforge.net** • **Swarm: www.swarm.org** • **DIAS: www.dis.anl.gov/projects/dias** **However, for example concerning risk analysis of CI and HRA, it is mentioned that dispite the large number of existing risk analysis and HRA techniques, very limited efforts have been made to provide user-friendly tools.**
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
All, depending on the method in question. For example, HRA uses qualitative and quantitative techniques to assess the human contribution to risk, in particular the likelihood of required human actions being performed when needed. These likelihoods can then be incorporated into the overall risk assessment, and combined with other probabilities, such as those of equipment faults, to estimate the overall likelihood of hazardous events.
1.9 Advantages and disadvantages with the methodology

Method	Advantages	Disadvantages
Complex network theory	Simple and fast analysis, which provides quantitative indicators of the topological characteristics of the network of connections underpinning a CI. Allows to identify topologically critical areas of the system	If used in isolation, it can provide only indications on the topology of the system, potentially failing to represent the other features related to the flow-driving characteristics
Risk analysis	Allows a systematic and logic analysis of vulnerability scenarios which may affect a CI, while at the same time allowing for their quantification of likelihood of occurrence and consequence, and for the identification of the critical CI components	The efforts in logic modelling and quantification are significant. The capability of providing an exhaustive analysis is limited, particularly in view of the unexpected emergent behaviours and of the many (inter) dependencies
Probabilistic modelling of cascades dynamics	The high-level of abstraction leads to a modelling which is still sufficiently slim to allow running what-if scenarios at reasonable computational expenses. The results of this add to the topological analysis by confirming or not certain network connectivity characteristics and critical points, in light of also the dynamic patterns of cascade evolution	Although dynamics is added to complement the topological analysis, it may still fail to capture physical aspects of the cascade dynamics related to the flowdriven processes actually occurring
Agent-based modeling	Close adherence to reality; capable to capture highly non-linear dynamics and emergent phenomena; integration of non-technical system elements	Usually requires a large number of model parameters and may imply long computational times
High-level architecture	As a promising approach for integrating different modelling methods, the distribution of simulation components improves the flexibility/ reusability of the simulation tool and decreases its overall complexity	It is not a ''plug-and play'' standard. Resources and time required to implement an HLA-compliant simulation tool could be significant
Human reliability and performance modelling	With a relatively simple and straightforward manner allows analysts to estimate human contribution to the risk, to calculate the possibility of the occurrence of a human error and to identify the factors that compromise human performance. In addition suggestions either to improve safety or to deal with the unpleasant consequences are provided	Lack of data and biased experts judgment can compromise the validity of the analysis. Findings may vary based on analysts experience, background and training. Complex techniques can only be used by experienced and trained analysts. The analysis can be both time-consuming and exhaustive

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

Categorisations and descriptions of different schemes, approaches and methods can be integrated to some extent into decision-making framework (Task 4.2) and/or INTACT reference guide.

2 Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

Yes. Different techniques incorporate uncertainty in different ways.

3 Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

1. **The methods of vulnerability analysis of CIs via complex network theory are shown with respect to their application to electrical infrastructures (pp. 84-93).**
2. **The example by Garrick et al. 2004 included in the book involves a risk assessment of a physical attack on a hypothetical electric power grid, following the step-by-step procedure. (pp. 103-109)**
3. **Exemplary Application to Failure Cascade Dynamics Modeling for a Single CI: The indicators of component criticality introduced have been computed for the topological network of the 380 kV Italian power transmission network, considering cascades evolving according to the extended failure propagation models. (pp. 118-120)**
4. **A specific application of ABM (agent based modeling) for assessing the reliability of an electric power system (EPS) is also demonstrated. Besides further substantiating the benefits and drawbacks of the method, the example might serve as a ''role model'' for the application to other single-type critical infrastructures or coupled systems. (pp. 137-142)**
5. **The HLA (high level architecture)-compliant experimental test-bed, which is part of an ongoing broaderscale project in the area of CI vulnerability and (inter)dependency studies at ETH Zurich, is an exemplary application of HLA. (pp. 152-156)**
6. **Different domains for HRA (human reliability analysis) are described: transport domain, railways, aviation, road transport of**

dangerous goods, electrical network , public health and information an communication technologies. (pp. 162-186)
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
See 1.7.
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
VTT
Complete reference of the reviewed document (include Internet links, if available):
Pitilakis, K. (2011) D2.1 - General methodology for systemic vulnerability assessment. SYNER-G project. Available at: http://www.vce.at/SYNER-G/files/dissemination/deliverables.html
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
EU project deliverable. SYNER-G-project: Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain. (Duration: November 2009 – 2012)
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
In SYNER-G project, the general methodology to assess the seismic vulnerability of an interconnected infrastructure was developed. The main features of the methodology are: • A detailed taxonomy of the Infrastructure in a number of interconnected infrastructural systems, consisting of the description of each system and of its components. • An object-oriented model of the Infrastructure describing the relations between all systems and components (inter- and intradependencies) within the taxonomy. • Consideration of all uncertainties in the problem, and in particular: on the seismic activity of the seismogenetic sources/faults, on the local seismic intensities at the sites for any given scenario, on the physical damageability of the components of the Infrastructure, on the functional consequences at component and/or system level of the physical damage at the component level, on the socio-economic consequences of physical damage, and, finally, the epistemic uncertainty in all the above models. • The categorization of performance indicators in three groups, based on the level within the Infrastructure where they are

evaluated: component, system or Infrastructure

- An integrated evaluation of physical and socio-economic performance indicators.´

In its final form the entire procedure is base on a sequence of three models: a) seismic hazard model, b) physical vulnerability model, and c) functional and socio-economic system model.

1.2 Scale

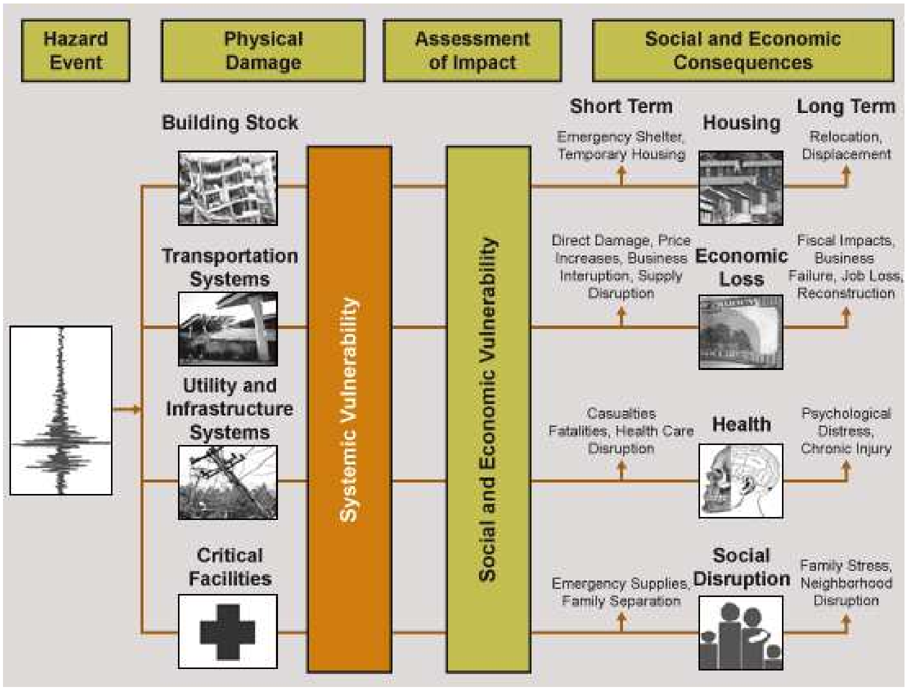
- Geographic scale (site specific, local, regional, national)
- Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Scale: urban and regional level as well as at complex infrastructure level. From a geometric point of view three categories can be identified:

- Point-like components (Critical facilities): single-site facilities whose importance for the functionality of the Infrastructure makes them critical, justifying a detailed description and analysis. Examples include hospitals, power-plants.
- Line-like components (networks, lifelines): distributed systems comprising a number of vulnerable point-like sub-systems in their vertices, and strongly characterized by their flow-transmission function. Examples include Electric networks with vulnerable power plants, sub-stations, etc, or road networks with vulnerable bridges.
- Area-like components: this is a special category specifically intended to model large popu-lations of residential, office and commercial buildings, that cannot be treated individually. These buildings make up the largest proportion of the built environment and generally give the predominant contribution to the total direct loss due to physical damage.

The Geographic interactions (physical proximity) are modelled in the seismic case by correctly incorporating within the seismic hazard model the statistical dependence structure between intensities at the same or close sites.

Both direct and indirect losses are taken into account in the methodology (see figure below: consequences).



Loss (direct): Loss incurred as a direct consequence of physical damage to systems' compo-nents. This category includes the economic value of damaged structural and non structural components (architectural, content, equipment, etc), the equivalent monetary value of lives lost.

Loss (indirect): Loss incurred as an indirect consequence of the physical damage and related to functional disruption in the systems. This category includes the monetary value of the increased travel times for people and goods on the damaged transportation system, the economic equivalent of the business interruption and industrial produc-tion, up to the complete halting of a whole economic sector in the affected region, the economic value of the social disruption.

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Focusing on seismic hazards.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Assessment of seismic vulnerability of an infrastructure incl. seismic hazard model, physical vulnerability model, and functional and socio-economic system model.
1.5 Parameters and data: Which are the input data/the data required by the method?
Development of the hazard model has the goal of providing a tool for sampling events in terms of epicentre, magnitude and faulting style according to the seismicity of the study region and predicting maps of seismic intensities at the sites of the vulnerable components in the Infrastructure. The model for the Infrastructure consists of two sets of models that form a sequence. The first set consists of the physical models of the systems making up the Infrastructure. These models take as an input the hazards and provide as an output the state of physical/functional damage of the Infra-structure. The second set of models consists of the socio-economic models that take as an input the output of the physical models and provide the socio-economic consequences of the event.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Simulation approach
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
The main outcome is an open source software tool to evaluate seismic vulnerability and losses considering both physical and socio-economic aspects.
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
No explicitly expressed advantages and disadvantages in the deliverable.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Possibly relevant to some extent for INTACT although seismic hazards are not on focus of INTACT.
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
Yes. The uncertainties entering the SYNER-G regional seismic vulnerability analysis are summarized in the deliverable: • **Seismic activity of the seismo-genetic sources/faults (modelled through magnitude-recurrence laws)** • **Local seismic intensities at the sites (modelled through ground-motion prediction equations, spatial correlation models, cross-IM correlation models and site amplification models, Sections** • **Physical damageability of the components of the Infrastructure (modelled by fragility mod-els)** • **Uncertainty in the functional consequences at component and/or system level of the physi-cal damage at the component level** • **Uncertainty in the socio-economic consequences of physical damage (non-structural com-ponents fragility models, probabilistic cost models, etc,)** • **Epistemic uncertainty in all the above models.**

3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
No case studies described in the deliverable. **From the the SYNER-G project point of view, the applicability of methodology and tools has been tested through several case studies (The City of Theassaloniki in Northern Greece, The Brigittenau district in Vienna, Austria, The medium-pressure gas distribution system of L'Aquila in Italy, The medium-pressure gas distribution system of L'Aquila in Italy, The Electric Power Network of Sicily in Italy, A Regional Health Care System and The Harbour of Thessaloniki in Greece).**
4 Software ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
An open source software tool to evaluate seismic vulnerability and losses.
5 Further comments ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
VTT
Complete reference of the reviewed document (include Internet links, if available):
Utne I. B.; Hokstad, P.; Kjølle, G; Vatn, J; Tøndel, I. A.; Bertelsen, D; Fridheim, H and Røstum J. (2008) Risk and Vulnerability Analysis of Critical Infrastructures - The DECRIS Approach. SAMRISK conference. **Available at:** **https://www.sintef.no/globalassets/project/samrisk/decris/documents/decris_paper_samrisk_final-080808.pdf** **Slides presented in SAMRISK conference (based on the paper above):** **Utne I. B. (2008) Risk and Vulnerability Analysis of Critical Infrastructures - The DECRIS Approach. SAMRISK conference 2008. SINTEF Technology and Society, Safety and Reliability / NTNU, Oslo, Norway, Sept. 1-2 , 2008.** **Available at:** **https://www.sintef.no/globalassets/project/samrisk/decris/documents/decris_samrisk_02092008_1.pdf** **Other Decris realated references *(in Norwegian)*** • **Vatn, J. (2009) DECRIS - Risk and Decisions Systems for Critical Infrastructures. SAMRISK conference. Trondheim, Norway, Nov. 2009. (conference paper)** • **Hokstad, P. Risk and Decision Systems for Critical Infrastructure. SINTEF, Trondheim. 6.10.2009 (Slides).** **Available at:** **http://www.sintef.no/Projectweb/SAMRISK/DECRIS/Documents/**

Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference paper (SAMRISK conference)
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
The conference paper and other DECRISs related references are based on the results of the DECRIS project. The DECRIS project utilizes experience from risk analyses within different critical infrastructures, and one of the main objectives is to develop an all-hazard generic RVA (risk and vulnerability analysis) methodology suitable for cross-sector infrastructure analysis. Both safety (accidents, technological failures etc.) and security (malicious attacks) aspects shall be included. **The method is called DECRIS (Risk and Decision Systems for Critical Infrastructures) and consists of the following steps:** **1. Establish event taxonomy and risk dimensions** **a. Establish a taxonomy (hierarchy) of unwanted events. The DECRIS taxonomy has the following main event categories: Natural events, Technical/human events (error/accident), and Malicious acts.** **b. Decide on the consequence dimensions used to analyze the unwanted events. DECRIS defines the following consequence categories: Life and health, Environment, Economy, Manageability, Political Trust, and Availability of delivery/supply of infrastructure.** **c. Calibrate risk matrices. The unwanted events are described with a probability category and a consequence category for each consequence category. These categories have to be established, and a discussion is needed to calibrate the resulting risk matrices.** **2. Perform a simple analysis (like a standard RVA/PHA):** **a. Identify all unwanted (hazardous) events.** **b. Assess the risks related to each unwanted event. In the simple analysis, the two dimensions “Life and health” and “Availability of delivery/supply of infrastructure” are considered.** **3. Select events for further detailed analyses. Potential candidates have usually high risk. In DECRIS specific information has been provided to support the selection, such as if the event has a gross accident potential, if there are relevant dependencies (in SCFs), and if there are communication challenges related to the event.** **4. Perform detailed analysis of selected events. The course of events and various consequences are investigated in more detail. These analyses shall include :** **i. Evaluation of interactions and other couplings in between the infrastructures, and how this affects the consequences of the unwanted events.** **ii. Evaluation of vulnerabilities (e.g. critical junctions or week barriers).** **iii. Suggesting and evaluating risk and vulnerability reducing measures.**
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
The method supports an “all hazards” approach across sectors; i.e., electricity supply, water supply, transport (road/rail), and information and communication systems (ICT). **In DECRIS, several dimensions are assessed e.g., safety, economic impact and loss of services.** **Interactions and other couplings in between the infrastructures are evaluated, and also how this affects the consequences of the unwanted events.**

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Natural hazards: Landslides and flooding
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The DECRIS approach is an enhanced RVA, focusing on serious events and emphasizing dependencies between the sectors.
1.5 Parameters and data: Which are the input data/the data required by the method?
Data required: basic data on unwanted events (e.g. name) and the infrastructures affected, data (scores) on probabilities and consequences (based on the categories established), data on interdependencies between infrastructures.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Risk and vulnerability analysis, assessment of all types of CIs is supported by the method. The current format of the Decris (as well as of an RVA) is very similar to a preliminary hazard analysis (PHA) where the starting point is the identification of undesired events, followed by a simple probability and consequence assessment of each event.
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method.
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Methodology is semi-quantitative and qualitative by nature.
1.9 Advantages and disadvantages with the methodology
It was recognized that quantitative of risk models (e.g. Probabilistic Safety Analysis (PSA) and Quantitative Risk Analysis (QRA)) require more knowledge and resources than available in small and medium enterprises and in the public sector. There is a need for a much simpler approach, like DECRIS is. **Disadvantages and challenges mentioned:** • **Critical infrastructures are complex combinations. How can we predict the outcomes of undesired events in such complex systems? In addition, a common scale is required so that the loss in one infrastructure is comparable to another.** • **Failure in any critical infrastructure is likely to impact most other parts of society, including other critical infrastructures. How should we address these interdependencies in evaluating the consequences of incidents?** • **Risk perception. How will the different stakeholders influence the analysis results, and how should we best communicate the results of a risk analysis to different stakeholders?** • **Lack of statistical data, data access: We often lack data for many relevant incidents in the critical infrastructures. Often very limited access to the competence and information about system architecture, sub systems and components, existing safety measures, users of the system etc.** • **Development speed: The rate of change is fast in critical infrastructures.** • **The distinction between safety and security introduce methodological challenges**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Possibly relevant to some extent for INTACT. Decris can be used, for example, as an easy-to-apply evaluation method in the early phase of decision-making. It is a general method that is applicabe to different EWEs and CIs.
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***

No.
3 Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
The case study i.e. the testing and applying of DECRIS method and process (see 1.1.), was made with the City of Oslo and representatives from the municipality's Emergency Preparedness. The case study results showed that there are dependencies between the undesired events, and that there really is a need for analyzing the infrastructures and the undesired events collectively, and not separately as most often are done in similar analyses.
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
The InfraRisk tool was mentioned. It is used during the DECRIS process for linking the risk contribution from each SCF (safety critical function) to the undesired events and facilitate viewing the events or SCF's in a risk matrix.
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
VTT
Complete reference of the reviewed document (include Internet links, if available):
EUR 25286 EN - Joint Research Centre – Institute for the Protection and Security of the Citizen Title: Risk assessment methodologies for Critical Infrastructure Protection. Part I: A state of the art Author(s): Georgios Giannopoulos, Roberto Filippini, Muriel Schimmer Luxembourg: Publications Office of the European Union 2012 – 70 pp. – 210 x 297 cm EUR – Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print) ISBN 978-92-79-23839-0 doi: 10.2788/22260 http://ec.europa.eu/home-affairs/doc_centre/terrorism/docs/RA-ver2.pdf
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Public report (JRC Technical Notes -series)

1 **Methodological approach** ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
1.5 Parameters and data: Which are the input data/the data required by the method?
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
1.9 Advantages and disadvantages with the methodology
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

2 Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

3 Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

The topic of the report is risk assessment methodologies for critical infrastructure protection. From its nature the report is a 'state of the art report'. The report lists and shortly describes 19 different risk assessment methodologies related to critical infrastructure protection according to the following criteria:

- Scope of the methodology: Which sector is addressed, to whom it is addressed (Policy makers, researchers, operators etc.).
- Objectives of the methodology
- Applied techniques and standards.
- Interdependencies coverage.
- Is resilience addressed?
- If cross-sectoral methodology, how are risks compared across sectors?

Each methodology is described in 1 or 2 pages and at the end of descriptions one source for additional information for each methodology is mentioned. Most often this is a link to a website or to a document in www. At the end of the report (as an appendix) there is a summary table of the methodologies covered in the report. Based on this information, nine of altogether 19 methodologies were 'All Hazards' methodologies, while the other were covering (only) e.g. 'Terrorist threats' or 'technical hazards'. The nine 'All Hazards' methodologies are listed below with the related link to additional information. These methodologies, as they possibly include also natural hazards and thus also extreme weather events, are possible candidates for further review in INTACT-project.

- Better Infrastructure Risk and Resilience http://www.dis.anl.gov/projects/ri.html
- BMI http://www.bmi.bund.de
- CARVER 2 http://www.ni2cie.org/CARVER2.asp
- CIMS (Critical Infrastructure Modeling Simulation) https://inlportal.inl.gov/portal/server.pt/community/national_and_homeland_security/273/modeling_and_simulation/1707
- CIPDSS (Critical Infrastructure Protection Decision Support System) http://www.lanl.gov/programs/nisac/cipdss.shtml
- CIPMA (Critical Infrastructure Protection Modeling and Analysis) http://www.csiro.au/Organisation-Structure/Divisions/Mathematics-Informatics-and-Statistics/CIPMA.aspx
- DECRIS http://www.sintef.no/project/SAMRISK/DECRIS/Documents/DECRIS_paper_SAMRISK_final%20080808.pdf
- EURACOM http://www.eos-eu.com
- FAIT (Fast Analysis Infrastructure Tool) http://www.sandia.gov/nisac/fait.htm

Template for D4.1:

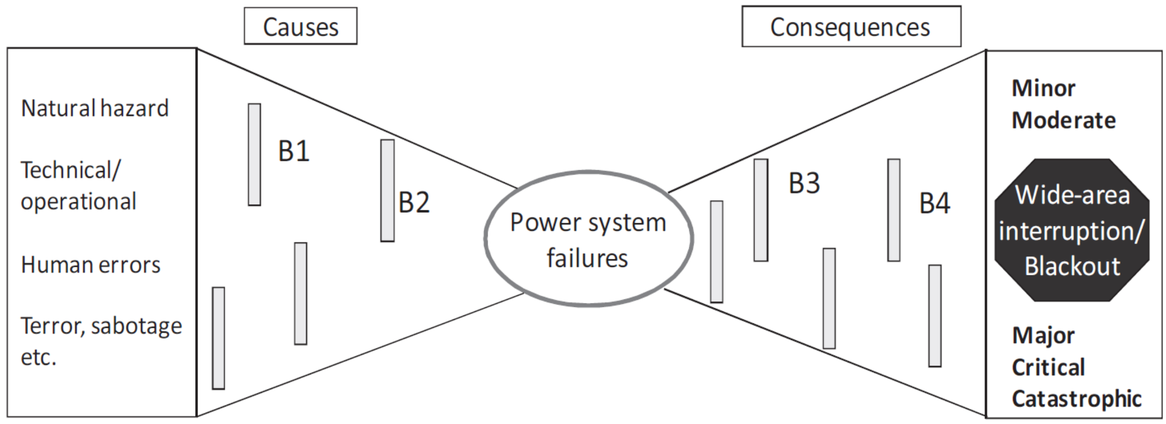
Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:
Complete reference of the reviewed document (include Internet links, if available):
George H. Baker. "A Vulnerability Assessment Methodology for Critical Infrastructure Sites" DHS Symposium: R&D Partnerships in Homeland Security. Boston, Massachusetts. Apr. 2005. Available at: http://works.bepress.com/cgi/viewcontent.cgi?article=1001&context=george_h_baker
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Symposium/conference paper [A SelectedWorks™ paper (http://works.bepress.com/)]
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
Paper describes a common vulnerability assessment methodology for individual critical infrastructure facilities. The methodology is designed to be comprehensive in terms of accommodating physical and cyber threats against the complete suite of mission-critical systems making up a facility. The methodology involves looking at the system elements and layout and their failure modes based on a given set of threats or "insults." The vulnerability assessment answers the basic question, "what can go wrong should the system be exposed to threats and hazards of concern?" Elements of the vulnerability assessment process are (should not be interpreted as strictly consecutive.): 1. Threat/Hazard Identification 2. Mission Identification 3. Supporting System Identification 4. Critical System Element Interconnections and Interdependencies 5. System Reconstitution 6. Determining Vulnerabilities 7. System Interdependencies 8. Personnel and Responsibilities 9. Endurability 10. Planned System Changes
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
The methodology focuses on individual facilities, but its results can also be used in larger scale regional assessments to rank infrastructure facilities based on their relative resilience, thus providing a basis for priority assignments and resource allocations. As the methodology focuses on the vulnerability assessment not on risk assessment, losses – direct or indirect – are really not in the scope of the methodology. These are in the scope of the actual and larger risk assessment process that uses the vulnerability assessment results to answer the following additional questions: (1) Based on the vulnerabilities identified, what is the likelihood that the system will fail? (2) What are the consequences of such failure (e.g. cost, lives)? (3) Are these consequences acceptable?
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
The vulnerability assessment methodology described is designed to be comprehensive in terms of accommodating physical and cyber threats against the complete suite of mission-critical systems making up a facility. Possible threats/hazards to be covered are e.g. accidents, criminal activity, sabotage/espionage, terrorism, information warfare (IW), civil unrest, natural disasters/accidents, conventional weapons and

weapons of mass destruction (WMD). As typical elements of natural disasters are given e.g. tornados, hurricanes, floods and earthquakes.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The described methodology focuses on the vulnerability assessment of individual critical infrastructure facilities. Vulnerability assessment is defined in the paper as a process, which involves looking at the system elements and layout and their failure modes based on a given set of threats or "insults." The vulnerability assessment answers the basic question, "what can go wrong should the system be exposed to threats and hazards of concern?".
1.5 Parameters and data: Which are the input data/the data required by the method?
Methodology is qualitative from its nature and doesn't necessarily need numerical input data.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Rating Matrice?
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
(Qualitative) methodology
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
?
1.9 Advantages and disadvantages with the methodology
No explicitly expressed advantages and disadvantages in the paper. One advantage could be the one that methodology is designed to be comprehensive in terms of accommodating both the physical and cyber threats.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Possibly relevant to some extent for INTACT although the methodology doesn't focus only on EWEs. The methodology could be used e.g. in self-assessments carried out by infrastructure service providers
2 Uncertainties *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
No.
3 Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
Not really. Only a hypothetical example of a system/threat matrix for a regional telecommunications operations center is provided in a one figure (Figure 5 in the paper).

