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SUMMARY

This report is a literature review on flood damage approaches and models with suggestion for model adaption, including the report on assessed damages in case study cities.

Flood Impact Assessment – A Literature Review

Contents

1 Introduction

The impacts of flooding on urban populations can be multi-faceted and wide-ranging. The objective of Work Package 3 is to develop a comprehensive and flexible framework that will combine different methodologies for the evaluation of all types of damage. This can mean the damage that is caused to property, interruptions to the economy, and the impacts on human health, which could include the loss of life and injury, as well as outbreaks of diseases that can occur following flooding. An improved knowledge of the flood impacts should enable the assessment of the vulnerability of cities, and allow for the evaluation of different flood risk management strategies and their effectiveness.

This report is intended to provide a systematic, objective and critical review of the existing approaches, models and results of their application, to provide a comprehensive insight to their data requirements, their applicability and their limitations. This review will describe some of the gaps within the literature, and consider how, as part of the CORFU project, they may be filled. This review will, in particular, focus on estimates that have been made in or near the case study cities, and will include estimates from real historical events.

Messner et al (2007) produced guidelines for flood damage estimation as part of the European Commission-funded FLOODsite project. That report was comprehensive in many areas, and it is unnecessary to repeat those sections for their own sake. However, the principal purpose of that report was to provide guidelines for practitioners on ex-ante flood damage evaluation. The focus of this report is to critically assess the different methodologies, and their appropriateness for use in the case study cities.

This review will also draw on information from several ongoing European research projects, including ConHaz (Cost of Natural Hazards), ENSURE (Enhancing resilience of communities and territories facing natural and na-tech hazards), and CapHazNet (Social Capacity building for natural hazards toward more resilient societies). ConHaz is a project that specifically aims to synthesise current cost assessment methods and strengthen the role of cost assessment in the development of natural hazard management and adaptation planning. The ConHaz project involves a range of natural hazards, including droughts, floods, storms, coastal hazards, and alpine hazards, whereas the CORFU project only considers flooding. This review also sources review papers in the published literature (Merz et al., 2010).

1.1 Flood damages, impacts, consequences, costs and losses

The terms ‘flood damage’, ‘flood impact’, ‘flood consequences’ and ‘flood loss’ are used regularly in the technical literature. To avoid confusion on the part of the reader, these terms will be defined and explained. These terms should be used consistently throughout this report and the CORFU project.

The terms ‘flood consequences’ and ‘flood impacts’ are synonymous, and both refer to the broad effects that flooding can have on people, to property and to the environment. These consequences or impacts can be both positive and negative, although it is common in the literature to see the terms used in a purely negative sense, especially in relation to human health, where health impact assessments are conducted (Fewtrell et al., 2008). The terms ‘loss’ and ‘damage’ are also used synonymously in the literature. Damage is the negative result of the spatial and temporal impact of an event on societal elements (people, buildings, etc.), societal processes (interruption of production, services, etc.) and the environment (Vetere Arellano et al., 2003).

The positive effects of flooding are referred to as the ‘benefits’ of flooding. In a report by the National Research Council of the United States, losses were differentiated from the term ‘costs’, with the latter referring to only to the payouts made by governments and insurers, whereas ‘losses’ had a broader connotation (Committee on Assessing the Costs of Natural Disasters, 1999).

For consistency, this report will use the term ‘impact’ in place of ‘consequence’, but ‘damage’ and ‘loss’ can be considered to be interchangeable. Additionally, this report makes the stylistic decision to use ‘damage’ to refer to both singular and multiple negative impacts, avoiding the use of the word ‘damages’, which does occur in the literature. The term ‘costs’ when used will not be considered synonymous with damage or loss.

1.2 The importance of flood impact assessment

Flood impact assessment is a key component of the practice of flood risk management. Flood risk is defined in the European Flood Directive as “the combination of the probability of a flood event and of the potential adverse impacts on human health, the environment, cultural heritage and economic activity associated with a flood event” (European Commission, 2007). There are several similar definitions in the literature, that agree that flood risk is the probability of a certain flood event, in combination with its impact (DEFRA/EA, 2006). With this definition, flood impact is therefore one half of the flood risk equation.

The estimates of the impacts caused by flooding can be used by a number of stakeholders for different purposes and these are summarised in Table 1 (Vetere-Arellano et al., 2003).

