D(3.1) Holistic and Multiple Risk Assessment Framework

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Executive Summary

This report describes the holistic and multiple risk assessment framework developed in PEARL. The report starts with a review of different approaches and frameworks for evaluation of risk in relation to different sources of hazards (i.e. tsunamis, earthquakes, landslides, etc.). The review highlights the need for an approach which would take into account formation and propagation of risk from the holistic perspective.

The holistic risk assessment framework starts from the assumption that risk emerges (or co-evolves) from interactions between different human systems (social, institutions, economy, etc.), physical environment and technological developments. One of the first steps in the development and implementation of a holistic flood risk assessment framework is formulation of ontology. Ontology is a formal naming and definition of the types, properties, and interrelationships of the entities within a particular domain. As such, it can be used for model specification. The connection between different concepts highlights the need to study interdependencies among different subsystems. In PEARL, ontological formulation is further enhanced with the notions and concepts coming from the extended FORIN and RRCA approaches. Such enhanced formulation is an important step for identifications of relevant actors, domain knowledge, systems and theories. It is also used to define the boundaries of the larger system and the relevant issues and scales of application in the study areas. In terms of the practical application in PEARL, this requires close synergy between work packages 1, 2, 3 and 5.

Furthermore, the PEARL holistic risk assessment framework also includes a wide spectrum of impacts ranging from qualitative risk perception to quantitative direct and indirect damage estimation. Different models and tools are being developed to support this framework. Moreover, a new methodology for evaluation of public health impacts and economic damages has been proposed. These methodologies aim to support better estimation of direct and indirect, tangible and intangible impacts/damages. Furthermore, the economic damage assessment methodology includes a business interruption economic model that can help in the estimation of cascading effects to other urban services due to extreme hydro-meteorological events.

Finally, the report also discusses potential methods that can be used to visualize risk (e.g., 2D maps, 3D visualization, etc.).

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Abbreviations

IWA	International Water Association
UNESCO-IHE	United Nations Educational, Scientific and Cultural Organization - Institute for Water Education
WMO	World Meteorological Organization
DHI	Danish Hydraulic Institute

1 Introduction

Floods are regarded as one of the most frequent types of disasters. Such events can be even more harmful if a combination of different types of floods coincides at a single point in time.

Rapid urbanisation in coastal areas combined with climate change and poor governance can lead to a significant increase in risk of pluvial flooding coinciding with fluvial and coastal flooding posing a greater risk of devastation to coastal communities (Djordjevic et al. 2011). The perception of flood risk and its impacts on life and daily activities can be significantly different amongst countries and cultures. The level of knowledge, awareness and understanding of flood risk in a given area is related to people's decisions to either adjust their way of living to such a risk or simply to ignore it.

Traditionally risk is defined as a combination of vulnerability and hazard for a particular event. Risk comes with the implicit concept of probability and it can be calculated for different events or a combination of them within a particular time period of analysis. The traditional approach also associates risk of a particular event with the potential impacts that can be incurred. Most of the time the impacts are monetized and this has led to the development of quantitative methods for risk assessment. This approach is valuable to take financial decisions. However, when dealing with complex dynamic systems such as urban environments other views or perspectives such as social justice, poverty, risk perception and acceptance need to be taken into account. In Vojinovic and Abbott (2012), a holistic approach to flood risk mitigation has been promoted in contrast to the narrow techno-centric approach. Besides technical aspects, the flood risk analysis should also incorporate qualitative aspects (e.g., perceptions, cultural values, etc.) into the overall analysis in order to arrive with more profound solutions (see also Vojinovic, 2014).

Rather than focusing on specific system components or subsystems, the holistic framework developed in PEARL focuses on gaining understanding of the structure and behaviour of the system as a whole to develop a holistic view on risk, its formation, propagation and cascading. The framework developed connects technology, social dimension and natural processes. The framework addresses processes that may span over a long period of time (i.e., strategic planning level in relation to policies whose implementation/effects may take longer period of time) and relate to emerging system characteristics relevant during disaster event (operational level).

The application of PEARL holistic risk assessment framework highlights the need to gain understanding in the formation of risk from processes which collectively may have an effect on vulnerability and risk. The framework is advancing the state of the art by combining the FORIN methodology together with the RRCA approach into the overall analysis. There are three chapters in this report including Introduction (Chapter 1) and references. Chapter 2 contains a literature review and the existing state of the art frameworks in flood risk assessment. Chapter 3 describes the holistic flood risk assessment framework developed in PEARL. The same chapter also includes an overview of different ways that can be used to visualize risk and interact with different stakeholders.

2 State of the art in disaster risk assessment methods

2.1 Definitions

The key terminologies in disaster risk assessment include hazard, exposure, vulnerability, risk, disaster and risk assessment. The literature review of a large number of sources have given multiple definitions for these terms based on, for example, method of analysis, type of event, and academic backgrounds. See for example definitions collected by Kelman (2003), Thywissen (2006) and FLOODsite (2009). Within the scope of PEARL project the following definitions were adopted.

Hazard refers to “the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources” (IPCC, 2012). Some sources address the natural or human factors as the key factors which stimulate or promote an event as triggering factors (UNIMIB, 2012) or climate-related drivers (IPCC, 2014a). However, there is a lack of consensus in relation to the term ‘hazard’ as they often refer to different processes (e.g., rainfall, storm surge, a flood event resulting from rainfall or storm surge, etc., see for example, IPCC, 2014 and UNISDR, 2009). In this report, we focus on flood hazard as a phenomena that is caused by natural triggering factors such as rainfall, hurricanes and storm surges.

Exposure refers to “the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected” (IPCC, 2012). The IPCC report emphasizes the possibility that even if an element is exposed, it does not necessarily mean that it will be damaged. That depends on the vulnerability of the element.

Vulnerability is “the propensity or predisposition of exposed elements such as human beings, their livelihoods, and assets to suffer adverse effects when impacted by hazard events” (IPCC, 2012).

Resilience is “the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions” (IPCC, 2012). Some literature sources consider resilience merely as the opposite of vulnerability (see for example, UNDP, 2011, p. 13).; whereas, some other sources define a resilient system as one which is less vulnerable to shocks across time, and which can recover from these shocks and adapt to changes (Gitz & Meybeck, 2012). Though the two concepts are complementary, in this report, we consider the resilience as a whole system concept which may be more than the scale defined in vulnerability analysis. A thorough synthesis about the complementary and conflicting nature of the two concepts is given in Miller et al. (2010).

Risk is regarded as “the probability of harmful consequences — casualties, damaged property, lost livelihoods, disrupted economic activity, and damage to the environment — resulting from interactions between natural or human-induced hazards and vulnerable conditions (UNDP, 2010). There are underlying risk drivers which shape risk patterns and trends (UNISDR, 2013). These can either be climatic systems such as climate change or socioeconomic processes such

as socioeconomic pathways, governance and adaptation and mitigation actions (IPCC, 2014a) or income and economic strength of countries (UNISDR, 2009a). These risk drivers affect either the hazard or vulnerability or exposure. For example, urbanization, environmental degradation and climate change affect the hazard; whereas, poverty, weak governance, badly planned and managed urban development shape vulnerability and exposure (UNISDR, 2013).

Impacts are regarded as “effects on natural and human systems of extreme weather and climate events and of climate change” (IPCC, 2014b). Impacts can be also referred to as consequences and outcomes (IPCC, 2014b), and also losses (UNISDR, 2013).

Disaster refers to “severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs that may require external support for recovery” (IPCC, 2012). Some may categorize disaster as a phenomenon on the basis of affected people or society’s capacity to cope. For example, a disaster can only be entered into the emergency database of the Centre for Research on the Epidemiology of Disasters (CRED) if at least one of the following criteria is fulfilled: 10 or more people reported killed, 100 or more people reported affected, declaration of a state of emergency, call for international assistance (Guha-Sapir et al., 2009). In this framework, the IPCC’s definition of disaster holds.

Risk assessment is “a methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that altogether could potentially harm exposed people, property, services, livelihoods and the environment on which they depend (UNISDR, 2009b). The assessment can be quantitative and/or qualitative estimation of risk (IPCC, 2014c) and the method is selected based on the required data and the purpose of the analysis (Jelínek et al., 2011). Qualitative analysis provides a general indication of the level of risk and usually carried out in a national or regional level; whereas, quantitative analysis is performed to obtain more specific information in a small, local level (Jelínek et al., 2011). A more elaborated description of qualitative and quantitative risk assessment methods, their strengths and weaknesses is also given by Vojinovic and Abbott, (2012) and Lee and Jones, (2004).

However, some literature sources add more terminologies within the risk assessment, arguing that risk assessment incorporates risk analysis and risk evaluation (Fell et al, 2005; Schanze, 2006; FLOODsite, 2009). According to these literature sources, risk analysis estimates risk based on the analysis of hazard, vulnerability and consequences; whereas, risk evaluation puts the estimated risk in perspective of individual or societal perception of risk and weighing of the tolerability of risk.

Scenario is regarded as “a plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships” (IPCC, 2012).

2.2 Review of Disaster Risk Assessment frameworks

The 2011 Global Assessment Report on Disaster Risk Reduction emphasised that countries should record disaster losses, measure the impacts and assess risks to justifiably invest in risk reductions (UNISDR, 2011). Disaster risk assessment provides decision makers where and how much to invest in disaster risk reduction and improvement of emergency management capabilities (G20/OECD, 2012). For example, the UK Environmental Agency (2007) illustrated the use of flood risk assessment tool to analyse whether failure of a tidal flap gate or pumps

poses a greater risk in a hypothetical catchment and how the assessment result could be used to support decisions about which asset to repair first.

Disaster risk can be a result of one of or a combination of several natural hazards. These hazards can be hydro-meteorological hazards such as floods, hurricanes, droughts, extreme temperatures and wildfire or geophysical hazards such as earthquakes, volcanos and landslides (Below et al., 2009). Since it is not in the scope of this report to go into a detailed review of definitions, these definitions of hazard types are not covered here. For such overview of definitions see Sivakumar (2005). In addition, this section does not give a detailed literature review but presents the risk assessment methods for selected hazard - see Cirella et al. (2014) for a thorough review on flood risk assessment in European context.

2.2.1 Tsunami risk assessment

Jelinek and Krausmann (2008, p. 39) developed a tsunami risk assessment framework which consists of five steps: (1) scope definition which defines the area under investigation, the purpose and level of detail of analysis and the type of approach used; (2) hazard analysis which includes tsunami characterisation, inundation modelling and frequency analysis; (3) consequences analysis which includes identification of elements at risk and the vulnerability of the elements; (4) risk estimation which is a quantitative or qualitative (or both) analysis of affected people in terms of injury and casualty and direct and indirect economic losses; and finally, (5) risk evaluation which determines the acceptability of the risk. Using a slightly modified framework, Jelínek et al. (2011) performed a tsunami risk assessment for the city of Cadiz, Spain. The authors selected five 'worst-case' scenarios for the study and categorized the risk based on five qualitative levels ranging from very low to very high. The colour coded maps produced identified tsunami hot-spot areas for fatalities. On the other hand, in its Intergovernmental Oceanographic Commission Manuals and Guides, UNESCO (2009, p. 9) developed guidelines for tsunami risk assessment, which is composed of three components – hazard assessment, vulnerability assessment and assessment of community preparedness. The first two components are assessed in a similar fashion as mentioned above; whereas, the third element tries to identify and appraise weakness in early warning systems and the responses of vulnerable groups in the event of warning and during the post-impact recovery, and it also assesses the application of risk transfer mechanisms. Strunz et. al. (2011) also performed tsunami risk assessment for people-centred early warning. In the vulnerability assessment, the authors analysed the exposure of people and critical assets and community preparedness to tsunami warning and their response capabilities (p 71-72). (See also LIPI/DLR/UNU-EHS, 2011)

2.2.2 Landslide risk assessment

Fell et al (2005) developed a landslide risk management framework that consists of two elements –risk analysis and risk evaluation. The former includes hazard analysis which characterizes the landslide and its probability of occurrence, and consequences analysis which identifies and quantifies exposure of people and properties and their vulnerability. On the other hand, the latter analysis the risk against values judgement and risk tolerance criteria. (see also Fell et al., 2008). Dai et al (2002) and UNISDR (2012) developed a basic framework for risk assessment which is composed of hazard, vulnerability and exposure assessments. Dai et al (2002) emphasised on the use of historic landslide data to characterise the hazard and vulnerability within GIS-based conceptual integrated system. However, the UNISDR report focused more on hazard and exposure assessments giving less weight to vulnerability analysis. Lee and Jones (2004) listed a variety of qualitative and semi-quantitative landslide risk assessment methods including risk registers, relative risk scoring, risk ranking matrices, relative risk rating and failure modes, effects

and criticality analysis. These methods emphasised more on hazard assessment and are characterized by mapping the area of interest, estimation of the likely magnitude, frequency and impact potential of land slide, and use of expert judgement. The quantitative risk assessment method given by the authors is based on direct and indirect loss estimation.

2.2.3 Earthquake risk assessment

Karimi et al. (2006) proposed an earthquake risk assessment method that consists of hazard, vulnerability and loss analysis. The authors focused mainly on dealing with uncertainties related to the correlation of seismic hazard, damage and loss parameters, and uncertainties concerning the likelihood of occurrence and intensity of the hazard. They, then, suggested using fuzzy relations for the first type of uncertainties and probability theory for the second ones. Antonioni et al. (2007) developed a quantitative seismic risk assessment procedure which is implemented in a GIS-based software tool. The procedure includes assessing the expected frequencies and magnitude of seismic events based on historical data, and assessing damage probability of equipment based on vulnerability curves. The procedure also included the identification of reference scenarios to be considered in the assessment of consequences. Pasquale et al. (2005) compared the use of a mean and probabilistic value of inputs such as occurrences of hazard, frequency of damage level (expressed in terms of economic damage) and value of loss for a given damage level to assess seismic risk on residential buildings in Italy. In their analysis, the authors showed that the loss estimation is sensitive to the seismic hazard analysis methods than the vulnerability analysis.

2.2.4 Drought risk assessment

Zhang (2004) assessed drought risk to maize using a drought disaster risk index (DDRI), which is a function of time, space and intensity frequencies of drought, consecutive intensity of drought and regional production level of maize. Based on DDRI and percentage reduction yield of maize to drought, the author carried out a fuzzy cluster analysis to finally divide the study area into four degrees of drought risk – high, medium, low and slight risks. Shahid and Behrawan (2008) and Kim et al. (2015) also computed drought risk using drought risk index (DRI). In their case, DRI is a product of drought hazard index (DHI) and drought vulnerability index (DVI). The DHI was dependent on weight and rating of severity of drought and effective precipitation (only the later used effective precipitation). The DVI, on the other hand, was based on the socio-economic and physical indicators of drought such as population density, female to male ratio, poverty level, agricultural occupation, percentage of irrigated land, soil water holding capacity and food production. The DRI was finally classified into four classes of low, moderate, high and very high indices. Li et al. (2009) assessed drought risk on major crop production based on regional or country drought risk index which is a function of drought disaster frequencies, drought severity, levels of production and drought adaptive capacity. In the study, the drought risk index reflected the potential adverse effects of drought in terms of yield reduction caused by meteorological drought. Zhang et al. (2011) assessed agricultural drought risk as combination weights of drought dangerousness, vulnerability, exposure and drought-resistibility. The methodology was based on indices of the four factors computed using variable fuzzy sets model, and the comprehensive agricultural drought risk was divided into five grades which varied from lowest to highest risk.

2.2.5 Flood risk assessment

Hall et al. (2003) developed and presented a national-scale flood risk assessment methodology for England and Wales. The authors determined flood impact zones based on failure scenarios

of flood defences and expressed flood risk in terms of an expected annual damage which is a function of flood depth. They computed the national or catchment level total expected annual damage by summing up damages in the impact zones within the given area. The authors also estimated social impact using Social Flood Vulnerability Indices and probability of flooding to a given depth. Koks et al. (2015) developed a flood risk assessment methodology on household level using hazard, exposure and vulnerability analysis. In their study, the authors stressed the importance of analysing socio-demographic characteristic such as monthly income, age, ethnicity, type of household (single-parent) and physical condition of houses to assess social vulnerability. The authors presented the risk in terms of number of inhabitants at risk per social vulnerability index per hazard zone. The EU Flood Directive (European Commission, 2007) oblige member states to prepare flood hazard and flood risk maps at river basin district level. The directive forwarded three flood scenarios to assess the hazard – floods with low, medium and high probability of occurrence. Then, the associated risk map which shows the potential adverse consequences is developed based on the number of inhabitants affected, economic damage and environmental or health damage. However, the directive does not explicitly talk about the vulnerability of society or economy of member states. Meyer et al. (2009) designed a multicriteria risk mapping approach which encompasses economic, social and environmental flood risk factors on river basin scale. The evaluation criteria for economic risk factor was annual average damage, for environmental risk factor was aggregated environmental risk, and for the social factor were annual average affected population and probability of vulnerable community locations being affected. The procedure for the risk mapping approach include determining inundation depth based on flood events and the spatial distribution of elements at risk, calculating absolute and mean damage per grid cell, calculating annual average damage, developing standardized risk maps for different risk factor criteria, and finally, developing weighted and aggregated multicriteria flood risk maps. Kubal et al. (2009) also used the multicriteria risk mapping approach on city scale. However, in the latter case the authors extended and modified the criteria used for social and economic risk factors to better describe the complexities of cities.

2.3 Review of flood impact assessment frameworks

Floods can have an impact on human interest in many directions and this imposes the necessity for a robust classification of flood impacts into categories. Flood consequence types were first classified by Penning-Rowsell et al. (1980) into direct or indirect, tangible or intangible, or a combination of both. Direct damages occur if the asset of interest is physically exposed to flood waters (i.e., buildings, people or environment). Indirect damages are outside the flooded area and usually take longer time to become distinguishable (Merz et al., 2010). A classic example of indirect losses is the interruption of production in a firm that might occur due to affected by flood supplier. Losses like that are not very well documented because typically they are not insured (Merz et al., 2010). Usually this type of loss is estimated in flows, whereas the direct damages are assessed in stock (Okuyama, 2007). For example Samuels (2009) considered the extra costs on emergency and other actions from flood event management as indirect damages, which Jonkman et al. (2008) classified as direct damages.

If flood consequences can be expressed in monetary terms they are then considered as tangible damages that can be approached through quantitative analysis (Dutta et al., 2003). Such damages include impacts to the build environment or infrastructure. Unlike tangible damages, intangible losses do not have a market price and it is very difficult to express them in monetary terms (Samuels, 2009). Examples of intangible damages are loss of life, public health problems, and loss of personal belongings or environmental degradation. Loss of time can be an interesting category, because it could just be presented in hours or opportunity cost (intangible), but it could

also be calculated as lost business hours based on average wages per hour (Parker and Green, 1987).

Depending on the aim and scope of flood damage estimation the impact assessment techniques can vary. The financial impacts take the viewpoint of direct losses to individual properties and usually are used by insurance companies. Comprehensive studies describing methods of financial evaluation of losses are Messner et al. (2007) and Penning-Rowsell (2010). The economic viewpoint of damages looks at the broader picture of the downturn in economic activities (i.e., production or consumption) in the whole economy (regional or national) (Okuyama, 2007). The economic effects measure secondary indirect impacts by evaluating the interaction between sectors."

2.3.1 Direct and indirect tangible damages

Tangible damages are usually divided into direct and indirect damages. Direct tangible damages are those that occur inside the flooded area (Jonkman, Bočkarjova et al. 2008) and, refer to infrastructure, property damages and other physical losses that take place as a result of direct interaction with flood waters (Vojinovic and Abbott 2012). Direct tangible damages or costs are also defined as the cost of reconstruction or replacement of the assets or infrastructure that have been damaged by the event (Hallegatte 2008; Hallegatte and Przyluski 2010).