4 Software
If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)
No mentioning about software tools developed.
5 Further comments
If you have further comments about the document that you have reviewed, please include it here

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
VTT
Complete reference of the reviewed document (include Internet links, if available):
Risk and Vulnerability Analysis of Power Systems Including Extraordinary Events Gjerde, O. (SINTEF Energy Res., Trondheim, Norway); Kjolle, G.H.; Detlefsen, N.K.; Bronmo, G. Source: 2011 IEEE PES PowerTech - Trondheim, p 5 pp., 2011
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference paper
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
The paper describes a framework and methodology for risk and vulnerability analysis including extraordinary events in power systems. The framework is based on a bow-tie structure (see Figure below) and identifies threats, unwanted events, barriers and consequences. The bow-tie methodology is a very general framework in risk management, and thus widely described also in other publications, books etc. related to risk management. In the methodology presented in the paper, and especially in the presented case study main methods applied were the well-known fault tree analysis and event tree analysis. The methodology was not by any means focused on extreme weather events only, as the major categories of threats included also such as technical/operational causes, human errors and antagonistic causes (terror or sabotage) as can be seen in the figure below.



1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Geographic scale is not likely a relevant aspect in the methodology. It is understood that the size of the power system to be studied can vary e.g. from a local power network to a nation-wide transmission system. The focus is on direct losses i.e. on the amount of disconnected load and stipulated average (weighted) duration.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
The described framework and methodology are not suited to extreme weather events only. Instead they could include threat categories like natural hazards (e.g. a major storm), technical/operational causes, human errors and antagonistic causes such as terror or sabotage.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The methodology covers all the aspects of the studied scenario i.e. threats, unwanted events, barriers and consequences.
1.5 Parameters and data: Which are the input data/the data required by the method?
The data required by the framework/methodology varies on the basis of that, what are the actual methods used in the different steps of the analysis. E.g. in the step "causal analysis" such methods as FMEA/FMECA, Fault tree analysis, Expert judgement, are mentioned as possible methods.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Engineering method / method based on fault and event trees.
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Semi-quantitative / quantitative method.
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
?

1.9 Advantages and disadvantages with the methodology
In the paper it is mentioned that the most challenging parts of a risk and vulnerability analysis is how to identify the vulnerable operational states and extraordinary events.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Possibly relevant to some extent for INTACT. However the framework/methodology described (so called bow-tie diagram/analysis) is a very general framework in risk management, and thus widely described also in other publications, books etc. related to risk management.
2 <u>Uncertainties</u> *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
No other discussion about uncertainties except that as the most challenging parts of a risk and vulnerability analysis was mentioned as how to identify the vulnerable operational states and extraordinary events.
3 <u>Case studies</u> *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
Yes, there was presented one case study in the paper (section III in the paper). In the case study the risk and vulnerability of extraordinary events in a 420 kV transmission system were analysed. In the study one of the identified unwanted events was described as "loss of both AC lines if import on AC lines is > 900 MW". The definition of the event in this way was based on the expert judgment, which stated that it is likely that the system will not withstand loss of the AC connection when import on the AC lines is higher than 900 MW. Threats or causes, leading to loss of both AC lines, were identified by expert judgment and they were 'unwanted unselective breaker tripping', 'thunderstorm', 'sabotage', 'transportation accident', 'earth line breakage', 'galloping lines', 'station fault' and 'power outage at feeding end'. After the identification of threats and unwanted events the study continued in steps of 'causal analysis', 'consequence analysis' and 'risk and vulnerability evaluation'. The study was not by any means focused on extreme weather events as can be seen from the earlier presented list of threats and causes covered in the study.
4 <u>Software</u> *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
No mentioning about software tools developed.
5 <u>Further comments</u> *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
J. Douglas
Complete reference of the reviewed document (include Internet links, if available):

PHYSICAL VULNERABILITY MODELLING IN NATURAL HAZARD RISK ASSESSMENT

Nat. Hazards Earth Syst. Sci., 7, 283–288, 2007

www.nat-hazards-earth-syst-sci.net/7/283/2007/

J. Douglas

BRGM – ARN/RIS, 3 avenue C. Guillemin, BP 36009, 45060 ORLEANS Cedex 2, France

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Journal article

1. Methodological approach

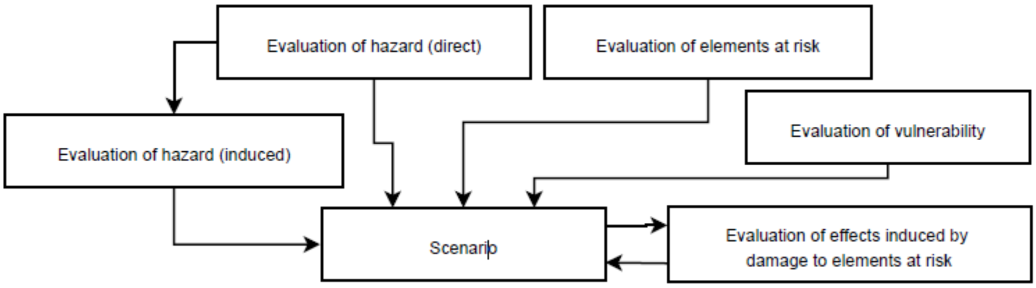
Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

To perform a risk assessment for an exposed element to the hazards of an event is necessary to consider and model the vulnerability of the affected elements. The article discusses the reasons, which generate the differences between approaches that affect the development of a risk assessment method for different risks caused exclusively by natural events and, in particular, focuses on the techniques used to evaluate earthquakes risks and how this assessment, can be used for other types of risks.

Also, the article, highlights with examples, why is not needed any vulnerability model for the different natural events, pointing and contrasting the parameters that are used to assess the earthquake event, where it is common to make vulnerability models.

The journal article, comment briefly, about new methods used to make fragility functions (used to make vulnerability models), for all the natural events, but those methods, have never been in practice and still under development.



1.2 Scale

- Geographic scale (site specific, local, regional, national)
- Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Geographic scale: It can be used on different scaled

Scale of losses: Focus on direct and indirect losses, also cascading effects are considered

1.3 Considered hazards

In this article are only considered natural hazards as landslides, volcanoes, earthquakes, floods, tsunamis, cyclones, etc.

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

Qualitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

The methodology used in this article is just qualitative, since compares, the different hazards generated by natural events and provides in the conclusions, differences between how should be earthquakes risks and others natural events risks, assessed, without using any quantitative calculation.

1.6 Parameters and data:

- **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?**
- **Which are the input data/the data required by the method?**

The methodology focuses on risk, pointing vulnerability and losses too.

The input data required, are the information provided by the different natural events assessed

1.7 Advantages and disadvantages with the methodology

The advantages provided by the method are clarifying the parameters of the different types of natural events in order to perform different risk and vulnerability assessment for, on one side, unpredictable events such as earthquakes, and on the other side, predictable events such as floods. In addition, it's indicated with examples, why, the vulnerability models are not as important for the natural events different of the earthquakes.

Nevertheless, the disadvantages are the lack of numerical calculations or models for the risk and vulnerability analysis.

2. Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

3. Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

This article does not propose any case by himself, but if it's referred in paragraph 3 the 2004 Indian Ocean tsunami case

4. Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

5. Further comments

If you have further comments about the document that you have reviewed, please include it here

The article concludes that for certain types of natural phenomena (e.g. coastal erosion) due to characteristics different to those of earthquakes the concept of explicitly using fragility curves may not be appropriate and the current method of hazard assessment coupled with a consideration of the exposure of vulnerable elements may be sufficient.

In addition, the goal of assessments for such hazards is different to that for earthquakes. They seek to pinpoint the area at danger for evacuation purposes or to intervene using an engineering approach to prevent the occurrence of the possible event rather than to estimate the possible impact of events (such as earthquakes) that cannot be predicted nor prevented.

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

André, C., Monfort, D., Bouzit & M., Vinchon, C. 2013.

Complete reference of the reviewed document (include Internet links, if available):

Natural Hazards and Earth System Sciences Discussion, Vol. 1, pp. 829-854.

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Journal article

1. Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

There are two main approaches in developing damage functions: synthetic methods and empirical ones. While synthetic approaches rely on expert judgment, empirical approaches use damage data derived from ex-post assessments of actual past events.

The method proposed in this document (empirical), try to analyze coastal flooding studying two real cases: Johanna (France 10 March 2008) and Cynthia (France and Spain28 February 2010).

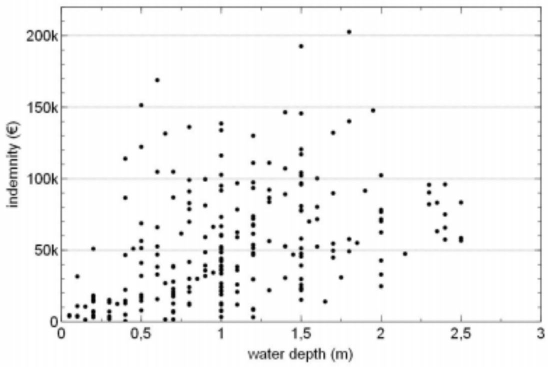
The input data comes from ex- post damage datasets from three significant French insurance companies, which provided access to their compensation datasets. Those records contain some basic information of the damage and this general information is called "first level of information" of the damage database.

However, residential buildings have been the type of assets most affected by the two storms, so that, are the most relevant to produce a statistical study. Therefore, from the "first level information" (that doesn't provides information on damage processes or on asset characteristics), a sampling of the most interesting residential buildings damages, was taken to made detailed adjustment reports by experts, which contains detailed information for residential building records. This new detailed data record is called "second level of information".

This data compilation was performed using database software that manage the information in blocks and in addition, in order to visualize the impact area of the events and to conduct a spatial analysis, the datasets of both levels were georeferenced in GIS software.

From the first level of information, the damage record lists contain all the records from the three insurance companies that allowed statistics to be computed about the comprehensive impact of the two storms.

For the second level of information, the detailed database compiled contains a smaller number of damage records, but it did allow the damages processes and costs to be analyzed in greater detail and a damage typology to be developed.



Damages are classified according to three principal types (Damages to main buildings, accessory buildings and outdoor buildings) that can be used to separate costs into homogeneous.

The method concludes that to have empirical direct damage data precision, standardizing data collection in the loss adjustment process is recommended to the insurance profession and that could significantly contribute to the production of empirical damage functions.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Geographic scale: local, regional, and national
Scale of losses: this method is focus on direct tangible losses, in particular to residential building damages

1.3 Considered hazards

Coastal flooding hazards (water depth, flood duration, flow velocity…)

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

Semi-quantitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

Empiric approach

1.6 Parameters and data:

- **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?**
- **Which are the input data/the data required by the method?**

The methodology is focus on vulnerability and loss, both linked with the economic aspect

1.7 Advantages and disadvantages with the methodology

Advantages: The method, sought to demonstrate the benefits and limits of using ex-post damage datasets to explain which kinds of data may be available within the insurance sector, under what form the information is stored, how it can be used for the purposes of processing damage functions, and how collecting and archiving data by insurers could be integrated in a framework liable to improve damage function processing.

Disadvantages: The method of this document only use two real cases of coastal flooding and because of it is an empirical assessment, with more cases to study, best results will be obtained.

2. Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

To draw up damage functions, cost estimates were intersected with water depth for each record but uncertainty on water depth measurements, variability on cost assessment processes, and variability on the architectural characteristics makes the information very heterogeneous. These observations present an obstacle to developing damage functions from insurance damage dataset, and need to be reinforced by other data sources.

To move on from an ex-post approach to an ex-ante approach for assessing potential future damage, numerical models will also be needed and to evaluate the vulnerability and initial value of assets, some data, in addition to that provided by insurance, can also be sought in institutional databases.

Furthermore, empirical damage functions from ex-post damage assessments raise questions on spatial transferability and temporal durability.

3. Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

In this method two real cases had been studied, Johanna (France 10 March 2008) and Cynthia (France and Spain 28 February 2010). These cases, redacted on the point 1.1 of the present document, with the datasets of the three French insurance companies provide the necessary information to obtain the results of the method.

4. Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

5. Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

European Commission SEC (2009) 92.

Complete reference of the reviewed document (include Internet links, if available):

European Commission

IMPACT ASSESSMENT GUIDELINES

15 January 2009

SEC(2009) 92

http://ec.europa.eu/smart-regulation/impact/commission_guidelines/commission_guidelines_en.htm

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Govt inst publication

1. Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

This document have described the guidelines that replace the Commission Guidelines adopted in June 2005 and updated in March 2006. Those guidelines consist of a core text (this document) and annexes. The core text explains what impact assessment (IA) is, presents the key actors, sets out the procedural rules for preparing, carrying out and presenting an IA, and gives guidance on the analytical steps to follow in the IA work.

The document is divided in three parts:

- Part I: Impact assessment Basics and procedures

- Part II: Key analytical steps in impact assessment

- Part III: Annexes (This part is within a separate document)

In the part I, the impact assessment (IA) is defined, and the key analytical steps, which have to be followed when carrying out an IA, are summarized in a table that answer a number of questions. It is also described, why is IA so important and is defined the objectives, the actors, the procedures and the scope and level of IA analysis.

Within the procedures, is presented a roadmap and the SPP cycle, also, The IA Steering Group is defined as well as the IA board and the steps for build a IA report (format, number of pages, etc). In addition, the key procedural steps to achieve an IA are presented in the table below.

	Summary of key procedural steps
1	Plan impact assessment: Roadmap, integration in the SPP cycle and timetable.
2	Work closely with your IA support unit throughout all steps of the IA process.
3	Set up an Impact Assessment Steering Group and involve it in all IA work phases.
4	Consult interested parties, collect expertise and analyse the results.
5	Carry out the IA analysis.
6	Present the findings in the IA report.
7	Present the draft IA report together with the executive summary to the Impact Assessment Board (IAB) and take into account the possible time needed to resubmit a revised version.
8	Finalise the IA report in the light of the IAB's recommendations.
9	IA report and IAB opinion(s) go into Inter-Service Consultation alongside the proposal.
10	Submission of IA report, executive summary, IAB opinion(s) and proposal to the College of Commissioners.
11	Transmission of the IA report and the executive summary with the proposal to the other Institutions.
12	Final IA report and IAB opinion(s) published on Europa website by SG.
13	In the light of new information or on request from the Council or the EP, the Commission may decide to update the IA report.

In this section of the document, is specified too, that good quality data are an essential part of any IA. This data is needed in order to define the problem and the baseline scenario, and to identify the impacts of alternative options for dealing with the problem. In addition is a treaty obligation consulting those who will be affected by a new policy or initiative or who will implement it, so, consulting stakeholders is fundamental, and the procedures for doing this consulting are specified to in this document.

In part II of the present document, the first step is to define the problem in order to describe and provide evidence of the nature and scale of it. The problem definition must include a clear baseline scenario as the basis for comparing policy options.

When the assumptions underlying the baseline scenario might vary as a result of external factors, a sensitivity analysis is needed to assess

whether the impacts of the policy options differ significantly for different values of the key variables. The document provides too how to carry out risk assessment and when it is required.

In this section of the document, policy objectives and procedures are defined (General objectives, Specific objectives, Operational objectives), as well as Policy options, with the details of the information obligations for businesses, for citizens and national/regional/local administrations that are likely to be added or eliminated if the option were implemented. There is also defined the likely economic, social and environmental impacts and how to approach the analysis with three steps expressed in the next image.

Step 1	Identification of economic, social and environmental impacts
Step 2	Qualitative assessment of the more significant impacts
Step 3	In-depth qualitative and quantitative analysis of the most significant impacts

The steps to compare the options are given and is expressed how to present it by:

- Cost-benefit analysis

- Cost-effectiveness analysis

- Cost benefit thinking through multi-criteria analysis

Finally, the document define how the evaluation criteria and the ranking options are, as well as provide arrangements for future monitoring and evaluation.

1.2 Scale

- Geographic scale (site specific, local, regional, national)
- Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Geographic scale: It's focus on the UE.

Scale of losses: Focus on direct and indirect losses.

1.3 Considered hazards

Economic, social and environmental hazards are considered

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

Qualitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

The method is a guideline that explains what impact assessment (IA) is, presents the key actors, sets out the procedural rules for preparing, carrying out and presenting an IA, and gives guidance on the analytical steps to follow in the IA work.

1.6 Parameters and data:

- Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?
- Which are the input data/the data required by the method?

The method is focus on impact assessment and the impact assessment work.

The input data is a good definition of the problem and clear understanding of what causes it.

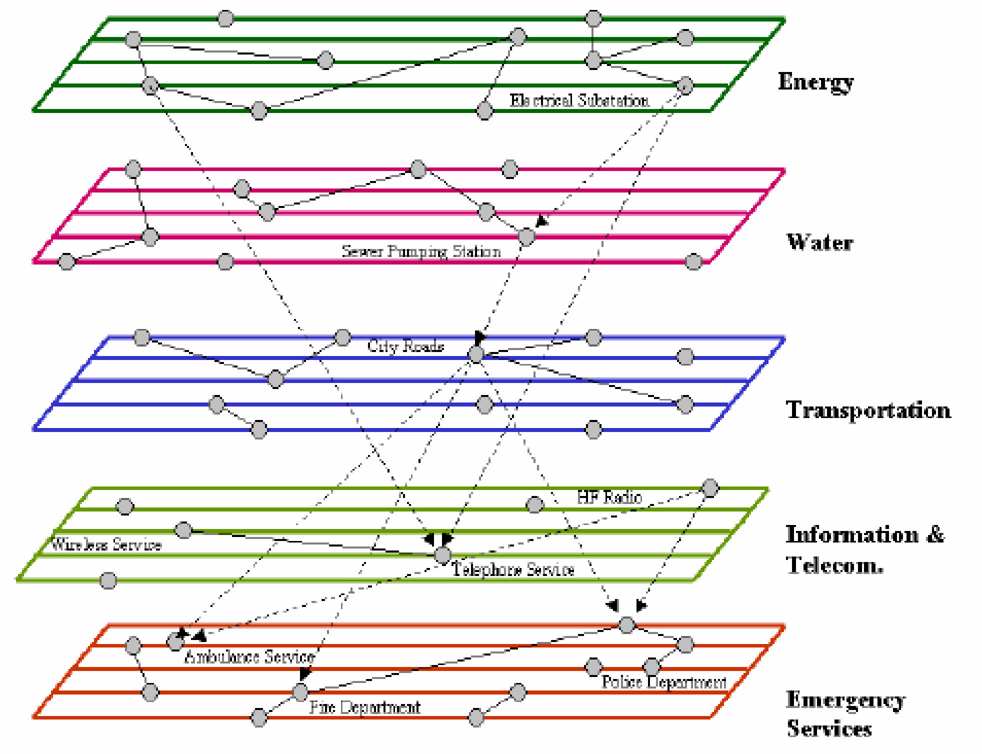
1.7 Advantages and disadvantages with the methodology

The advantages: This document clarify, with the steps to be followed, the procedure of an impact assessment. **The disadvantages: These Guidelines do not define which Commission initiatives need to be accompanied by an IA.**
2. **Uncertainties** ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
3. **Case studies** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
4. **Software** ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
5. **Further comments** ***If you have further comments about the document that you have reviewed, please include it here***

Literature to section 3.3:

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Ruben Vogel, Olaf Koops
Complete reference of the reviewed document (include Internet links, if available):
CIMS: A FRAMEWORK FOR INFRASTRUCTURE INTERDEPENDENCY MODELING AND ANALYSIS **Donald D. Dudenhoeffer** **May R. Permann** **Idaho National Laboratory** **P.O. Box 1625** **Idaho Falls, ID 83415-3605, U.S.A.** **Milos Manic** **Department of Computer Science** **University of Idaho at Idaho Falls** **Idaho Falls, ID 83402, U.S.A.**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference paper
1. **Methodological approach**

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).
While modeling and simulation tools have provided insight into the behavior of individual infrastructure networks, a far less understood area is that of the interrelationships among multiple infrastructure networks including the potential cascading effects that may result due to these interdependencies.
1.1 Methodological approach description
The paper describes a modeling and simulation framework called CIMS© CIMS© was developed to examine the interrelationships between infrastructure networks and more specifically, the emergent systems behaviors that develop when one or more nodes within the system are perturbed. This paper has presented a formalization to categorize infrastructure interdependencies. The purpose in this formalization attempt is to create a common language for discussion, algorithmic development, and analysis.
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Geographic scale: It can be used on different scaled (case scale: New Orleans) **Scale of losses: Focus on interdependencies an thus potential cascading effects**
1.3 Considered hazards
All (flooding is used in case)
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)
Semi-quantitative
1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)
The CIMS© architecture uses an agent-based approach (ABM) (Rocha 1999) to model infrastructure elements, the relations between elements, and individual component behavior.
1.6 Parameters and data: • **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?** • **Which are the input data/the data required by the method?**
The methodology focuses on the interdependencies between infrastructures
1.7 Advantages and disadvantages with the methodology
CIMS© takes a command-level approach seeking to provide decision makers with sufficient information in terms of mission capability without digging into the engineering level.
2. **<u>Uncertainties</u>** ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
-
3. **<u>Case studies</u>** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
An example is used that is very similar to the situation in New Orleans during Hurricane Katrina. Interdependencies between several infrastructures are modelled (emergency services, transport, ICT, water, energy)



4. <u>Software</u>

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

The interdependency modeling framework CIMS© was introduced as a tool for infrastructure analysis supporting the ability to conduct "what if" scenario analysis.

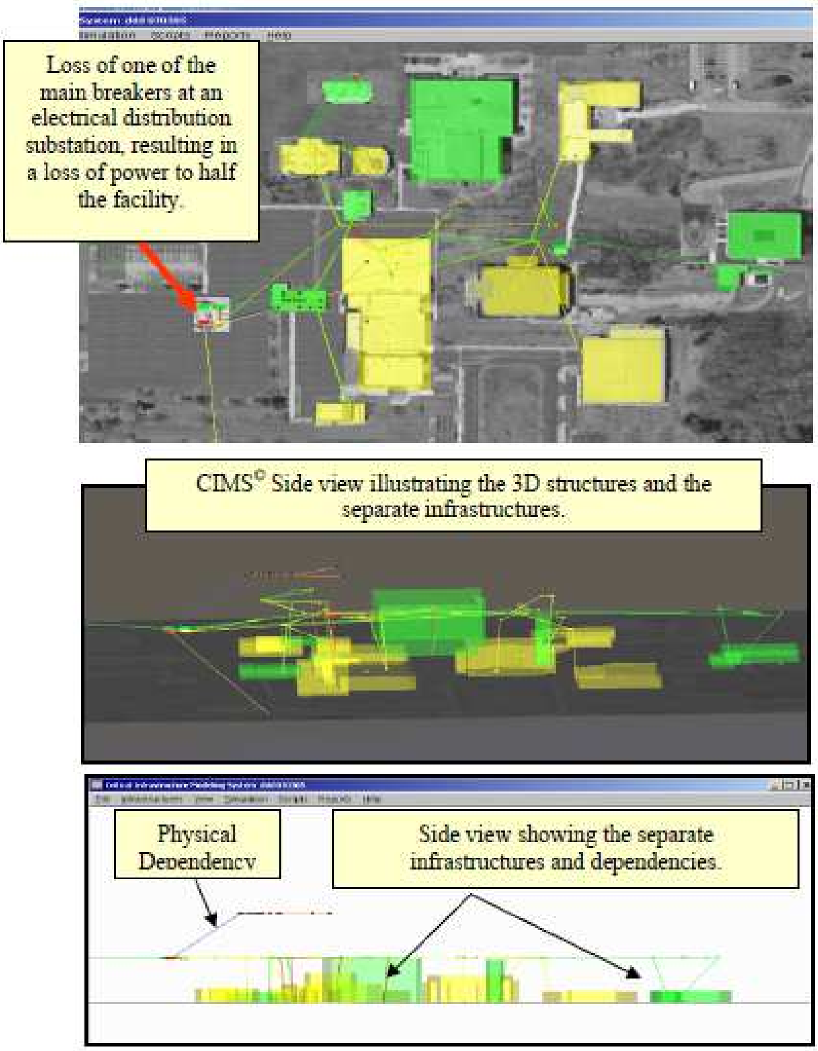


Figure 3: Infrastructure Components Surrounding a Facility

5. <u>Further comments</u>

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

Vogel, Ruben en Koops, Olaf

Complete reference of the reviewed document (include Internet links, if available):

Luiijf, H.A.M., Nieuwenhuijs, A.H., Klaver, M.H.A., van Eeten, M.J.G. and Cruz, E. (2010)
Empirical findings on European critical infrastructure dependencies,
Int. J. System of Systems Engineering, Vol. 2, No. 1, pp.3–18

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Journal paper

6 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

At the core of our analysis is a database with public reports of CI disruptions, collected from open sources like newspapers and internet news outlets. Based on this subset, we empirically study CI (inter)dependencies. A CI dependency is the relationship between two CI products or services in which one product or service is required for the generation of the other product or service; a CI interdependency is a mutual CI dependency.