Table 1 - Areas where damage estimation results can be used (adapted from Vetere-Arellano et al, 2003)

Area	Description of possible damage estimation input
Decision making and risk management	To assist decision makers in carrying put adequate risk management policy initiatives
Policy-making	To assist policy makers in preparing, revising and updating existing legislationso as to ensure optimum protection of the citizen
Civil protection	To assist competent authorities to target civil protection methods
Spatial and land-use planning	To assist urban, rural and regional planners to adopt both prevention and mitigation measures to face potential threats
Emergency preparedness and response	To assist competent authorities in the preparation, revision, and updating of emergency plans
Disaster recovery/relief	To assist in prioritising and better targeting the allocation of disaster recovery and relief resources
Construction and re-construction	To assist managers of buildings and other vulnerable facilities to improve construction practice
Insurance and reinsurance	To provide feedback to insurance and reinsurance companies, so that premiums can be established
Damage estimation practice	To improve damage estimation techniques
Damage estimation research	To identify areas of research where advances can be made, as well as providing a better understanding of hazards and how they impact on societies.

Flood damage estimates are, therefore, useful at all the stages of what is known as the Flood Mitigation Cycle, shown in Figure 1 (Mark and Djordjevic, 2006). The Flood Mitigation Cycle forms the basis for the development of strategies for flood protection and flood responses. The flood mitigation cycle can be considered as three stages, by considering the strategies that affect the system's response, relative to the timing of the flood. The strategies can be considered as those which:

- Aim at improving the system's readiness and preparedness prior to a flood event;
- Aim at improving the system's response during a flood event;
- Aim at improving the system's recovery following a flood event.

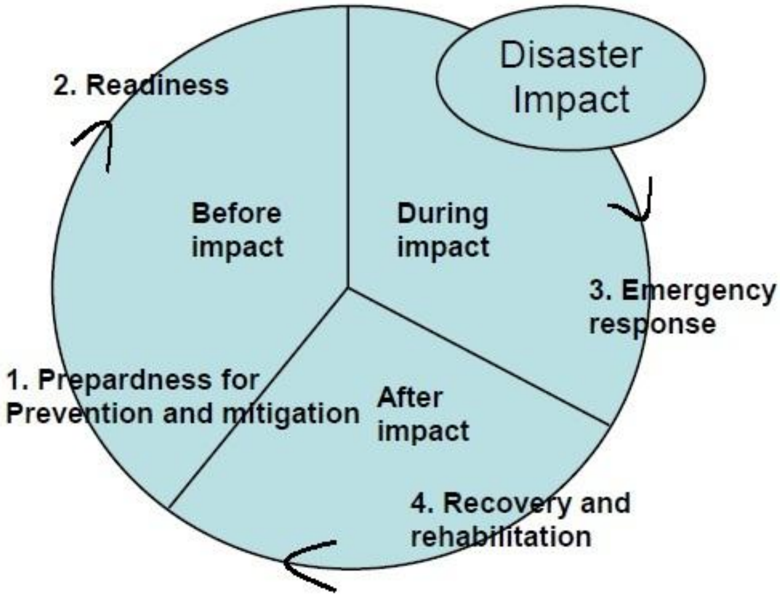

Figure 1 - Flood Mitigation Cycle (taken from Mark and Djordjevic (2006))

1.3 The problem of divergent flood damage estimates

As flood impact assessment is so critical to the practice of flood risk management, any estimates of damage should be as reliable and as accurate as possible. However, there is no common methodology that is applied to estimate flood damage internationally.

As part of the EU-funded FLOODsite project, Meyer and Messner (2005) described the variety of methods that are used in four European states (the UK, Germany, the Netherlands and the Czech Republic). The differences related to a) the objective of the evaluation, (b) the damage categories considered, (c) the level of detail, (d) the scale of the analysis and (e) the basic evaluation principles. Vetere-Arellano et al (2003) demonstrated the variety of methods employed in other European countries, including Bulgaria, Greece and Sweden. As this report will show, these different methods have their advantages and disadvantages, relying as they do on different assumptions.