Damages on residences, buildings, roads, utilities and communication infrastructure as well as business interruption inside the flooded area are considered direct tangible damages (Jonkman, Bočkarjova et al. 2008).

Conversely, according to Messner et al. (2007) indirect tangible damages take place when there is no contact with flood water; the loss or damage is suffered by goods or functions that are distant from the flood.

Another definition of indirect damage is the disruption of the relationships between different sectors of the economy as a result of the disturbance caused by floods on productive activities. These damages occur outside the flooded area (Jonkman, Bočkarjova et al. 2008).

Hallegatte (2008) and Ranger et al. (2011) define indirect tangible damages or costs as the reduction in production of goods and services measured as value-added losses. These costs have influence on consumption patterns and, as a result, affect people's welfare.

Finally, Hallegatte and Przyluski (2010) stated that "costs are indirect if they are spanning over a longer period of time, a larger spatial scale or in a different economic sector than the disaster itself".

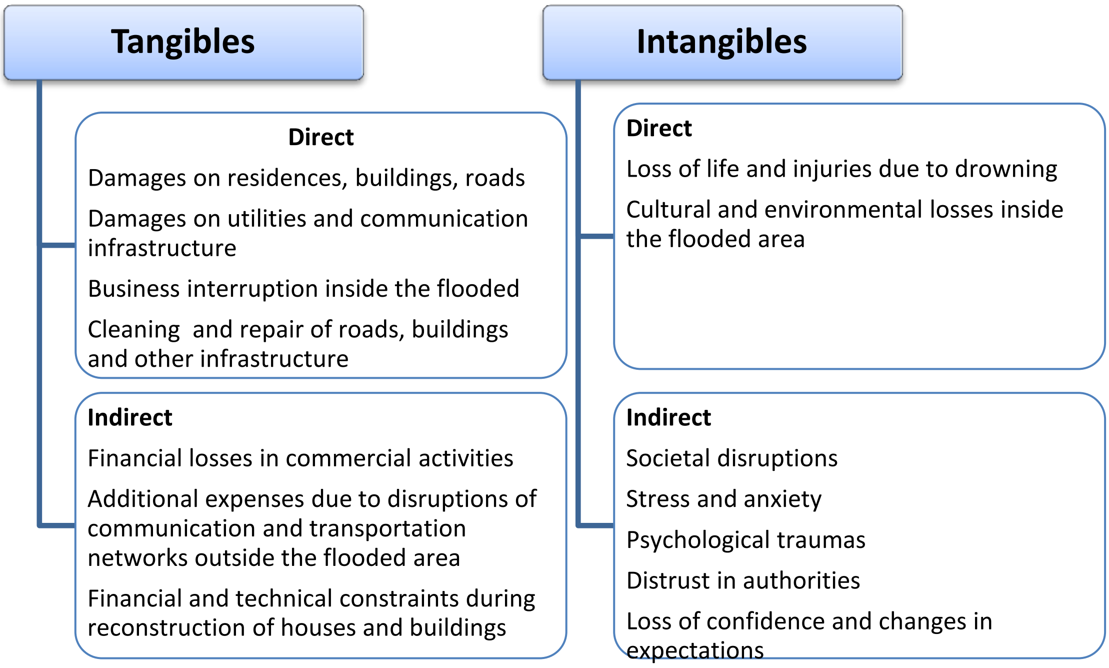
Examples of indirect tangible damages are financial losses in commercial activities, additional expenses due to disruptions of communication and transportation networks outside the flooded area and financial and technical constraints during reconstruction of houses and buildings.

Some authors refer to intangible damages in a general way while some others classify them in direct and indirect damages as it is done for tangible damages.

Direct intangible damages examples are the loss of life and injuries due to drowning, cultural and environmental losses inside the flooded area (Jonkman, 2008, Bočkarjova et al. 2008).

Societal disruptions, stress and anxiety, psychological traumas and distrust in authorities, loss of confidence and changes in expectations are identified as indirect intangible damages (Jonkman, Bočkarjova et al. 2008; Ranger et al. 2011)

Figure 2.1 shows a typical classification of damages as it is often reported on the literature.



Source: (Jonkman, Bočkarjova et al. 2008; Vojinovic and Abbott 2012)

Figure 2.1 Types of damages

2.4 Economic evaluation methods

Flood damage assessment is an issue which has not been sufficiently studied to date. There are some novel experiences (Francés et al., 2008), but in general, flood risk assessments, such as in the Catalan flood risk management plan, INUNCAT (GENCAT, 2006), tend to assess the impacts using methodologies from other countries. For the INUNCAT case, the methodology developed in the USA (USACE, 2000) was directly applied to Catalonia, without adapting it. Estimation of damages caused by flooding normally focus on flood depth. That is why depth damage or stage damage curves have been adopted in multiple locations around the world as the most commonly used technique to assess flood impacts. Depending on the information available and the goals of the assessment, there are several types of depth damage curves (Merz et al., 2010). In some cases, when there is a lot of data available, empirical curves can be created by interpolating a function with the depths and costs relationships (Nascimento et al., 2007). Alternatively, synthetic curves use the expertise in flood impact assessment to create the curves via a what-if analysis (Penning-Rowsell et al., 2010). Additionally, depth damage curves can also be classified as absolute or relative, depending if the cost is given in economic terms or as a percentage of the total value of the affected asset.

In contrast to the direct tangible damages, the indirect tangible losses occur due to a flood event but without the physical contact with the water. The indirect tangible losses can be greater than the direct ones and can occur outside the flooded area and for a period of time longer than the flood itself (Messner et al., 2007). They are related with flows of capital and goods, in contrast of the assets and stocks that are considered as direct tangible damages. Indirect tangible losses are less explored than the direct tangible ones and are more difficult to be quantified. There is no agreement in the scientific community about the best methodology to do it. The existing methodologies according to Cochrane (2004); Messner et al. (2007); Jonkman et al. (2008); Hammond et al. (2015) and Balbi et al. (2013) are:

- Post-event economic surveys
- Input-Output models (I/O)
- Computable General Equilibrium
- Integrated economic models
- Regional econometric models
- Linear programming-optimization models
- Benefit transfer

Some methodologies for economic valuation of indirect damages have been identified but their application is yet not as extensive as it is for those aimed to assess direct tangible damages. The case studies are mainly related to floods and earthquakes.

Figure 2.2 illustrates the structure of reviewed methods for damage assessment.

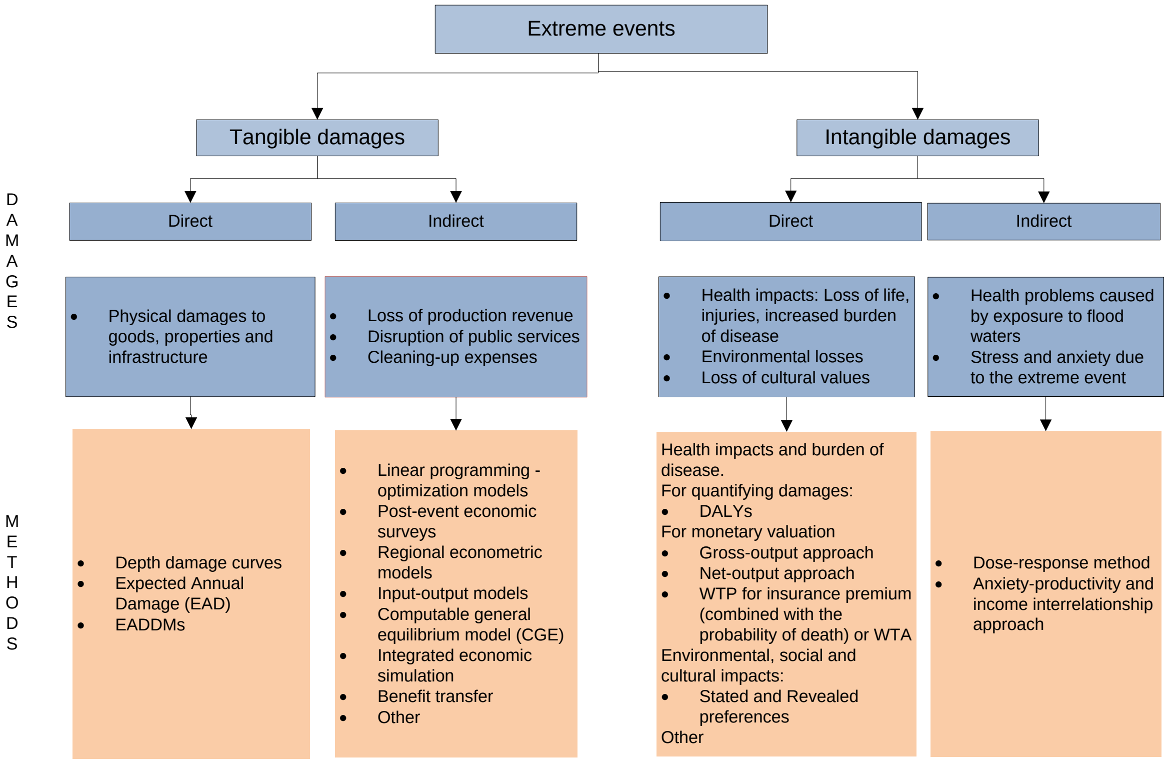


Figure 2.2 Methods for damage assessment

Rendon Valencia (2014), conducted a desk study on economic damage assessment models for PEARL, the report is available upon request. The literature review identified that no model has combined a good enough definition with an easy application. For this reason a new model has been proposed with the objective of achieving both goals at the same time.

2.5 Discussion on existing disaster risk assessment methods and frameworks

Given the high number of concepts in this area and the fact that various terminologies are used for same concepts, besides the definitions above, we would like to contribute to the literature by proposing an ontology for flood risk assessment. The importance of an ontology for flood risk

assessment has already been emphasized in (Scheuer et al. 2013) that proposed the technical details of such ontology as a formal knowledge base. In this research, we focus on the comprehensiveness of the concepts in the ontology in our holistic point of view, and rely on the technicalities proposed by Scheuer et al. (2013). The holistic flood risk assessment (HFRA) ontology which would provide a shared dictionary of concepts in this area will be explained in Annex 2. The ontology is the outcome of the research conducted and the arguments made in Section 3.2 regarding the definitions used in our proposed flood risk assessment framework.

The literature review above shows that even if the hazards are different, the general risk assessment frameworks have similar nature. As such, some researchers performed multi-risk assessment in a single location (Greiving, 2006; Grünthal et al., 2006; Marzocchi et al., 2009). On the other hand, the risk assessment frameworks exhibit differences by giving a particular emphasis either to hazard assessment or vulnerability assessment. Some authors tried to combine the role of stakeholders and also highlighted the importance of considering social vulnerability while others have completely ignored those elements. Those differences might be due to differences in scientific backgrounds and experiences of authors.

We introduce the concept of HFRA as a generic and inclusive paradigm. Before defining the notion of holistic, we shall talk about the concept of 'integrated' and how it differs from 'holistic'.

The term integrated has been commonly used to solely refer to combining or putting parts of a system together. For example, by integrated risk assessment, Greiving (2006) referred to producing a risk map by overlaying a combined hazards map and overall vulnerability of a region. Chen et al. (2003) also suggested combining and linking data of different types such as physical, socioeconomic and management related for integrated risk assessment. The traditional integrated urban flood risk management refers to the coordination and integration (or a sum/collection) of tools, approaches, methods and resources into the practices for the purpose of maximising benefits (or minimising flood risk) and minimising costs (see for example Vojinovic 2015). It recognises the added value of a comprehensive plan but not necessarily seeks to understand interactions, interrelatedness and interdependences between different kinds of processes (or parts of the whole) that can lead to the formation, propagation and accumulation of risk. It puts the parts in front of the whole (which is a characteristic of a mechanistic way of thinking).

On the other hand, the term holistic derives its origin from the Greek word *holos* that refers to a view or an understanding in terms of interrelated wholes whose properties cannot be understood in isolation. The holistic way of thinking puts the whole and the relationships in front of the parts. Holistic flood risk refers to a view of flood risk phenomena which arises from a whole through interactions and interdependences, which in turn can help us to gain better understanding of the complexities involved so we can develop more adaptive solutions which are not only economically and technologically efficient but more importantly, are ecologically sustainable and socially just. Apart from looking at phenomena through interactions and relationships, a holistic way of working towards adaptation and resilience would also aim for a profound engagement in activities by seeking multiple benefits to services and functions of ecosystems.

3 The PEARL holistic flood risk assessment framework

3.1 Introduction

The holistic flood risk assessment framework presented in this report is developed for extreme flood events in coastal, urban environments. Before presenting the framework, we will define what an extreme flood event is and its relationship with disasters.

Since the concept of "extremeness" is strongly contextual, it has been a challenge to define extreme events in a generally acceptable way. In addition, four words are often being used to describe similar events – severe, rare, extreme and high impact (Stephenson, 2008). Hence, definitions are given on the basis of rarity, intensity and severity or high impact (Beniston and Stephenson, 2004; Stephenson, 2008). For example, in one of its special reports, the Intergovernmental Panel on Climate Change defined extreme event as "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable" (IPCC, 2012). The definition was updated to be more explicit as "an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations" (IPCC, 2013). However, both reports emphasized that extreme events are time and place specific. The IPCC (2012) report also emphasized that its definition of extreme event is based solely on the initial and consequent physical phenomena and not to the impacts.

In contrast, (Nadim and Glade, 2006) defined an extreme event based both on rarity and severity – an extreme event is an undesirable hazard with extremely low probability of occurrence (in their case a tsunami hazard) and with the potential of extremely high impacts. The authors also mentioned that extreme or rare events are events which often have a stronger place in societal memory. According to the taxonomy of extreme events given by Stephenson (2008), rarity is the first criteria to classify an event as "extreme". But the author also noted that not all rare events are severe (with high impact) since severity depends also on the degree of exposure and vulnerability of the impacted system (see also Sarewitz et al., 2003). The IPCC (2012) report also indicated that there is no one-to-one relationship between extreme events (in statistical terms) and disasters. Unless vulnerable communities are exposed to those extreme events, there will not be a disaster. Disasters can be triggered by extreme or not extreme events. However, disasters are results of extreme impacts suffered by society or on the physical environment or on ecosystem. The report elaborated that disasters happen when extreme impacts surpass thresholds in which either damages cannot be easily restored, or recovery takes much longer time, or the society or community cannot repair itself, or a combination of the circumstances.

In PEARL we adopt the definition of extreme events given by Nadim and Glade (2006) – defining extreme events based on both statistics and severity.

3.2 The Holistic Risk assessment Framework and onTology (RAFT)

Our starting point is the view that risk emerges (or co-evolves) from actions and interactions within and between human systems and the natural environment. Human systems can be also regarded as socio-technical systems which consist of a social system (actors, behaviour, institutional structures) and a technical system (urban infrastructure, drainage, flood defences,

industrial networks, agricultural systems, etc.). These two co-evolve through decisions about the use of the system and its development, changing infrastructure, policy and regulation through strategic management and governance. This implies that risk emerges from actions and interactions within and between human systems and the natural environment

The formulation of the Ontology starts with a review of concepts and definitions that are embedded in the formulation of PEARL, some of which were briefly discussed at the beginning of Chapter 2. This review led to development of the PEARL mindmap of concepts. The Ontology has evolved from the mind map as a connected graph of concepts, which lists the central PEARL concepts and definitions. The definitions are based on two main sources: the IPCC report from 2012, and the draft PEARL glossary from Vojinovic (2015).

The Ontology serves two purposes: It forms a shared knowledge-base on flood risk assessment within the PEARL project and for usage in the PEARL tasks and methods, and it informs the agent-based models (ABM) that are developed in PEARL. An intermediate step between the Ontology and the ABMs is the MAIA framework from Ghorbani (2013), which is used to decompose, structure and conceptualize socio-technical systems with an agent-oriented perspective. The next step is to structure the concepts and definitions from the Ontology in the MAIA framework. To accommodate this, the Ontology concepts are defined in terms of the other concepts in order to formalise the interrelations, and concept attributes.

Deciding on the exact concepts and definitions in the Ontology is a complex task. Definitions should be as concrete as possible, but should not infringe on the desired general applicability of the concepts. Furthermore, for many terms different definitions exist in literature. Finally, the concepts and definitions should connect to the content and meaning of concepts used in the PEARL methods, tasks and deliverables, including the ABMs. This includes obtaining a compatible and useful level of detail of concepts. For these reasons, developing the final Ontology requires iterative discussions between the PEARL partners (especially from WP3, WP1 and WP5).

Figure 3.1 shows different concepts in the current Ontology, as well as some important linkages between the concepts. These linkages are important to define the system and to define how system components affect each other and the main processes.

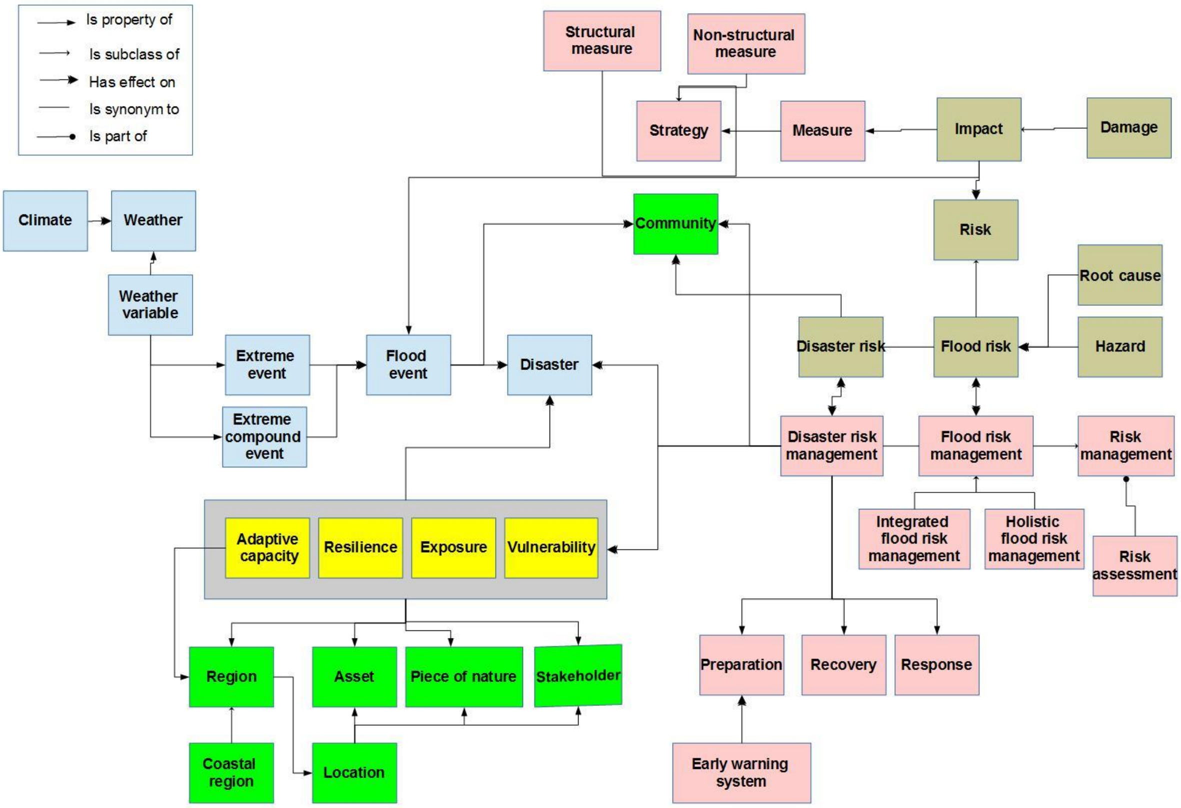


Figure 3.1 Graphical representation of the Ontology.