Table 1: Categorisation of number of CI disruption events (number of events).

CI Sector	Cascade initiating	Cascade resulting	Independent	Total	Sample size
Education	0	3	1	4	4
Energy	146	76	388	609	590
Financial Services	1	26	33	60	60
Food	0	4	3	8	8
Government	2	40	26	68	67
Health	1	16	22	39	39
Industry	5	15	7	27	27
Internet	15	51	95	161	160
Postal Services	1	0	0	1	1
Telecom	69	125	114	308	295
Transport	19	128	276	423	422
Water	9	18	51	78	76
Total	268	501	1017	1786	1749

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Local critical Infrastructure disruptions all over Europe

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

No explicit focus on EWE, focus on CI disruption

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling,

more general on risk, risk management etc.)
The focus is on the potential cascading effects of a critical infrastructure disruption
1.5 Parameters and data: Which are the input data/the data required by the method?
Reported incidents of Ci disruptions in Europe from open sources like newspapers and internet news outlets
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Database analysis
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
-
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Qualitative
1.9 Advantages and disadvantages with the methodology
Dependent on indirect sources such as news, etc.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
It gives an insight in to what extent the domino effects of cascading infrastructures occurs in reality
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
-
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
-
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
-
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

Vogel, Ruben en Koops, Olaf (TNO)

Complete reference of the reviewed document (include Internet links, if available):

Inter-Infrastructure Simulations across Telecom, Power, and Emergency Services
Gerard O'Reilly1, Member, IEEE, Huseyin Uzunalioglu1, Stephen Conrad2, Walt Beyeler2
1Bell Laboratories, Lucent Technologies, 101 Crawfords Corner Road, Holmdel, NJ 07733 USA
2Sandia National Laboratories, Albuquerque, NM
E-mail: goreilly@lucent.com, huseyin@lucent.com, sconrad@sandia.gov, wbeyeler@sandia.gov

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Journal Paper

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

Figure 2 shows the potential cascading of events across infrastructures.

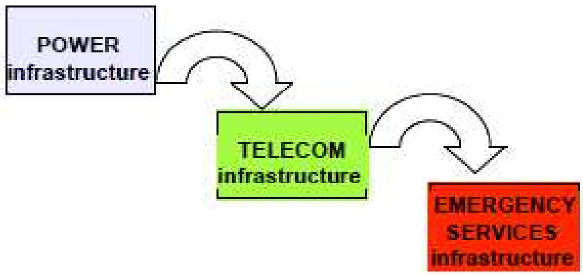


Figure 2 - Cascading of Impacts across infrastructures

1.1 Methodological approach description

The simulation models are implemented using Vensim [3], which can be used for dynamic simulation of other industry infrastructures

1.2 Scale

- Geographic scale (site specific, local, regional, national)
- Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Relation of infrastructures power, telecom, emergency services in a fictional metropolitan area of five million people.

Comprehensive costs include not only the economic cost components, but also a measure of the value of lost quality of life associated with the deaths and injuries, that is, what society is willing to pay to prevent them.

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

No EWE, 'random' black-out is starting point

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Focus on comprehensive costs

1.5 Parameters and data: Which are the input data/the data required by the method?

Number of wireline and wireless network subscribers, black out model
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Simulation approach
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Vensim model
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative methodology
1.9 Advantages and disadvantages with the methodology
There have to be made some assumptions on, yes or no simultaneous infrastructure disruption to the telecom network, except for that caused by lack of power.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
The paper shows how the interactions between infrastructures, such as power, telecom and emergency services can be modeled. And what the expected comprehensive costs for society will be.
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
-
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
-
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
Vensim model
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:

Vogel, Ruben en Koops, Olaf

Complete reference of the reviewed document (include Internet links, if available):

Luiijf, H.A.M., Nieuwenhuijs, A.H., Klaver, M.H.A., van Eeten, M.J.G. and Cruz, E. (2010)

Empirical findings on European critical infrastructure dependencies,

Int. J. System of Systems Engineering, Vol. 2, No. 1, pp.3–18

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Journal paper

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

At the core of our analysis is a database with public reports of CI disruptions, collected from open

sources like newspapers and internet news outlets. Based on this subset, we empirically study CI (inter)dependencies. A CI dependency is the relationship between two CI products or services in which one product or service is required for the generation of the other product or service; a CI interdependency is a mutual CI dependency.

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1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Local critical Infrastructure disruptions all over Europe

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

No explicit focus on EWE, focus on CI disruption

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The focus is on the potential cascading effects of a critical infrastructure disruption
1.5 Parameters and data: Which are the input data/the data required by the method?
Reported incidents of Ci disruptions in Europe from open sources like newspapers and internet news outlets
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Database analysis
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
-
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Qualitative
1.9 Advantages and disadvantages with the methodology
Dependent on indirect sources such as news, etc.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
It gives an insight in to what extent the domino effects of cascading infrastructures occurs in reality
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
-
3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
-
4 Software ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
-

5 **Further comments**	

If you have further comments about the document that you have reviewed, please include it here

Literature to section 3.4:

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

HR Wallingford

Complete reference of the reviewed document (include Internet links, if available):

HR Wallingford (2012) – Development of spatial indicators to monitor changes in exposure and vulnerability to flooding and the uptake of adaptation actions to manage flood risk in England: Results Report

http://archive.theccc.org.uk/aws/ASC/2012%20report/HR%20Wallingford%20flooding%20indicators%20results%20reportAMND.pdf

HR Wallingford (2012) – Development of spatial indicators to monitor changes in exposure and vulnerability to flooding and the uptake of adaptation actions to manage flood risk in England: Technical Report

http://archive.theccc.org.uk/aws/ASC/2012%20report/HR%20Wallingford%20flooding%20indicators%20technical%20report.pdf

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Contributing report to:

Adaptation Sub-Committee (2014). Climate change – is the UK preparing for flooding and water scarcity?

http://archive.theccc.org.uk/aws/ASC/CCC_ASC_2012_interactive_2.pdf

1. **Methodological approach**

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

A method for developing spatial indicators of risk, action and impact was devised by HR Wallingford to provide evidence that fed into the ASC's second report, on preparedness for flooding and water scarcity. The method is based upon the use of a Geographical Information System (GIS) to spatially pre-process data from the most robust and reliable sources of readily available, national scale, data. Pre-processing first involves converting the data into the required spatial format and then clipping the data to tiles and sub-dividing the data into a grid. For this assessment, multiple layers of gridded data on hazards (e.g. flooding) and assets are then built up into a high-resolution spatial database. Queries are subsequently run on the data to identify where the chosen assets and hazards intersect and therefore exposure of the asset to the hazard is possible. Trends may also be identified between different hazards, assets and time periods. Typically, using traditional GIS methods, performing spatial comparison between a large number of mapping datasets can be very time consuming, particularly when processing very complex continuous (e.g. polygon) data. As additional layers are added, it can become impractical due to increasing complexity of the unique combinations through all datasets. The more efficient assessment approach adopted here, using gridded information held within a database, is reliable, unbiased, repeatable, easily validated and can be efficiently extended in the future for new indicators or new snapshots in time.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

National

Direct losses

1.3 Considered hazards

- Critical services and emergency infrastructure in areas of flood likelihood

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

Indicator-based

1.6 Parameters and data:

- **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?**
- **Which are the input data/the data required by the method?**

Vulnerability, exposure.

Data required:

- Ordnance Survey MasterMap AddressLayer 2001, 2008, 2011
- Environment Agency: NaFRA Spatial Internal Grid

1.7 Advantages and disadvantages with the methodology

Handles large datasets in a repeatable manner.

2. Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

No

3. Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

No

4. Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

Workbenches for FME were developed and data was stored in an SQL Server database. These were used for the overlaying of data and reporting the results. They are not generally available.

5. Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

HR Wallingford

Complete reference of the reviewed document (include Internet links, if available):

HR Wallingford (2014) for the Adaptation Sub-Committee. Indicators to assess the exposure of critical infrastructure in England to current and projected impacts of climate change.

http://www.theccc.org.uk/wp-content/uploads/2014/07/5-MCR5195-RT003-R05-00.pdf

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Contributing report to:

Adaptation Sub-Committee (2014). Managing climate risks to well-being and the economy.

http://www.theccc.org.uk/wp-content/uploads/2014/07/Final_ASC-2014_web-version-4.pdf

1. Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

A method for developing spatial indicators of risk, action and impact was devised by HR Wallingford to provide evidence that fed into the ASC's second report, on preparedness for flooding and water scarcity. The method is based upon the use of a Geographical Information System (GIS) to spatially pre-process data from the most robust and reliable sources of readily available, national scale, data. Pre-processing first involves converting the data into the required spatial format and then clipping the data to tiles and sub-dividing the data into a grid. For this assessment, multiple layers of gridded data on hazards (e.g. flooding) and assets are then built up into a high-resolution spatial database. Queries are subsequently run on the data to identify where the chosen assets and hazards intersect and therefore exposure of the asset to the hazard is possible. Trends may also be identified between different hazards, assets and time periods. Typically, using traditional GIS methods, performing spatial comparison between a large number of mapping datasets can be very time consuming, particularly when processing very complex continuous (e.g. polygon) data. As additional layers are added, it can become impractical due to increasing complexity of the unique combinations through all datasets. The more efficient assessment approach adopted here, using gridded information held within a database, is reliable, unbiased, repeatable, easily validated and can be efficiently extended in the future for new indicators or new snapshots in time.

The 91 indicators of exposure taken forward for spatial analysis cover 6 infrastructure sectors and 7 weather related-hazards: flooding from rivers or the sea, flooding from surface water, flooding from groundwater, coastal erosion, shrink-swell subsidence, natural landslides and river scour.

Table 1: Indicators of exposure

		Flooding (River and Coastal)	Flooding (groundwater)	Flooding (surface water)	Coastal erosion	Shrink-swell subsidence	Natural landslides	Bridge scour
Education	Schools	✓	✔	✔	✓	✔	✔	
Energy	Substations	✓	✔	✔	✓	✔	✔	
	Power stations	✓	✔	✔	✓	✔		
	Towers				✓	✔	✔	
	Turbines	✓	✔		✓	✔	✔	
	Cable				✓	✔		
	Gas pipes				✓	✔		
Health	Care homes	✓	✓	✓	✓	✓	✓	
	Emergency services	✓	✔	✔	✓	✔	✔	
	GPs	✓	✔	✔	✓	✔		
	Hospitals	✓	✔	✔	✓	✔		
ICT	Data centres	✓	✔	✔	✓	✔	✔	
	Mobile telecommunication masts				✓	✔	✔	
Transport	Railway stations	✓	✓	✓	✓	✓	✓	
	Railway lines	✓	✔	✔	✓	✔	✔	
	Roads	✓	✓	✓	✓	✓	✓	
	Road and rail bridges					✔		✓
Water	Clean water treatment works	✓	✔	✔	✓	✔		
	Waste water treatment works	✓	✔	✔	✓	✔		

Source: ***✔present day only was assessed. ✓present day and recent trends or future projections assessed. Not all assessed results are presented in the chapters.***

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

National

Direct losses

1.3 Considered hazards

- Flooding (river and coastal)

- Flooding (groundwater)
- Flooding (surface water)
- Bridge scour
- Shrink-swell subsidence
- Natural landslides
- Coastal Erosion

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

Indicator-based

1.6 Parameters and data:

- **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?**
- **Which are the input data/the data required by the method?**

Vulnerability, exposure.

Data required:

Hazards

- Environment Agency: NaFRA Spatial Internal Grid 2013 (flooding from rivers or the sea).
- Environment Agency: Updated Flood Map for Surface Water
- Environment Agency: National Coastal Erosion Risk Map (NCERM) 2011.
- British Geological Survey: Map of susceptibility to natural landslides. British Geological Survey © NERC. All rights reserved.
- British Geological Survey: Map of susceptibility to shrink-swell subsidence. British Geological Survey © NERC. All rights reserved.
- ESI: Groundwater flooding risk map. ESI Groundwater Flood Risk Map of England and Wales © http://esinternational.com/

Assets

- Department for Education (DfE): 2013 Performance Statistics Spine Data (school location).
- DfE: 2013 School Census (number of pupils).
- Care Quality Commission: Registered care homes (March 2008, January 2012 and November 2013).
- Ordnance Survey MasterMap, October 2013: Emergency services locations.
- Health and Social Care Information Centre: GP practices Q4 2013 and Hospital Estates and Facilities Statistics, 2012/2013.
- National Grid: Electricity transmission substations, underground electricity cable, towers locations (2013).
- Energy Networks Association: Substations in a floodplain.
- National Grid Distribution, Wales and West Utilities, Southern Gas Networks and Northern Gas Networks: Underground gas pipe location, with the help of the Health and Safety Laboratory (2013).
- Renewable UK: Wind farm location (2013).
- Environment Agency (EA): Power stations locations (derived from IPCC licences) (2010).
- **Data Centre Map © Data Centre Map.**
- OFCOM: Mobile telecommunications masts (May, 2013).
- Network Rail: Railway line criticality 2013.
- Ordnance Survey data © Crown copyright and database right 2013: Railway stations.
- OpenStreetMap: Road network © OpenStreetMap contributors http://www.openstreetmap.org/copyright Rail/Road bridges
- Department for Transport: Annual Average Daily Flow 2001, 2008 and 2012.
- Department for Transport: Major Road link network, 2013.
- Ordnance Survey MasterMap, October 2013, Clean water treatment locations.
- Yorkshire Water 2013, Clean water treatment locations
- Severn Trent Water 2013: Clean water treatment locations.
- Environment Agency: Consented Discharges to Controlled Waters, 2013.

1.7 Advantages and disadvantages with the methodology

Handles large datasets in a repeatable manner.

There were considerable difficulties that needed to be overcome to gather the required data.

2. **Uncertainties** ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No explicit discussion about uncertainty but it is discussed with regard to UKCP09 future projections and National Coastal Erosion Risk Map (NCERM) pojections of erosion rates.
3. **Case studies** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
No
4. **Software** ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
Workbenches for FME were developed and data was stored in an SQL Server database. These were used for the overlaying of data and reporting the results. They are not generally available.
5. **Further comments** ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HR Wallingford and CRIDF
Complete reference of the reviewed document (include Internet links, if available):
CRIDF Climate Vulnerability Tool **http://geoservergisweb2.hrwallingford.co.uk/CRIDF/CCVmap.htm**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Website
1. **Methodological approach** ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
The CRIDF Climate Vulnerability Tool is used to bring together datasets to be used in a climate vulnerability assessment of CRIDF projects. CRIDF is DFID's new water infrastructure program for southern Africa. Over the next three years, the Facility will design and deliver sustainable small-scale infrastructure across 11 SADC countries. **The user is able to search for a particular location, click on the map and see data from the various layers available for display on the map and**

use that information to feed into decisions made on water infrastructure projects.

1.1 Methodological approach description

Identify appropriate layers for inclusion in the tool. These were found primarily from the Aqueduct dataset, but also from CCAPS and some CMIP5 data was used.

Some layers were combined to create new layers to indicate, for example, an overall risk to people.
Generate new layers for the tool that apply climate change.
The resilient populations layer combined population density with household and community resilience and governance. This layer was then combined with a physical water risks layer to produce baseline risks to people. The climate change scenario was then added to produce and overall future risks to people layer.

1.2 Scale

- Geographic scale (site specific, local, regional, national)
- Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Regional – SADC countries with particular interest in trans-national basins.

1.3 Considered hazards

- Baseline water stress
- Inter-annual variability
- Seasonal variability
- Flood frequency
- Drought severity
- Upstream storage
- Groundwater stress
- Household and community resilience
- Population density
- Resilient populations
- Baseline risks to people
- Climate change pressures
- Water risk under climate change
- Future risks to people

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

Indicator-based

1.6 Parameters and data:

- Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?
- Which are the input data/the data required by the method?

Vulnerability

- Gassert, F., M. Luck, M. Landis, P. Reig, and T. Shiao. 2013. Aqueduct Global Maps 2.0. Working Paper. Washington, DC: World Resources Institute.
- Climate security vulnerablilty Mode, Version 3.0 Methodology April 2013. Joshua Busby, Todd G. Smith, Nisha Krishnan and Mesfin Bekalo.
- CMIP5 climate data: National Institute of Meteorological Research, HadGEM2-AO

1.7 Advantages and disadvantages with the methodology

Brings together several datasets from disparate sources so that they can be used in conjunction with each other.

Combines composite layers – without understanding of the contributing layers, these may be misapplied.

Considers only one climate change scenario.

2. <u>Uncertainties</u> *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
No
3. <u>Case studies</u> *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
No
4. <u>Software</u> *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
Website for Chrome, Firefox and Safari browsers
5. <u>Further comments</u> *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HR Wallingford (HRW)
Complete reference of the reviewed document (include Internet links, if available):
http://www.oiip.ac.at/fileadmin/Unterlagen/Dateien/Publikationen/FINAL_RECIPE_manual.pdf   **Klaver et al 2011, RECIPE Good Practices Manual for CIP Policies**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Project report (EU-funded)
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***

1.1 Methodological approach description
This is a summary document, that collated information from across and Europe and wider afield, and included stakeholder discussions to understand existing policies and practices for improving the protection of CI. It provides a set of examples of good practice, with clear examples and references, so that policy makers on other countries can see what has already been done elsewhere.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Considers all scales and examples from across the world.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Considers a range of hazards and provides examples of how they were dealt with.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Covers all aspects related to CI, including public-private interaction, CI dependencies, risk management, crisis management.
1.5 Parameters and data: Which are the input data/the data required by the method?
N/A
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Guidance document, with examples and reference material to be followed up if required
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Methodology (theory & practice)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Qualitative
1.9 Advantages and disadvantages with the methodology
N/A
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Relates to CI and how this can be better protected, and integrated into national policy frameworks
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
N/A

3 **Case studies** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Document includes many case studies covering a wide range of countries, topics etc.
4 **Software** ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
N/A
5 **Further comments** ***If you have further comments about the document that you have reviewed, please include it here***
This document should be reviewed by others working on the other chapters of the SOTA report.
RECIPE (Good Practices Manual for CIP Policies) **Important to know where and in what ways the functioning of assets can be affected. Risk management shows which components are being addressed, show the relative significance of the impacts, and where the most benefit can be achieved. RM can be used across all levels of assessment. National RA will also include societal impact. Providing a common risk framework and set of tools will assist in allowing organisations to carry out compatible assessments, and in turn this can ensure that societal impacts are also considered. RA methodologies are well-established in several countries, such as UK, Germany and Denmark (e.g. Danish RVA Method). Can either provide guidance and tools to help organisations adopt RM, or have mandatory requirement for such an assessment, or carry out a national risk assessment, which includes all relevant risks and stakeholders in the assessment.** **Crisis management requires involvement of CI operators in some form of the CM process. Governmental CM will consider roles, responsibilities and resources that are needed. CI operation may also be critical to the CM process and assist in the response, recovery etc., so important that the CI is kept going or recovers quickly.**

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HR Wallingford (HRW)
Complete reference of the reviewed document (include Internet links, if available):
Heikkilä, A.-M., Molarius, R., Rosqvist, T. & Perrels, A. (2012). Mitigating the impacts of extreme weather originated disasters by simulating the effects of different preparation and action decisions of crisis management. Second Nordic International Conference on Climate Change. **www.nordicadaptation2012.net/Doc/Poster_presentations/P25_Heikkila.pdf**

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

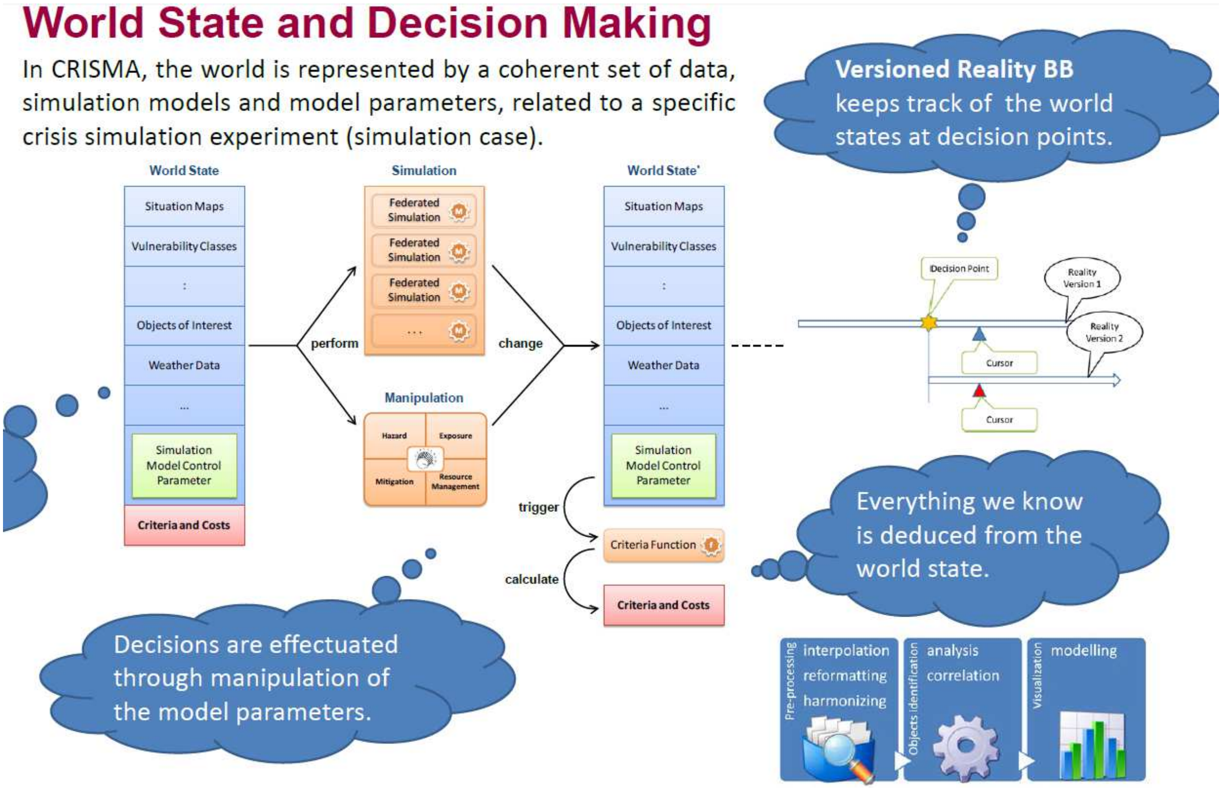
Conference poster

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

CRISMA Integrated Project - integration of existing and future models, tools and data like GMES, in order to simulate complex crisis scenarios like: natural hazards with irreversible damages and related vulnerability, potential response actions and their impacts, and technical, organisational and social preparedness of a region or regions with respect to the natural hazards.



1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Regional / large scale

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Non-specific (any)

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Mitigation, impact of various decisions, risk management
1.5 Parameters and data: Which are the input data/the data required by the method?
Data and parameters related to specific crisis simulation experiment
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Simulation approach
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Software tool – a framework for integration of data, models, visualization
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
quantitative
1.9 Advantages and disadvantages with the methodology
n/a
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Relates to extreme weather hazards and associated vulnerabilities and impacts, integrates them into a framework and evaluates the responses
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Two case studies mentioned in the paper, more at: **http://www.crismaproject.eu/usecases.htm** **One pilot case refers to different flooding scenarios in terms of the hazard (tide/rain, wind), vulnerability (dyke breeches) and responses. The other is related to severe Nordic winter.**
4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)
A framework for integration of data and models has been developed within CRISMA project, **http://www.crismaproject.eu** **The framework simulates the impact of crisis depending on both the external factors driving the crisis development and the various actions of the crisis management team. Can be used for response analysis, response training and response planning.**
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HR Wallingford (HRW)
Complete reference of the reviewed document (include Internet links, if available):
IPCC (2012). Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), 594 p. **http://ipcc-wg2.gov/SREX/report/**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
IPCC project report
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
This report explores the understanding and managing the risks of climate extremes to advance climate change adaptation. Some types of extreme weather and climate events have increased in frequency or magnitude, but populations and assets at risk have also increased, with consequences for disaster risk. Report analyses both observed and projected changes. **The report reviews previous research and provides information on how:** **a) Natural climate variability and human-generated climate change influence the frequency, intensity, spatial extent, and duration of some extreme weather and climate events;** **b) The vulnerability of exposed human society and ecosystems interacts with these events to determine impacts and the likelihood of disasters;** **c) Different development pathways can make future populations more or less vulnerable to extreme events;** **d) Experience with climate extremes and adaptation to climate change provides lessons on ways to**

better manage current and future risks related to extreme weather and climate events, and; **e) Populations can become more resilient before disasters strike.**
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Local to international
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Any based on temperature/precipitation/wind extremes, , e.g. droughts, floods, extreme sea levels, waves, glacier, geomorphological, high latitude (incl. permafrost changes), sand and dust storms
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Covers hazards, in general terms also exposure, vulnerability, impact and risk management
1.5 Parameters and data: Which are the input data/the data required by the method?
Weather and climate variables
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Refers to: CC models for extreme weather; exposure and vulnerability through various environmental, social, economic metrics, expressed as indices;
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Review with references to various approaches
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative/qualitative
1.9 Advantages and disadvantages with the methodology
n/a
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
A more general review (i.e. not specifically related to infrastructure), but with references to water use (p243); chapter with references to infrastructure on p248-250, and risk-management related to infrastructure p366-368

2	**Uncertainties**

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

Yes - based on the Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Two metrics for communicating the degree of certainty in key findings, which is based on author teams' evaluations of underlying scientific understanding:

• Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively.

• Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment).

3 Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

Several cases are presented, both projected and observed (Chapter 9, worldwide)

4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

n/a

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

HR Wallingford (HRW)

Complete reference of the reviewed document (include Internet links, if available):

Homeland Security (2013) Supplemental Tool: Executing a Critical Infrastructure Risk Management Approach.
http://www.dhs.gov/publication/executing-critical-infrastructure-risk-management-approach

Homeland Security (2013) Supplemental Tool: connecting to the NICC and NCCIC.

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Paper

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc.

are considered; you can include figures (with respective references).

This supplement describes a critical infrastructure risk management approach, which supports the risk management framework depicted below.

Figure 1: Critical Infrastructure Risk Management Framework

The critical infrastructure risk management framework supports a common, unifying approach to risk management that all critical infrastructure partners can use, relate to, and align with their own risk management models and activities.

1.1 Methodological approach description

The critical infrastructure risk management approach includes the following activities:

- Set Goals and Objectives: Define specific outcomes, conditions, end points, or performance targets that collectively describe an effective and desired risk management posture.
- Identify Infrastructure: Identify assets, systems, and networks that contribute to critical functionality and collect information pertinent to risk management, including analysis of dependencies and interdependencies.
- Assess and Analyze Risks: Evaluate the risk, taking into consideration the potential direct and indirect consequences of an incident, known vulnerabilities to various potential threats or hazards, and general or specific threat information.
- Implement Risk Management Activities: Make decisions and implement risk management approaches to control, accept, transfer, or avoid risks. Approaches can include prevention, protection, mitigation, response, and recovery activities.
- Measure Effectiveness: Use metrics and other evaluation procedures to measure progress and assess the effectiveness of efforts to secure and strengthen the resilience of critical infrastructure.

Information sharing mechanisms include the following online resources:

- Homeland Security Information Network – Critical Infrastructure (HSIN-CI) provides secure networked information sharing covering the full range of critical infrastructure interests. Validated critical infrastructure partners can access HSIN-CI.
- United States Computer Emergency Readiness Team (US-CERT) and Industrial Control Systems CyberEmergency Response Team (ICS-CERT) portal
- The US-CERT.gov Web site provides extensive vulnerability and mitigation information to partners around the world, including:
    - A control systems section containing Control Systems Advisories and reports of particular interest to critical infrastructure owners and operators.
    - A National Cyber Awareness System, which provides timely alerts, bulletins, tips, and technical documents to those who sign up.
    - Cybersecurity incident reporting, providing critical infrastructure partners with a secure means to report cybersecurity incidents.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

National

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Non-specific

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Risk management
1.5 Parameters and data: Which are the input data/the data required by the method?
Specific to each case
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Indicator based
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Web tools
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
quantitative
1.9 Advantages and disadvantages with the methodology
n/a
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Critical infrastructure risk management approach, with the integration of strategies, capabilities, and governance structures to enable risk-informed decision making
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
n/a
4 Software ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
n/a
5 Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HR Wallingford (HRW)
Complete reference of the reviewed document (include Internet links, if available):
V. Holzhauer, M. Müller and A. Assmann (2008). RISK-EOS flood risk analysis service for Europe. Proc. FLOODRISK conference, Oxford, UK. **Y. Desmazières and M. Paganini (2007). RISK-EOS, Flood and forest fire risk information service. Proc. 'Envisat Symposium 2007', Montreux, Switzerland.** **https://earth.esa.int/workshops/envisatsymposium/proceedings/sessions/4S3/589389de.pdf**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference papers
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
The RISK-EOS services combine the use of satellite observation data with exogenous data (in-situ data, socio-economic data, etc.) and modelling techniques. **They are targeted to serve the needs of all risk management actors at European, National and Regional levels (civil protections, fire fighting and rescue services, land planning and risks prevention services, territorial communities).** **The RISK-EOS Service Network is managed in full cooperation with the Users communities. End-users are well represented and federated by a User Executive Body, which is in charge of driving the services improvement, based on systematic users' feedbacks collection process, organized every year.** **Fire:** **Automatic Burn Scar Mapping service provides during the summer fire season, daily products regarding burn scars mapping at medium-resolution for burnt areas larger than 50 hectares. The maps are an important information source for a fast damage assessment at National to Regional level.**

The Burn Scar Mapping service package provides, seasonally, after the summer and winter fire seasons, information products regarding burn scar mapping at high-resolution (Landsat, SPOT, IRS data) for support to fire fighting and other planning services at regional/provincial scales.

Flooding:

The Flash Flood Early Warning is an alert service for anticipation of flash floods based on AIGA methodology and:

- structural basin parameters derived from satellite observation;

- real-time precipitation data retrieved from hydrological radars.

The Flood Risk Analysis services consist of the production and maintenance of geo-information to

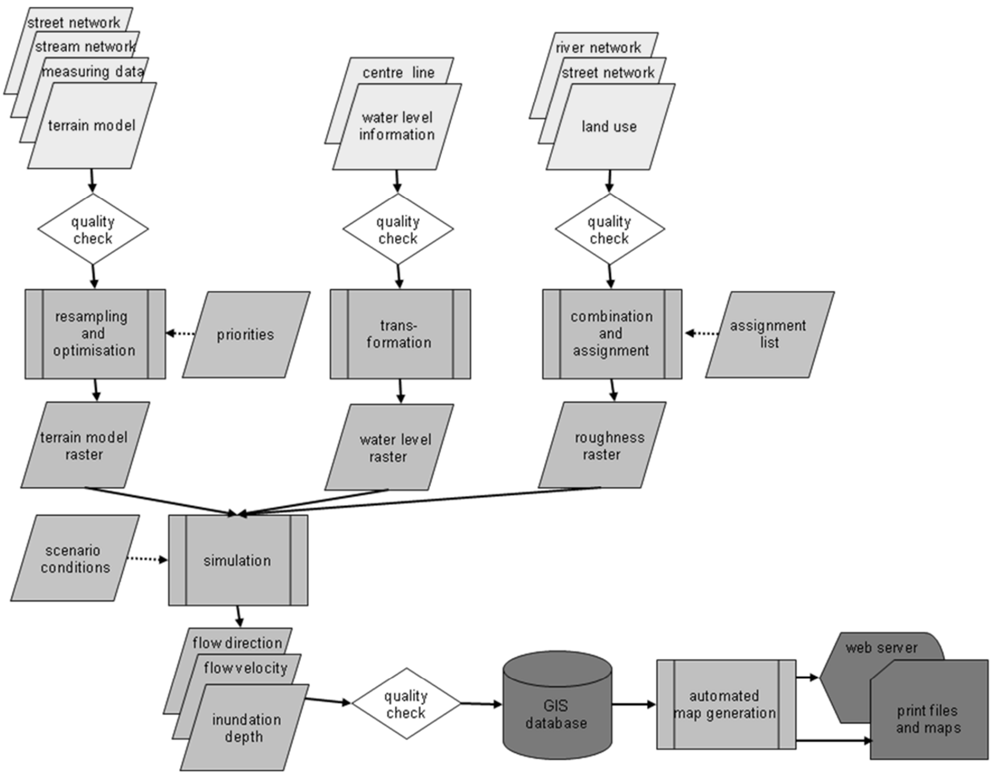
support decision making process in plain flood risk management duties. It produces and maintains geoinformation about the risk-prone areas, i.e. these areas that are potentially subject to floods:

- Past Flood event map (hazard map based on archived satellite data)

- Flood Hazard Map: observations complemented by simulations of flood events by hydraulic models (ArcGIS based FloodArea HPC) with additional data relevant to flood hazard (flow depth, velocity and direction)

- Flood Damage Assessment Map: includes estimated losses and damages, based on land use and statistical data from municipalities, processed with adapted ArcGIS Model Builder

- Flood Information System: flood database with various types of information



Source: Holzhauer et al (2008).

1.2 Scale

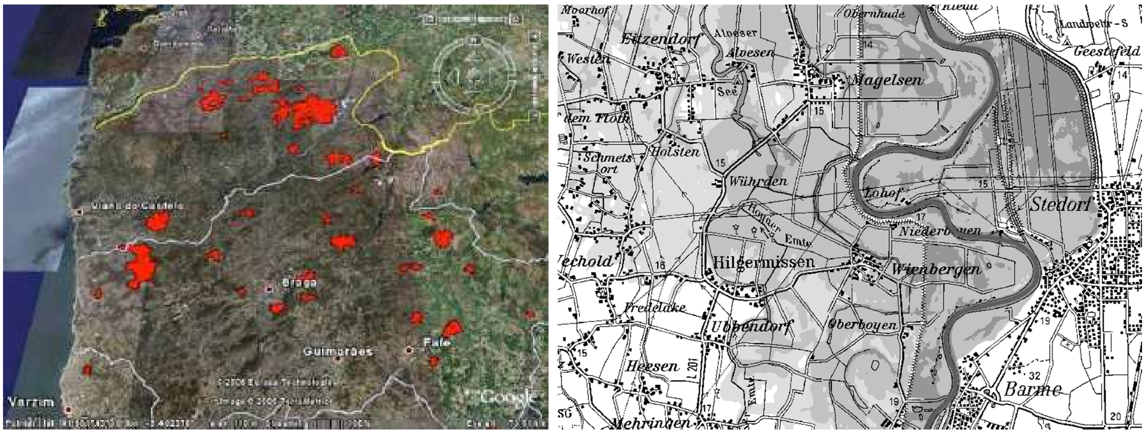
• Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Regional / large scale
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Non-specific (any)
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard, risk
1.5 Parameters and data: Which are the input data/the data required by the method?
Data and parameters related to specific analysis. For floods at least: - Digital terrain model - Land use data set (here satellite based data sets) - Street network (like NAVTEQ) - River network (delivered by the water agencies) - Statistics on population and economy - Existing modelling information (to produce consistent results) - All available past event information (for validation)
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Simulation approach for flooding, calculation (evaluation of impact)
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Software tool
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
quantitative
1.9 Advantages and disadvantages with the methodology
n/a
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Relates to extreme weather hazards and associated vulnerabilities and impacts (fire, flood)

2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***	

No

3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***	

The references briefly present a few examples of fire module for Iberian peninsula and flooding for Germany for various products.



Source: Desmazières and Paganini (2007) – fire mapping,left, Holzhauer et al. (2008) – flood mapping, right.

4 Software ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***	

Web-version of software with Flood Event, Flood Hazard and Flood Risk Maps, developed in the project and its continuation (SAFER) can be found at:

http://www.floodrisk.eu/

5 Further comments ***If you have further comments about the document that you have reviewed, please include it here***	

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:
HR Wallingford (HRW)
Complete reference of the reviewed document (include Internet links, if available):
https://dhs-summit.us/
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Software webpage
1 <u>Methodological approach</u> *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
SUMMIT stands for Standard Unified Modelling, Mapping and Integration Toolkit. It links together existing models and data to create an integrated modeling capability and also distributes SUMMIT repository data over web services to allow other tools to access and leverage this data for emergency management activities. In addition, SUMMIT links together best-in-class data visualization capabilities for this integrated dataset, providing a common operating picture for modeling and simulation (M&S) results
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
n/a
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Non-specific
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Impact, risk management
1.5 Parameters and data: Which are the input data/the data required by the method?
Data and parameters related to specific crisis simulation experiment
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Modelling/data analysis approach
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Software tool – a framework for integration of data, models, visualization

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

quantitative

1.9 Advantages and disadvantages with the methodology

n/a

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

General (not infrastructure or extreme weather specific) crisis management tool, provides a frame for integration of hazard/vulnerability/risk data and models

2 Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

No

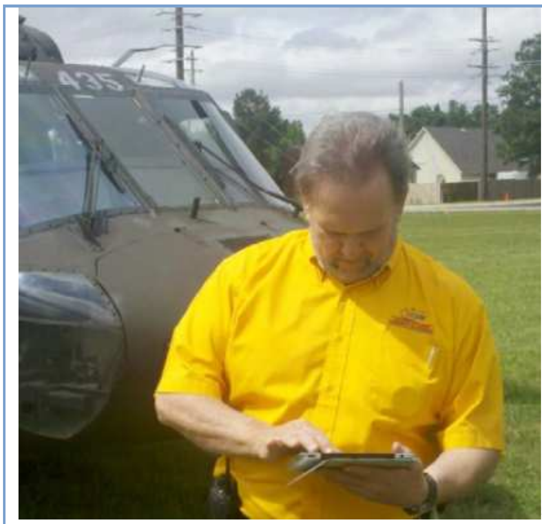
3 Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

It has been applied to exercise and management programs

https://dhs-summit.us/summit-in-action.html

Exercises:




Typically, models are used to create scenario data. The data is then adjudicated with exercise planners using the SUMMIT scenario adjudication tool, and then the finalized data displayed in SUMMIT and linked to virtual environment visualizations. First responders role-playing in the exercise have iPads™ available to them with the SUMMIT software, while others in the Master Control Cell are able to see the visualization software on large screens.

Threat and Hazard Identification and Risk Assessment:

Using SUMMIT, models were integrated and run to calculate impacts for several threat and hazard

scenarios across preparedness core capabilities including mass care services, economic recovery, and public health/medical services. e models utilized for this eort included dispersion models, an epidemic model, a health care surge model, and economic disruption models.

SUMMIT's output enabled emergency planners to quantify and compare impacts across different scenarios; in turn, these impacts were used to set capability targets.

4 <u>Software</u>

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

The software is used for planning, exercises, or operational response.

Linking of models/data:

Through the use of the SUMMIT Software Development Kit (SDK), model and simulation developers can "wrap" their model with an interface that allows the SUMMIT server to communicate with the model.

Model owners can make their models SUMMIT-compliant to become part of the SUMMIT model library and part of the initial deployments of SUMMIT [i.e. at the FEMA National Exercise and Simulation Center (NESC) and at various national and regional exercises].

Tool owners can make their tools SUMMIT-compatible to communicate with the SUMMIT web services to access SUMMIT repository data for use in their tool.

5 <u>Further comments</u>

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HR Wallingford (HRW)
Complete reference of the reviewed document (include Internet links, if available):
Several internal, draft reports, including a literature review of approaches for assessing water security under climate change and extreme weather (These should be available, but I will need to check-Andy)
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Internal research report(s)
1. **Methodological approach** ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
This project will provide the underpinning research and development of a national and catchment scale set of "Water Security" indicators. These will bring together available data sets and appropriate models to quantify water related risks (e.g. droughts) and water availability for growing crops, drinking water, and industrial uses. A preliminary Water Security Indicator System will be developed based on application of a number of gridded hydrological data sets, water allocation models and socio-economic data (from the World Bank, UN etc..) to estimate current and future water availability. The project will also explore "user needs" through discussion with Government clients, like DFID, to determine what information they require on water security at a national level.
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
National/regional
1.3 Considered hazards
Drought
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)
1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)
1.6 Parameters and data: • **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?** • **Which are the input data/the data required by the method?**

1.7 Advantages and disadvantages with the methodology
2. **<u>Uncertainties</u>** ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
3. **<u>Case studies</u>** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
4. **<u>Software</u>** ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
5. **<u>Further comments</u>** ***If you have further comments about the document that you have reviewed, please include it here***
This research will be completed by March 2015 at the latest

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HRW
Complete reference of the reviewed document (include Internet links, if available):
Kruchten P., Woo C., Sotoodeh M., Monu K. (2007) A Human-Centered Conceptual Model of Disasters Affecting Critical Infrastructures. Proceedings of the 4th International ISCRAM Conference (B. Van de Walle, P. Burghardt and C. Nieuwenhuis, eds.) Delft, the Netherlands, May 2007.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference proceedings

1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
Conceptual model of disasters affecting critical infrastructures. **Distinguish between the physical and social interdependencies between infrastructures, where the social layer deals with communication and coordination among representatives (either humans or intelligent agents) from the various critical infrastructures.**
1.1 Methodological approach description
The model is organized around four groups of concepts (See Figure): **1. Concepts to describe a region and the people that occupy it, and their well-being** **2. Concepts to describe the various infrastructures that serve this region** **3. Concepts to describe events such as a disaster and its impact on people, directly or indirectly through the infrastructures.** **4. Concepts to describe communication and coordination between infrastructures, and with the regions and people.**

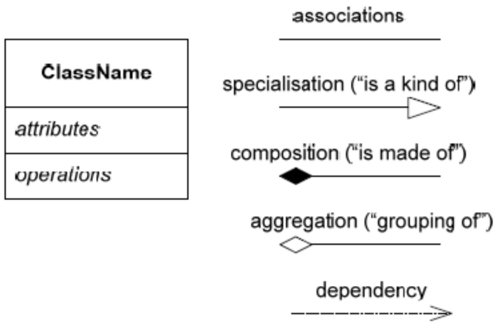
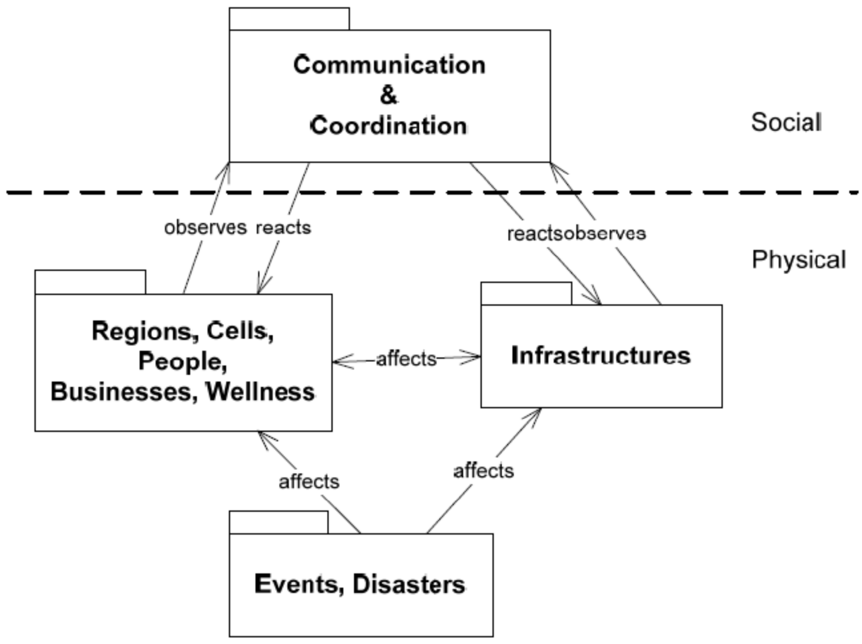


Figure 3: UML key symbols



We define a Cell as an entity that has a geographic location (an area), that contains a certain number of people, and has also an attribute of Wellness, called the Collective Wellness. In our model we distinguish several kinds of cells:

- **Residential cells, containing people.**
- **Government cells, containing people that play a special role in the case of disasters, such as police, fire halls, government, army, etc.**
- **Economic cells: areas where commercial or industrial activities are conducted**

A Resource is something that contributes significantly to wellness. An Infrastructure is that thing that produces and transports a given resource to the cells. Infrastructure elements have a state. Similar to the individual wellness, we can define a simple scalar scale for the state of an infrastructure element, representing its current ability to handle or transport the associated resource, its health. Distribution points link a cell to a type of infrastructure.

There are several kinds of physical interdependencies between infrastructures:

• Dependent: infrastructure A is connected and dependent on infrastructure B, meaning that if B is down, A is down. This is the case of a water pump depending on electrical power.

• Dependent, with delay: A is connected with B, and a failure of B will ultimately lead to a failure of A, over time. This is the case of a telephone equipment, with battery backup, depending on electrical power, but equipped with some battery back up (to hold a few hours) or with a generator (to hold for a few days).

• Collocated: this is a variant of dependent: two or more infrastructures are using the same physical space in a way that makes them fail simultaneously: a road bridge that carries a gas pipeline and a fiber optic are examples of such connections.

Disaster events are external events that "happen" and affect the state of cells and infrastructure elements. A disaster event, depending on its characteristics will instantaneously or over time change the wellness of cells or the state of infrastructure elements. An earthquake will kill people in cells near the epicenter, bring the wellness to low levels in adjacent cells, and over time affect the wellness of many other cells (lack of power, lack of food). The same earthquake will also immediately destroy some infrastructures (electrical tower, water pipes), with or without

some cascading effect to adjacent elements, and more effects over time.

A conceptual agent is an abstract entity that has goals (objective), beliefs (based on its observation of the world), and states (internal variables that can be compared with the goal). It can observe the surrounding environment, reason on how to bring it closer to its goal, and act accordingly. Some of the more sophisticated agents will also be able to learn, by observing the positive and negative effects on the discrepancy of previous attempts to satisfy their goals, and changing or adapting the strategies.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

N/A – Conceptual model

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

As input

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Impact of a hazard from a human perspective

Assist disaster management

1.5 Parameters and data: Which are the input data/the data required by the method?

Location of Infrastructure assets

Linkages between infrastructure

Hazard extent

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Simulation approach

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Conceptual model

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Qualitative
1.9 Advantages and disadvantages with the methodology
Provides a framework that could be built upon
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Conceptually applied to a town
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
Unclear
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
HRW
Complete reference of the reviewed document (include Internet links, if available):

Karin Marianne DE BRUIJN (2005) RESILIENCE AND FLOOD RISK MANAGEMENT: A SYSTEMS APPROACH APPLIED TO LOWLAND RIVERS

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Phd thesis

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

Flood resilience concept

1.1 Methodological approach description

The objective was to establish whether applying the resilience concept facilitates the development of comprehensive strategies for flood risk management of large lowland river systems.