There is also a difficulty in obtaining reliable historical flood damage estimates on which to base research into flood damage estimation. Downton and Pielke (2005) studied flood

damage estimates in the US, and concluded that there were often significant differences between estimates made by different agencies. These differences were more acute for floods that had occurred in small, localised areas, while these differences were averaged out over larger and more extensive floods. The damage estimates used in this study had been collected using a variety of methods, including working with local officials, insurance agents and newspaper reports, as well as detailed surveys that might take up to five years after an event to complete.
A report by the National Research Council of the US stated that

> *"Somewhat surprisingly, however, the total economic losses that natural disasters cause the nation are not consistently calculated. Following a natural disaster, different agencies and organizations provide damage estimates, but these estimates usually vary widely, cover a range of costs, and change (usually increasing) through time. There is no widely accepted framework or formula for estimating the losses of natural disasters to the nation" (Committee on Assessing the Costs of Natural Disasters, 1999).*

It has been noted that in general, disaster damage data are of poor quality, and collected using a variety of different methods for different purposes (Bouwer et al., 2007). Much of the data is held by disparate organisations such as insurance companies, government agencies and research bodies. A notable database on disasters is the EM-DAT database held at the Centre for Research on the Epidemiology of Disasters (CRED) in Belgium, which has collected data on natural disasters since 1988. The database contains information on the

1.4 The benefits of a common approach to flood impact assessment

It has been argued that a common framework for the assessment of damage, conducted in a consistent manner, including a variety of complementary models, would support policy and decision making (Jonkman et al., 2008a). Such a methodology would reflect the complexity and variety of impacts of flooding upon society. Lack of such an approach may lead to inadequate flood risk management strategies, and therefore limited preparedness and the inability to promote recovery following a flooding event.

The EU Flood Directive requires that EU member states should conduct an assessment of the potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity for major river basins (European Commission, 2007). Tsakiris et al (2009) argue that developing a unified approach is a key technical issue in the implementation of the Directive.

A workshop was hosted at the University of Twente in 2003, as part of the European Commission's NEDIES project, to consider the feasibility of developing a common methodology on the estimation of flood damage (NEDIES, 2003).

For such a unified approach, there would need to be unified vocabulary of concepts. The methodology would however, have to take into consideration the fact that different countries will be vulnerable to different types of flooding, and therefore their prioritisation for certain consequences may be different. For example, the flash floods that affect cities like Barcelona are different to the less responsive and longer lasting flood events that take places on rivers such as the Danube.

1.5 Some problematic areas in flood impact assessment

The field of flood impact or damage assessment is not without its problems. Van der Veen and Logtmeijer (2005) argued that there are five problems in the assessment of flood damage.

a) There is no agreement on the economic points of departure. Financial appraisals are confused with cost-benefit analyses (CBA). In the latter, the usual concept is economic cost, which relates to opportunity costs in welfare economics, whereas a financial appraisal is often used to assess the sum of money that should be recovered for insurance purposes.
b) There is often confusion over temporal and spatial scales. A financial appraisal will usually refer to a single organisation, whereas, conducted properly, a CBA will require wider borders, such as that of a city, a region, or a nation, for example.
c) There is confusion over the definition of direct costs.
d) Stock concepts are confused with flow concepts
e) The boundary between direct and indirect costs is not well defined.

To counter these problems, Messner et al (2007) argued for six key principles of the economic valuation of flood impacts

1. Define the appropriate time and spatial boundaries of the study
2. Apply scarcity prices for the evaluation of market goods
3. Only consider real effects, and ignore inflationary effects
4. Consider that stock and flow are two sides of the same economic coin, to avoid double counting.
5. Apply depreciated values and not full replacement costs
6. Use the net present value of benefits and costs in the context of cost-benefit analyses.

Point 1) is important as it raises the issue of the difference between financial and economic damage or losses. Financial losses refer to the sum of impacts upon individuals or organisations, whereas economic losses take a broader approach and consider losses to a regional or national economy as a whole. Consider an individual business that is flooded. That business will lose trade for a period during the flood and the clean-up process. However, in an ideally functioning economy, that trade will simply be transferred to another business. As such, from the financial perspective there is a loss, but from the economic perspective, there is no loss to the overall economy.