The Ontology is the starting point for the formulation of the holistic risk assessment framework. All concepts were used as an input to generate an interconnected model of the socio-technical system (Figure 3.2).

In dealings with hydro-meteorological events, the development and location of urban infrastructure, drainage infrastructure, flood defence systems, early warning systems and so on result from multiple interactions between technical systems and their developers and users, who design parts thereof taking into account causal relationships between design and risk in relation to natural processes (e.g., rainfall, storm surges, winds and so on). While the actors in the social system pursue short-term and long-term goals, none of them controls the system as a whole which evolves from that process. At multiple hierarchical levels, the technical systems are shaped by social processes and vice-versa, with feedback loops running across multiple levels and time scales.

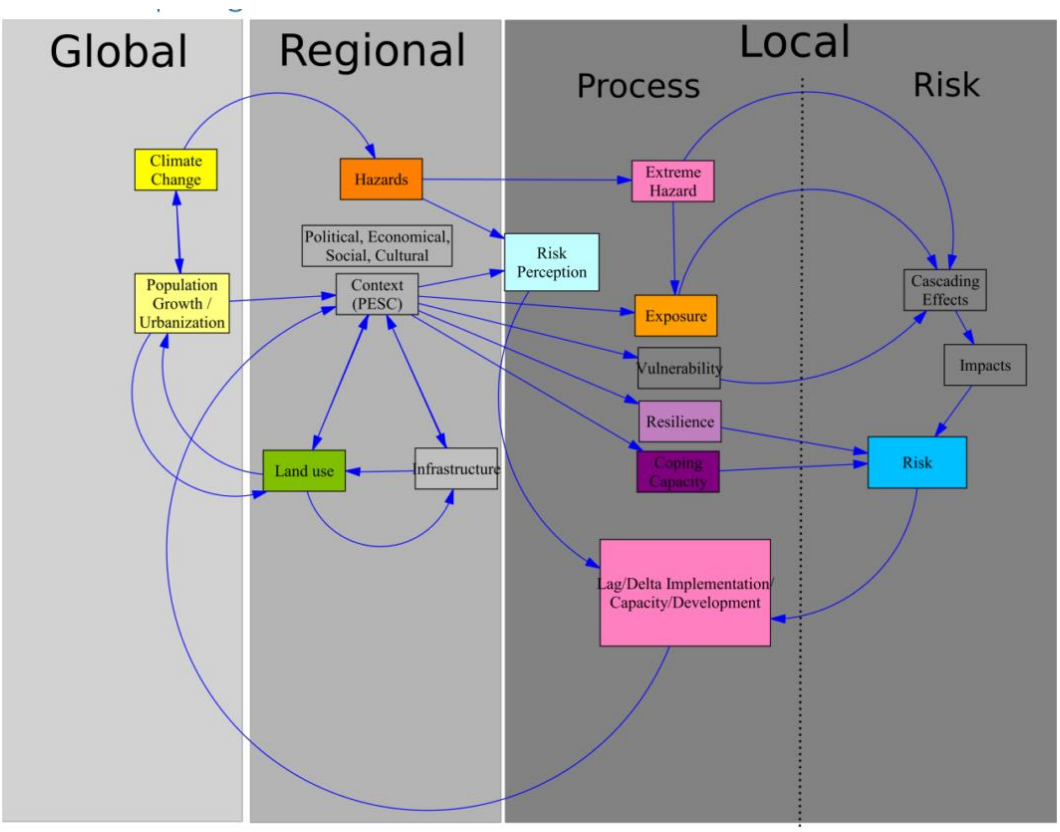


Figure 3.2 Causal loop diagram showing the key components/drivers for flood risk

A very important initial step in the holistic flood risk assessment (HFRA) is to understand the drivers/root causes of hazard, vulnerability, exposure and risk by looking at a range of factors and their interdependencies and interrelations. The drivers of hazard include natural and anthropogenic climate change or variability; whereas, drivers of exposure and vulnerability include socioeconomic pathways, climate change adaptation and mitigation actions and governance (IPCC, 2014a). The two sides of drivers are also related through different governance structures such as land-use policies and emissions. In the HFRA framework, the FORIN approach (IRDR, 2011) is used to scientifically investigate the disaster root causes and through process identifies relevant actors, domain knowledge, systems and theories. Figure 3.3 presents the overall framework for Risk assessment. The description of this framework corresponds to Milestone MS9 ("A concept for Holistic and multiple risk assessment"). The framework starts with system definition, and continues with identification of key stakeholders using the FORIN methodology. The analysis of the stakeholders together with the Ontology provide the input for the formalization of the MAIA metamodel. The MAIA framework generates the rules and behaviour for the agent-based models that are developed in PEARL. Once all Agent attributes, relations among the Agents and Agent actions and interactions are defined, an agent-based model can be formalised. After that, different initial conditions or scenarios can be assessed to quantify impacts and risk.

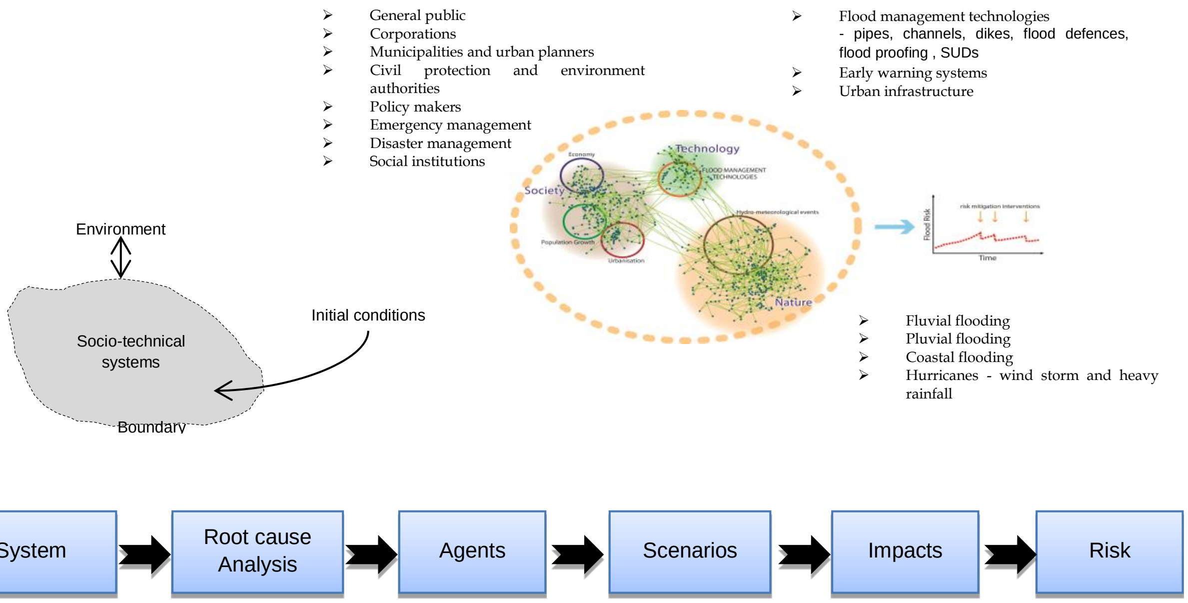


Figure 3.3 Schematisation of the overall RAFT framework

Once the basic information of actors, governing directives, policies, strategies, regulations, plans, decisions and relationships are collected, defined and conceptualized, the next step is to replicate and thoroughly understand the system. That can be achieved through computational simulations. In the holistic framework, an agent-based modelling (ABM) computational simulation approach is implemented and it provides a platform to integrate subsystems to a whole to visualize, understand and reason about implications of underlying processes.

The ABM is built based on the MAIA (Modelling Agent system based on an Institutional Analysis meta-model, which helps to decompose, structure and conceptualize socio-technical systems with an agent-oriented perspective (Ghorbani 2013; Ghorbani et al 2013).

3.2.1 System Identification

In the holistic perspective, flood risk emerges (co-evolves) from relationships and interactions within and between the socio-technical system and the natural system, as shown in Figure 3.4 below. The social system includes general public, businesses, municipalities and urban planners, authorities such as civil protection authority and environment authority, policy makers in supranational, national, regional and local levels; and emergency and disaster management entities. The social system is defined with the application of the Root Cause analysis that is described in the next section. The technical system includes flood management technologies like pipes, channels, dikes, flood defences, flood proofing and SUDs; early warning systems; and urban infrastructure. The natural system includes hydro-meteorological events such as fluvial, pluvial and coastal flooding and hurricanes which incorporate strong wind and heavy rainfall.

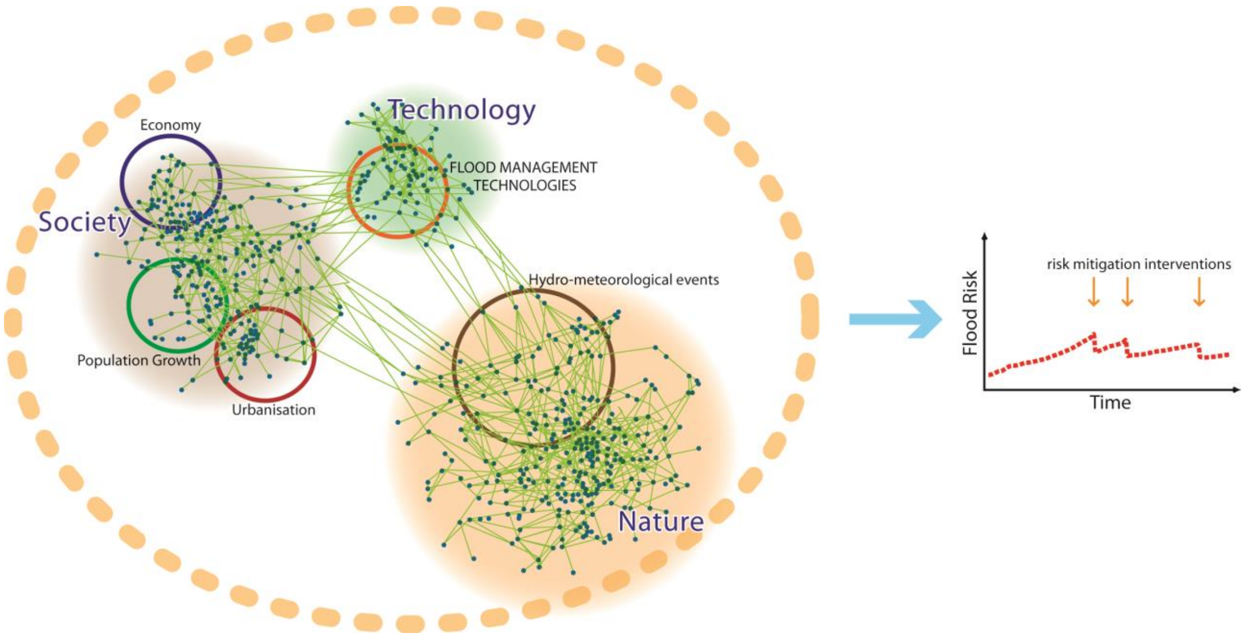


Figure 3.4 Formation and propagation of risk is the result from the coevolutionary nonlinear process between the ever changing social, technical and natural processes (dots illustrate sub-processes and activities, whereas lines illustrate their interactions) (source: Vojinovic, 2015*)*

The socio-technical system consists of decision making entities which are governed by directives, policies, regulations, strategic plans and their governance. In dealings with hydro-meteorological events, the development and location of urban infrastructure, drainage infrastructure, flood defence systems, early warning systems and so on result from multiple interactions between the technical systems and their developers and users.

3.2.2 Root Cause analysis

The purpose of risk analysis is to address the interconnections and complexities between factors in different contexts and across different scales, to provide a basis for effective and sustainable solutions. An important initial step in the HFRA is to understand the drivers and root causes of risk (as hazard, vulnerability, exposure), where drivers are the activities and processes that translate root causes into unsafe conditions, while root causes are the structures and processes that go beyond an individual crisis or event (DKKV 2012). The aim of Root Cause analysis in PEARL has been to explore root causes in a greater depth than previous research and improve understanding of the formation of risks and vulnerabilities in coastal regions, in particular those that give rise to small-scale events, albeit with high local impact.

In the HFRA framework, two existing methodologies were assessed and integrated to develop a PEARL Risk and Root Cause Assessment (RRCA) framework. The first, the FORIN (or the FORensic INvestigations of disasters) approach (IRDR, 2011) promotes scientific investigations of disaster causes which, in line with the aims of PEARL, aim to shift the paradigm of disaster management policies towards more holistic, multi-disciplinary (or even inter-disciplinary and trans-disciplinary) approaches. Two of the essential elements of the FORIN approach are investigation of the circumstances, causes and consequences of losses in disasters, and identification of the key factors in disaster risk (IRDR, 2011). FORIN prioritises governance as a key driver of disaster risk, particularly questions of institutional responsibility and accountability and the policy choices made before, during and after disaster events. However, extending

FORIN, the PEARL RRCA framework seeks to connect a backward-looking, historical perspective on disaster risk causation to a forward-looking, scenarios-based analysis. The second Root Cause Analysis framework, developed by UNU-EHS on behalf of DKKV[1], makes further additional distinctions to the FORIN framework, separating drivers from root causes, and incorporating the Disaster Risk Management process as an element driving vulnerability. However, the PEARL RRCA framework aims to assess both the physical and socio-economic drivers of risk, and here goes beyond the DKKV approach. In addition, work based on the PEARL RRCA framework considers how actions and decision-making are set within the interaction of social and ecological processes in ways that are dynamic, and potentially non-linear (Miller et al. 2010). The resulting PEARL RRCA framework is shown in Figure 3.5. In applying these existing frameworks to PEARL, it was important to recognise differing requirements of scale. While FORIN studies have so far concentrated on single, large disaster events, PEARL focusses on small-scale, possibly recurrent, but locally important, disasters.

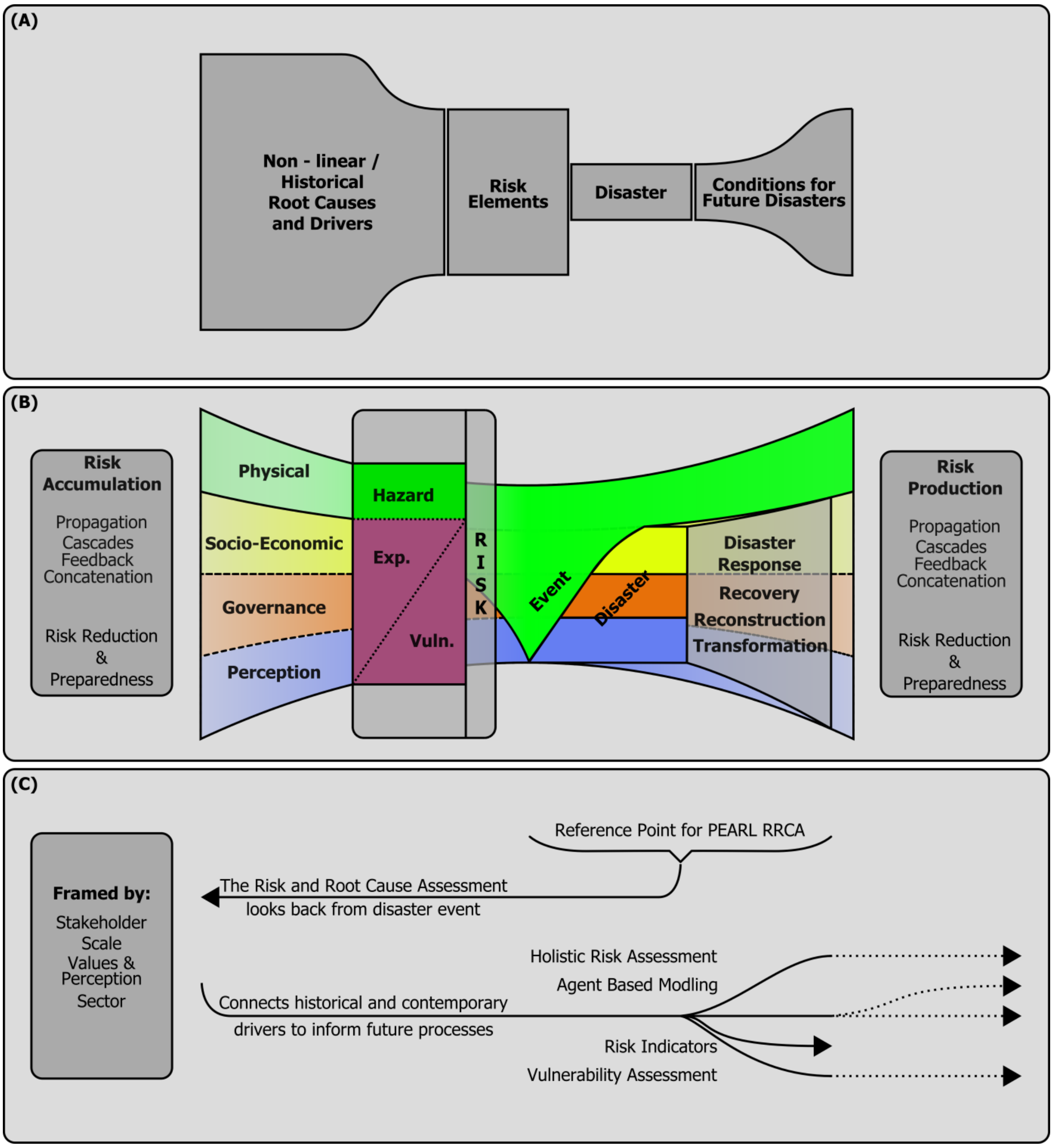


Figure 3.5 Proposed RRCA Framework for PEARL

[1] DKKV (Deutsches Komitee für Katastrophenvorsorge / German Committee for Disaster Reduction)

Further, the scale of institutional analysis in PEARL differs. Local government and associated local scale actors are the primary stakeholders for development and risk management decision-making in small scale events, with national and international actors secondary (although their influence is still important and is still discussed in PEARL).

PEARL RRCA investigations centre on an in-depth qualitative investigation of the root causes and drivers of risk in different case studies, with a desk-based literature review undertaken alongside semi-structured key informant interviews. In addition to informant interviews in key institutions, the work includes interviews with affected stakeholders, whether by sector (e.g. port, tourism) and / or directly affected population groups.

RRCA case study research plays a major role in defining the actors and institutions in the HFRA framework, and also re-defines the spatial, temporal and institutional scales across which we might understand socio-technical systems and their evolution. Through a deeper understanding of root causes – grounded in investigation that takes the disaster event, rather than other pre-defined lines of analysis, as its starting point – the RRCA Framework illustrates the involvement of actors across spaces in disaster creation and mitigation, the historical pathways that define existing policy decisions and the role of institutions from the local to the supra-national. The focus of institutional assessment work also moves from one centred exclusively on disaster management actors to one that incorporates wider development policy and practices, and the implications of other policy domains for disaster risk.

3.2.3 Agent Based Model(ABM) / Institutional model

Institutions are “rules and norms held in common by social actors that guide, constrain, and shape human interaction” (IPCC, 2014b). Institutions can be formal, such as laws, policies, directives, regulations, strategic plans, or informal, such as norms, conventions and cultures (IPCC, 2014b). Institutional analysis is used to study socio-technical systems using ABMs as institutions help develop tangible assumptions about agent decision making and behaviour (Ghorbani, 2013).