These aspects of resilience are

(1) the amplitude of the reaction (Expected Annual Damage (EAD) and the Expected Annual Number of Casualties (EANC))

(2) the graduality of the increase of reaction with increasing disturbances (relative increase of discharge in percentages by the corresponding relative increase of damage)

(3) the recovery rate. The physical characteristics of the system determine how fast the area dries out. The economic characteristics reflect the availability of funds for reconstruction and expected

support from nonflooded areas. The social characteristics which could enhance recovery are the functioning of social networks, the preparedness of the inhabitants and organisations in the system, and the human capital of the inhabitants (their health and skills). The recovery capacity analysis is qualitative and results in a score between one and ten. The resilience of a system is larger when the amplitudes are smaller, the graduality is larger or the recovery rate is higher.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Case studies are local / regional

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Flood

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Risk management – systems approach

1.5 Parameters and data: Which are the input data/the data required by the method?

Hydrodynamic models / results (economic damages and loss of life)

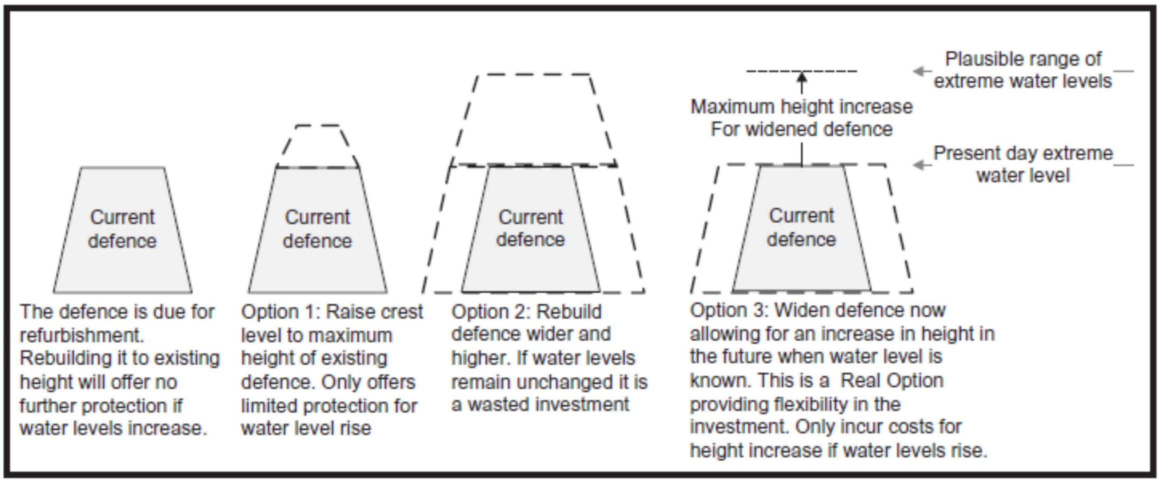
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Systems approach

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method - quantitative
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Method - quantitative
1.9 Advantages and disadvantages with the methodology
Method and concepts can be applied to other locations and hazards
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
Discussion on uncertainties in FRM **Sensitivity analysis**
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Lower Rhine **Most flood waves will not result in any reaction, but if an extreme flood wave occurs, damage is enormous. The system can, however, rapidly recover from the flood impacts thanks to the high level of welfare and organisation in the Netherlands. This reaction is reflected by the indicator values: the current system was found to have a low amplitude, caused by the low flood frequency, a low graduality and a high recovery rate. The resistance of the current system appeared to be high because floods are rare.** **Different strategies were studied: a compartmentalization strategy, three variants of a green river strategy ('floodway') and the socalled RiverandLand strategy. The results showed that these strategies reduce the amplitude and increase the graduality by flood probability differentiation, land use adaptations and measures to prevent the flooding of cities and other vulnerable areas.** **Meuse** **The case study area includes the river and floodprone area between Eijsden and Mook situated in Belgium and the Netherlands. The values for the resilience indicators were calculated for the Meuse system as it was in 1900, 1993, and 2000, and as it is expected to be in 2015 and 2100.** **In 1900 the amplitude was low and graduality high. Between 1900 and 1993 the graduality decreased and the amplitude increased, mainly due to economic growth and reduction of the floodprone area. Between 1993 and 2015 the amplitude is expected to decrease due to measures that reduce the flood frequency of villages and cities, but also the graduality is expected to decrease.** **Mekong River – lowland**

Agriculture and fisheries, transport and the way people build their houses and construct roads are all adapted to the frequent floods. The current resilience of the Mekong River was expected to be very high, because the whole country seems to be adapted to the annual floods. Although the graduality was found to be very high indeed, the amplitude proved to be high also and the recovery rate low. The high amplitude is caused by frequent severe flood damages and the low recovery rate by relative poverty.
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
No
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
HRW
Complete reference of the reviewed document (include Internet links, if available):
M. Woodward, B. Gouldby, Z. Kapelan, S.-T. Khu and I. Townend (2012) Real Options in flood risk management decision making. Journal of Flood Risk Management 4 (2011) 339–349.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal Paper
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
Flood Risk Analysis and Real Options Analysis Real Options is a mechanism for evaluating flexibility in an investment decision and is founded in the analysis of financial decision making. Real Options allows a decision maker to make changes to an investment when new information arises in the future. Opportunities such as delaying the investment, abandoning, switching, expanding, contracting and having multiple options interacting together. The Real Options philosophy seeks to identify opportunities for incorporating flexibility into the decision making process to mitigate the potential impact of uncertainties. For example, where it is beyond doubt that a flood defence has come to the end of its useful life and requires major refurbishment there are a range of possible decisions. Assuming a worst case climate change scenario and constructing a flood defence based on this assumption is likely to be suboptimum as it requires significant up-front expenditure and may well constitute an over-design should the worst case scenario not be realised. Constructing a defence that is inherently flexible and capable of future modification is one approach for implementing a Real Option within a flood risk system.



1.1 Methodological approach description

Risk analysis

A continuous extreme value distribution of hydraulic loads is discretised into a series of k loading levels l1 . . . lq. The flood defences are treated as Bernoulli random variables either remaining intact or breached (structurally failed) with their performance defined by fragility curves (Platt, 1995; Simm et al., 2009; Schultz et al., 2010). Defence system states are sampled using a standard Monte Carlo procedure for each of the loading levels and a hydraulic flood spreading model is used to represent the propagation of floodwater across the floodplain according to the topography of the land. An economic consequence of flooding is estimated using depth damage curves that analyse the damage to properties according to the spread of floodwater (Penning-Roswell et al., 2005).

Options analysis

Calculation of the flood risk associated with an intervention at a future point in time can be achieved by expressing the future state in the model. Intervention measures can be applied in the model by modifying the fragility curves, defence characteristics or depth damage curves.

The standard approach to assess the benefit of making an investment is determined by calculating the difference in risk between the intervention measure and a 'do nothing' option. These are

summed up over the planning horizon to obtain the overall benefits in EAD of an intervention strategy.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Applied on local to regional scale – Thames Estuary

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Flood

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Risk - EAD

1.5 Parameters and data: Which are the input data/the data required by the method?

Flood levels for a number of return periods, Asset Data including fragility curves, Damage Data,

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Simulation approach
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Methodology and Software Tool
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Ad – Full risk assessment **Dis – Amount of data required**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
Yes – future climate
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Thames Estuary **It is assumed at the outset that the defences are beyond reasonable economic repair and refurbishment is required. 3 options:** **1 traditional - widen defence base and increase height** **2 traditional - refurbish, widen base and increase height** **3 real options – widen base and increase level according to SLR** **Costs and benefits calculated for each option**
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
Software tool(s) owned by HR Wallingford
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Literature to section 4.1:

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
José Manuel Gutiérrez Llorente (manuel.gutierrez@unican.es), Joaquín Bedia Jiménez (bediaj@unican.es) and Sixto Herrera García (herreras@unican.es) , CSIC
Complete reference of the reviewed document (include Internet links, if available):
Sillman, J., and R. Roeckner (2008), Indices for extreme events in projections of anthropogenic climate change, Clim. Change, 86, 83–104, doi:10.1007/s10584-007-9308-6.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
Several extreme precipitation and temperature indices are calculated for the simulations of a global climate model (ECAHM5/MPI-OM) for the 20c3m, A1B and B1 emission scenarios. None effect on critical infrastructures has been considered.
1.1 Methodological approach description
Daily precipitation and maximum and minimum 2 m temperature data were used to calculate 27 indices for climate extremes as defined by the Expert Team on Climate Change Detection Monitoring and Indices (ETCCDMI). Threshold-based indices that have to be calculated relative to a base period were calculated according to the bootstrap method.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
The study considers global simulations.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Cool nights/days, warm nights/days, monthly maximum/minimum of daily minimum/maximum temperature,, frost days, ice days, summer days, tropical nights, growing season length, diurnal temperature range, maximum 1-day/5-days precipitation amount, simple daily intensity index, number of heavy/very heavy precipitation days, consecutive dry/wet days, very wet days and annual total wet-day precipitation.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The work is focused in changes of these 27 indices in climate change conditions.
1.5 Parameters and data: Which are the input data/the data required by the method?
Maximum and minimum daily 2 m temperature, and daily precipitation.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Indicator-based method.
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method

(qualitative/quantitative/semi-quantitative), methodology/theory)
To build the indices defined in this work the package ClimDex has been developed in differente programming languages (R, Fortran, etc.) under the following license: http://www.climdex.org/licence.html
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
The methodology used could be considered as quantitative in the sense that the study has quantified the change of these 27 indices according to the different emission scenarios considered.
1.9 Advantages and disadvantages with the methodology
The main advantage is the simplicity of the calculations needed to estimate the indices and the climate change signal. The main shortcoming is the low resolution of the results, the needed of to consider a multi-model, multi-scenario ensemble and the treatment of the uncertainty associated to these ensemble.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
This work defines some of the indices which will be used within the INTACT project according to the needed of the different case studies.
2 Uncertainties *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
The uncertainty considered in this study is given by the two emission scenarios considered in the future (A1B and B1) .
3 Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

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Complete reference of the reviewed document (include Internet links, if available):
Morán-Tejeda, E., Herrera, S., López-Moreno, J.I., Revuelto, J., Lehmann, A., and Beniston, M. (2013), Evolution and frequency (1970–2007) of combined temperature– precipitation modes in the Spanish mountains and sensitivity of snow cover, Regional Environmental Change, 134, 873-885, doi: 10.1007/s10113-012-0380-8
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
Several combined precipitation-temperature modes are defined to stablish weather situations favorable for the snow accumulation and

melt.
1.1 Methodological approach description
Precipitation and temperature have been used to define and estimate weather modes which affect the snowpack in the mountain ranges.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
The study considers the mountain ranges of the Iberian Peninsula.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Number of dry-warm, dry-cold, wet-warm and wet-cold days per year. Average and maximum duration of dry-warm, dry-cold, wet-warm and wet-cold spells per year.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The work is focused in the evolution and trend of the modes in the period 1970-2007.
1.5 Parameters and data: Which are the input data/the data required by the method?
Mean daily temperature and daily precipitation.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Indicator-based method.
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
The methodology used could be considered as quantitative in the sense that the study has quantified the evolution of these modes in the period considered.
1.9 Advantages and disadvantages with the methodology
The main advantage is the simplicity of the calculations needed to estimate the indices and the trend in the target period.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
This work defines some of the indices which will be used within the INTACT project according to the needed of the different case studies.
2 Uncertainties *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
The observational uncertainty has been considered in this work by mean the comparison with the results obtained using the Spanish Meteorological Agency (AEMET) network.
3 Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

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Complete reference of the reviewed document (include Internet links, if available):
Guide to Flood Emergencies and the Protocol for Multi-Agency Response to Flood Emergencies published by The Major Emergency Management website (www.mem.ie). Available online in the following link: http://www.mem.ie/guidancedocuments/A%20Guide%20to%20Flood%20Emergencies%20-%20Ver2%2011%20%28July%202013%29.pdf
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Technical report
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
This technical report is a guide for flood emergencies and, then, it does not contain specific technical and methodological information but some guidelines which should be taken into account to identify the potential risk, mitigate the consequences and planning and coordinate the emergency response.
1.1 Methodological approach description
Meteorological variables (wind, precipitation, temperature, etc.) have been used to define weather extreme and to stablish the warming system in the Éireann Meteorological Service.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
The geographical scale is national but these extreme weather events could be generalized for other regions.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Weather element	GREEN (NO SIGNIFICANT HAZARDOUS WEATHER)	YELLOW – WEATHER ALERT	ORANGE – WEATHER WARNING	RED – SEVERE WEATHER WARNING
Wind - Warnings normally issued on gust speeds and gusts tend to do the most damage.	Gusts less than 80km/h	Mean speeds between 50km/h (27kts) and 65km/h (35kts) Gusts between 90 km/h (45kts) and 110km/h (60kts)	Mean speeds between 65 km/h (35kts) and 80km/h (45kts) Gusts between 110km/h (60kts) and 130km/h (70kts)	Mean speeds greater than 80km/h (45kts) Gusts in excess of 130km/h (70kts)
Coastal Wind Warnings - For up to 20 nautical miles offshore	Winds less than Gale Force	Gale Force 8 or Strong Gale Force 9 (mean speeds)	Storm Force 10 (mean speeds)	Violent Storm of Force 11 or greater (mean speeds)
Rain - Lesser criteria may merit a warning if a prior very wet spell has resulted in saturated ground.	Less than 30mm in 24hrs Less than 25mm in 12hrs Less than 20mm in 6hrs	30mm – 50mm in 24 hrs 25mm - 40mm in 12 hrs 20mm – 30mm in 6 hrs	50mm – 70mm in 24 hrs 40mm – 50mm in 12 hrs 30mm - 40mm in 6 hrs	70mm or greater in 24 hrs 50mm or greater in 12 hrs 40mm or greater in 6 hours
Snow / Ice - Accumulations on high ground or in drifting should not merit a warning.	No snow, or some snow showers possible, mainly above 250m altitude.	Scattered snow showers giving accumulations of less than 3 cm below 250m AMSL. Slippery paths and roads due to accumulation of ice on untreated surfaces; situation improving.	Significant falls of snow likely to cause accumulations of 3 cm or greater below 250m AMSL. Slippery paths and roads due to accumulation of ice on untreated surfaces; situation stable.	Significant falls of snow likely to cause accumulations of 8 cm or greater below 250 m AMSL. Slippery paths and roads due to accumulation of ice on untreated surfaces; situation likely to worsen.
Thunder	None	No Criteria	Widespread thundery activity over an area of several counties	No Criteria
Low Temperature Warning	Minima higher than minus 3C and maxima higher than plus 2C.	Minima of minus 3C or minus 4C expected. Maxima of plus 1C or plus 2C expected.	Minima of minus 5C to minus 9C expected. Maxima of 0C or minus 1C expected.	Minima of minus 10C or lower expected. Maxima of minus 2C or lower expected.
High Temperature Warnings	Maxima less than 27C	Maxima in excess of 27C expected	Maxima in excess of 30C or minima in excess of 20C expected in a 24hr period	As Orange criteria but persisting for two or more consecutive nights
Fog	None	No criteria	Dense fog likely to cause a widespread and significant driving hazard on national primary routes.	No criteria

Figure 10: Met Éireann Weather Warning criteria

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The technical report gives a general framework for the management of flood risk. This framework includes since the preparation for flood events to the coordination of the response to flood emergencies.
1.5 Parameters and data: Which are the input data/the data required by the method?
The weather parameters are the wind, precipitation, snow/ice, temperatures, fog and thunders. In the case of the flood, the main parameter is the probability of flooding defined by mean return periods.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
This technical report does not define any specific methodology. Taking into account the definition of weather extreme event and the probability of flood, it could be considered that it defines indicator-based methods.
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
All the analysis of this technical report are qualitative.
1.9 Advantages and disadvantages with the methodology
The main advantage is the relative simplicity of the calculations needed to estimate the indices.

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
This technical report considers one of the case studies defined within the WP5 of INTACT and, then, it is interesting to identify the weather events affecting this particular case study and use them as an starting point to generalize the results to other regions.
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
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Complete reference of the reviewed document (include Internet links, if available):
Gouldby BP, Sayers P, Mulet-Marti J, Hassan M, Benwell D (2008): A Methodology for Regional Scale Flood Risk Assessment , Proc. Inst. Civ. Eng Wat. Man., Volume 161, Issue WM3 . A 2 pages preview is available online in the following link: http://www.icevirtuallibrary.com/content/article/10.1680/wama.2008.161.3.169
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference/workshop article
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
In this work a method to assess flood risk from fluvial and coastal source has been developed. This method considers explicitly possible defence failures which lead to a more realistic evaluation of the true risk.
1.1 Methodological approach description
The method considers the defence failures through fragility curves of the multiple defence sections. As a case study, the method has been applied to the Thames Estuary.
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
The consideration of flooding scenarios involving multiple defence section failures limits the method to be applied to local scale.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
The work is focussed on flood risk.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The main focus of this work is the risk evaluation considering different scenarios, including the defence failure which is the main contribution

of the paper.

1.5 Parameters and data: Which are the input data/the data required by the method?

Take into account the focus of the paper, to characterize properly a flood system the meteorological variables needed usually are precipitation, temperature and wind.

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

The method shown in this work reflects the flood risk of a specific area in order to be used to support decisions related with the strategic flood risk management. Then, it includes engineering and simulation approaches.

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

This work defines a quantitative methodology/theory to evaluate the flood risk.

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

The results of the application of the method shown are quantitative in the sense of they reflect the true flood risk.

1.9 Advantages and disadvantages with the methodology

The main contribution of this work with respect to the previous ones is to consider explicitly the possibility of a defence failure in the evaluation of the flood risk.

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

This method let the case studies to have more realistic information about the flood risk of their respective areas of interest.

2 Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

Implicitly, the work is including a previously unconsidered uncertainty associated with the defence failures. This method considers it explicitly.

3 Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

The method has not been applied in the specific target areas of the case studies. However, this method could be interesting for the case studies defined within the WP5 related with flood risk.

4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

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Complete reference of the reviewed document (include Internet links, if available):

Klein Tank, A.M.G. and Coauthors, 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European

Climate Assessment. Int. J. of Climatol., 22, 1441-1453. http://onlinelibrary.wiley.com/doi/10.1002/joc.773/abstract
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1. Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
European scale
1.3 Considered hazards
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)
1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)
1.6 Parameters and data: • Do the methodology focus on vulnerability, loss, more general on risk or on other parameters? • Which are the input data/the data required by the method?
1.7 Advantages and disadvantages with the methodology
The dataset developed in this work is a public European-wide data basis of several meteorological parameters, most of them of great interest for the INTACT project.
2. Uncertainties *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
3. Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
4. Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
5. Further comments

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Complete reference of the reviewed document (include Internet links, if available):
Haylock, M.R., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones and M. New. 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res (Atmospheres), 113, D20119, doi:10.1029/2008JD10201
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1. **Methodological approach** ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
European scale
1.3 Considered hazards
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)
1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)
1.6 Parameters and data: • **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?** • **Which are the input data/the data required by the method?**
1.7 Advantages and disadvantages with the methodology
The dataset developed in this work is a public European-wide gridded data basis of precipitation, temperature and sea level pressure which is

the current reference dataset for European studies.
2. Uncertainties *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
3. Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
4. Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
5. Further comments *If you have further comments about the document that you have reviewed, please include it here*

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Complete reference of the reviewed document (include Internet links, if available):
F. A. Isotta, C. Frei, V. Weilguni, M. P. Tadic, P. Lassègues, B. Rudolf, V. Pavan, C. Cacciamani, G. Antolini, S. M. Ratto, M. Munari, S. Micheletti, V. Bonati, C. Lussana, C. Ronchi, E. Panettieri, G. Marigo and G. Vertacnik. 2014: The climate of daily precipitation in the Alps: development and analysis of a high-resolution grid dataset from pan-Alpine rain-gauge data. Int. J. Climatol., 34: 1657-1675. doi: 10.1002/joc.3794.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1. Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Regional scale. In particular, the dataset developed in this study covers the Alpine region.
1.3 Considered hazards
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)
1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)
1.6 Parameters and data: • **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?** • **Which are the input data/the data required by the method?**
1.7 Advantages and disadvantages with the methodology
The dataset developed in this work is a public gridded data basis of precipitation.
***2.* Uncertainties** *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
***3.* Case studies** *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
***4.* Software** *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
***5.* Further comments** *If you have further comments about the document that you have reviewed, please include it here*

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José Manuel Gutiérrez Llorente (manuel.gutierrez@unican.es), Joaquín Bedia Jiménez (bediaj@unican.es) and Sixto Herrera García (herreras@unican.es) , CSIC

Complete reference of the reviewed document (include Internet links, if available):
Herrera, S., 2011: Desarrollo, validación y aplicaciones de Spain02: Una rejilla de alta resolución de observaciones interpoladas para precipitación y temperatura en España. Ph.D. thesis, Universidad de Cantabria, available at http://www.meteo.unican.es/tesis/herrera. Herrera, S., J. M. Gutiérrez, R. Ancell, M. R. Pons, M. D. Frías, and J. Fernández, 2012: Development and analysis of a 50-year high-resolution daily gridded precipitation dataset over Spain (Spain02). Int. J. Climatol., 32, 74–85 Herrera, S., J. Fernández and J. M. Gutiérrez, 2014: Update of the Spain02 Gridded Observational Dataset for Euro-CORDEX evaluation: Assessing the Effect of the Interpolation Methodology. Submitted to Int. J. Climatol.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1. Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
National scale. Spanish peninsular and Balearic Islands.
1.3 Considered hazards
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)
1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)
1.6 Parameters and data: • Do the methodology focus on vulnerability, loss, more general on risk or on other parameters? • Which are the input data/the data required by the method?
1.7 Advantages and disadvantages with the methodology
The dataset developed in this work is a public gridded data basis of daily precipitation, maximum, minimum and mean temperature over the Spanish peninsular and Balearic Island.
2. Uncertainties *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
These studies take into account different uncertainties associated to the develop of gridded datasets. In particular, the observational dataset and the interpolation methodology used, and the inclusion of covariables in the interpolation process.
3. Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*

4. Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
5. Further comments *If you have further comments about the document that you have reviewed, please include it here*
These three studies describe the develop of the different version of the Spain02 dataset, which is one of the reference dataset used in CORDEX and VALUE initiatives.

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
José Manuel Gutiérrez Llorente (manuel.gutierrez@unican.es), Joaquín Bedia Jiménez (bediaj@unican.es) and Sixto Herrera García (herreras@unican.es) , CSIC
Complete reference of the reviewed document (include Internet links, if available):
HR Wallingford (2014) Indicators to assess the exposure of critical infrastructure in England to current and projected impacts of climate change. **http://www.theccc.org.uk/wp-content/uploads/2014/07/5-MCR5195-RT003-R05-00.pdf**
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Project report
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
The method described in this report is based upon the use of a Geographical Information System (GIS) to spatially pre-process, analyze the data and develop spatial indicators of risk, action and impact. The spatial analysis was based on 91 indicator of exposure covering 6 infrastructure sectors and 7 weather related-hazards.
1.1 Methodological approach description
First, the available quality controlled data should be converted to the required spatial format and then divided into a grid. Queries are subsequently run on the data to identify where the chosen assets and hazards intersect and therefore exposure of the asset to the hazard is possible.
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses? Are indirect losses and cascading effects also included?**
National scale. The report is focused on the exposure, not in the losses.
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Coastal erosion, flooding (groundwater, surface water, and river and coastal), natural landslides, shrink-swell subsidence and river scour.
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
The work is focused in exposure and hazard.
1.5 Parameters and data: Which are the input data/the data required by the method?
There is not a specific definition of the parameters needed. In a general way, in the GIS is introduced all the available quality-controlled data, both meteorological, hazard and assets.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
The methodology shown in the technical report is an indicator-based technique using different layers of a GIS.
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
The methodology is quantitative.
1.9 Advantages and disadvantages with the methodology
To use a GIS let the user to include as much layers as could be necessary, according with the different hazards considered. The main disadvantage is the needed of the proper data which has been a limitation to extend the study to other variables/events.
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
This work defines a methodology to evaluate the exposure to different hazards. Then, it could be used to stablish the basis to generalize it to other regions.
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
4 Software ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
5 Further comments ***If you have further comments about the document that you have reviewed, please include it here***

Literature to section 4.2:

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Vogel, Ruben & Koops, Olaf (TNO)

Complete reference of the reviewed document (include Internet links, if available):

Flooding of tunnels: quantifying climate change effects on infrastructure
J.N. Huibregtse, O. Morales Napoles & M.S. de Wit
TNO, Delft, The Netherlands

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Journal paper

1. Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

The methodology that is proposed in this paper is based on probabilistic risk assessment as applied in civil engineering (e.g. Vrouwenvelder et al. 2000). The assessment is structured in a number of steps, i.e. definition of scope and system, hazard identification, modelling and quantification of risk, risk judgement, and the identification and evaluation of risk management strategies and measures. This is schematically represented in Figure 1.

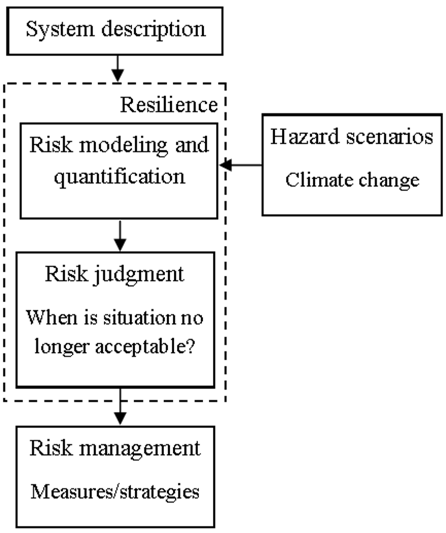


Figure 1. Risk assessment approach.

1.1 Methodological approach description

The assessment identifies which resilience the system has at present, how the resilience will develop or diminish over time, and at which point in time the resilience will be depleted and the situation is no longer acceptable. The system resilience can be determined from the combination of the (time dependent) risk quantification and the risk judgment (which may also vary over time), as illustrated in Figure 1.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Geographical scale: Site specific (fictitious tunnel)

1.3 Considered hazards

Flooding due to extreme rain

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

For a random shower, a joint probability distribution for these two variables was modeled on the basis of copulas. A bivariate copula is a joint distribution on the unit square with uniform one dimensional margins:

$$F_{X,Y}(x,y) = C_{\theta}\left(F_X(x), F_Y(y)\right)$$

1.6 Parameters and data:

- **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?**
- **Which are the input data/the data required by the method?**

Vulnerability

Both the probability of failure as well as the consequences of failure are taken into account, as described in Equation 1. Failure of the drainage system of a tunnel affects the direct surroundings of the tunnel, i.e. the tunnel is closed for traffic resulting in traffic jams and extra travel time. However, the performance of the total network might also be affected by the unavailability of one tunnel, since traffic jams might be extended over larger parts of the network and other parts of the network will be used as alternative routes. This effect on the total network is amongst others, a function of the traffic volume depending on the particular tunnel and the number of alternative routes.