Pielke Jr (2000) describes some of the problems that exist with flood damage assessment. Firstly, there is the problem of contingency. When a flood occurs, some damage caused will be obviously apparent. However, there may be impacts that may be further reaching and longer lasting. The analyst should consider carefully the signal of impacts, which may be difficult to discern. Secondly, there is the problem of attribution, and understanding what precisely has caused some damage. It may be well be that the damage is caused by the flooding itself, but human action and poor planning may lead to some of the impacts. Thirdly, there is the problem of measurement. The cost of repairing a damaged structure may be clear, but the value of a human life is a trickier question. This also raises ethical questions which the analyst will need to consider. Fourthly, there is the problem of aggregation and scale. On an individual level, one organisation may benefit from flooding, as it wins business that would otherwise have gone to a rival. However, on a regional or national scale, the picture may be different. Finally, there is the problem of socio-economic changes, which may lead to the problem of increasing damage over time from floods, from no other reason than the increase in material wealth exposed to a flood hazard.

Overall, when assessing flood impacts, it can be argued that there is no one right way to assess them. Therefore, it is important to make clear the assumptions that were made, the categories that are being considered and the methodologies that are being used to assess the impacts.

1.6 Typology of damage

To understand the damage or losses that floods can cause, it can be useful to categorise them. Within the literature, there is a broad consensus on the categorisation of flood damage.

The first distinction that is commonly made is between tangible and intangible damage. A tangible damage is a damage that is capable of being assessed in monetary terms (Smith and Ward, 1998). A similar but slightly different definition is given by Messner et al (2007), who define a tangible damage as one that can be “easily specified in monetary terms”.

Intangible are those, in contrast, which cannot be so easily specified. Tangible damage includes the cost of physical damage to property, or the loss of business due to interruptions in the economy during and following a flood event. Intangible damage might include the loss of human life, or the increased burden of disease. The distinction between the two is not necessarily clear, as there have been some attempts in the literature to "monetise" intangible losses, through concepts such as Willingness to Pay (WTP), which will be described later in this report. Because of this difficulty, some authors have provided a slightly different definition, by describing tangible damage as that which can be priced whereas intangible damage cannot be priced, and where no market exists (Jonkman et al., 2008a). Parker (2000) makes a subtle distinction in describing intangible losses as those where monetary estimates are considered to be undesirable or unacceptable.

The second common distinction is between direct and indirect damage. Typically, a direct damage is defined as any loss that is caused by the immediate physical contact of flood water with humans, property and the environment. An indirect damage is induced by the direct impacts and may occur – in space or time – outside the flood event. Jonkman et al (2008a) refer to direct losses as occurring within the flooded area, and indirect damage occurring outside of the flooded area. Messner et al (2007) state that direct damage is usually measured as damage stock, whereas an indirect damage relates to interruptions to flows and linkages. Some authors describe an indirect damage as any damage that is simply not caused directly by flooding, i.e. anything that is not a direct damage. From the perspective of this review, the most appropriate definition of a direct damage is one that arises from direct physical contact with the flood water, following the FLOODsite Project, and an indirect damage is any damage that is not direct.

An additional distinction is made by Smith and Ward (1998), who state that both tangible and intangible losses can be subdivided into primary and secondary damage. Primary damage results from the event itself, and secondary damage is described as being at least one causal step removed from the flood. An indirect tangible example might be the disruption of trade in an area, which would be considered as a primary loss, whereas the reduced spending power in the community would be a secondary loss. A direct intangible example might be the loss of life through drowning, which would be a primary loss, whereas the ill-health of flooded people would be a secondary loss. Parker (2000) even discusses the idea of fixed tertiary losses that are even further removed from the flooding incident, but few authors seem to have used this additional category. These additional categories may complicate the question.

Table 2, adapted from Messner et al (2007) and Jonkman et al (2008a) shows the typology of damage with examples of each.

1.7 Study scale

The topic of scale has been introduced in previous sections. Typically, damage or impact studies have been classified into three scale classes; macro, meso, and micro (Messner et al 2007). Macro studies use coarser data, and consider larger areas, which can be transnational. They typically require less data and data that is used is typically aggregated. Meso-scale studies are more detailed studies, and consider regions Finally, micro-scale studies investigate smaller areas, such as municipalities, or sections of municipalities. The data requirements are high, and properties are often considered on an individual basis.