The ABM built for this study is based on the MAIA meta-model (or framework), which helps to decompose, structure and conceptualize socio-technical systems with an agent-oriented perspective (Ghorbani 2013; Ghorbani et al 2013). The framework also captures and explains agents’ behaviour, characteristics and decision making, and defines their relationship with social structures. According to Ghorbani et al (2013), MAIA (Modelling Agent system based on Institutional Analysis) is a meta-model which is based on the Institutional Analysis and Development framework (IAD) (Ostrom 2005) that is used in analysing social systems with institutional settings. MAIA is preferred and will be used in this research as it includes social structures such as norms and cultures, and can also include features such as personal values and preferences that affect their behaviour.

The MAIA meta-model is organised into five structures: the collective structure, which defines the actors and their attributes; the constitutional structure, which defines the social context such as role of actors and rules that govern their behaviour; the physical structure, which defines the physical aspects of the system; the operational structure, which defines the dynamics of the system; and finally, the evaluative structure, which defines the concepts that are used to validate and measure the outcomes of the system (Ghorbani et al 2013).

In MAIA meta-model, the decision making process by actors is modelled using multi-criteria decision making (MCDM). Actors make decisions based on multiple criteria, and hence, a weight

is given for each criterion. Then the actor decides to perform an action if the weighted sum of aspects is bigger than a specified threshold (Ghorbani et al 2013).

Using the MAIA meta-model, a first exploratory work has been conducted for the case study of Saint Maarten by UNESCO-IHE. The first three structures (collective, constitutional and physical structures) can be summarized as follows:

- *Collective Structure*

Based on preliminary studies, the following table identifies six different agents: households, businesses, developers, permit department, inspection department and new projects department. The last three departments are under the Ministry of Public Housing, Spatial Planning, Environment and Infrastructure of the Government of Sint Maarten, but with different mandates. Agents have properties, personal values, information and possible roles. For example, households (private residential houses) have properties such as income; level of risk they take which is determined based on factors such as location of the house (i.e., exposure), and age and building material they used to build the house (i.e., vulnerability); level of risk awareness and their coping capacity. These agents have safety as their personal value. Residents have early warning information before hydro-meteorological hazards happen. They also have information about land use and building policies.

- *Constitutional Structure*

The constitutional structure defines the role of actors and rules and conventions that govern their behaviour. Institutional statements such as rules and conventions are formulated using the ADICO syntax (a detailed explanation of ADICO is given in Ghorbani 2013). For example, the role of the inspection department is that of a rule enforcer; it checks if developers comply with zoning and building regulations once they get the permit to develop real estates. If developers do not follow the rules, the rule enforcer may fine them. However, the rule enforcer can be corrupt and refrain from fining illegal constructions or constructions that do not follow the rules.

- *Physical Structure*

The physical components that seem to be relevant in the model build up include residential houses, real estates, hotels, infrastructure (which includes roads, drainage channels and pipes) and hazard triggering factors such as precipitation, hurricane and storm surge. The physical components have properties, type, behaviours and affordances. For example, all kinds of buildings have vulnerability factors such as age, material and floor height; and exposure factors such as location as their property. Since all the buildings are owned by a person or company, they are defined as private properties for the agents. The behaviour of buildings is ‘ageing’ or ‘deterioration’. The affordances of buildings are ‘being build’, ‘maintained’, ‘used’, ‘sold’ and ‘bought’.

Regarding model validation, as mentioned in Section 2.4, it is difficult to validate modelled human behaviour. As a result, instead of validating individuals’ behaviour, the study focuses on validating consequences of actors’ decisions and ABM results. For example, urban growth can be validated based on satellite images, and scale and magnitude of flood impact can be validated based on insurance and government records. Considering the different nature of case studies, impacts will be validated based on local aspects such as number of houses flooded, sections of roads flooded, historical or cultural sites and objects flooded and so on.

3.2.4 Scenarios and Alternatives analysis

Scenario analysis is performed to study the effect of possible changes to climate, land use and population dynamics which cannot be controlled by local planning entities. On the other hand, alternatives analysis will be carried out to identify desired and undesired implications of directives (for example EU Floods Directive), regional or country wise policies, plans and decisions made in the case study areas, and their amendments before testing and implementing them on the actual system.

The development of scenarios and alternative analysis within flood risk assessment considers the changes in urban areas, population growth and land use change. The application of urban growth models addressing future land use change facilitates the assessment of consequences of various flood event scenarios (The flood event scenarios also considers inputs from climate change scenarios developed in WP 2) and for different planning horizons in the case study cities. The differences in case study areas in terms of what is considered to be an "extreme" event is part of the answer within a holistic flood risk assessment framework. Geographical, climate, cultural and socio-economic conditions, differing for each case study, highly affect the dynamics of the urban development, hence, how flood risk evolves in time. By examining aspects of interplay between the dynamics of urban growth and flood event evolution, PEARL makes a step forward towards the holistic risk assessment. Land use change modelling is being considered in three case studies, Rethymno (Greece), Genoa (Italy) and Marbella (Spain). The land use change modelling is carried out with cellular automata models. This type of models belong to the simulation modelling paradigm and their output cannot be considered as a forecast but rather as a possible outcome. The output of the model is a raster file showing the expansion of the urban area. The map of possible future developments enrich the assessment and discussion of future scenarios of urban flood risk.

3.2.5 Vulnerability Assessment

The established FORIN approach and the revisions proposed to it sit within a tradition of political ecology research that emphasises social determinants of vulnerability. Consequently we propose our logic for the selection of vulnerability indictors draw from this tradition too. This view is well expressed in the work of Birkmann 2013 (drawing from Wisner 2002 and Wisner et al. 2004) that states "[...] vulnerability assessment[s] should focus on the likelihood of injury, loss, disruption of livelihood and other harm in an extreme event" and that this encompasses the "[...] identification of the variables that make people vulnerable and that show major differences in the susceptibility, coping and adaptive capacity of the people". This allows the elements of vulnerability (and hence of risk) to be assessed across broader spatial scales and in comparative metrics, and integrated with hazards data.

As mentioned in the introduction a compound index as a result of the quantitative vulnerability assessment will be designed drawing on definitions used by the IPCC (2014) and building on research methods that are widely acknowledged in the scientific literature. Therefore the three components of vulnerability (susceptibility, coping capacity, adaptive capacity) will be assessed separately via suitable indicators.

Examples for such assessments (although in some cases as sub-parts of an overall risk assessment) can be found in the scientific literature as well as in reports and in grey literature (see amongst others O'Brien et al. 2004, Adger 2006, Pelling 2013). Birkmann et al (2010) and Depietri et al (2013) present local applications for cities in Germany and Spain, Greiving (2013) develops an approach for European regions and Cardona and Careno (2013) as well as Welle et al. (2013) provide assessment methods that can be applied on a national or sub-national levels.

For the assessment in PEARL, the three components of vulnerability will be juxtaposed to the four spheres of the societal processes introduced in the RRCA framework (see Table 3.1).

Table 3.1 Matrix covering the components of risk and societal processes as a basis for the PEARL vulnerability assessment.

			Societal Processes (based on RRCA framework)			
			Socio-Economic	Governance	Values & Perception	Physical
Components of Risk (IPCC 2014)	Vulnerability	Susceptibility				
		Adaptive Capacity				
		Coping Capacity				
	Exposure / Hazard					

Looking at the vulnerability in the case study region the assessment will sideline physical processes and concentrate on the susceptibility, adaptive capacity, and coping capacity at a given time which is the result of socio-economic, governance, and perception processes as drivers, and root causes (see the RRCA Method). These exercises are highly dependent on data availability which determines the scale of analysis at the same time. The aim is to calculate results on a scale as fine as possible (maximum borough level).

The indicators describing the components of vulnerability on the ground are set by the results of the RRCA Method, with the vulnerability assessment meant to "[test] hypotheses of risk causality (hazards, land use, built environment, development paths, values and perceptions, lack of accountability, governance and others), developed under T1.4"´(PEARL DoW, European Commission Directorate-General for Research and Innovation 2013). Nevertheless the vulnerability assessment can also be conducted as a stand-alone exercise to inform policy makers, planners and managers or to be integrated in future planning and management processes.

Thus, suitable statistical information has to be selected accordingly. Based on that - as originally proposed - quantitative data gathering will map indicators using (1) existing data bases on the respective scale, (2) geo-spatial information (such as land use, population density, etc.), (3) expert interviews (to gather information e.g. on local conditions and also data sources and availability) and (4) household surveys to get a representative overview of the susceptibilities and capacities of the households on a spatial scale.

In the course of data acquisition the researcher team will employ several sources and techniques (including data validation). Here a strong collaboration with the research teams working on other work packages (3, and 5) is necessary.

1. Statistical and geospatial data will be provided by the stakeholders and local representatives.
2. Additional statistical and geospatial data (e.g. land use data) will be accessed through open data bases such as the CORINE (http://www.eea.europa.eu/data-and-maps/) land cover data set.
3. The initial expert interviews will be coupled with the research undertaken under the RRCA Method.

4. Further, interviews will be conducted by the research team of WP1. These interviews will be semi-structured and – like all interviews conducted under WP1 – aim at providing results to other tasks within PEARL (e.g. ABM in WP3).
5. The design and roll-out of the household surveys will encompass the following steps
   5.1. Development of the questionnaire, statistical validation and first ground-test will be done by the WP1 team.
   5.2. The household data sets will be provided by local representatives (e.g. by statistical offices). Here it is essential that the data sets are representative for a number of spatial entities (as discussed above as fine as possible resolution is the aspiration). The sample size is dependent on the population and the number of spatial entities at the respective scale.
   5.3. The survey will be conducted by students of local universities under the direct supervision of the PEARL researcher team (the survey will be anonymously conducted and no names will be used during the survey). Here it is important to provide an in-depth introduction to the topic and the techniques needed for the survey. Hence it will be aimed at embedding this exercise in a course at the respective university. If this should not be feasible in one of the case study areas the responsible partners will explore the opportunity to employ local academics the support the field research. The local teams will also transfer the data surveyed to a digital format that can be transferred over to software for statistical analysis (e.g. SPSS).
   5.4. The analysis of the data sets will be done using a statistical analysis tool. The statistical validation of the results will be tested.
   5.5. The results can then be used to accomplish the statistic and geospatial information mentioned above.
6. The statistical validation of all data sets will be done separately to ensure their equipartition and liability.

The results of the vulnerability assessment will - presented in maps or ranked lists - be tractable to policy-makers at the respective scales and can be integrated in ongoing or future spatial planning or management processes.

3.2.6 Hazard analysis

The Deliverable 2.1 describes a novel hazard assessment framework and novel modelling concepts and tools for simulation of individual and combined/coinciding events. The hazard analysis will come from the application of different modelling tools in the case study area.

Schematisation of the hazard assessment framework described in Deliverable 2.1 is shown in Figure 3.6 .The novelties researched within this framework are marked with asterisk symbol (*).

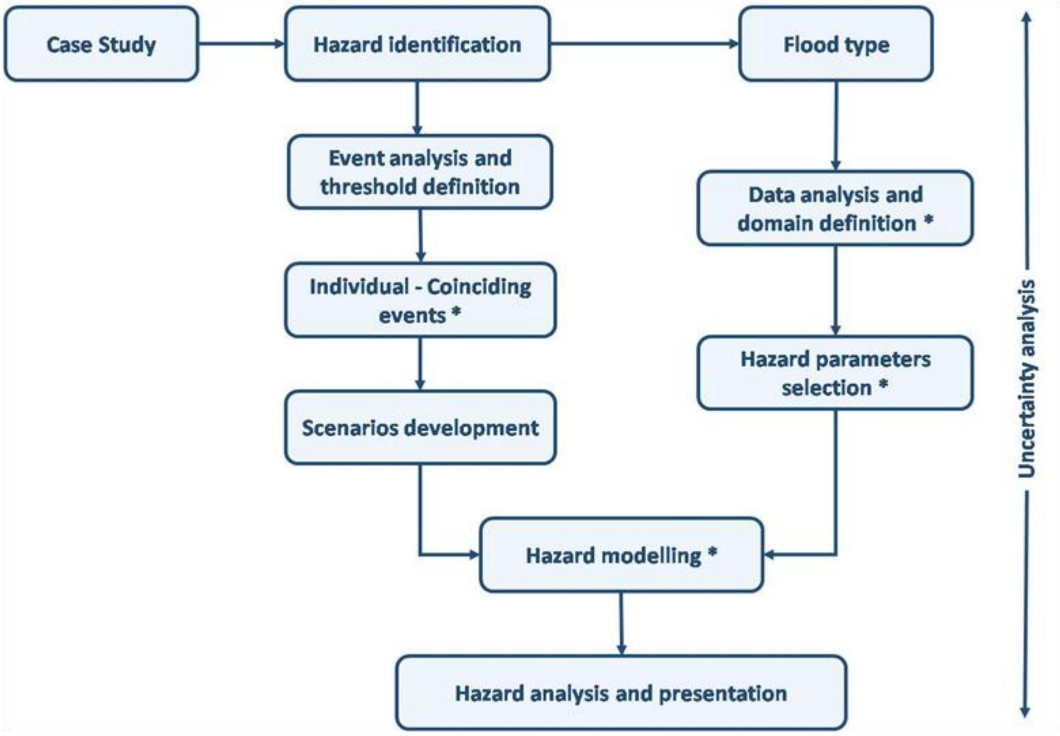


Figure 3.6 Flowchart presenting the framework for hazard assessment (* Novelty in PEARL)

For further discussion and details of the above framework and modelling concepts and tools please refer to Deliverable 2.1 report. The output of the hazard analysis is a series of maps for the study area and respective scenario depicting the changes in water depth and velocities in the modelling area. The maps are used as an input for another model in the impact analysis framework to estimate the impacts of the flooding event on a particular sub-system in the urban area.

3.2.7 Impact analysis

The assessment of risk in each case study depends on the information available and the tools that can be applied in each of them. The overall structure is presented in Figure 3.7. The tool kit to assess different impacts include: traffic simulation, crowd simulation, public health assessment and economic damages.

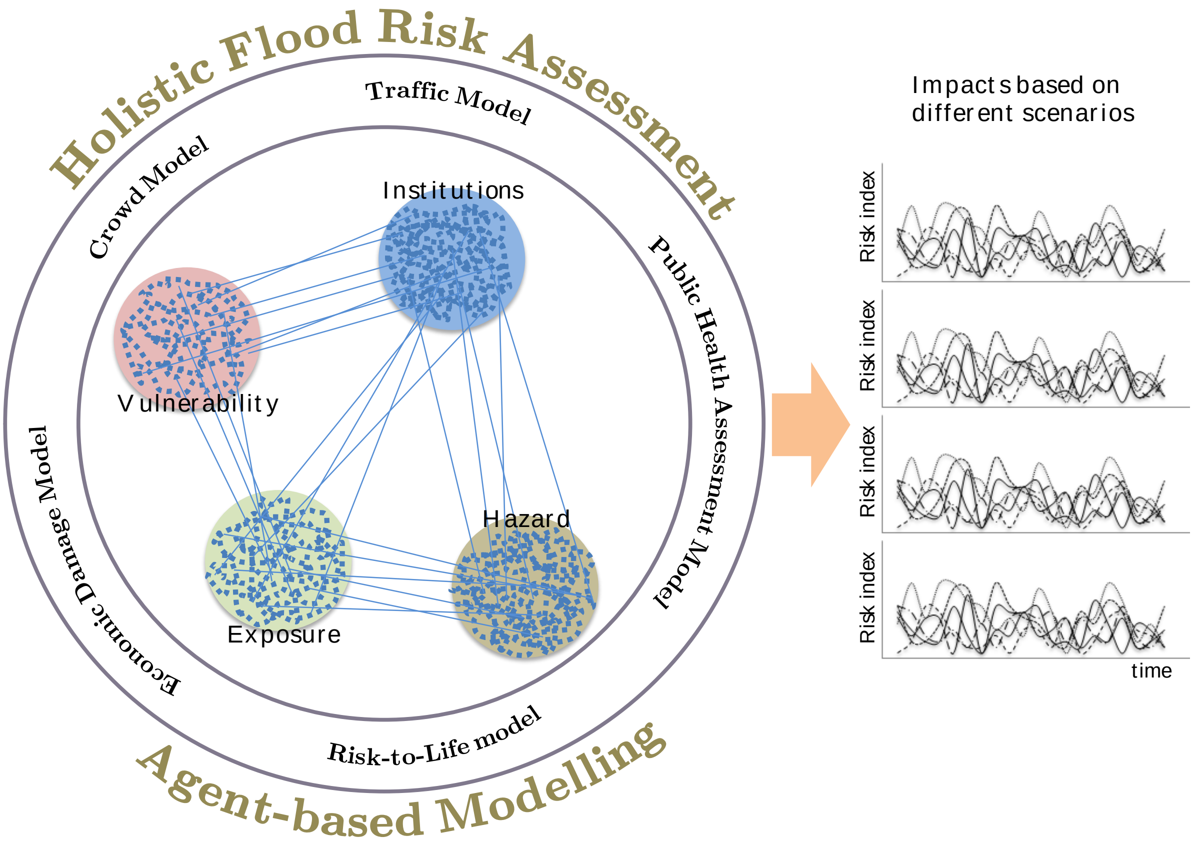


Figure 3.7 Risk assessment tool kit.

Since floods can cause multiple impacts across spatial and temporal scales PEARL adopts a holistic approach to assess a variety of such impacts. To shape a comprehensive understanding of all studied impacts, the PEARL framework will segregate different types of consequences before bringing them together. It takes a traditional approach to classify flood impact into direct, indirect, tangible and intangible. This approach was first proposed by Penning-Rowsell et al. (1980) and has been widely accepted afterwards. PEARL assesses flood impacts in each of the categories in different tasks of Work Package 3 (WP3). Figure 3.7 illustrates the types of flood impacts that are assessed within the PEARL framework. It is certainly never possible to take into account absolutely all possible impacts. Hence, PEARL introduces novelties in the assessment in each of the studied types of impacts that provides a wide spectrum. For an effective comparison between different types of flood impacts, the intangible impacts will undergo a monetization procedure. In such a way the methodology allows equal weights to the importance of different flood impact types.

3.2.7.1 Cascading effects

Risk emerges (or co-evolves) from actions and interactions within and between human systems and the natural environment. Cities are socio-technical systems that consist of a social system (actors, behaviour, institutional structures) and a technical system (urban infrastructure, drainage, flood defences, industrial networks, agricultural systems, etc.), figure 3.8 shows the main public services/infrastructure. The urban system co-evolves through decisions within the the system and its development, changing infrastructure, policy and regulation through strategic management and governance. This implies that risk emerges from actions and interactions

within and between human systems and the natural environment. Therefore, the cascading effects are represented as indirect impacts or damages. They can be described as “domino effects”, after an event occurs (hazard) different elements in the critical infrastructure of the city can be affected, leading to unexpected damages or losses. Figure 3.8 represents the urban system as a whole. During an event, the propagation of flood water can cause disruption of the critical infrastructure (e.g., electricity, transportation, water distribution, communication, etc.) which in turn can case multiple effects to other sub-systems in the urban environment.