To obtain a probabilistic model for these variables, an empirical dataset from the KNMI was used as a basis. The datasets consist of recorded rain amounts in mm per six minutes, measured in Rotterdam, from 1974-1993. Consecutive six minutes intervals with more than 0.1 mm rainfall were assumed to be part of a single shower. In this way a dataset of showers was constructed, each with a total amount of rainfall (mm) and a duration (min).

1.7 Advantages and disadvantages with the methodology

It must be noted that there are several factors that influence the total extra travel on a location. Examples are the number of incidents (incident probability), the severity of an incident (number of lanes that are closed and the duration of an incident), the traffic volumes, the mixture of traffic (passenger and freight traffic), the number of route-alternatives and the travel time on those alternatives, information provision, the alternatives in mode choice, destination choice and departure time and the possibility to stay at home. This means that data need to be carefully interpreted when at-tempting to relate it to the level of importance of tunnels (or other network components).

2. Uncertainties

Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment

The representation of uncertainties in future developments in terms of scenarios is not fully compliant with a probabilistic risk assessment approach. However, the use of climate scenarios is developing into common practice in policy and decision making concerning climate change. Therefore, a combined approach is proposed, in which risks at a certain point in time are modelled probabilistically, but their change over time will be described in terms of scenarios.

3. Case studies

Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done

The methodology as described in the previous chapter is applied to a fictitious, but realistic test case.
To determine the resilience of the tunnel in terms of water drainage, both a risk analysis as well as a description of the acceptable probability of failure is required. In the risk analysis the limit state of the tunnel sys-tem is derived, consisting of both the loads on the tunnel as well as the strength of the tunnel. The considered strength of the system is in this case the water bearing capacity of the tunnel. For this study the capacity is considered deterministically and time independent. In this case the load on the tunnel is represented by the rain (intensity and duration), changing over time due to climate change.

4. Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

Matlab

5. Further comments

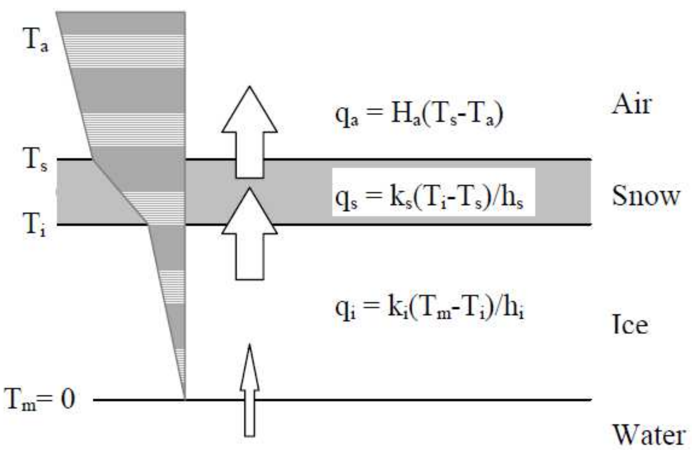
If you have further comments about the document that you have reviewed, please include it here

Literature to section 4.3:

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Craig Goff, HRW
Complete reference of the reviewed document (include Internet links, if available):
USBR 1987, Design of Small Dams 3rd Ed., US Bureau of Reclamation
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Book
1. Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
Consideration of ice loading (extreme weather) on dams (critical infrastructure)
1.1 Methodological approach description
Ice pressures can produce a significant load against the face of a dam in locations where winter temperatures are cold enough to cause relatively thick ice cover. Ice pressure is created by thermal expansion of the ice and by wind drag. Pressures caused by thermal expansion of the ice depend on the temperature rise of the ice, thickness of the ice sheet, the coefficient of thermal expansion, the elastic modulus, and the strength of the ice. Wind drag depends on the size and shape of the exposed area, the roughness of the surface, and the direction and velocity of the wind. Ice pressure is generally considered to be transitory loading. Many dams are subjected to little if any ice pressure. The designer should decide, after consideration of the above factors, whether an allowance for ice pressure is appropriate. The method of Monfore and Taylor may be used to analyze anticipated ice pressures if the necessary basic data are available. When the basic data are not available to compute pressures, an acceptable estimate of the ice load to be expected on the face of the structure may be taken as 10,000 lb/lin ft of contact between the ice and the dam for an assumed depth of 2 feet or more. (USBR 1987, p321)
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Site specific
1.3 Considered hazards

Ice and wind
1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)
Semi-quantitative
1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)
Engineering method
1.6 Parameters and data: • **Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?** • **Which are the input data/the data required by the method?**
Focuses on vulnerability of a structure at a specific location **For data required see 1.1**
1.7 Advantages and disadvantages with the methodology
Advantage: Simple, Disadvantage: Subjective
2. **<u>Uncertainties</u>** ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3. **<u>Case studies</u>** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
No (I assume Craig means not by HRW – Andy)
4. **<u>Software</u>** ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
N/A
5. **<u>Further comments</u>** ***If you have further comments about the document that you have reviewed, please include it here***

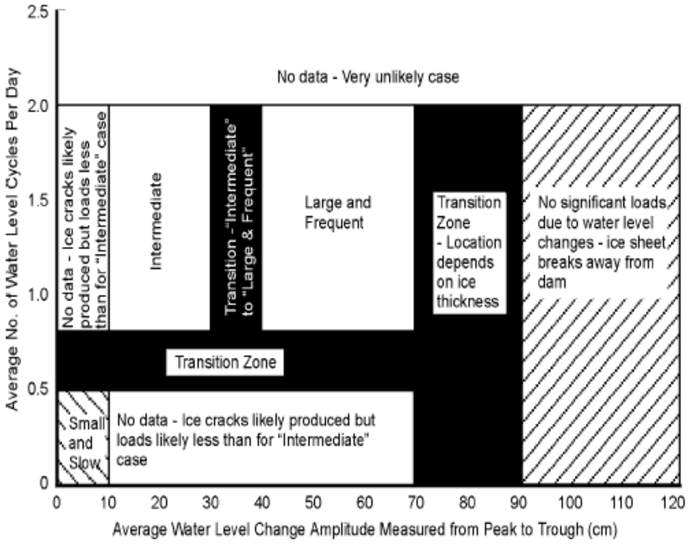
Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
G. Comfort, and R. Abdelnour (2013). Ice Thickness Prediction: A Comparison of Various Practical Approaches. 17th Workshop on River Ice, Committee on River Ice Processes and the Environment.

Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference paper
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*
1.1 Methodological approach description
Authors compare various methods for prediction of ice thickness, which is one of the key parameters in estimating ice loads on dams. The methods range from simple (Freezing Degree Days) to complex relations describing heat transfer and other phenomena. The paper makes comparisons among various methods illustrated with a practical example from authors' experience. Temperature Distribution  **Figure 4.1** Heat Flux Through an Ice Cover
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Site specific **Application to losses not considered**
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Ice
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard
1.5 Parameters and data: Which are the input data/the data required by the method?
Varies depending on method: FDD (accumulated freezing degree days) ; full set of meteorological data

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Engineering method ; simulation approach
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: FDD-simple; model- data still commonly available, good predictions overall **Disadvantage: FDD – empirical coefficient that has to be calibrated (often difficult) or estimated, not always good results;**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts loads (hazards) on dams (critical infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Ice thicknesses measured in Lake St Francis from period 1970-2000 were used as a sample case for comparing the results of various ice growth predictors. Daily growth of ice was predicted as well as annual maximum.
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
No
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***
For the case considered here, the simplified methods underestimated the ice thickness obtained using extreme value analyses done with measured ice thickness data. The authors believe this to be due, in large part, to the fact that the simplified models don't account for ice surface growth. This is a serious limitation in some cases.

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
G. Comfort, Y. Gong, S. Singh, and R. Abdelnour (2003): Static ice loads on dams. Can. J. Civ. Eng. 30: 42–68 (2003).
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
journal paper
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
Extensive field work was undertaken over nine winters in the period of 1991-2000 to measure the loads in the ice sheet near a dam, the load distribution between a gate and a pier, and to compare the loads on wooden and steel stoplogs. Parallel work was conducted to develop analytical predictors for static ice loads. Two components of load are taken into account: thermal load (expansion of ice with a change in temperature) and load due to water level change. Ice temperature changes were modelled with an environmental model. An analytical method was developed to extend the results obtained in this project to other stoplog or gate configurations (i.e., spans, flexural rigidities, etc.) and pier lengths.

Fig. 5. Water level change regime map.



1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

National

Application to losses not considered

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Ice

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Hazard

1.5 Parameters and data: Which are the input data/the data required by the method?

Daily meteorological data (air temperature, precipitation, ?wind, ?radiation), water level operation

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

(Simple) simulation approach

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Method (quantitative)

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.9 Advantages and disadvantages with the methodology
Advantage: based on readily available input data, good predictions **Disadvantage: only verified with data from Canada**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts loads (hazards) on dams (critical infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
The prediction method for ice load on dam has been applied on several cases in Canada and verified against observed data
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
No
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
G. Comfort, A. Liddiard, R. Abdelnour (2004). A method and tool for predicting static ice loads on dams, 17th International Symposium on Ice, IAHR, Saint Petersburg.

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Conference paper

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

Based on extensive field survey in the period of 1991-2000, where loads on hydropower dams were measured, algorithms were developed to predict these loads. Ice Load Design Guide was made that: (i) synthesized the results; and (ii) established a statistical database which allowed loads to be calculated using a computer program for: (a) the long face of dam; and (b) stoplogs.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

National

Application to losses not considered

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

Ice

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Hazard

1.5 Parameters and data: Which are the input data/the data required by the method?

Daily meteorological data (air temperature, precipitation, ?wind, ?radiation), water level operation

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

(Simple) simulation approach

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Software tool (no information on license and pricing)

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.9 Advantages and disadvantages with the methodology

Advantage: tool simple to use, good predictions

Disadvantage: only applicable to Canada

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts loads (hazards) on dams (critical infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
There is a discussion on extrapolation, which is said to be reliable.
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
No
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
An Ice Load Calculation Program was developed in MS Excel to calculate ice load for dam safety analysis. It operates as a database program using the station locations and the fitted load distributions for each of them. There is no information about the availability of the program.
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

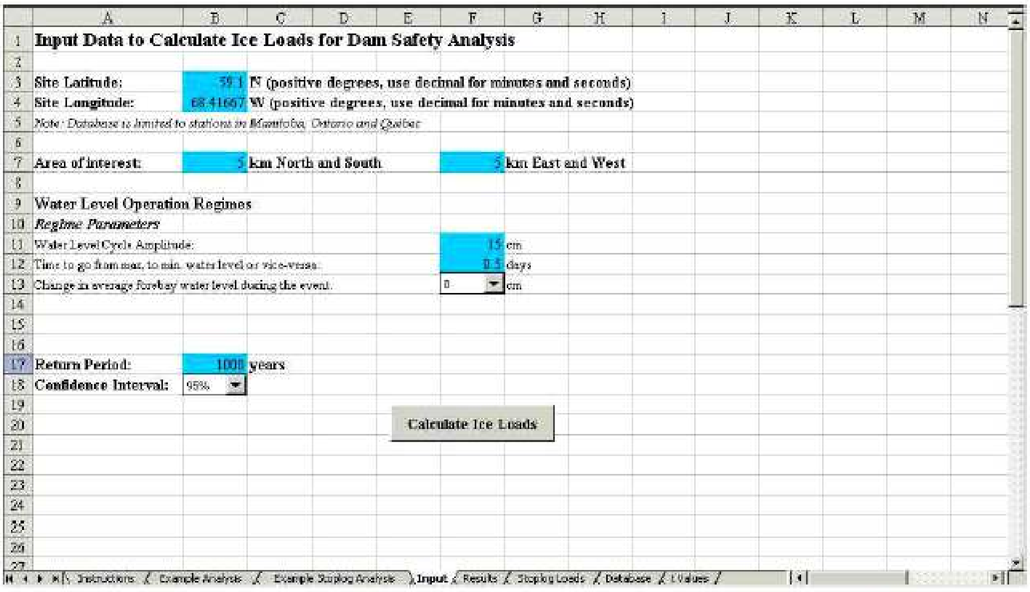


Fig. 10. Ice Loads Calculation Program: Input Screen for Calculating Ice Loads for Dam Safety Analyses

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
S. Gebre, N. Timalsina and K. Alfredsen (2014). Some Aspects of Ice-Hydropower Interaction in a Changing Climate. Energies 2014, 7.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
Authors investigate how existing ice effects and problems will manifest themselves in a future changed climate. They use different modeling results to investigate future freshwater ice conditions. The modeling approaches include using temperature derived winter indices, using one-dimensional (1D) hydrodynamic and ice cover model on three case study reservoirs, and using a 1D river hydrodynamic and ice cover model for a river reach. Expected ice problems under climate change in general using large scale climatology indices are evaluated and detailed investigations **using numerical models with case studies are made. The impacts on the following hydropower components are investigated: dams, spillways, reservoirs, trash racks, intake gates, water outlets, rivers, operational constraints.**
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Site specific/Local **Focus is on direct (operational) losses**
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Ice
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard, impact
1.5 Parameters and data: Which are the input data/the data required by the method?
Temperature and precipitation form 1x1 km grid from the Norwegian Meteorological Institute **Global climate models predictions**

Data on river (40 km reach) and reservoirs
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Simulation approach
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Software, method
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: detailed predictions, type of input data readily available, good predictions of water temperature and ice processes **Disadvantage: high resolution of the input data**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts impacts of ice regime on dams (critical infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
The Orkla River in central Norway is an example of a typical high-head hydropower system. The river system has been regulated with three reservoirs and five hydropower plants and a number of water transfers with secondary intakes. The Orkla hydropower system was simulated with the current climate and several future climate scenarios. A modified hydropower system **consisting only of one dam and intake to evaluate the impacts on a typical run of the river** **system was also simulated. The purpose was to evaluate how currently reported problems might be influenced in the future.**
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
No

5 **Further comments**	
If you have further comments about the document that you have reviewed, please include it here	

Literature to section 4.4

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
Environment Agency (2013). Risk Assessment in Reservoir Safety Management: Piloting summary report. UK Environment Agency, Report – SC090001/R3
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Public report
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
A number of dams in England and Wales were assessed using the new methodologies and guidance of UK Environment Agency. From the dams offered by owners for assessment a team of experts selected a range of ages, sizes and types that would most closely represent the widest possible population of UK dams and also meet the requirements for the trials. The new methodology proposes a three tier approach. Tier 1 is qualitative and consists of ranking of potential failure modes, order of magnitude likelihood and consequences using a descriptive risk matrix. Tier 2 is simplified quantitative approach where threshold analyses can be done with hand calculations with optional sensitivity analysis. The study applied approaches and analytical methods in Tiers 1 and 2 but was not extended to include those outlined in Tier 3. Tier 3 refers to detailed quantitative assessments that are complex and costly to perform; they will be undertaken by a team of specialist engineers, using numerical/computer models.
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
National **Direct losses**
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

EWE: Flood, hazard: dam failure
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard
1.5 Parameters and data: Which are the input data/the data required by the method?
Detail varies by approach: **Dam parameters and condition, reservoir parameters and condition, flood magnitude for various recurrence periods, maps/GIS data on buildings/population**
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Engineering method
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Qualitative (Tier 1) / Quantitative (Tier 2)
1.9 Advantages and disadvantages with the methodology
The approach and structure of method was generally found to be sound and the **concepts easily understood.** **Flexibility built into guidance can be both beneficial and problematic. Where** **options are available, information on how to decide on an appropriate route** **or choice of analysis is required.**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts risks associated to dams safety (critical infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***

The pilot study assessed eleven dams of height between 6 and 72 m and volume of 20,000 – 50,000,000 m^3 and between 40 to 200 years old.

They were tested with Tier 1 (qualitative) and Tier 2 (simplified quantitative) approach. Eight embankment dams, two concrete dams and one composite dam were analysed.

4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

No

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

The document states that there were changes made to the guide during its development addressing comments from the project team and steering group reviews, the methodology in the draft guide (issued January 2013) was also refined where the piloting suggested that the output was 'not reasonable' (and the results of the pilots adjusted for the revised methodology).

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

Gregor Petkovsek, HRW

Complete reference of the reviewed document (include Internet links, if available):

Fridolf T. (2004). Dam safety in a hydrological perspective - case study of the historical water system in Sala silver mine. Licentiate Thesis, KTH Institute of Technology, Land and Water Resources Engineering, Stockholm, Sweden.

Type of document (e.g. book, journal paper, internal project report, public report, etc.)

Thesis

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

Firstly, rainfall events with different return periods were estimated and used as input for hydrological modelling of the watershed. The rain sequences were determined by frequency analysis based on annual maximum precipitation values from the period 1961-2000 from a station placed about 3 km southeast of Sala (the modelled area). The Gumbel-, Lognormal- and Log-Pearson type III frequency distributions were used . The distribution parameters were estimated by the method of moments and the goodness of fit was tested by chi-square test.

The hydrological model used was HEC-HMS. The model was calibrated for a rainstorm during the period Nov 1st - Dec 15th 2000. The November 2000 flood is considered an upper limit of what the water system can handle in a safe way with present conditions. The model was validated for a rainstorm during the period April 12th-April 30th 1999. Dam break analysis for two dams was done

according to the Dam safety guidelines of Washington State Department of Ecology (1992).

Potential risk sources for dam safety evaluation were determined. Event tree has been constructed as shown below and probabilities

assigned to each of its items.

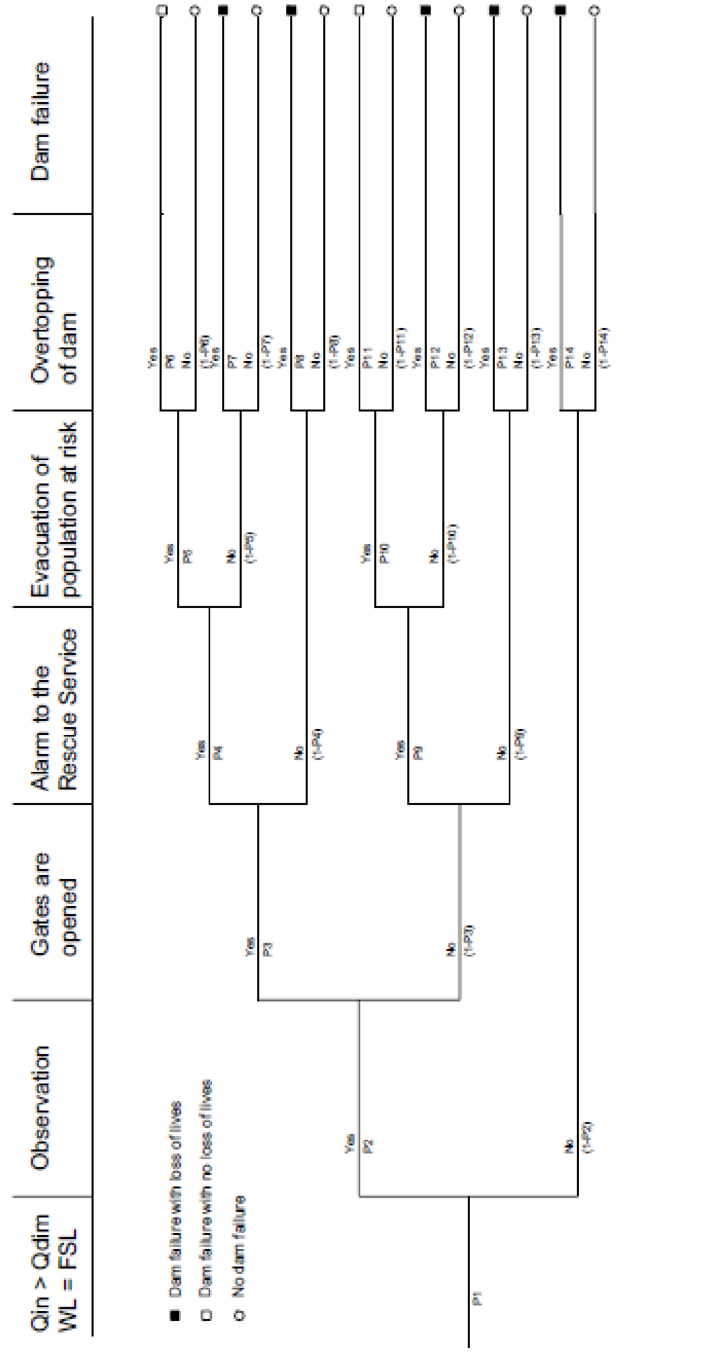


Figure 4.4 Event tree for initiating event $Q_{in} > Q_{dim}$ (FSL=Full supply level)

Consequences of dam(s) failure are discussed and quantified to some extent (potential loss of life, environmental damages, economic damage, bad publicity). Tolerable risk level and existing flood guidance are compared and risk reduction alternatives presented.

1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Site specific **Direct losses considered**
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
EWE: Flood, hazard: dam failure
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard, loss and impact
1.5 Parameters and data: Which are the input data/the data required by the method?
Catchment topology, reservoir volumes and levels, long term rainfall data series, observed discharges for calibration **Initial water level in the reservoir (and floodplain), topography of the floodplain (LiDAR), roughness coefficient, data on culverts, population data**
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Hydrologic simulation, event/fault tree for dam failure
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: uses data that is readily available **Disadvantage: assessment of consequences rather brief**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Assessment of probability of dam failure (critical infrastructure)
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No

3 Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
The method as described above was applied to an extensive water system with dams in central Sweden, near the city of Sala. The dams were constructed centuries ago to supply hydropower for silver mining. The dams consist of long earth walls just a few metres high and often covered with trees. Today the water system has a great value as a recreational area and as a historical monument. The area contributing with runoff is approximately 84 km^2 and the total available storage volume of the water system has been estimated to about 16 million m^3.
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
None
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
A.S. Gebregiorgis and F. Hossain (2012). Hydrological Risk Assessment of Old Dams: Case Study on Wilson Dam of Tennessee River Basin. Journal of Hydrologic Engineering, 17/1.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
The hydrological risk of the hydropower Wilson Dam was systematically analyzed by considering annual peak flow and maximum reservoir volume. Hydrological risk is considered in this paper as the chance of downstream flooding attributable to uncontrolled water release from a reservoir, resulting in the loss of life and property. **The inflow volume was converted to elevation using area elevation-area-storage curves based on reservoir surveys. A constant storage loss**

due to sedimentation is assumed.

L-Moment Method was used for Risk Analysis. Frequency models are not designed for analyzing regulated flows (e.g. peaks regulated by reservoirs). The authors have treated the regulated peak flow as a combination of two components: the deterministic component (taken as minimum flow/release from the reservoir) and the stochastic component (above minimum flow). The frequency distribution model was then fitted to the stochastic component. Before fitting the distribution model to the annual maximum flow series, the validity of the stationarity assumption was checked using various approaches. Three theoretical distributions were tested and GEV was selected. Probability of failure in a lifetime of a dam was calculated.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Site specific

Application to losses not considered

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

EWE: Flood, hazard: overtopping

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Hazard

1.5 Parameters and data: Which are the input data/the data required by the method?

annual maximum discharge data

reservoir levels and volumes, sedimentation rate

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Engineering method

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Quantitative method(s)

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative

1.9 Advantages and disadvantages with the methodology

Advantage: predicts probabilities over lifetime of a reservoir, takes into account sedimentation

Disadvantage: simplifications related to sedimentation process

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

Predicts overtopping risk on dams (critical infrastructure)

2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
Uncertainty boundaries presented according to selected probabilistic model
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
The method was applied to the hydropower Wilson Dam, Tennessee, USA.
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
No
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
E. Goodarzi, L.T. Shui and M. Ziaei (2013). Dam overtopping risk using probabilistic concepts – Case study: The Meijaran Dam, Iran. Ain Shams Engineering Journal, Volume 4, Issue 2.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***

1.1 Methodological approach description

This study presents the application of risk and uncertainty analysis to dam overtopping due to various inflows and wind speeds. The procedure includes univariate flood and wind speed frequency analyses, reservoir routing, and integration of wind set-up and run-up to calculate the reservoir water elevation. Afterwards, the probability of overtopping was assessed by applying two uncertainty analysis methods (Monte Carlo simulation and Latin hypercube sampling), and considering the quantile of flood peak discharge, initial depth of water in the reservoir, and spillway discharge coefficient as uncertain variables.