Table 2 - Categories of flood damage, after Messner et al (2007) and Jonkman et al (2008a)

		Measurement	
		Tangible	Intangible
Form of damage	Direct	Physical damage to assets: • Buildings • Contents • Infrastructure • Agricultural land Evacuation and rescue operations Clean up costs	Fatalities and injuries Diseases Historical and cultural losses Loss of ecological and environmental goods Inconvenience
	Indirect	Loss of industrial production Traffic disruption Emergency costs Temporary housing of evacuees	Societal disruption Increased vulnerability of survivors Undermined trust in public authorities Psychological trauma

1.8 Ex-ante and ex-post estimates of flood damage

An important distinction should be made between *ex-ante* and *ex-post* damage estimation. Ex-ante damage estimation refers to damage estimates that are made before the event, and can be considered as 'what-if' analyses. Ex-post damage estimates are made after (or even during) an actual flood event. However, for the purposes of conducting ex-ante analyses, ex-post analyses are required to provide the background to the assumptions made, and to benchmark the studies. Ex-post assessments are an opportunity to improve the techniques used to perform ex-ante estimates.

The estimation of ex-post damage will be considered briefly. Although the main focus of this report is on ex-ante damage estimation, ex-post estimates, as described earlier, are an opportunity to improve ex-ante flood damage estimation techniques.

Ex-post damage estimation involves considering the damage caused by an event after it has occurred, and requires observation and measurements of the impacts, relying on various types of surveys. Several data sources have been suggested for the ex-post estimation of flood damage (ECLAC, 1991);

- Strategic information sources
- Press coverage
- Cartography
- Reconnaissance missions
- Surveys
- Analysis of secondary data
- Long-distance interpersonal communication
- Aerial photography
- Remote sensing images

Most of these categories are relatively self-explanatory. Surveys and questionnaires are particularly useful sources of information, and are usually conducted by government agencies. However, the collection of primary information can be expensive and time-consuming. Secondary information can include insurance data, data on the release of disaster relief funds and small business loans. An example of the use of this is to estimate the total economic damage by applying a ratio to the insured losses. This method is simple, although its accuracy is limited.

2 Tangible damage estimation

It has been noted that a tangible damage is a damage to which a price can be specified, and is typically subdivided into direct and indirect tangible damage. This section will describe the impacts and the methods that can be used to assess them.

2.1 Direct tangible damage

Direct tangible damage refers to the physical damage caused to property and contents in both residential and non-residential (industrial and public sector) sectors by direct contact with flood waters.

The estimation of direct damage involves four steps, according to Messner et al (2007). The first of these is to select an approach, depending on the spatial scale, the objective of the study, the availability of resources, and the availability of pre-existing data. Secondly, the direct, tangible damage categories that are being considered must be determined. Thirdly, the data is collected, and fourthly, the calculations are undertaken. The data required for direct, tangible damage estimation is discussed in the Section 2.2

2.2 Data requirements

The estimation of direct tangible damage can be very data intensive. To estimate the direct tangible damage, there are four main data sources.

Land-use data

Firstly, information is required on the number, location, and type of assets (commercial building, residential properties, etc) that is potentially exposed to flooding. Land-use data can be broadly categorised as being of one of two types; object-oriented data, and aggregated land-use data.

Object-oriented data records individual properties and buildings, whereas aggregated data, by its nature, records aggregated information of more or less homogeneous areas. An example of an object-oriented land use database is the UK's National Property Dataset. It includes information on every single property in the country, using address-point data. An example of an aggregated land-use database is the CORINE Land cover (CLC) database, that was developed by the European Environment Agency. This database covers most European Countries at a scale of 1:100,000, and distinguishes 44 types of land-cover, including 'continuous urban fabric', 'airports' and 'arable land'. A clear benefit of this data is that it covers wide areas, so that transnational studies can be conducted. For example, in one study, CORINE land-cover data was used to estimate the flood risk on the River Rhine.

A more detailed aggregated land-use database is the ATKIS-DLM database developed in Germany. This is at a finer scale than the CLC data, and incorporates over 100 land-use classes at scales ranging from 1:10000 to 1:25000.

In one study, the two land-use data types were used on a study on the River Mulde in Saxony in Germany, to estimate the damage caused by flooding in August 2002 (Wunsch et al., 2009). In this study, the two data sets were used and disaggregated in an attempt to produce finer land-use data sets, using a variety of techniques. The finer ATKIS-DLM data produced more accurate results, and the authors of that study concluded that more accurate disaggregated data would improve flood loss estimation.