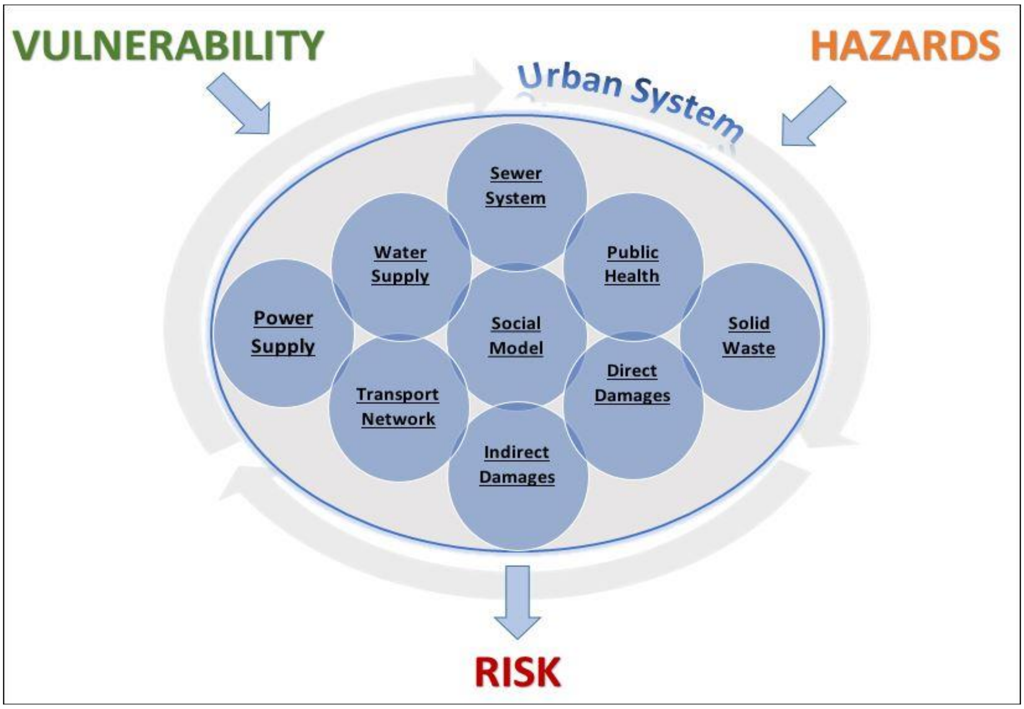


Figure 3.8: Urban system as a whole.

Within the economic assessment framework a new business interruption model is included to account for part of the indirect tangible damages. It is considered a business interruption due to the damage done to a business that is not related to the direct contact with water. In this sense, a particular industry that is flooded is considered a direct damage, but the reduction in the purchases of inputs, which will affect a supplier of the fabrication plant, is considered an indirect damage. Numerous models are available that can be used to calculate business interruption. However, as explained before, some models are data demanding while other models are not sufficiently accurate. In order to tackle this issue, an improved econometric model is proposed and described in the next section of this report. Figure 3.9 shows the overall framework for impact assessment. It shows connection with different models and the estimation of damages (direct and indirect). The description of this models is presented in the following section.

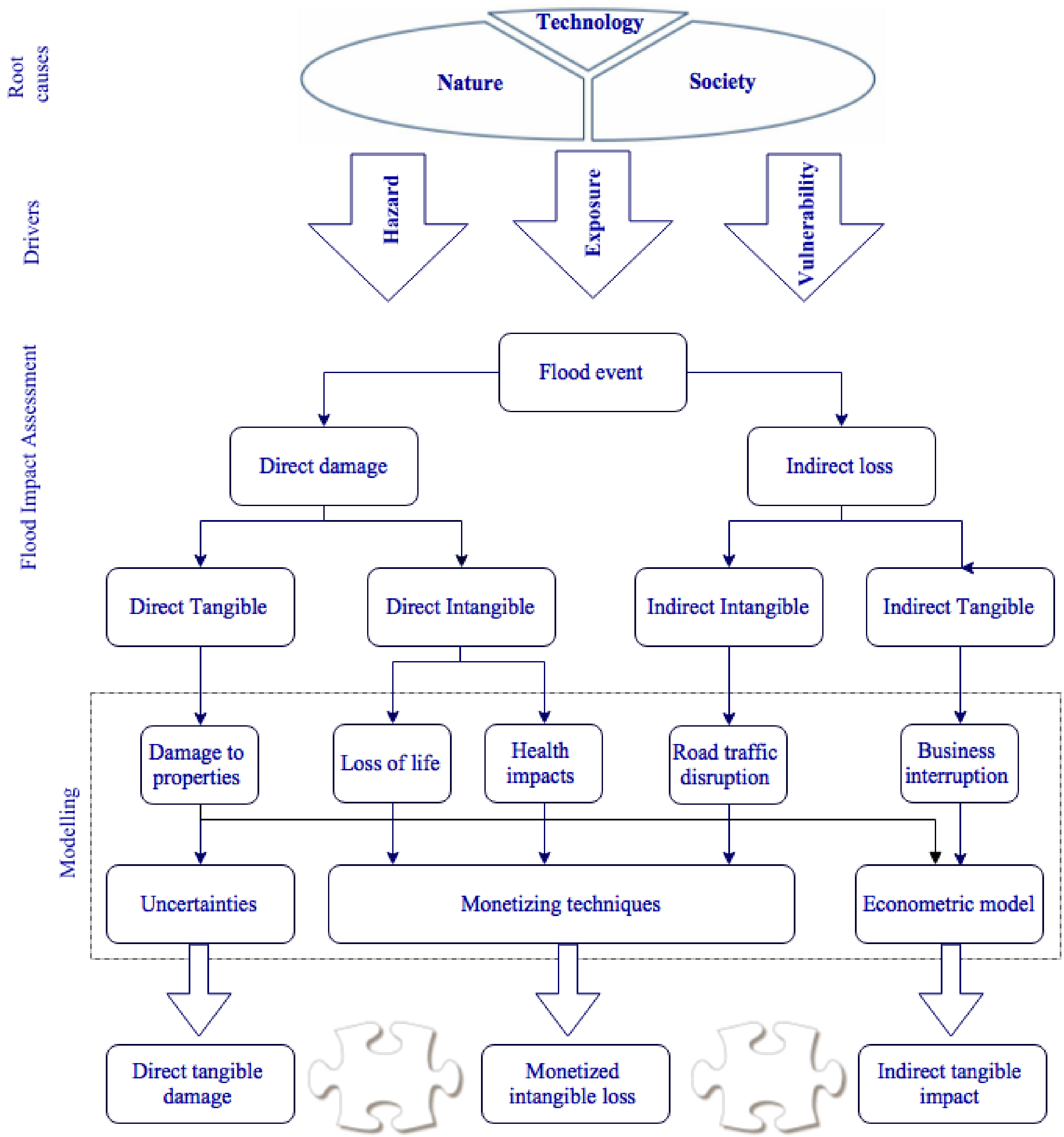


Figure 3.9 PEARL's framework for impact assessment.

3.2.7.2 Direct tangible damage - Damage to properties

The direct tangible damage to residential, non-residential properties and infrastructure is the most commonly estimated type of flood impact. Its fiscal expression allows easier comparison of different resilient strategies and it depends on the hazard intensity and its spatial variations. The exposed assets are identified on the basis of the flood extent. The flood characteristics (i.e., depth, velocity or duration) determine directly the financial impact to the exposed assets. The total damage also depends on the resistance parameter, which is a characteristic of the property itself: e.g., building size, fabric or structure (Thieken et al., 2005; Merz et al., 2010; Meyer et al.,

2013). Essentially, the resistance parameter is a way to derive the vulnerability of the exposed assets. The total damage can be estimated after the following three elements are computed (Jonkman et al., 2008): 1) Flood hazard maps (most often based on flood depth); 2) Land use map; 3) Flood characteristic-damage functions (e.g., depth-damage curves). The flood characteristic-damage function is a description of the interaction of flood water and the exposed elements. For a comprehensive understanding of damages, different characteristic-damage functions are derived for different land uses. Thus potential losses occurring with increasing intensities can be estimated. This approach is widely accepted for damage assessments (in the UK -Parker and Green, (1987); Penning-Rowsell et al. (1980); in Germany - Merz et al. (2004); The Netherlands - Klijn et al. (2007) Australia - Emergency Management Australia, (2002); USA - Federal Emergency Management Agency (FEMA), (2003); Scawthorn et al. (2006); Japan - Dutta et al. ; Brazil - Nascimento et al. (2006); Bangladesh - Khan et al., 2012); etc.), Spain - (Velasco et al., 2015).

PEARL uses a similar approach for damage assessment with novelty contribution in two main areas: computation of damage under different hydrodynamic conditions and uncertainty analysis of the results. The damage to properties is estimated, using an enhanced version of the damage tool developed in CORFU (Collaborative research on flood resilience in urban areas) project. The enhanced version of the tool is designed to address specific PEARL objectives – 1) damage assessment due to multiple causes and 2) uncertainty estimation.

The work developed in CORFU project aimed to establish a framework to assess flood damage in urban areas from the very beginning. The final output obtained was presented in the form of the flood damage maps, allowing the identification of the most critical areas of the studied area. By calculating the costs for different return periods, the expected annual damage (EAD) of the studied domain could be obtained, being able to express to what extent is the area affected by floods. To demonstrate this methodology, the whole process was applied in an urban area affected by floods (the Raval district of Barcelona), where no previous damage assessments have been carried out.

The outputs from the impact assessment methodology developed in CORFU were direct tangible damages at a micro-scale level, obtained by using synthetic depth damage curves. In order to carry out a damage assessment, three key elements are required as inputs: depth damage curves, detailed flood depth maps and land-use maps. More details on the methodology developed and applied in Barcelona can be found in Annex 2 in this report.

As PEARL focuses on coastal regions, the dynamics of coastal flood waters plays an important role. The type of flooding (coastal, riverine or pluvial) governs the usage of different damage functions, according to different combinations of depth and velocity. Thus, damage is not only a direct function of depth-velocity combinations, but also it is dictated by the type of flooding. By introducing this capability in the CORFU tool, the methodology establishes a clear relationship between multiple causes of flooding and spatial distribution of damage.

Within PEARL, the uncertainties of flood damage models will be introduced into the same CORFU damage tool. The actual uncertainty estimates will be based on a comparison between the available data and data obtained from household surveys in case study areas. For those case studies where the data for validation is limited, the uncertainty analysis will be based on existing relative uncertainties taken from previous studies. Jongman et al. (2012) compared seven different flood models and found significant discrepancies in the way damage is calculated, particularly in the shallow water depth (up to 0.5 m) (see also Vojinovic and Tutulic,2009). The incorporation of more capabilities in the existing tool enables faster and easier multiple plausible scenarios to be run and can effectively provide more detail about the possible consequences of flood disasters.

3.2.7.3 Direct intangible – Crowd simulation - flood risk model

An ABM will be used to assess the operational emergency component of risk. This model will be used to test evacuation strategies of costal urban cities under extreme hydro-meteorological events. The starting point to build this model is the review and classification of different theories and frameworks of human behaviour and disaster psychology, and to select and combine those that can be used in the construction of a city evacuation model under extreme hydro-meteorological events.

The ABM model will start by simulating the daily behaviour of agents within the city. This is the behaviour in the phase prior to event. For this model the agents will be the citizens (individual agents) and the emergency bodies (organizational agents). Then, a hazard will be introduced into the model; it can be storm surge, river flood, flash flood, coastal flood, pluvial flood, defence failure or a combination of the above. The hazard event will change the behaviour of agents in the model in the so-called warning phase. Here, both types of agents enter in a perception of the risk phase, followed by an appraisal phase and finally the agents enter into an action phase during the unfolding of the event.

The definition of the behaviours in these phases is crucial for this research due to the fact that people's cognitive and emotional states and behaviour will vary significantly across the phases. The success and/or effectiveness of this behavioural model rely on a good and solid understanding of the behaviour in each of these phases. Equally important is to emphasise that failing in the characterization of behaviour can put at risk the whole model. The individual agents and their behaviours will be classified based on quantitative data such as age, gender, employment status, and also using qualitative data such as awareness, flood risk perception and irrationality.

For the construction of the ABM, a set of GIS data will be used (e.g., building, roads, railways, river, coast lines, water bodies, topography and land use maps). In addition, to incorporate the hazard into the model the results from hydrodynamic models will be introduced as a raster format with water extent, flood depth and water velocity. To characterize the behaviour of individuals, a literature review of psychology will be used as a primary source as well as surveys in the case studies and the work that is carried out in WP1.

To conclude, the ABM model for evacuation strategies will be used to evaluate different evacuation strategies to minimize risk and to prove the feasibility of new warning dissemination tools. In this context, this research will address: i) creation of a framework to classify human behaviour under extreme hydro-meteorological events. ii) Evaluation of ABM to simulate different scenarios for city evacuation under extreme hydro-meteorological events. iii). Integration of ABM and GIS for risk assessment. iv). Test new technologies for warning dissemination to reduce risk and exposure.

The outputs from this model will be then used to explore the importance of warning times, new dissemination strategies to give people sufficient time and information to reach designated areas, extract behavioural patterns from emergency situations and to test evacuation routes and safe area systems. It will also enable to carry out analysis of how people and communities react and how communities are affected by the flood disaster, and to have a new information to update or create emergency plans.

3.2.7.4 Direct intangible - Public health assessment model

Quantitative assessment of health impacts during and after flood events is performed using a combination of hydrodynamic and water quality flood modelling and Quantitative Microbial Risk Assessment (QMRA).

In an urban area with a combined sewer system, stormwater and wastewater are collected and transported within the same pipe network towards a treatment point and/or an outlet (i.e. a body of water) (Butler and Davies, 2011). Wastewater flows dominate during dry weather periods, but during rainfall, flows significantly increase with the stormwater component. A combined system introduces a polluted mixture of stormwater and wastewater into the environment, especially during flood event. In this project, a method for quantitative assessment of flood impacts, especially those from combined sewers, on human health is developed and evaluated.

A coupled 1D-2D hydrodynamic flood model with an advection-dispersion process computation module is used to simulate water flows and pollutant transport in the sewer network and over the land surface during flooding (Hartnack et al, 2009). It builds on the method that was developed and used in the CORFU project, where it was applied in a developing country case (Djordjević et al, 2011; Mark et al, 2015). The method will be extended and adapted to cover exposure scenarios in a European context.

The model simulates flows and transport of wastewater through sewers as well as over the urban surface. It estimates the fractions of wastewater and stormwater in flood waters and calculates the concentrations of selected pathogens (e.g. Norovirus) based on estimated or measured pathogen concentrations in the wastewater. Transport and dilution of stormwater and wastewater containing pathogens in the sewers is modelled using a 1D hydrodynamic model, which has facilities for performing advection-dispersion process calculations (Garsdal et al, 1995). When the capacity of the drainage system is exceeded and water starts flowing above ground, surface flows are simulated using a hydrodynamic 2D flow model, which also includes advection-dispersion processes in the calculations.

Quantitative microbial risk assessment (QMRA) is dynamically performed with the flood and water quality modelling to estimate the risk of illness caused by infection (e.g. by Norovirus) through contact with flood waters. The QMRA involves the use of probability density functions for pathogen concentrations in wastewater, as well as exposure rates (i.e. ingestion and hand-to-mouth) for different population groups (e.g. children, adults)(de Man et al, 2014). The probability of infection is then determined through the use of a dose response relationship and Monte Carlo simulation (Mark et al., 2015).

The new methodology presented in Figure 3.10, which dynamically links flood and water quality modelling with QMRA will enable the calculation of time-varying and spatially-distributed values for water depths, flow velocities, pollutant concentrations and illness probabilities in the whole model domain.

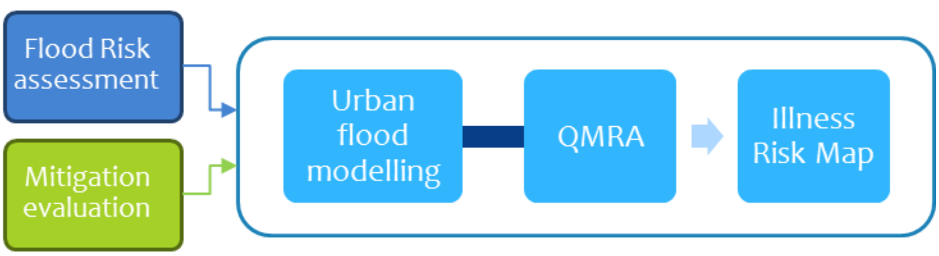


Figure 3.10 Improved public health framework proposed and developed in PEARL

3.2.7.5 Indirect intangible – traffic disruption

PEARL adopts a novel methodology for the assessment of flood impacts on road transportation. This is achieved through integrating flood and traffic models. Since both flood and transportation processes exhibit dynamic features in time and space, a dynamic integration of models is necessary to capture their interaction. To date a dynamic integration of flood and traffic models has not been employed in previous studies. To address this issue, PEARL uses a microscopic traffic model (SUMO) to simulate the movement of individual vehicles in the transportation network. Unlike macroscopic models, which represent the traffic as a fluid stream, microscopic models enable a detailed description of the selection of alternative routes, whilst roads are closed due to flooding. It also allows the modelling of different vehicle types and their specifications. For example, according to certain flood conditions, a road can be closed for all vehicles except ambulances and emergency vehicles.

The flood impact on the road transportation network depends on the spatial-temporal varied system status. Road closures or reduced traffic capacity could occur during different stages of flooding. To describe such phenomena in modelling, constrains can be set to represent different obstacles (e.g. complete/partial closure, reduced travelling speed) so the SUMO can simulate the traffic dynamic under flooding scenarios. Journeys travelling through flooded areas will be redirected to unfavourable routes, or being cancelled if the destinations are not reachable. Other journeys outside the flooded areas may be indirectly affected by the changed traffic conditions in the transportation system and the influence can also be simulated. The overall flood impact to traffic is measured per single vehicle in lost business hours, additional fuel consumption and additional CO_2 emissions. The lost business hours and additional fuel consumption are consequently monetized to achieve comparable results to other flood impacts. In this way the flood impacts to traffic disruption fits well within the overall flood impact assessment framework within PEARL. A detailed description of PEARL's methodology for integrating flood and traffic models can be found in Pyatkova et al. (in press).

The overall objective of the research is not only to estimate the flood impacts on road transportation, but also to develop a tool that integrates the flood and the traffic models. Such a tool facilitates the dynamic interpretation of the model integration and also empowers an easy and straight forward simulation of multiple scenarios of different flooding and traffic conditions.

3.2.7.6 Indirect tangible – Economic Damage model

Cetaqua has been working on the assessment of tangible damages, both direct and indirect. A methodology was previously developed in two projects CORFU and PREPARED regarding the assessment of direct damages (Velasco et al., 2015) and taken further in PEARL. CORFU project was funded by the European Commission through Framework Programme 7, Grant Number 244047. PREPARED (PREPARED Enabling change) project was funded by the European Commission through Framework Programme 7, Grant Number 244232.

This methodology was applied within the FP7 project CORFU in the case study of Barcelona. In the PEARL project, the same methodology is further enhanced with a new capability to assess the indirect tangible damages and as such applied in the Marbella case study.

Figure 3.11 illustrates the relationships between direct and indirect damage models. These relationships will allow to link direct and indirect damages. In terms of indirect damages, business and traffic interruption are mainly considered.