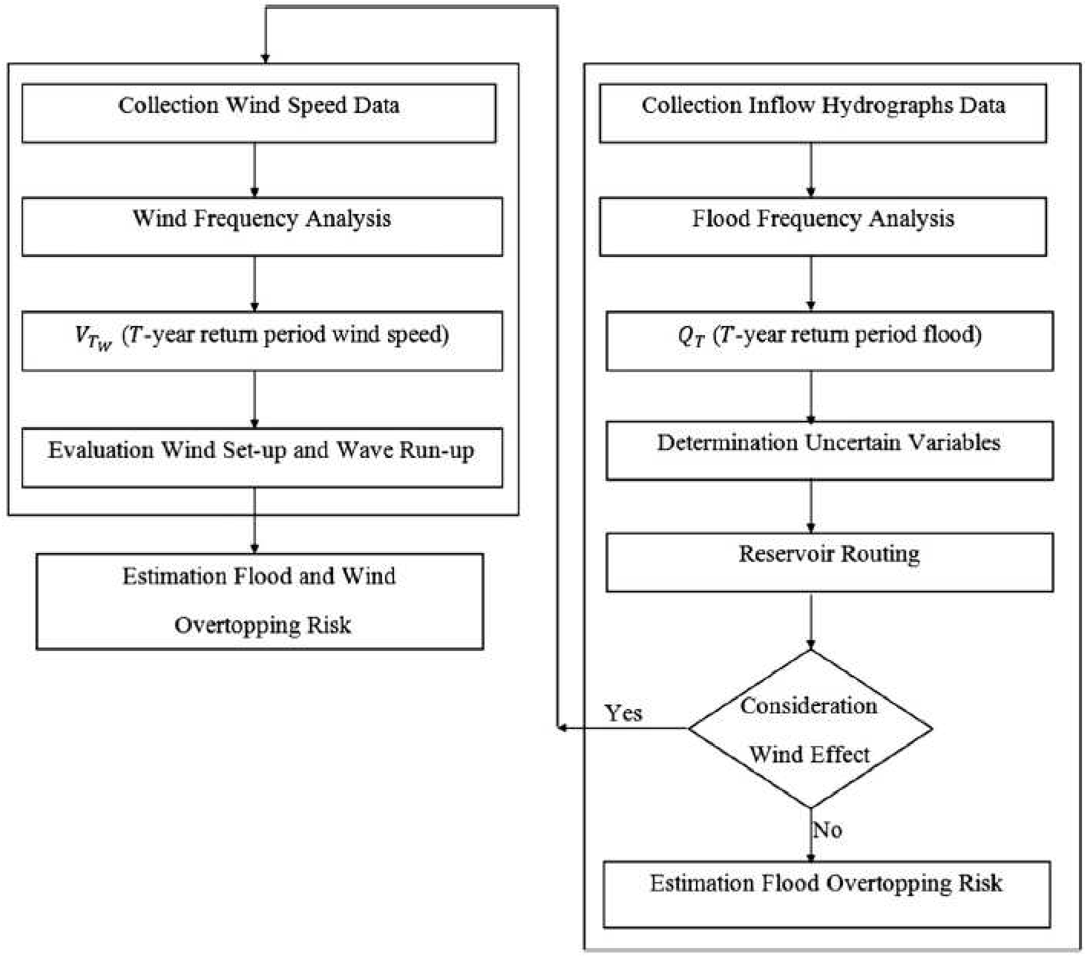


Figure 1 Flow chart for dam overtopping probability.

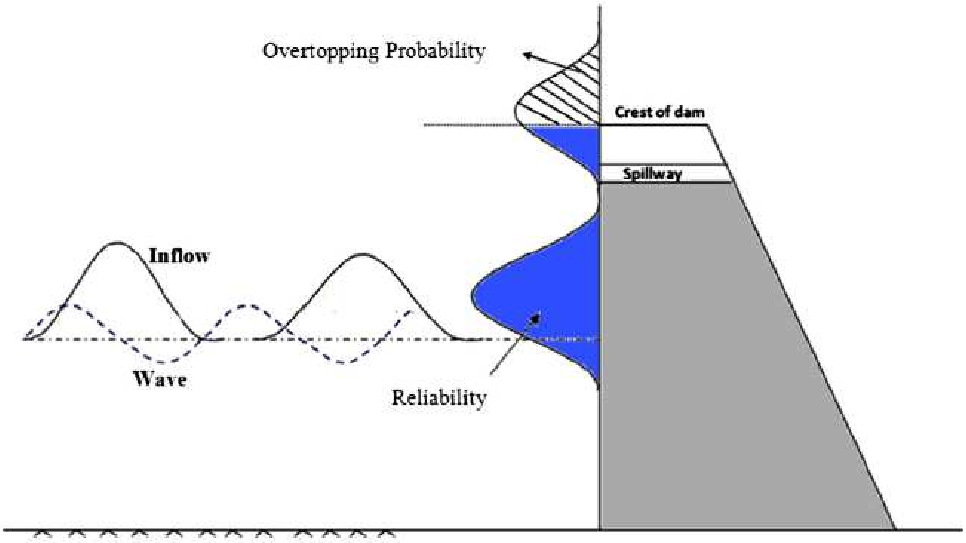


Figure 2 Overtopping risk concept based on probabilistic approach.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Site specific

Application to losses not considered

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

EWE: Flood, wind; hazard: overtopping

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Hazard

1.5 Parameters and data: Which are the input data/the data required by the method?

Inflow hydrographs data

Wind speed data

Reservoir levels and volumes

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Engineering method

1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)

Quantitative method(s)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: takes into account wind **Disadvantage: limited selection of parameters subject to uncertainty**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts overtopping risk on dams (critical infrastructure)
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
Uncertainty arising from peak discharges, initial water levels, and spillway discharge coefficient are considered. The Monte-Carlo simulation (MCS) and Latin hypercube sampling (LHS were applied to perform the uncertainty analysis. Large sample numbers (20,000 for Monte-Carlo and 10,000 for LHS) were considered in this study to increase calculation precision.
3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
This study presents the application of risk and uncertainty analysis to dam overtopping due to different floods alone and due to combination of flood and wind for the Meijaran Dam in the north of Iran.
4 Software ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
No
5 Further comments ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:

Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
K. Jan-Tai, Y. Ben-Chie, H. Yung-Chia and L. Huei-Fen (2007). Risk Analysis for Dam Overtopping—Feitsui Reservoir as a Case Study. Journal of Hydraulic Engineering, 133/8.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
Risk and uncertainty analysis by mathematical and statistical methods is used to assess systematic risks and uncertainties. This research presents the procedure and application of risk and reliability analysis to dam overtopping. Annual maximum series of peak discharges of Feitsui Reservoir in northern Taiwan are used to analyze five extreme flood events with different frequencies. The highest water levels of the five extreme flood events were computed by using reservoir routing and considering seven factors subject to uncertainty. Afterward, the overtopping risk of Feitsui Dam was assessed by five uncertainty analysis methods: Rosenblueth's point estimation method (RPEM), Harr's point estimation method (HPEM), Monte Carlo simulation, Latin hypercube sampling, and the mean-value first-order second-moment (MFOSM) method.

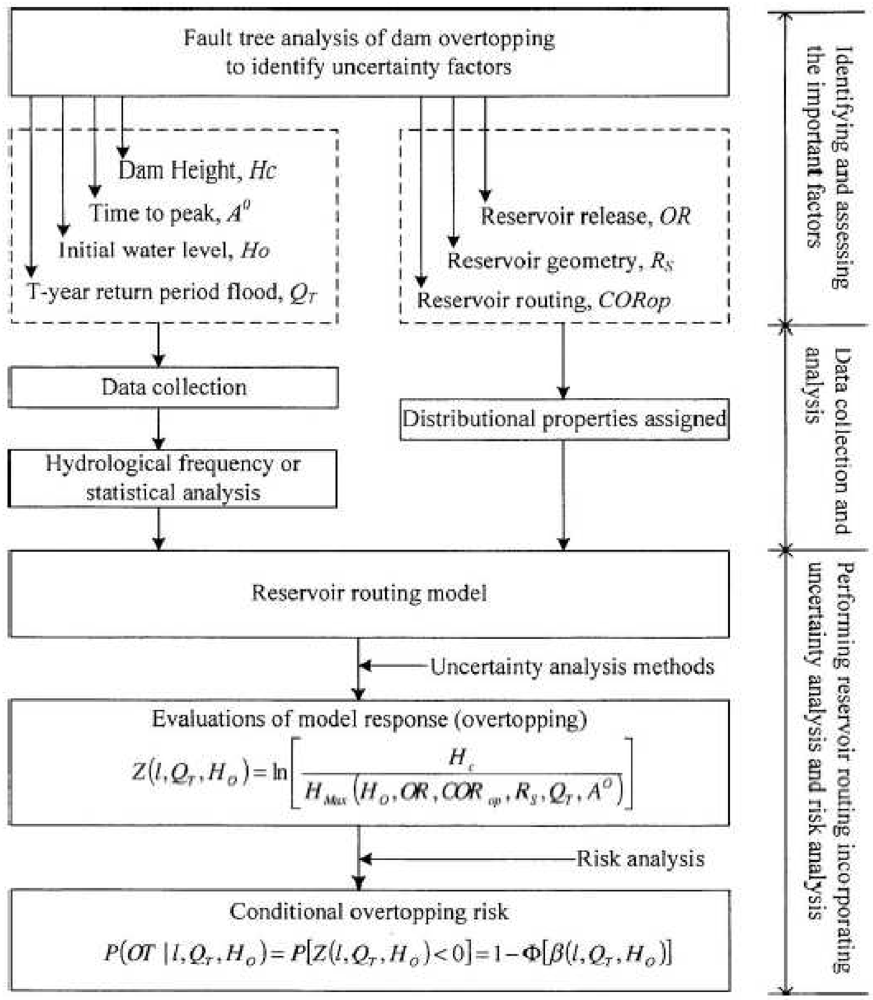


Fig. 1. Flow chart for overtopping risk analysis

1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Site specific **Application to losses not considered**
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
EWE: Flood, hazard: overtopping
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard
1.5 Parameters and data: Which are the input data/the data required by the method?
annual maximum discharge data

reservoir levels and volumes, release rules and capacity
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Engineering method
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Quantitative method(s)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: five methods tested, most yielded accurate estimations, some able to handle high number of random variables **Disadvantage: long dataset required; some methods had problems when non-linearity of models or factor of uncertainty level increased**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts overtopping risk on dams (critical infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
Yes. Uncertainty factors associated with seven parameters: (1) dam crest height – thermal expansion of dam body, (2) initial water level, (3) reservoir release, (4) reservoir routing – numerical error, (5) reservoir geometry, (6) peak flow magnitude at given return period, (7) time of concentration
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
The overtopping risk of Feitsui Dam was assessed by five uncertainty analysis methods, taking into account seven input parameters subject to uncertainty. The safety of the dam is a top concern as millions of people live downstream in metropolitan Taipei. The double-curvature arch dam is 122.5 m tall, with upstream catchment area of 303 km2 and the total storage volume of 406 million m3. The main functions of the reservoir are domestic water supply, hydropower generation, and flood control.

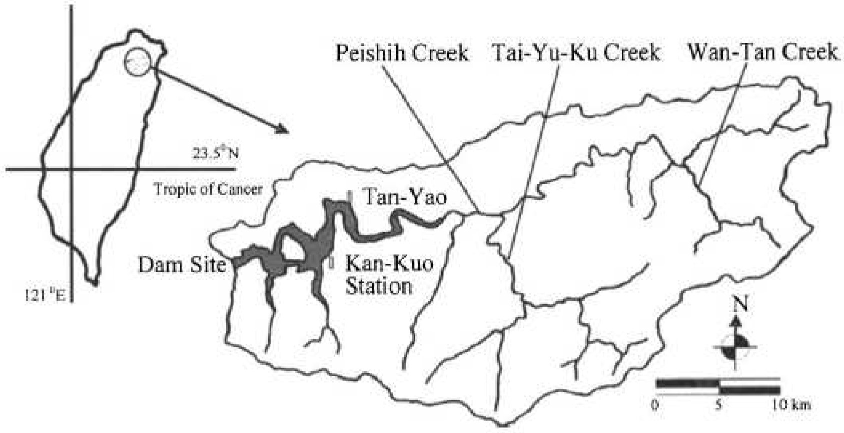


Fig. 2. Feitsui Reservoir watershed

4 **Software** *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
No
5 **Further comments** *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
P.J. Mason (2010). Loyne Dam - Stability Review based on QRA, Event Tree Approach. 16th Conference of British Dam society, University of Strathclyde.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference paper
1 **Methodological approach** *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*

1.1 Methodological approach description
Quantitative risk assessment for a concrete gravity dam is performed. The author has followed the approach used in the recent USBR Unified method for erosion of fill dams and adapted it for assessing the risks associated with the stability of concrete gravity section at Loyne dam (UK). The failure modes to be considered, the associated events which would have to take place for failure to occur and likelihood factors for each of those events were determined based on collective experience. The event tree was prepared, consisting of eight events that would need to appear for failure to occur. Outflow from the reservoir was calculated and compared to previous flooding studies to assess the number of persons at risk in the concerned reach. The values of annual probability of failure and persons at risk were compared to ranges of acceptability according to Interim guide to Quantitative Risk assessment (QRA) for UK Reservoirs (2004) and Guidelines for Achieving Public Protection in Dam Safety Decision Making (US, 2003).
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Site specific Application to life loss is considered
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
EWE: Flood, hazard: dambreak
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard, loss, risk, risk management
1.5 Parameters and data: Which are the input data/the data required by the method?
Outflow recurrence curve obtained from the dam and reservoir level data Data on dam structure Topography and population data for floodplain
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Event tree method
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Quantitative method(s)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: compares the risk to acceptability levels Disadvantage:

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts risks associated to dams safety (critical infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
The methodology was applied to Loyne dam and compared to previous studies regarding downstream population at risk.
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
No
5 <u>Further comments</u> ***If you have further comments about the document that you have reviewed, please include it here***

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
A.C. Morison and S.J. King (2010). Dunalastair Dam - Interaction of Risk Assessment and Emergency Response Plan. 16th Conference of British Dam society, University of Strathclyde.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference paper
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***

1.1 Methodological approach description
Quantitative risk assessment for Dunalastair Dam in Scotland, UK, is performed and risk to the village of Tummel Bridge is assessed. The catchment of the reservoir is extensively developed for hydropower. A number of hydrological assessments of the complex catchment have been made, taking into account snowmelt and gate operation. The paper refers to winter PMF. Flood assessments with return periods of 1:100, 1:1,000 and 1:10,000 according to Flood Estimation Handbook method (1999) and Flood studies report (1975) are also compared. No clearly effective engineering solutions are available to improve dam safety and proactive preparation of emergency plans for the downstream community to mitigate the risk was considered. Risk and mitigation measures were therefore assessed as follows. Flood modelling was conducted with a 1D model based on LiDAR ground level data. An instantaneous failure of the entire dam was assumed as the worst-case scenario, in addition to a gate failure scenario. Further structural assessments are discussed in the text. Three scenarios for expected loss of life from dambreak incident are presented: no warning; more than one hour warning, but no evacuation plan; and more than one hour warning and an effective evacuation plan.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Site specific Application to life loss is considered
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
EWE: Flood, hazard: dambreak
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard, loss, risk, risk management
1.5 Parameters and data: Which are the input data/the data required by the method?
PMF derived from catchment structure, snow cover/snow melt, gate operation, dam and reservoir data Topography and population data for floodplain
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
simulation
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Quantitative method(s)
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: also includes assessment of mitigation measures Disadvantage:

1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Predicts risks associated to dams safety (critical infrastructure)
2 <u>Uncertainties</u> *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
A range of estimated annual probabilities of failure considered (1:10,000-1:50,000) and compared to acceptance categories (unacceptable; ALARP; broadly acceptable)
3 <u>Case studies</u> *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
The methodology was applied to Dunalastair dam (hydrologic analysis for PMF) and Tummel village downstream (flood modelling and population at risk assessment).
4 <u>Software</u> *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
No
5 <u>Further comments</u> *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
A.D. Smith, C.A. Goff and M. Panzeri (2014). Enhancements in reservoir flood risk mapping: example application for Ulley . 18th Conference of British Dam society, Belfast.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Conference paper
1 <u>Methodological approach</u> *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*

1.1 Methodological approach description
This paper proposes an enhanced flood risk assessment in three stages: (i) probabilistic modelling of a failure scenario using embankment breach models; (ii) hydrodynamic inundation modelling for assessment of flood water spreading, depths and velocities; (iii) spatio-temporal population modelling to assess the risk to the population likely to be present. The combination with spatio-temporal population outputs aims to demonstrate the enhancements achievable in reservoir flood risk mapping when vulnerable populations are concerned.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Site specific **Direct losses considered**
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
EWE: Flood, hazard: dam failure
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard, loss and impact
1.5 Parameters and data: Which are the input data/the data required by the method?
Initial water level in the reservoir (and floodplain), topography of the floodplain (LiDAR), roughness coefficient, data on culverts, population data
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Simulation
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
A set of software tools
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: combination of flood and spatio-temporal population modelling **Disadvantage: detailed data required**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)

Modelling of flooding and predicts the impact on population at different times of the day
2 Uncertainties *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
No
3 Case studies *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
Yes. It was applied to the Ulley reservoir risk assessment and flood event in 2007, assuming no emergency preventive action had been taken. Evolution of breach and resulting outflow was modelled, then spread of flooding was modelled with TELEMAC-2D and finally the spatio-temporal population modelling was performed to evaluate the population at risk for different (day)times of dam failure.
4 Software *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
EMBREA/AREBA for breach modelling – predicts outflow hydrograph **TELEMAC-2D – inundation modelling** **SurfaceBuilder24/7 tool - spatio-temporal modelling of population**
5 Further comments *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
Brekke, L. D., E. P. Maurer, J. D. Anderson, M. D. Dettinger, E. S. Townsley, A. Harrison, and T. Pruitt (2009), Assessing reservoir operations risk under climate change, Water Resour. Res., 45, W04411.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*

1.1 Methodological approach description

The risk assessment methodology includes four steps:

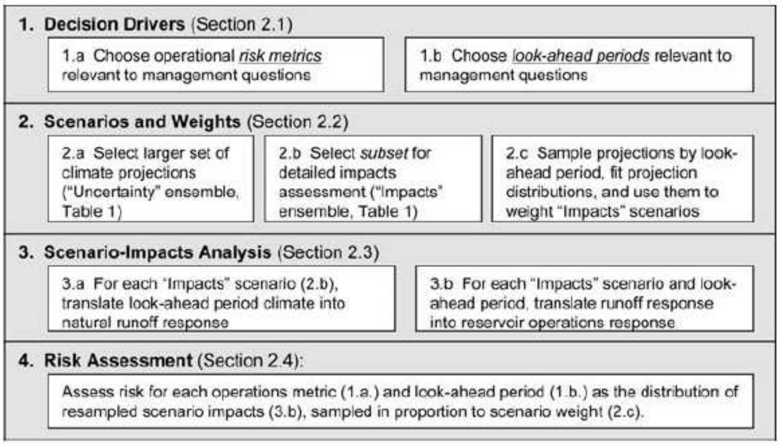


Figure 2. Outline of risk assessment framework (see section 2). Steps 1–4 are described in sections 2.1–2.4, respectively.

Of several possible decision drivers, two metrics were chosen for the analysis: mean annual water delivery and carry-over storage for the next year.

Risk scenarios were based on climate projections in this study. Projection density functions for mean annual temperature and precipitation were prepared and used for subsequent analyses.

Based on meteorological inputs, reservoir inflows were generated by a hydrologic model. The chosen model was the Sacramento Soil Moisture Accounting (SacSMA) model [Burnash et al., 1973] coupled to the ''Snow17'' model on the basis of the Anderson snow model [Anderson, 1973], provided by the National Weather Service (NWS) California Nevada River Forecasting Center (CNRFC). Model calibrations were conducted by CNRFC staff according to NWS procedures [Anderson, 2002] and involved multiple objectives, including matching peak flow rates and monthly volumes.

The outputs of the hydrologic model were fed into CalSimII, a monthly time step decision model developed for exploring what-if supply, demand, and constraint scenarios concerning long-term operations. Water demands, institutional, regulatory, and operating constraints in CalSim II were kept the same for all scenarios.

Risk were then evaluated and impact values for the given metrics used to generate density and distribution functions.

The authors analysed additional scenarios to account for (i) assumptions about future flood control constraints; and (ii) estimation of scenario weights. These were also the base for the sensitivity analysis.

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Regional

Direct and indirect losses considered

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

hazard: drought, indirectly floods (through flood control constraints)

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Hazard, impact
1.5 Parameters and data: Which are the input data/the data required by the method?
Temperature, rainfall, operation constraints, recorded flows
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
simulation
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Software, methodology
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Flexible framework for assessment of reservoir operation risk and impact on delivery of water to water supply systems **Site specific, but can be adapted to other locations**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Assessment of impacts of draughts on water supply (infrastructure)
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
Sensitivity analysis has been performed though it is mainly relevant for long-term climate change scenarios
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
The demonstration focuses on operations risk for California's Central Valley Project and State Water Project systems. The proposed risk assessment framework was applied multiple times to reveal sensitivity of portrayed risk to analytical design
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
(existing software used)
5 <u>Further comments</u>

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
B. Lehner, P. Döll, J. Alcamo, T. Henrichs and F. Kaspar (2006). Estimating the Impact of Global Change on Flood and Drought Risks in Europe: A Continental, Integrated Analysis . Climatic Change (2006) 75: 273–299.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper
1 Methodological approach ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
This paper presents a continental, integrated analysis of possible impacts of climate and water use change on future flood and drought frequencies in Europe. The global integrated water model WaterGAP is evaluated regarding its capability to simulate high and low-flow regimes and is then applied to calculate relative changes in flood and drought frequencies. WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model. It calculates daily vertical canopy and soil-water balances for grid-cells at a spatial resolution of 0.5◦ longitude × 0.5◦ latitude. The European continent is covered by more than 6000 cells which represent approx. 500 first-order river basins. The model routes the derived cell runoff along a global drainage direction map and takes evaporation from lakes, reservoirs, and wetlands into account. Finally, consumptive water use is subtracted from the natural flow and river discharges are computed for every grid cell **of the river network. Snow storage is simulated by applying a simple degree-day method. All WaterGAP calculations are performed in daily time steps. WaterGAP is driven by climate inputs (mainly temperature and precipitation), and by a set of scenario assumptions for changes in human water use.** **Flood Events are defined through daily peak flows, representing the state of maximum inundation or potential damage. The annual maximum flood event is selected from WaterGAP's daily discharge calculations.** **Drought Events are defined as persistent periods where the river discharge** **stays below a reference minimum flow. In this 'threshold level method', each drought spell is characterized by its time of occurrence, duration, minimum flow, and deficit volume (the latter is the measure of the severity of a drought event). This study applies the long-term median of monthly discharges, based on the time series 1961–1990, as a constant threshold value for all data over time (i.e. both for the present and the future).**

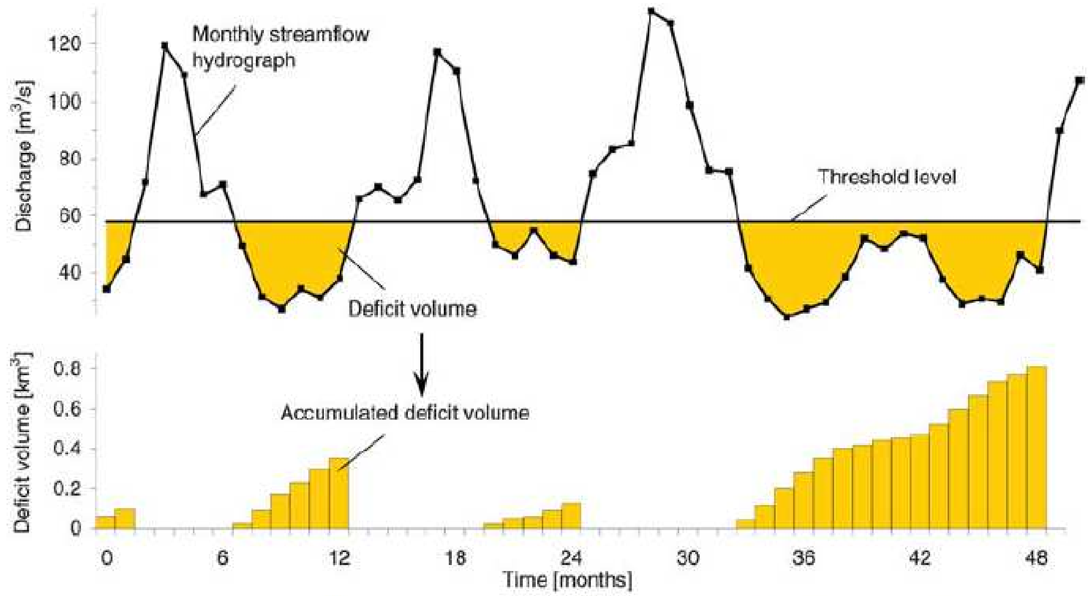


Figure 1. Definition of drought events and deficit volumes: a drought event is defined to start when the discharge falls below the threshold value and to end when the discharge exceeds the threshold. The deficit volume (or severity) of the identified drought event is calculated by accumulating the monthly differences between threshold and actual discharge values over time.