Much of the data that is available for flood damage estimation is secondary data, but it is possible to collect primary information on land-use with field surveys, especially for small areas, and when a high level of detail is required.

Determination of the assets at risk

Secondly, it is necessary to collect information on the value-at-risk of the properties. However, before any detail is discussed, it is necessary to introduce the concept of relative and absolute damage functions. *Absolute* damage functions relate the absolute damage caused by the flood to its characteristics (usually depth), whereas the *relative* damage functions relates the damage as a proportion of the value of the property to the flood characteristics.

If relative damage functions are to be used in a study, it is necessary to estimate the total value of the elements at risk in the study area. This is a noticeable disadvantage to this approach. The need to estimate the total value of assets introduces additional uncertainty. However, relative damage functions have the advantage that they are more easily transferable in space and time. If absolute damage functions are to be used in a study, the damage functions will produce absolute damage estates, usually as a function of the property areas, and the value of the elements at risk is integrated in these functions. A key disadvantage of absolute damage functions is that they need regular recalibration as market values change, for example.

Data on the total value of the elements at risk can come from a number of sources. Firstly, aggregated data from official statistics can be used. This approach was used in a study on Cologne in Germany, where data were taken from state data on the gross stock of fixed assets (Grünthal et al., 2006). These data source often cover municipalities, which are not sufficiently accurate for much damage estimation. The data needs to be disaggregated to land-use classes. In the study on Cologne, unit values for a fixed area were developed and applied. Other methods that can be applied include data on standardised construction costs. Insurance data can be applied, and often is in studies conducted by insurers.

Object-oriented assessment of property values can be conducted using either market value data, or standard construction costs. In Australia, construction costs per square metre of different building types were published by the authorities. This method was then applied using ratios to different building types for a study in Queensland (Blong, 2003).

Data for other fixed assets such as contents can be more difficult to obtain. Insurance company data has been used in some studies. However more specialised surveys may be necessary for some studies (Penning-Rowsell et al., 2005b). For cars, Messner et al (2007) quote several methods. Some studies have taken approximate values of news cars and depreciated those values. In some studies, the approximate market value of cars has been taken from specialised consultancies and applied. For infrastructure such as streets and railways, Messner et al (2007) quote the use of official statistics, or methods to obtain data from relevant ministries.

Damage function data

Thirdly, damage functions are necessary. This section will describe the parameters that determine damage and then how damage functions are developed.

Damage influencing characteristics

There are various characteristics of any flooding that influence flood damage, of which some may be more significant than others. These characteristics will be of more importance to some categories of damage than others.

- Area (extent) of flooding;
- Depth of flooding;
- Duration of flooding;
- Velocity of flood water;
- Rate of rise of flood water;
- Time of occurrence;
- Contamination and debris loads of the flood water;
- Whether the water is fresh or salt water;
- Warning time;
- Building age construction, age, materials and condition;
- Previous experience of flooding;
- Preparation before flooding.

Merz et al (2010) distinguished between *impact parameters* and *resistance parameters.* The former include the characteristics of the flood that causes the damage, whereas the latter include those parameters such as the building type that depend upon the resisting object.

In practice, much of the focus on estimating the damage caused by flooding has been on the flooded depth. Gilbert White at the University of Chicago was one of the first researchers to estimate the damage caused by flooding, and introduced the concept of stage-damage curves. Depth-damage or stage-damage curves have been adopted in multiple locations around the world (Smith, 1994), so much so that the technique is commonly used in the field of flood risk management.

In the early work, velocity was also presumed to be an important parameter in flood damage estimation (White, 1945). However given the different types of floods, ranging from slow-rising river floods, to rapid, flash urban flooding, the importance of other parameters may be important in different situations. Some research has considered the importance of other parameters, such as velocity (Kreibich et al., 2009). However, in this study, the influence of velocity was only found to be significant on structural damage to road infrastructure. It was recommended in that study that flow velocity should not be considered. This study was based on the Elbe catchment in Germany, and the conclusions would not necessarily hold for the other case studies in the project. Merz et al (2004) studied nine flood events in Germany from 1978 to 1994, and reported that the variation in flood damage to properties could not be explained by inundation depth alone. This means that there is significant uncertainty when assessing flood damage.