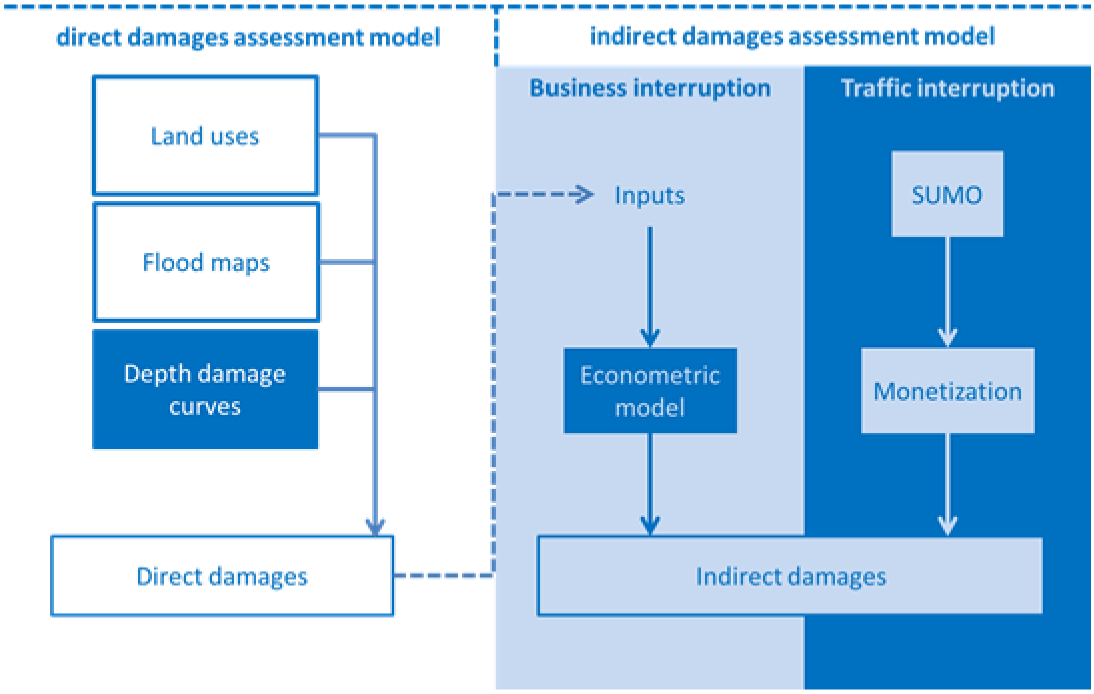


Figure 3.11: Relations between direct and indirect damages models.

The model developed consists of two independent models. One of the two independent models is an econometric model based on the relation between direct and indirect damages. This part is enhanced with a capability of using different land uses in the flooded area as an input variable. Land uses are commonly used in the direct damages models and the idea is to replicate the same approach for indirect damages.

This model has two important benefits in comparison with other models: the results are more accurate than in other econometric models, and a smaller amount of data is needed, i.e. precisely the same data are needed as for the direct damages models (which are mainly flood maps, affected land uses and direct damages). However, for the calibration of the econometric model, indirect damages data related to direct damage data and land use data is going to be needed. An I/O model is going to be applied in order to obtain accurate indirect damages data.

With the use of an I/O model in the calibration process, the implementation of the new econometric model will have a greater precision compared to the model that is currently used.

On the other hand, a monetization of the output of traffic model will be done in order to make the aggregation of both impacts. The data needed for the monetization process will only be the output of the traffic model itself, which will be the difference in km, the difference in time and the difference in CO_2 emissions due to the change of the trips.

The global result of the model is expected to be a quantity of money (€) that will summarize all indirect damages occurred due to each flood event. In addition, functions that relate to direct and indirect damages will be beneficial output from the model, as they can be used to assess other events in other locations.

Both models and their relation with the direct damages model are represented in Figure 3.11. In the following sections, a detailed explanation of each model and inputs are described.

Business interruption model

The business interruption model is expected to be the more impacting part of the indirect tangible damages. It is considered a business interruption and all the damage done to business that is not related to the direct contact of water. In this sense, for example, a fabrication plant that is flooded is considered a direct damage, but the reduction in the purchases of inputs, which will affect a supplier of the fabrication plant, is considered an indirect damage. Numerous models are available to calculate business interruption. However, as explained earlier, some are data demanding while the others are not as accurate as they should be. In order to tackle this issue, an improved econometric model is developed and adjusted by land uses.

Initially, data concerning direct and indirect damages is needed to parameterise the econometric specification. In the case of Marbella, the data concerning direct damages is provided by Consorcio de Compensación de Seguros, a public reinsurer company that has such data from the flood events in the region. Then, an Input-Output model is applied in order to obtain the indirect damages data. The Input-Output model is chosen because of the high grade of accuracy that it brings. Then, using the direct and indirect data, and adding data of the land uses affected by that damage, the econometric model is calibrated. Finally, an additional event is needed to verify the parameterisation.

Once the model is calibrated, the data concerning direct damages per land uses are needed for implementation. This is due to the direct damage model which is marked with the discontinuous line in Figure 3.11. Finally, the output of the model is the amount of money, expressed in the currency of the direct damages.

Traffic disruption monetization

The output from SUMO model, which was described in the indirect intangible section, becomes a tangible damage through the monetization process that is explained in this section.

As a result of the application of the SUMO model, an output of the traffic disruption is given. In the indirect tangible damages model, the monetization of the output is performed. These outputs are measured per single vehicle in lost business hours, additional fuel consumption and additional CO_2 emissions.

In all three cases there is a market price for fuel, for labour hours and for CO_2 emissions, and a market valuation is applied. Thus, the data needed for the calculation involves the output of the SUMO model itself and the price tags. The price depends on the place of the impact. These are typically different in different regions and countries and depend on when the damage occurs (e.g. the fuel price is very volatile). Due to this, it is not wise to attach a price per each case. What is needed is to found the prices in every single event. Finally, the output from the monetization is the amount of money, expressed in the currency of prices used for calculation.

3.3 Flood Risk Mapping and Visualiztion

3.3.1 Flood Risk Maps

The output from the holistic flood risk assessment work contains information about vulnerabilities, hazards and the potential impacts to different sub-systems. This information is then combined in GIS Maps to represent morphology of risk in space and time. For example in

Ayutthaya, a holistic approach for flood risk assessment that combines quantitative and qualitative aspects was applied.

This approach was developed and applied in the Ayutthaya region in Thailand, which is a UNESCO World Heritage Site. First, flood risk was assessed traditionally as a product of hazard and vulnerability. Both qualitative and quantitative data were gathered from publicly available sources and through interviews, questionnaires, and focus group discussions to assess the vulnerability, using various weights for different vulnerability dimensions. The hazard was assessed using a coupled 1D-2D flood model, and the resulting vulnerability and risk were mapped.

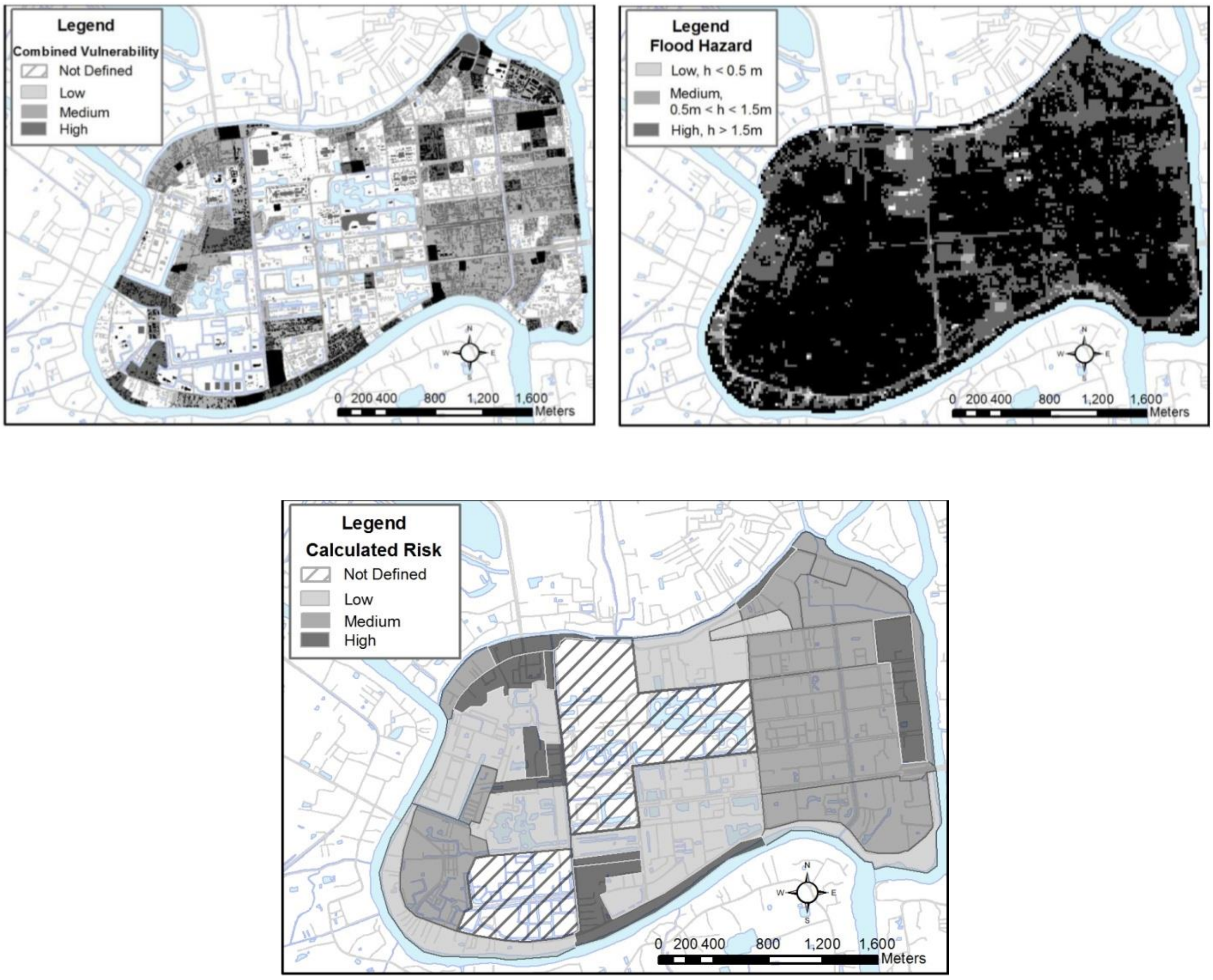


Figure 3.12: Flood hazard estimation for the extreme event of 2011 (traditional approach).

Second, an alternative flood risk map was produced based on group mapping exercises with local residents, which captures the level of perceived risk. The traditional flood risk map was adjusted by varying the vulnerability weights to better match the perceived risk map. The analysis of these two maps revealed that two approaches to flood risk assessment can be used effectively in gaining different insights of the phenomena and as such they both should be used in flood risk management planning.

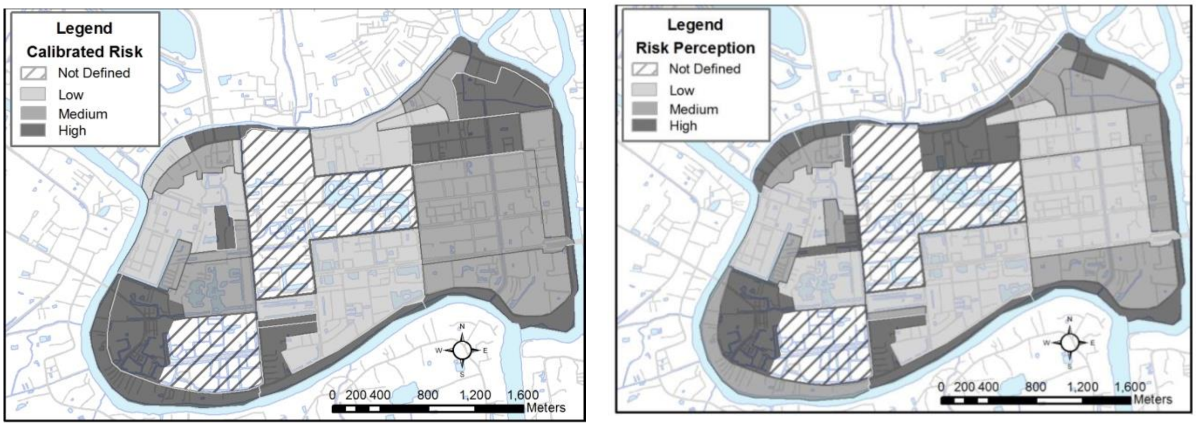


Figure 3.13 Estimation of flood risk by traditional approach and the perceived risk from the community map

The two approaches described here produced results that are not easily compatible, and it proved the challenge of combining quantitative and qualitative data. In the case of Ayutthaya, the aim of the adjustment of one map by comparing it to the other is not intended to be a strictly mechanical rigorous process. Rather we have demonstrated an attempt to combine quantitative and qualitative data, and this process is explorative and relies on judgment and skill.

We showed that the spatial resolutions of the two flood risk maps are very different. The traditional (quantitative or analytical) approach provides a raster flood risk map with a fixed cell size of a few metres, whereas people tend to assess risk on a large scale. This raises interesting questions over the best way to communicate flood risk. An over-reliance on the results of computational models may not be the most appropriate to relate to the spatial scale that people use to assess and communicate risk.

The holistic risk assessment approach emphasizes the need for a combination of quantitative and qualitative data and methods which can range from observations, measurements, model simulations, and economic analysis to signs, statements, experiences, feelings and perceptions. It places a strong emphasis on social and ethical aspects and assessment of community's attitudes towards risk and risk-benefit tradeoffs. It also applies social justice principles (e.g., maximising welfare, fairness, respecting individual rights and equality and promoting virtue) in combination with sharp analysis of social, ethical and wider ecological considerations, while remaining technologically and economically efficient.

The work done in the case study area of Ayutthaya has been published in the journal of Natural hazards (Vojinovic et al 2015).

3.3.2 3D Visualization

The advancement in computer graphics and the new web technologies have revolutionized the possibilities for visualization. Latest trends such as the 3D visualization and animation have changed the way of providing information to the general public and decision makers and has also enhanced territorial analysis methods.

With the introduction of the third dimension (and in some cases also the fourth dimension, which is the temporal one), objects and complex systems can be visualized and studied in a more effective way.

3D visualization is becoming an important part in many sectors, including territorial, environmental and risk management. The success of 3D visualization in the geographic information field has, in fact, fostered the development of advanced tools for representing and analysing the 3D world.

Over the last decade application of Geographic Information Systems (GIS) in flood risk mapping and modelling has been proved as a valuable tool for planning, analysis and prediction. The visualization of these GIS analysis and modelling results, through the modern techniques offered by the 3D tools, generates detailed and impressive flood maps that can be efficiently used to predict potential hazards and zoning, at building level, the affected areas according to the specific envisaged risk.

Spatial and mapped information on flood risk visualized into a 3D tool would be essential for developing local prevention strategies (planning flood defence, preparing evacuation plans, rising citizens awareness, designing new city plans) as well as to facilitate emergency response and the coordination of efforts and logistics during and after extreme events.

In the framework of the Genova case study in PEARL, a 3D visualization tool is being tested, with the purpose to integrate all data from the GIS analysis and hydraulic/hydrogeological modelling work in order to provide, at a client side, the possibility to identify buildings and infrastructures that could be impacted during flood events generated by different meteorological conditions.

The first step in implementing the 3D visualization of a flood prone area is the selection of the most appropriate technological tool.

In order to choose the most appropriate software tool to perform 3D display in PEARL, different criteria (e.g., Open Source, easy to use for the user and cross-platform) was applied. For these reasons, the Cesium WebGL-based virtual globe and map engine was selected.

Cesium (Analytics Graphics, Inc., 2011) is an Open Source JavaScript library for creating 3D globes and 2D maps in modern web browser without install additional plugin. It uses WebGL for hardware-accelerated graphics, and is cross-platform, cross-browser, and tuned for dynamic-data visualization.

Cesium is open source under the Apache 2.0 license. It is the most suitable for dynamic geospatial data visualization with the help of Cesium Language (CZML). CZML is a JSON based schema, which describes geospatial data along with their properties that vary over the time.

Cesium can integrate layer imageries from different sources, including standard image files. Also external WMS (Web Mapping Service) can be integrated within. Each layer then can be visualized according to specific visualization properties (brightness, contrast or saturation).

Cesium supports also 3D models, including key-frame animation, skinning, and individual node picking, using glTF, an emerging industry-standard format for 3D models on the web. Cesium also provides a web-based tool to convert COLLADA models (COLLAborative Design Activity, an interchange file format for interactive 3D applications) to glTF for optimal use with Cesium.

With the advancement in 3D visualization techniques, it has been possible to develop 3D GIS analysis capabilities, which are quite helpful in urban planning, disaster management and environmental planning.

In the case of Genova, GIS applications related to 3D city modelling have been deployed starting from regional technical maps 1:5000 (CTR 1:5000), to derive a DEM (Digital Elevation Model) composed by two different layers such as the DTM (Digital Terrain Model) and the extruded buildings. This datasets are used in Cesium for a 3D territorial representation of the studied area, which is located in final part of the Bisagno River Basin.

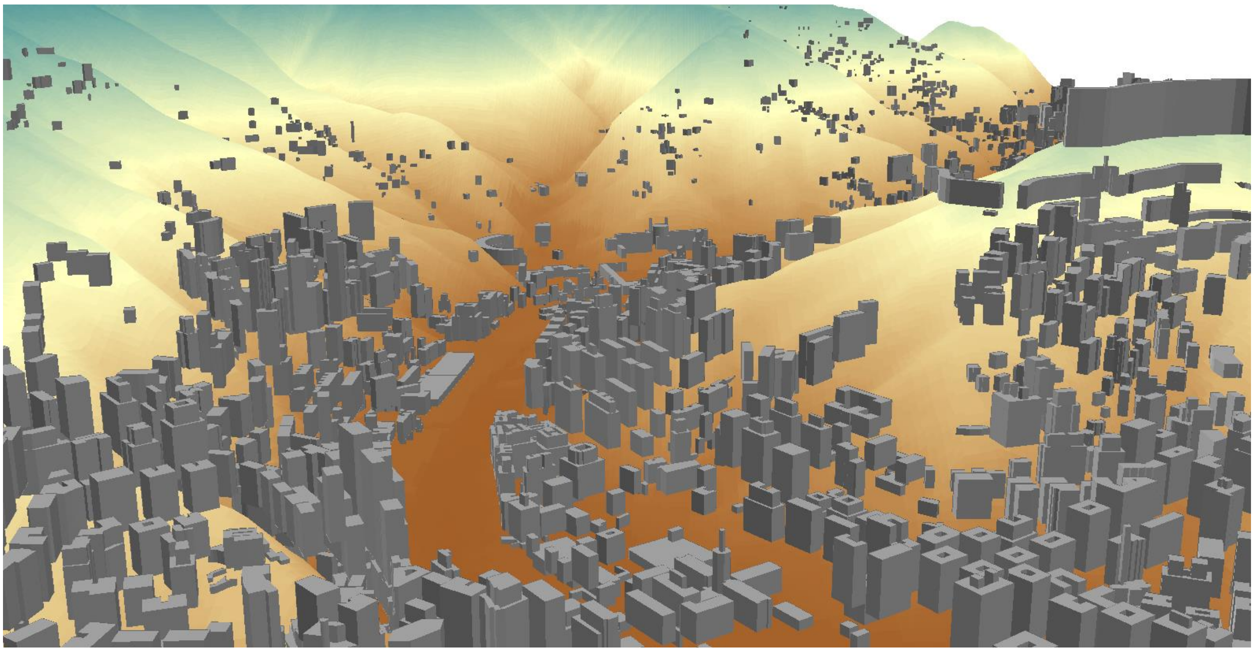


Figure 3.14: Visualization of the Genova case study with Digital Elevation Model (Terrain + Buildings) using the ESRI tool Arc Scene.