TheWaterGAP model has been tuned for 126 drainage basins and sub-basins within Europe, (65% of the studied area), by adjusting a runoff coefficient such that the simulated long-term average discharge differs by less than 1% from the measured discharge. For all other basins the runoff coefficient has been regionalized by a multiple regression analysis based on selected physical basin

characteristics. The performance of the model was further confirmed with respect to flood (100-year flood discharge) and drought frequency calculations (100-year drought deficiency volume).

1.2 Scale

- **Geographic scale (site specific, local, regional, national)**
- **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**

Regional

Direct losses considered

1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)

EWE: precipitation, temperature, hazard: flood, drought

1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)

Hazard, impact

1.5 Parameters and data: Which are the input data/the data required by the method?

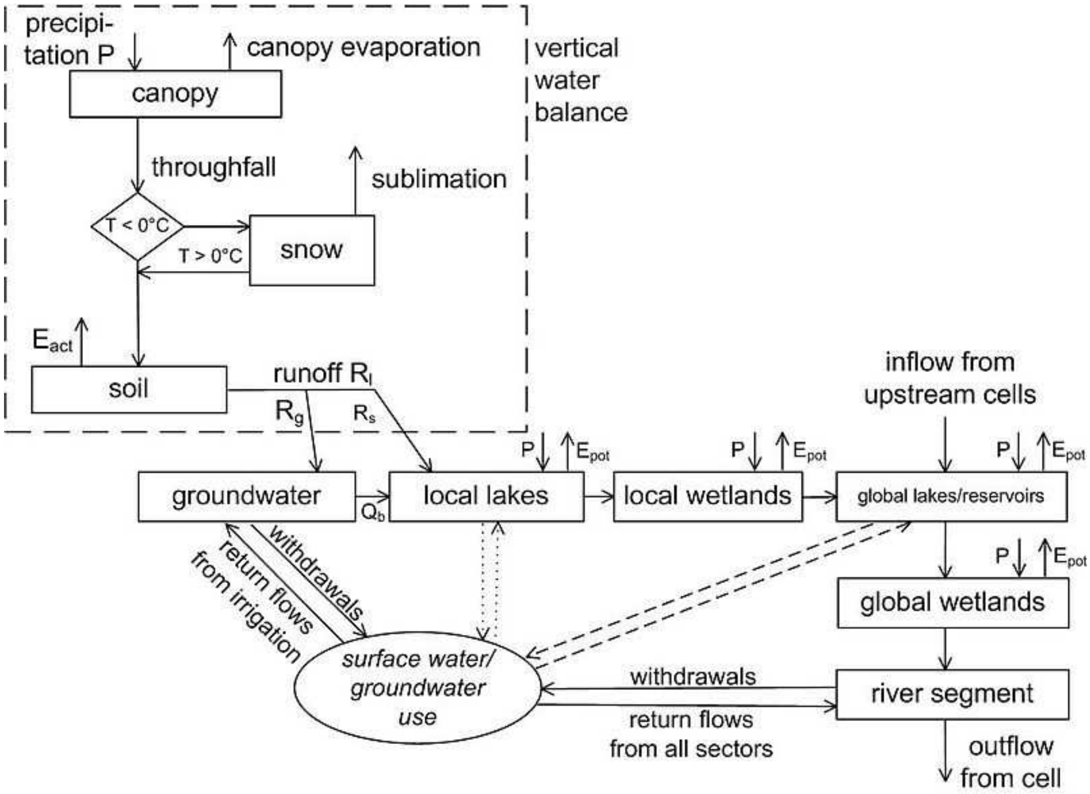
Monthly temperature, precipitation, number of wet days, radiation

1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)

Simulation
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
A software tool
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: integrated approach to flood and drought risk on a continental scale **Disadvantage: coarse scenario assumptions (but typical in climate change analyses), no uncertainty analysis**
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Modelling of flood and drought – as inputs for evaluating vulnerability of water supply and drainage systems as well as other infrastructures
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Applied to future climate change and water use scenarios in Europe. The applied scenarios are largely consistent with the no-climate-policy IPCC-IS92a scenario estimates of the IPCC (1992) and the intermediate Baseline-A scenario as developed by the Dutch National Institute of Public Health and Environment (RIVM). They represent a set of 'business-as-usual' assumptions about population growth, economic growth and economic activity, and imply an average annual increase of carbon dioxide emissions of 1% per year. The population of Europe is projected to grow from 745 million in 1995 to 882 million in 2075. The Gross Domestic Product (GDP) per capita, as an **indicator for economic growth, is assumed to increase at a rate between 1.7 and 4% for European countries, which is slightly lower than historically. WaterGAP also considers structural and technological changes based on extrapolations of historic trends that reflect a change in behavior, industry and water supply infrastructure, as well as the effect of improved water use efficiencies over time. The scenarios are applied on a country basis, but the influence of population density and their classification (rural versus urban) leads to variations within countries. The extent of irrigated area is assumed to remain more or less constant within Europe throughout the century (Henrichs et al., 2002). The impact of climate change on irrigation, which represents the dominant water use sector in southern Europe, is simulated as a shift of the growing season and a changed daily irrigation requirement.**
4 <u>Software</u> ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
WaterGAP (Water – Global Assessment and Prognosis) transforms current and future climate and water use conditions into time series of river flows. It thus allows for a combined analysis of the effects of climate change as well as demographic, socioeconomic and technological trends on large-scale discharge regimes. WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use

Model. The Global Hydrology Model simulates the characteristic

macro-scale behavior of the terrestrial water cycle and estimates natural water availability defined as total river discharge, i.e. combined surface runoff and groundwater recharge. The Global Water Use Model consists of four submodels which compute water use for the sectors households, industry, irrigation, and livestock. The model distinguishes between total water withdrawals and consumptive water use (i.e. withdrawals minus return flows).



Water storages (boxes) and flows (arrows) modelled for each grid cell of WGHM (WaterGAP Global Hydrology Model), Döll et al. (2012)

Döll, P., Hoffmann-Dobrev, H., Portmann, F.T., Siebert, S., Eicker, A., Rodell, M., Strassberg, G., Scanlon, B. (2012): Impact of water withdrawals from groundwater and surface water on continental water storage variations. J. Geodyn. 59-60, 143-156, doi:10.1016/j.jog.2011.05.001.

http://www.watergap.de/

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:
Gregor Petkovsek, HRW
Complete reference of the reviewed document (include Internet links, if available):
S.D. Wade, J. Rance and N. Reynard (2013) The UK Climate Change Risk Assessment 2012: Assessing the Impacts on Water Resources to Inform Policy Makers. Water Resources Management, Volume 27, Issue 4, pp 1085-1109.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Journal paper

1 Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

This paper describes the research completed on the impacts of climate change on the UK water sector, involving stakeholder engagement and a mix of literature review, expert elicitation and broad-scale quantitative analysis to develop ten climate change risk metrics. These include measures of the demand for water, impacts on supply, water quality and asset performance using future scenarios based on the UK Climate Projections 2009 and future population projections from the Office for National Statistics. Steps were taken as shown below:

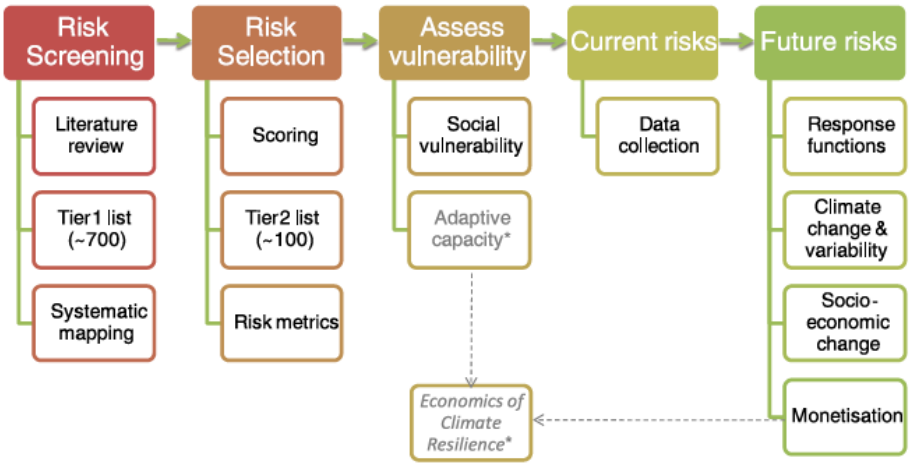


Fig. 1 Simplified summary of the CCRA methodology and links with the economics of climate resilience project. * ongoing studies to inform the NAP

The four metrics further analysed in this paper are: relative aridity, Q95 low flows, supply-demand deficits and number of sites meeting WFD environmental flow indicators.

The relative aridity quantitative metric is a basic hydrological measure of how warm and dry the climate is relative to 1961–1990. The analysis was based on a modification of an existing aridity index which combines rainfall and temperature data to define drought periods, using the equation of Marsh (2004).

To determine the low river flows, the study used two main sources of evidence: (1) hydrological modelling completed by the Centre for Ecology and Hydrology (CEH) for the Environment Agency (Environment Agency 2008c); and (2) Similar work completed for the UKWater Industry that was based on modelling 70 UK catchments using a sub-sample of UKCP09 (UKWIR 2009). These studies had developed national modelling capabilities to convert future climate change scenarios to changes in flow using the 'delta change' method for perturbing climate

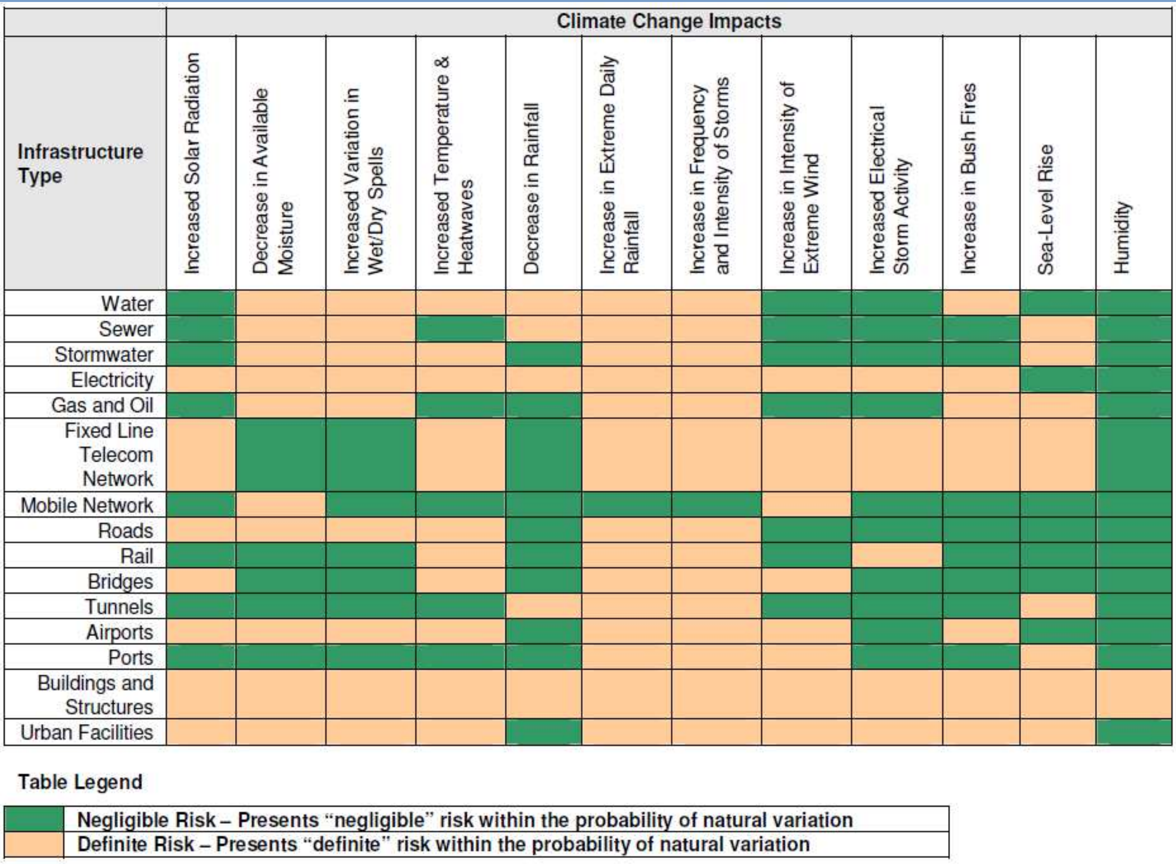
data (Hay et al. 2000) and then running these data through gridded or lumped catchment hydrological models. The results from these studies were used to produce a response function for regional average percentage change in the low flow statistic, Q95, in relation to relative aridity of the climate series used to run the models. Supply-demand balance was calculated firstly based on climate change only, then to include consideration of socio-economic changes by combining the results on changes in Deployable Outputs and the household demand for water with additional information on future population projections. The population change is based on different ONS forecasts for population growth, with 'low', 'principal' and 'high' following the naming convention of these forecasts. Environmental Flow Indicators (EFIs) relate flow to the ecological quality of water bodies and have been developed by the Environment Agency for WFD implementation. A sensitivity analysis was carried out using existing data which established the number of river water bodies in England and Wales complying with their current EFIs for 10, 15 and 20 % reductions in Q95 flow (Entec 2010).
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
National Direct losses considered
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
hazard: flood, drought
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Hazard, impact
1.5 Parameters and data: Which are the input data/the data required by the method?
Temperature, rainfall, flows, population dynamics parameters
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Indicator-based method
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Quantitative
1.9 Advantages and disadvantages with the methodology
Advantage: the results of existing studies may be used Disadvantage: climate change focus, may be difficult to apply to individual events
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
Assessment of flood and drought through indicators – as inputs for evaluating vulnerability of water supply and drainage systems as well as

other infrastructures
2 <u>Uncertainties</u> *Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment*
Several climate change scenarios were considered (low, high emission), years (e.g. dry, normal, wet) and population/water use dynamics.
3 <u>Case studies</u> *Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done*
The assessments for the mentioned four indicators were applied nationally or to selected UK river basins corresponding to various climate change projection periods and scenarios.
4 <u>Software</u> *If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)*
5 <u>Further comments</u> *If you have further comments about the document that you have reviewed, please include it here*

Template for D4.1: Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment
Name(s), and partner acronym:
HRW
Complete reference of the reviewed document (include Internet links, if available):
Holper, P.N., S. Lucy, M. Nolan, C. Senese, and K. Hennessy, 2007: Infrastructure and Climate Change Risk Assessment for Victoria. Consultancy Report to the Victorian Government prepared by CSIRO, Maunsell Australia, and Phillips Fox, Aspendale, Victoria, Australia,84 pp
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Report
1 <u>Methodological approach</u> *Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).*

1.1 Methodological approach description
This report examines the likely impacts of climate change on Victoria's infrastructure and outlines opportunities for adaptation responses. Based on the Australian Standard for identification and assessment of risk, the report assesses the following infrastructure types: water, power, telecommunications, transport and buildings. For each infrastructure category, the authors have assessed the likely impact of climate change on infrastructure services (the infrastructure itself and its functions), social amenity (including health and public response), governance and the costs of maintenance, repair and replacement.
1.2 Scale • Geographic scale (site specific, local, regional, national) • Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?
Regional
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Extreme rainfall, storm, wind, heat, flood
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Focus is on risk assessment
1.5 Parameters and data: Which are the input data/the data required by the method?
The climate change variables considered in this report include: Solar radiation – Changes to solar radiation levels and exposure Available moisture – Changes to evaporation rates and levels of rainfall impacting available moisture Variation in wet/dry spells – Changes to water table, surface and subsoil inundation cycles Temperature and heatwaves – Changes in frequency of extreme max temp, and length of heat spells Rainfall – Changes in annual rainfall Extreme daily rainfall – Changes to flood levels of extreme rainfall events Frequency and intensity of storms – Changes to the intensity and number of storm events. Intensity of extreme wind - Changes in the intensity of low pressure system wind events Electrical storm activity - Changes in frequency and intensity of lightning events Infrastructure and Climate Change Risk Assessment for Victoria Bush fires – Changes in the frequency and intensity of bush fires Sea-level rise – Changes to average sea level Humidity - Changes in annual average relative humidity
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
Indicator based
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Method, semi-quantitative

1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)
Semi-Quantitative
1.9 Advantages and disadvantages with the methodology
Comprehensive assessment, according to Australian standards
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
A case study of risk assessment of various types of infrastructure
2 <u>Uncertainties</u> ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 <u>Case studies</u> ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Australian risk assessment standards applied to climate change projections for infrastructure in Victoria. Where possible quantitative measures were used to classify the level of risk. **The aspects assessed are as follows:** **a) Infrastructure services (negative impacts to human-made physical infrastructure and the intended service it provides to the community, industry, government and the natural environment);** **b) Social (negative impacts to human health, amenity and community; level of public response to impacts);** **c) Governance (negative impacts to management of organisations and government; legal, regulatory and management responses); and** **d) Finance – Costs including necessarily ancillary plant/equipment to maintain (e.g. air conditioning equipment), repair and replace infrastructure and the intended service it provides. Wider economic impacts are not implied.** **Risk rating matrix was prepared based on likelihood and consequences.**



4 Software

If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)

n/a

5 Further comments

If you have further comments about the document that you have reviewed, please include it here

Template for D4.1:

Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment

Name(s), and partner acronym:

HRW

Complete reference of the reviewed document (include Internet links, if available):

European Environment Agency (2010). Mapping the impacts of natural hazards and technological accidents in Europe. EEA Technical report No 13/2010
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Report
1 <u>Methodological approach</u> ***Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).***
1.1 Methodological approach description
This is a summary document listing the impacts of extreme weather events (storms, droughts, floods, extreme heat among others) in Europe. Methodology is concerned with analysis of event occurrence and event impact (economic, fatalities), sometimes in context of climate change and estimates of impacts due to the parameters of changed climate and thus provides spatial analysis and temporal trends.
1.2 Scale • **Geographic scale (site specific, local, regional, national)** • **Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?**
Continental
1.3 Considered EWE or resulting hazards (e.g. flood, storm, landslides, cold & heat waves etc.)
Storms, floods, droughts, extreme heat, cold spells
1.4 Risk perspective/conceptual reference (Do the methodology focus on hazard, exposure vulnerability, loss, impact, network modelling, more general on risk, risk management etc.)
Focus is on impact assessment
1.5 Parameters and data: Which are the input data/the data required by the method?
This is more of statistical analysis of past events, i.e. data related to them is used. Discussion mentions climate change impacts and adaptation.
1.6 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc. Methodology developed especially for CI should be classified according to Yusta et al. 2011: Relational Databases, Network Theory, Rating Matrices, System Dynamics, Agents)
1.7 Type of conceptual reference (software / software tool (licensing &pricing), software prototype (licensing &pricing), method (qualitative/quantitative/semi-quantitative), methodology/theory)
Statistical method
1.8 Perspective (qualitative, semi-quantitative or quantitative methodology)

Quantitative/qualitative
1.9 Advantages and disadvantages with the methodology
n/a
1.10 Relevancy for INTACT (Describe to which extent the reference is relevant for INTACT)
It provides an overview of relevant events and impacts in Europe. On the other hand, contribution from the perspective of assessment tools is modest. Much of analyses are qualitative only.
2 Uncertainties ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
No
3 Case studies ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
Several extreme weather events in Europe were analysed and projection for the future presented in some cases.
4 Software ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
n/a
5 Further comments ***If you have further comments about the document that you have reviewed, please include it here***

Literature to section 4.5

Template for D4.1: **Literature review to establish SOTA of Modelling Approaches for CI vulnerability assessment**
Name(s), and partner acronym:
De Groeve, T., Poljansek, K. & Ehrlich, D.
Complete reference of the reviewed document (include Internet links, if available):
JRC Scientific and policy Reports. 72 pages, 2013.
Type of document (e.g. book, journal paper, internal project report, public report, etc.)
Govt inst publication

1. Methodological approach

Note: In this part, please write down an overview of the methodological background used; please indicate how risk, vulnerability, losses, etc. are considered; you can include figures (with respective references).

1.1 Methodological approach description

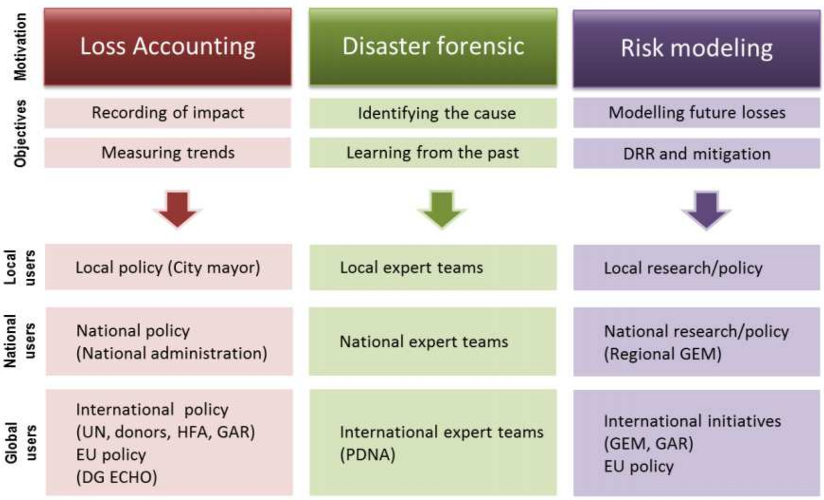
Loss databases cannot be combined due to the diversity of purposes and data collection procedure. That makes impossible to develop loss trends, infer vulnerability of society or monitoring the success of the disaster reduction measures.

The document, with Italy and Slovenia as examples, realizes that, the biggest problems are differences between global databases and national databases. There is also a difference in methods used in data-rich countries and data-poor countries. In addition the systematic loss accounting, that is part of internal government procedures, is not publicly shared, like in the Slovenia example.

First of all, the different levels of the scope and scale of loss data for loss accounting, are defined in the document, in order to understand the proposed method.

The method describe that there are at least three linked application areas that require overlapping loss information:

- **Loss Accounting**
- **Disaster forensic**
- **Risk modeling**



Those three areas differ in scale (precision) and scope (coverage) requirements.

A theoretical model point out that the key is to engage actors at local level to establish loss databases for operational use, which can then be aggregated at national and global level for strategic and policy making purposes.

That's why, a new European approach is needed to be developed by taking stock of existing international experiences and existing EU laws. The technical requirements for an EU approach are derived from the needs in the three application areas already mentioned.

The EU methodology should be standardized at local level, and the data model encompasses three entities:

- hazard event identification,
- affected elements
- loss indicators describing damage/loss of affected elements.

The method describe in detail some different scenarios for implementing loss database in a country. They are provided with cost-benefit analysis and appropriateness for different policies. The method ends explaining that specific implementation will depend on:

- the flexibility of existing systems,
- how much a Member State plans to invest in establishing new systems
- which application areas are of their interest.

Finally, the document indicate some standard guidelines for development of EU loss data, and point out the INSPIRE legislation, as interchange data mechanism.

1.2 Scale

- Geographic scale (site specific, local, regional, national)
- Scale of losses: Is the focus on direct losses are indirect losses and cascading effects also included?

Geographic scale: It can be used on different scaled, but is focus on the UE.

Scale of losses: Focus on direct and indirect losses, and macroeconomic effects

1.3 Considered hazards

In this document are considered all type of hazards

1.4 Perspective (qualitative, semi-quantitative or quantitative methodology)

qualitative

1.5 Classification of methodology (e.g. engineering method, simulation approach, indicator-based method, event or fault-tree method, artificial intelligence based, etc.)

Guidelines for Recording Disaster Losses

1.6 Parameters and data:

- Do the methodology focus on vulnerability, loss, more general on risk or on other parameters?
- Which are the input data/the data required by the method?

1.7 Advantages and disadvantages with the methodology

The advantages: Clarifies the difficulties of loss accounting data and provides solutions through different scenarios and how to implement

standardized loss database in a country.
2. **<u>Uncertainties</u>** ***Is there an explicit discussion about uncertainties on risk quantification (and/or on its components?) If Yes, please comment***
3. **<u>Case studies</u>** ***Are there 'case studies' in which the methodology was applied? If so, make a brief description of what was done***
The method describe in detail some different scenarios for implementing loss database in a country. They are provided with cost-benefit analysis and appropriateness for different policies.
4. **<u>Software</u>** ***If a Software tool has been developed, please comment it (e.g. purpose, availability, kind of analysis, links, etc.)***
5. **<u>Further comments</u>** ***If you have further comments about the document that you have reviewed, please include it here***