A second phase in the implementation of the 3D visualization tool is the integration between the DEM and the 2D flooding model outputs within Cesium. Simulations in the Genova case study have been carried out for two different rainfall events (the one from October 2014, and the severe event of the Cinque Terre from November 2011, translated on the Bisagno Basin) with a time step of 20 minutes. The results from hydrodynamic models were used to produce maps of flooded areas and the water depth for each point of the simulation grid. The resulting flood maps will be included, in a dynamic way, into the 3D city model visualized through Cesium. Cesium allows creation of data-driven time-dynamic scenes using a special JSON schema named CZML. CZML describes lines, points, billboards (markers), models, and other graphical primitives, and specifies how they change with time. While Cesium has a rich client-side API, CZML allows it to be data-driven so that a generic Cesium viewer can display a rich scene without the need for any custom code. Final results will be a 3D animation showing, along the time interested by the event, the flood propagation through the city.

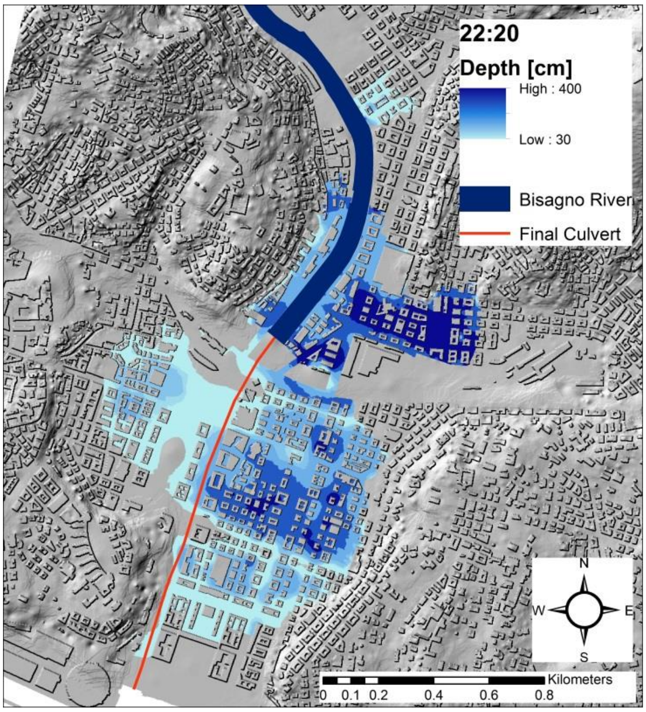


Figure 3.15: Flood extent and water depth obtained from the modelling activities in the Genova.

Further applications that could be carried out with a 3D visualization and analysis tools is the identification of vulnerable buildings and their categorization (with the help of colors) according to their exposure to the flooding event.

3.3.3 The Web LP (Learning and Planning Platform)

The PEARL interactive web-based learning and planning platform (WebLP) is based on the CEF (Chameleon Enterprise Framework) platform leveraging its modularity and expandability. As such the WebLP follows the logical architecture of CEF and expands it in order to take into account the capability to execute PEARL tools in the aforementioned different modes. The platform incorporates the latest industry standards (OSGi, OGC, OASIS etc.) and includes organization, tools, data access, 2D / 3D GIS, and web plugins modules and services that are integrated in a common user interface. (Satways, 2016 plugin developer manual)

The learning and planning platform will be populated with one set of risk analysis results for each EU case study. The data set includes the output from different models and methods developed for each case study area, including different scenario runs to provide sufficient exploration space for the stakeholder mode function.

The exploration space within which users will be able to navigate would be enriched with outputs that will be developed as part of T3.7 (“risk assessment due to combined extreme events”) where risk assessment in all EU case studies will be carried out. The users will have access to main parameters/decision variables and will be able to visualize the effect of changes in these parameters (e.g. different strategies, governance options and interventions) on the evolution of risk through time for their own case. In other words, the platform will present the stakeholders with alternative risk futures on the basis of the chain of decisions taken.

Through the "Flood Tools" module the platform allows for a customized experience in which different combination of choices by the stakeholders will extract different modelling results from the platform's database (e.g. Labiosa et al., 2013). The platform is also integrating other tools like the Flood resilience index. The FRI considers a multi-scale risk assessment that starts with the analysis of the urban system, considering different scales. The flood risk assessment is respectively characterized through different scales (macro and micro) with variations in land use, assets and vulnerability as well as differences in variation of strategies. The application of the models depends greatly on the availability of data and the performed analysis by the local team in the study area. Figure 3.16 shows a screenshot of the Web LP interface and the available option for risk visualization.

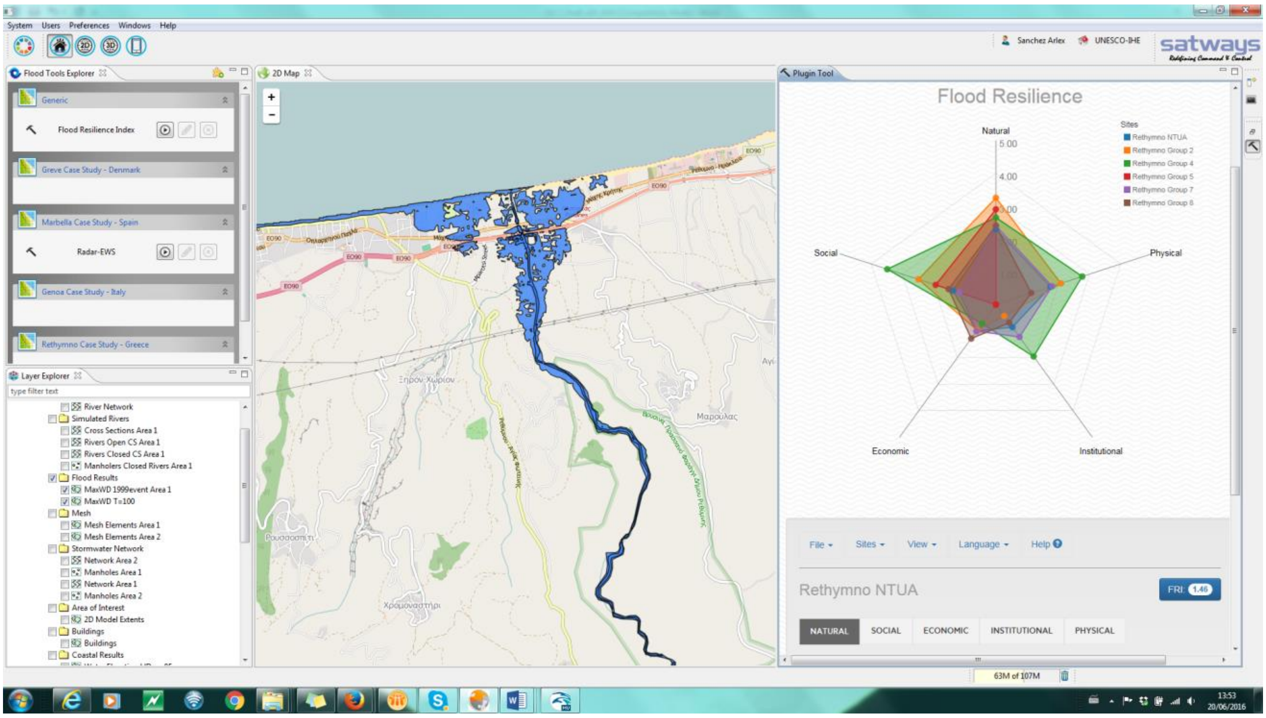


Figure 3.166 flood extend and water depth derived by the modelling activities in the Genova.

The assumption here is that stakeholders learn better when they can experiment in a safe environment in which they can ask what-if questions and visualize the effects of their decisions on indicators they are interested in (e.g. public security, regional expenditure and losses, investment costs etc.).

4 References

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5 Annex 1: Ontology for Flood Risk Assessment

Introductory notes

Position in PEARL

- The flood risk assessment ontology is part of *Task 3.1* in PEARL, which deals with the development of a RAFT: 'Risk Assessment Framework and onTology.'
- The ontology serves two goals:
  - 1) Form a shared knowledge base on flood risk assessment that is compatible with the PEARL methods, tasks and deliverables.
  - 2) Form a conceptual framework for agent-based modelling (ABM) within PEARL
- An intermediate product between the ontology and ABMs will be a MAIA model (Modelling agent systems using institutional analysis, Ghorbani (2013)), which further formalises the concepts, relations and attributes for the purpose of agent-based modelling.

About the ontology

- Please note that the concepts in this ontology are specific to the domain of ***flood risk management for coastal regions***, and therefore cannot be generalized to other contexts.
- The **concepts** should be defined in terms of the other concepts in order to formalize the relations. Other concepts are indicated in bold.
- The **definitions** should be as *concrete* as is possible (in the PEARL context), without infringing on their desired *general applicability*.
- The **possible attributes**are added to clarify the (use of the) concepts further.
  - Some attributes represent a semantic property, i.e. a relation with another concept. This is indicated in bold.
  - In the light of ABM, most concepts are seen as (agent or object) *classes*, but some are seen as *attributes*, e.g. vulnerability. This is indicated in the possible attributes column.
- In the current set of concepts and definitions, we made the choice to use generic concept names (e.g., 'hazard' instead of 'flood hazard'), even though the concept definitions are specific to flood risk management.

Notes on concepts

- If *risk* is indeed completely defined by *hazard*, *exposure* and *vulnerability* (as the IPCC Model of Risk suggests (see Figure 1 in D1.1)), and given that *risk* is also probability times *impact*, probability and *impact* should somehow be covered by *hazard*, *exposure* and *vulnerability*. Perhaps *vulnerability* covers *impact* (because *impact* is determined by *vulnerability*), and *hazard* covers probability. Indeed, 'recurrence interval' is an attribute of *hazard*, and this determines its probability.
- An *extreme event* may (or may not) lead to a *flood event*. A flood event may (or may not) be a *disaster,* depending on *impact* level.

Candidate concepts

- ❑ Institution (can institutions also have adaptive capacity)?
- ❑ Loss

- Risk perception

Ontology

Concept	Definition	**Possible attributes**	**Notes & questions**
Adaptive capacity	The ability of risk bearers, assets or components of nature to adapt to changes in root causes, hazards, and flood risks in the *long term*.	This is an attribute of the classes **risk bearer**, **asset**, and **component of nature**	Inspired by IPCC (2012) and D1.1. How is *resilience* different ? See long note under *resilience.* Is *coping capacity* part of *adaptive capacity*, or are they separate concepts? D1.1. suggests that they are separate elements of vulnerability. Is adaptive capacity indeed the capacity to respond to root causes, hazards *and* flood risk (which are of different nature)?
Asset	Physical artefactowned by a stakeholder, which may be subject to flood risk and/or be usedfor flood risk management.	At risk? (True/false) For flood risk management? (True/false) **Location** Monetary value **Adaptive capacity** **Coping capacity** **Resilience** **Exposure** **Susceptibility** **Vulnerability**	
Climate	Average values of the weather variables in a certain region over the last 30 years.		The 30 years is from the glossary in IPCC (2015)
Coastal region	Region at a coastline.	Hazard Map of locations Map of stakeholders Map of assets Map of components of nature	Subclass of *region* This concept is a central one in the PEARL project description, so must be included. A *coastalregion* is subject to *hazard*.
Community	A group of individuals and organisations, that is located in a certain region, is bound together geographically, culturally, socially, economically, and/or institutionally, and is subject to flood risk.	Region Network of risk bearers	We defined this such that the community consists of the part of the stakeholders that is subject to flood risk (see definition of *stakeholder*). Is indeed the entire community subject to (varying degrees of) flood risk? Can there be multiple communities in one region? (According to the current definition: yes)

Component of nature	A part of the natural environment of a region.	Location Total value (environmental) Adaptive capacity Coping capacity Resilience Exposure Susceptibility Vulnerability	• Examples: a certain land area in the region, a part of a river in the region, a part of the airspace in the region
Concatenation	A situation where one extreme event precipitates one or more other extreme events.		• Definition from D1.1. • Can the term be more specific, so that it becomes apparent it is about extreme events / climate change? • How would one now if such a situation has arisen? The fact that a second extreme event occurred after the first does not mean yet that the first 'precipitated' the second. ○ Change 'precipitates' to 'is followed by'?
Coping capacity	The ability of risk bearers, assets, or components of nature to adapt to changes in root causes, hazards, andfloodrisksin the *short term*.	This is an attribute of the classes risk bearer, asset, and component of nature	• Inspired by IPCC (2012) and D1.1. • Is the distinction between *adaptive capacity* (long-term) and *coping capacity* (short-term) useful? Could it be made concrete what kind of changes people would make in the short run vs. long run? • Does it make sense to speak of short-term changes to root causes and flood risks (which may not be/feel very alarming)?
Damage	Negative impact of a flood event.		• Synonyms: harm, loss (?) • Can impact on health and loss of life be labelled 'damage'? • Can the loss of assets be labelled 'damage'?

Disaster (*due to flood event*)	Severe alterations in the normal functioning of a community, due to a flood event, leading to widespread adverse human, material, economic, or environmental impacts that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.	Region Minimum total impact level	• Adapted from IPCC (2012) and IPCC (2014) definitions • An *extreme event* may (or may not) lead to a *flood event*. A flood event may (or may not) be a *disaster,* depending on impact level. • For a *flood event* to be qualified as a *disaster*, a minimum total *impact* level must be reached. • Given the above, can we view the disaster as a subclass of *flood event*? • If *coping capacity/resilience* prevents severe alterations, it means that there is no disaster (?) • How are 'severe alterations in normal functioning' defined? Can this be based on a minimum total impact level, or a minimum level of specific impacts?
Disaster risk	The riskof adisaster.	Region Considered time period Probability Minimum total impact level	• Subclass of *risk* • Disaster risk is different from *flood risk*, as a *flood event* does not always be a *disaster*. • For a *flood event* to be qualified as a *disaster*, a minimum total *impact* level must be reached.
Disaster risk management	The management of disaster risks, or in other words, risk management of disasters.		• Disaster risk management is different from *flood risk management*, as a *flood event* is not always a disaster.
Early warning system	An asset that is used to generate and disseminate timely warning information to enable communities threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of damage.		• Adapted from IPCC (2012) definition • This was defined as 'the set of capacities', but this is probably not specific enough. Is an early warning system indeed a physical artifact (see def. of *asset*)?
Evacuation	Process of relocating risk bearers to reduce their exposure, which is part of the response phase.		• Own definition. • Useful concept? • If people are either exposed or not, then evacuation 'removes' exposure.

Exposure	The degree to whichrisk bearers, assets and components of natureare exposed to a hazard due to their location.		• Inspired by IPCC (2012) definition and draft PEARL glossary definition • Originally 'the presence at locations that could be flooded', but if all locations could be flooded this is not a very useful definition. • The 'degree of exposure' is a function of the flood duration, water depth and water velocity that the risk bearer/assets/component of nature can be expected to face at a specific location given the hazard and location attributes.
Extreme compound event	Extreme event that involves the rare, simultaneous occurrence of values of two or more weather variables above (or below) respective threshold values.		• Adapted from IPCC (2012), page 116. • The combination of weather variable values is rare, not necessarily the individual values. Therefore the threshold values are likely to be different from the threshold values for *extreme events*.
Extreme event	The rare occurrence of a value of a weather variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable, which may trigger the occurrence of a flood event. This threshold value is time and place specific, and may be either an absolute value or correspond to the chance of occurrence within a certain time period (which is derived from a certain reference period).		• Adapted from IPCC (2012) definition ('weather variable' added). Last sentence added following IPCC (2012) page 116. • Synonyms: extreme hydro-meteorological event (in the context of PEARL), or extreme weather event (IPCC (2015)). • An *extreme event* may (or may not) lead to a *flood event*. A flood event may (or may not) be a *disaster.* • The word 'extreme' in this def. relates to rarity but not to level of impact (the word 'rare' has been added to emphasize this), because only a *disaster* has by definition widespread impacts.
Feedback	The ways in which both the response and recovery processes have effects that may feed back into the underlying conditions for ongoing risk and subsequent disasters, potentially		• Adapted from definition in D1.1. • This will be hard to formalize for ABM • Is this a useful concept in holistic flood risk assessment, i.e. will feedback relations be

	altering the nature of these conditions.		identified explicitly? • Can we change 'underlying conditions' into 'root causes'?
Flood event	The accumulation of water over areas in a region that are not normally submerged, which is often caused by an extreme event or extreme compound event, and which may cause a disaster.	Type(fluvial, pluvial, coastal, estuarine, flash) Duration (overall) Extent (locations flooded, over time) Water depth (per location, over time) Water velocity (per location, over time) Impacts Root causes	• Adapted from IPCC (2012) definition. • Synonym: flood • An *extreme event* may (or may not) lead to a *flood event*. A flood event may (or may not) be a *disaster,* depending on impact level. • Aflood event is an actual event, a *hazard*is its possible occurrence. • According to the EU Directive (as mentioned by Scheuer et al. (2013)), there are also 'medium probability events', so a flood is not always caused by an extreme event. Therefore the word 'often' in the definition. • The 'not normally' part was in the IPCC (2012) definition. Correct? (Can flooding become something normal?) • Should the definition refer to a water level threshold value? • Scheuer et al. (2013) include the 'intensity parameters' inundation depth, duration, and extent (locations), and recurrence interval. The last one is an attribute of *hazard*.
Flood risk	The riskofa flood event.	Region Considered time period Probability Impacts Root causes	• Subclass of *risk* • Food risk is different from *disaster risk*, as a *flood event* does not always lead to a *disaster*.
Flood risk assessment	The assessment of flood risks, or in other words, therisk assessment of flood events, which is part of the process offloodrisk management, and is part of the preparation phase.		
Flood risk management	The management of flood risks, or in other words, therisk management of flood events, which spans the processes of preparation, recovery and response.		• Flood risk management is different from *disaster risk management*, because a *flood event* does not always lead to a *disaster*. • Is flood risk management something that only the risk managers are doing? (People are also preparing,

			responding, and recovering themselves.) Is a person building a wall around his house a risk manager?
Hazard	A flood event that could occur in a certain region and in a certain time period.	Type(fluvial, pluvial, coastal, estuarine, flash) Recurrence interval Duration (overall) Extent (locations flooded, over time) Water depth (per location, over time) Water velocity (per location, over time)	• Adapted from IPCC (2012) and PEARL glossary definitions. Seems in line with 'source of potential harm' (ISO, 2009). • A *flood event* is an actual event, a *hazard* is its possible occurrence. • The probability of a flood event is captured by its recurrence interval attribute. • A hazard is relevant to the (scale of) *region*. Completely flood-proof *locations* could be indicated to always have a water depth of zero.
Holistic flood risk management	Flood risk management in which a holistic approach is applied, taking into account the interdependences between social, technical and natural processes in regions, including those between flood risk management processes and the broader development processes within such regions.		• Subclass of *flood risk management* • Adapted from PEARL glossary definition
Impact	The (positive and negative) effect of a flood eventormeasure onrisk bearers, assets, and/orcomponents of nature.	Direct? (True/false) Tangible? (True/false) Dimension of impact (physical, economic, social, environmental) Type of impact (e.g. well-being, human security, human health, injury, loss of life, damage to property, damage to infrastructure, damage to cultural heritage, social disruption, economic disruption, environmental degradation) Affected risk bearer(s) Affected asset(s) Affected component(s) of nature Impact value (number of casualties and injured, monetary value	• Adapted from IPCC (2012) definition • A *flood event*can have multiple impacts (in order to distinguish between e.g. different types of impact)

		of total damage)	
Integrated flood risk management	Flood risk management in which the use of tools, approaches, methods and resources is coordinated and integrated.		• Subclass of *flood risk management* • Adapted from PEARL glossary definition
Location	Specific geographical point within a region, at whichstakeholders, assets, or components of nature may be positioned.	Region Altitude Land type Coverage Quality of soil Quality of groundwater	• Point or area?
Measure	A policy intervention that is taken in the frame of flood risk management.	Structural? (True/false) Scale (regional, local) Executing risk manager	• Is it always a policy intervention? • A measure is 'structural' if it involves physical construction; a measure is 'non-structural' if it uses knowledge, practice or agreement (PEARL glossary).
Preparation	The phase of flood risk management before the flood event, which involves the implementation of measures to reduce flood risk.		• Synonym (?): preparedness, pre-disaster • Includes prevention and protection. • On an EC website preparedness is described as 'informing the population about flood risks and what to do in the event of a flood'. Additional concept? • Does preparation also include self-preparation of people? If so, preparation is not just a risk management phase, unless that also can be considered risk management (*see remark on flood risk management*)!
Recovery	The phase of flood risk management after the flood event, which includes the restoration, and improvement where appropriate, of assets, livelihoods and living conditions of affected communities, including efforts to reduce flood risk factors		• Adapted from UNISDR (2009) (cited in D1.1) • Synonym: post-disaster • A related term is reconstruction, which may be the recovery of (certain types of) assets. Is it a useful additional term? • Does recovery also include self-recovery of people/nature? If so, recovery is not just a risk management phase, unless that also can be considered risk management (*see*

			remark on flood risk management)!
Region	Geographical area thatis considered in the frame of flood risk management.	Hazard Map of locations Map of stakeholders Map of assets Map of components of nature	• A regionis subject to *hazard* (which might have a recurrence interval of zero, if floods never happen).

Resilience	The ability of risk bearers, assets or components of nature to prepare for, respond to, and recover from the impact of a flood event in a timely and efficient manner.	This is an attribute of the classes risk bearer, asset, and component of nature	• Adapted from IPCC (2012) definition
			• Definition of resilience should be distinct from *adaptive capacity* or one of both should be removed.
			  ○ Right now, *resilience* refers to flood events, whereas *adaptive capacity* refers to flood risk. Correct difference?
			  ○ Acc. to IPCC (2015) this refers to systems, but why can people/assets not be resilient?
			• Why 'in a timely and efficient manner'? (How would that be determined?)
			• Does it make sense that both people and non-living elements have resilience?

Response	The phase of flood risk management during the flood event, which includes the provision of emergency services and public assistance during or immediately after a flood event in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the individual risk bearers.		• Adapted from UNISDR (2009) (cited in D1.1) • Synonym: emergency response, during-disaster phase • Could it be defined more specifically *when* a flood event is still occurring, and when the process of *recovery* starts? • The UNISDR (2009) speaks of *disaster* instead of *flood event*, but flood event is more generic (not all flood events are disasters). • Does response also include response of people? If so, response is not just a risk management phase, unless that also can be considered risk management (*see remark on flood risk management*)!
Risk (*of flood*	A probability of	Region	• Adapted from PEARL

event or disaster)	endangerment that is a function of hazard, exposure, and vulnerability. It can be estimated by the probability in a certain region and time period, times the total impact.	Considered time period Probability Impacts	glossary definition, Scheiderbauer and Ehrlich (2004), and D1.1. • Because *hazard*, *exposure* and *vulnerability* completely cover risk, probability and impact should be covered by these elements too. *Impact* directly follows from *vulnerability*; *hazard* includes probability (see 'Notes'). • The calculation of risk also incorporates possible (minor) positive impacts.
Risk accumulation	The potential result of the processes of risk propagation, risk cascading, feedback and concatenation, where risks concentrate across different spatial and temporal scales.		• Definition is from D1.1. • This will be hard to formalize for ABM
Risk assessment	A systematic process of evaluating the potential risks that may be involved in a projected activity or undertaking, which is part of the process of risk management, and is part of the preparation phase.		• Definition is based on Oxford Dictionaries (2015)
Risk bearer	Stakeholderwho bearsflood risk.	Individual? (True/false) Current location(if individual) Owned assets Health (if individual) Daily revenue (if organisation) Adaptive capacity Coping capacity Resilience Exposure Susceptibility Vulnerability	• Subclass of *stakeholder* • Suggestion for another term than 'risk bearer'?
Risk cascading	The cascade of effects of risk from first order, direct impacts to second order, indirect impacts and to third order, systemic risks.		• Definition is from D1.1. • Can we see it like this: a risk is about possible flood impacts, and when these impacts occur, system/community conditions change, and new risks emerge. • This will be hard to formalize for ABM
Risk driver	The activity or process by whicha root causedevelops into flood risk.		• Adapted from definition in D1.1. • This will be hard to formalize for ABM

Risk management	The process of data and information gathering, risk assessment, appraisal of strategies and measures, and making, implementing and reviewing decisions to reduce, control, accept or redistribute risks.		• Adapted from the PEARL glossary definition of flood risk management
Risk manager	Stakeholder who manages flood risk.	Individual? (True/false) Current location(if individual) Owned assets	• Subclass of *stakeholder*
Risk mitigation	The process of lessening flood risk through measures, which is part of the preparation phase.		• Based on IPCC (2012) definition
Risk propagation	The distribution of the influence of risk over wide spatial and temporal domains, includingthe distribution of systemic impacts which may not be easily identifiable and may manifest themselves at different points in time in relation to the actual flood event.		• Adapted from D1.1. • So risk propagation contains all effects of risk, i.e. all changes carried out by stakeholders because of the risk, plus flood impacts (?) • This will be hard to formalize for ABM
Root cause	Structure or process that is an underlying cause of a floodrisk or flood event.		• Adapted from definition in D1.1. • How could a root cause be expressed? Can we be more explicit? Can it be a historical event, and/or a certain societal characteristic, and/or …? • Will the list of root causes of a *flood risk* be different from that of a *flood event*? • D1.1 often uses 'disaster root causes' and 'root causes of risk', but the focal point in the ontology is the *flood event*.
Root cause analysis	A structured investigation that aims to identify root causes.		• Adapted from DKKV (2012) definition (cited in D1.1.)
Stakeholder	Organisation or individual, located in a certain region,who is a risk manager and/or a risk bearer.	Individual? (True/false) Risk manager? (True/false) Risk bearer? (True/false) Current location (if individual) Owned assets	• Synonym: actor, agent • A stakeholder could be both a *risk manager* and a *risk bearer*.
Strategy	A coherent plan or set of	Applying risk manager	• Adapted from PEARL

	plans that set out goals, specific targets, decision points and the mix and performance of both structural and non-structural measures to be employed in the frame of flood risk management.		glossary definition • A strategy concerns the decision logic (mindset / world view) of a *risk manager*. This strategy may be very concrete, and include a plant to implement specific *measures*. Alternatively, it may just outline the process of selecting measures.
Susceptibility	The level of damage that risk bearers, assets and components of nature receive from a flood event, considering exposure,but not adaptive capacity.	This is an attribute of the classes risk bearer, asset, and component of nature	• Definition derived from PEARL Deliverable Report 1.1 (2014) • *Adaptive capacity*, *coping capacity* and/or *resilience* in this definition? ○ Resilience fits best if that one is the only one referring to flood events alone.
Transformation	The process of re-aligning the structures underpinning the flood event to ensure future resilience and sustainability in a region.		• Adapted from definition in D1.1. • Can the definition be made more specific, e.g. by changing ‘structures’ to ‘root causes’? • Should ‘sustainability’ be in the definition? The central objective in PEAR is resilience, not sustainability. If yes, should it be a separate concept?

Vulnerability	The level of damage that risk bearers, assets and components of nature receive from a flood event, considering both their susceptibility and adaptive capacity.	This is an attribute of the classes risk bearer, asset, and component of nature	• Definition derived from PEARL Deliverable Report 1.1 (2014)
			• *Adaptive capacity*, *coping capacity* or *resilience* in this definition?
			  ○ Resilience fits best if that one is the only one referring to flood events alone.
			  ○ In section 5.3 of D1.1, *adapt. cap.* and *coping cap.* are both mentioned as components of vulnerability!

Weather	Current values of the weather variables in a certain region.		
Weather variable	A meteorological variable (such as rainfall level or wind speed).		• Alternative terms: meteorological variable, atmospheric process

6 Annex 2: CORFU Direct tangible damages methodology

The CORFU FP7 project developed a methodology to assess the direct tangible damages in urban areas. This methodology will be reviewed in the PEARL project and completed by adding the model to calculate indirect tangible losses. The following chapters summarize the methodology developed and presented in Velasco et al. (2015).

Since the study developed in the CORFU project pretends to assess impacts from a starting point in which there is no data at all, only one typology of damages have been considered. Given that in urban areas industrial uses are not so important, and considering that the main communication roads are generally surrounding urban areas, only direct damages have been considered. In addition, since the goal is to calculate the damages in economic terms so the EAD can be obtained, only the tangible ones have been included in the assessment.

The spatial variability of urban damages is very high. The impacts induced by urban floods can differ a lot from one street to the next one. Therefore, in terms of the spatial scale, assessments in urban areas clearly require a microscale study.

Flood damage assessment is a recent research field that has not been deeply studied in some countries, such as Spain. Considering this as a starting point, and assuming that there is a lack of historical damage data, synthetic absolute depth damage curves must be developed. These curves will not take into account flood velocities, because the construction typology and materials of European (and more particularly Spanish) buildings are less affected by this variable.

Summarizing, the outputs of this impact assessment are **direct tangible damages at a micro-scale level**, by using synthetic depth damage curves. In order to carry out a damage assessment, and particularly for this one, three key elements are required as inputs: **depth damage curves, detailed flood depth maps** and **land-use maps**. These inputs and outputs required in the model are detailed in the following sub-sections.

Furthermore, in order to ease the calculation of the final flood damage maps, a GIS-based toolbox has been developed (Hammond et al., 2012). This toolbox enables the user to automatize the three following steps, increasing the speed of the post processing of data and so, easing the simulation of several events:

(1) Read the value of water depth in each building from flood hazard maps.

(2) Interpolate this value in the stage damage curve to obtain the relative cost.

(3) Multiply the relative cost by the area, obtaining the total damage value per each block.

Finally, a shape file with the total cost values is obtained, being able to calculate the total costs that have been caused by the extreme rainfall event. This process can be easily repeated for several flood-driven events.

Using this toolbox and data described in the following sections, synthetic rain events for several return periods can be simulated. These results will be used to calculate the EAD of the studied area, which is used to better understand the potential damages caused by a hazardous event.

EAD is an estimate of the average flood damages computed over a number of years (Arnell, 1989) and it is obtained by integrating the relationship between the expected costs for an event and its probability (Dawson et al., 2008).

Since it is difficult to accurately define the relationship between the probability of a flood event and the costs it would cause, the most common methodology to calculate EAD consists on simulating several events of different return periods (which means that they have a different probability associated) and calculate the damages for each case. Then, by calculating the area under the curve that these points define, the EAD can be obtained.

The proposed methodology applied to Barcelona is described in box 1.
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Box1. Description of the Barcelona example from CORFU project

Barcelona, with a population of 1,620,943 within its administrative limits on a land area of 101.4 km2, is located in Catalonia, on the Northeast coast of the Iberian Peninsula, facing the Mediterranean Sea, on a plateau limited by the mountain range of Collserola, the Llobregat river to the south-west and the Besòs river to the north east. The average population density of the city is 15,985 inhab./km^2, which approximately becomes19,200 inhab./km^2 if the forest area of Collserola mountain is not considered.

Barcelona presents a classic Mediterranean climate with cool winters and even warm summers, occasionally suffering heavy rainfalls of great intensities and flash floods events. The yearly average rainfall is 600 mm, but the maximum intensity in 5 minutes corresponding to a return period of 10 years is 202.47 mm/h and it is not rare that 50% of the annual precipitation occurs during two or three rainfall events. The intensity duration frequency (IDF) curves were generated using a rainfall series data of 81 years (from 1927 to 1992 and from 1995 to 2009). With these IDFs several synthetic storms for several return periods were obtained for the design of the sewer network (Rodríguez et al., 2013).

The morphology of Barcelona presents areas close to Collserola Mountain with high gradients with (withan average of 4%%) and maximum values of 15–20% and other flat areas near to the Mediterranean Sea with mild slopes (close to0–1%). The Raval district is located in a low-lying area of the city. With almost 50,000 inhabitants in an area of 1.09 km^2, it is one of the most densely populated areas in Europe (approx. 44,000 inh./km^2). The district area is highly impervious with several vulnerable elements (such as schools, hospitals, museums, historic buildings, etc.).

This area suffers from flooding problems when heavy storm events occur. These problems are caused by the excess of surface runoff and the poor capacity of the sewer system in some of the upstream basins in the city. In addition, the hydrological response time of the catchment is very short (less than 30 minutes). As a result, there is significant hazard for the vehicular and pedestrian circulation and economic damage (goods and properties).

To calculate the EAD several events of different return periods must be simulated. In this study, five storm events were used. These events correspond to a really extreme event (T 100 years), a precipitation event that starts to create some damage (T 1 year) and three intermediate ones. Since the Barcelona sewer network is predominantly designed to cope with a 10-year return period event, this will be the third return period used (T 10 years). The other two return periods are some more intermediate values of the three ones described, which are 5 and 20 years. Such rain events have been simulated by using the hyetographs developed from the IDF curves (Rodríguez et al., 2013).

In the following sections, the information and procedures used to create the depth damage curves, the land-use maps and the flood maps are presented.

Depth damage curves

Since there were no curves specifically representing the flood damages in the studied area, synthetic absolute depth damage curves were developed in the frame of the study. Such curves are used to obtain costs for a certain water depth relative to the extent flooded. Then, multiplying the obtained value by the affected area of the building, the damage cost at a block scale is acquired.

These curves have been created for different types of land-use. Taking into account the main uses identified in the case study area, six different categories were defined in the CORFU project (warehouses and parking areas; commercial; residential; hotels and leisure; public and cultural buildings; and sites of interest - such as museums, churches or historical buildings). Then, via a what-if analysis and using flood expertise acquired from past flood events, a stage damage curve for each type of building and economic activity has been obtained. These final stage damage functions are composed by two independent curves.

The first ones, related to the re-conditioning of the building (cleaning, painting the walls, changing the floors or doors, etc.), have been obtained through the expertise gained in past local floods. In the CORFU project, this study was developed with the collaboration of an independent flood damage appraiser with expertise in the Barcelona city area (Lucena, 2012).

The process to develop these curves is described following:

(i) a standard building has been defined for each of the six land-use categories considered;
(ii) the costs of the several cleaning and refurbishment works required have been assigned to different water depths;
(iii) these costs have been normalized using the surface of the standard building defined; and
(iv) adding the several categories the final building depth damage curve is obtained.

The second component of the curves is related to damage to the contents that can be found inside the buildings. In order to create them, the same standard buildings defined for the building curves have been used. For each land-use category, several assets and goods were placed inside the standard buildings. Then, using the FloReTo tool (Manojlovic & Pasche, 2010), a database of flood depth damage curves, and introducing the Spanish market prices of the exposed assets, the contents curves can be obtained. Again, by normalising the values using the surfaces of the standard buildings, the relative depth damage curves have been created.

The curves developed for both buildings and contents, can be seen in **Error! Reference source ot found.**.This is an example of the curves developed in the CORFU project; similar curves will be developed in the PEARL project for the Marbella case study.

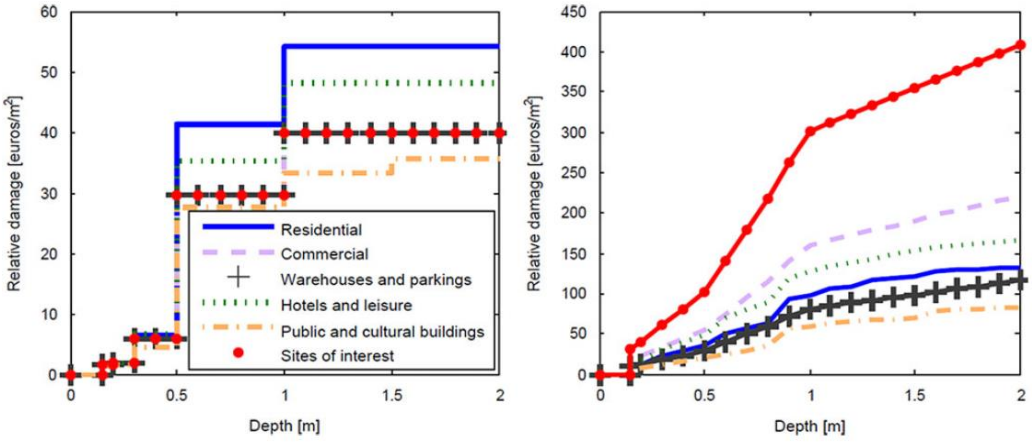

Figure 6.1. Depth damage curves for the buildings (left) and content (right) taking into account the local conditions of the Raval district

The relationship between building and contents damages strongly depends on the type of land-use considered. Whereas in households the building costs tend to be higher than the contents' (Thieken et al., 2005), this trend is not so clear in other land-uses. In the case of commercial use, flood losses are highly variable due to the differences depending on the kind of business considered (Gissing & Blong, 2004). In this case, the methodology used considering the several standard buildings has led to curves that define, for the commercial land-use, the damages of contents up to five times greater than the building ones.

The validation of the curves is crucial in order to assess their ability to represent the damages produced. As much information as possible regarding flood impacts in the studied area was gathered. Firstly, the information of the interviews previously mentioned was used for the validation process. On the other hand, actual damage data from the Consorcio de Compensación de Seguros (CCS), the reassurance that covers the catastrophic and extreme situations in Spain, can be obtained. The information from the two sources is then used to adjust and validate the curves. The general trends and behaviours extrapolated from the surveys are taken into account; and the CCS damage data is compared to the simulated values.

When comparing simulated damages with the reported ones, the simulated damages can be bigger than the reported ones. However, this can be explained because:

- Some of the flooded buildings may have not reported their damages to the CCS because they were low, the property was not insured or they were not aware that they could be compensated.
- The simulated damages are assuming that no flood risk reduction strategies are being used. However, since some of the local population have suffered from previous flood events, some measures are taken to protect their assets, by placing wood gates in their doors, or moving goods to higher areas.
- The water depth inside the building has been assumed as the average of the maximum water depths of all the mesh elements in contact to each block. This hypothesis is conservative as it is an upper bound of the water that will actually be inside the building.

Land-use information

A GIS map is developed using data from the local land registry at block level. For each block, more than one land-use type is possible, so the area related to the several land-use types is given. Multiplying these values by the relative damages obtained from the stage damage curves,

the total costs of the block can be obtained. Additionally, it is possible to calculate the risk map for goods and properties, which shows the maximum potential impacts in monetary units.

Flood depths

The estimation of flood depth in a very accurate way is crucial for a micro scale assessment such as this one. Therefore, there is a need for a coupled 1D/2Dapproach in order to take into account surface flows coming from upstream catchments and the interactions between the two drainage layers (known, respectively, as 'major system' formed by streets, sidewalks, squares, etc. and 'minor system' formed by the sewer network). A detailed 1D/2D coupled model, simulating surface and sewer flows is under development for the Marbella case study within the PEARL project.

The model only represents the water depth in the streets and green urban areas (as the buildings are considered as void areas for the surface layer and the runoff generated is directly conveyed into the underground sewers).Given that it is complicated to accurately determine the relationship between water depths inside the building and on the streets, a hypothesis is used: the water depth inside the building is the result of calculating the average of the maximum water depths of all the mesh elements in contact to each block. This overestimation of water depths obviously leads to an upped bound of the actual damages. Nevertheless, it is preferred to work with an upper bound of the depths and damages, so the results are conservative and it can be sure that the simulation results are never below the actual value.