Chang et al (2008) presented a short summary of some of parameters that are thought to influence flood damage and some articles that had studied them. These are presented in Table 3.

Table 3 - Parameters that influence flood damage and related studies (after Chang et al, 2008)

Parameter	**Study**
Building type	McBean et al (1988), Smith (1994)
Floor area	McBean et al (1988)
Family income	McBean et al (1988)
Flood warning system and lead time	Ford (2001), Wind et al (1999)
Previous experience of flooding	Krasovskaia (2001)
Preparation before disaster	Penning-Rowsell et al (2005b)
Duration of flooding	Tortetot et al (1992)
Velocity of flood waters	Smith (1994)

Number of people at risk	Shaw et al (2005b)
Location of household	Shaw et al (2005b)

Development of damage functions and data requirements

There are two main approaches to developing damage functions. The first of these is through the use of real flood damage data, or survey data. This is often referred to as the *empirical* method, and it used to derive functions based on observed flood characteristics such as depth and velocity, related to the observed flood damage. The second approach is referred to as a *synthetic* approach, which is a hypothetical analysis based on land cover and land use patterns, type of objects, information of questionnaire survey, etc. It is akin to a 'what-if' analysis, and asks what damage would be caused if the flood waters were to reach a certain depth within a property. The database of absolute damage functions, developed at the Flood Hazard Research Centre in Middlesex is an example of a synthetically derived database. In Germany, the HOWAS database is a collection of empirical flood damage data.

Merz et al (2010) list some of the advantages and disadvantages of empirical or synthetic damage curves. Some authors have argued that empirical damage curves derived from real data are more accurate than synthetic data (Gissing and Blong, 2004). The variability of the data within a category (such as residential) can be quantified. However, detailed damage data following floods is rate, so that the models may be based on poor quality data. The transferability in time and space of these models can be difficult if the data used to derive the curves was very location or event specific. The paucity of information may require the use of extrapolation techniques, which increases the uncertainty of the data. Synthetic data has the advantage that it provides a higher level of standardisation and therefore allows for a greater comparability of flood damage estimates. The data can be transferred more easily to different geographic areas. However, much effort is required to conduct these what-if analyses to produce databases, and the analyses can be subjective, resulting in uncertain estimates. In contrast to the damage curves based on real data, synthetic curves may not reproduce the variation within a property category.

There are several studies on the development of depth-damage curves in different geographical settings (Nascimento et al., 2007, Penning-Rowsell and Chatterton, 1977). According to Freni et al (2010), the main bottleneck in the estimation of damage curves used to estimate direct, tangible damage is the limited availability of good quality flood damage data.

Damage to infrastructure

In this section, a short mention of the damage to infrastructure should be made. This area is complicated, and perhaps one of the areas that the CORFU project will be able to make significant progress. Infrastructure can include public utilities such as water supply, sewerage and drainage, and telecommunications, as well as transportation facilities, particularly roads and railways. Some studies have included facilities such as hospitals and schools in this category.

In the US, the HAZUS-MH methodology data is used to estimate the damage to point facilities such as hospitals and bridges (Scawthorn et al., 2006).

Dutta et al (2001) proposed a model for use in Japan that could consider damage to water, gas and power supply, as well as sewerage and drainage, telecommunications and transport. However, in practice, only data was available for the assessment of transport losses. Data were sourced from the Japanese Ministry of Transportation.

The Multicoloured Manual in the UK (Penning-Rowsell et al., 2005b) adopts simple models to estimate the damaged caused by traffic interruptions, by incorporating additional travel time costs and additional vehicle operating costs. This method requires data on traffic flows, the particular mix of traffic, resource costs and the value of time from the UK government sources. In addition, a three-step filtering process is proposed to present a short-lit of assets for a detailed economic assessment:

- Enumerate the relevant assets at risk by assessing their sizes and value;
- Assess the total risk for each infrastructure by classifying approximately the likelihood of damage and the scale of the impact as high, medium or low;
- Quantify the damage for high and very high risk assets only.

Damage to agriculture

The focus of the CORFU project is on urban flooding, and therefore agricultural damage will not be particularly relevant. However, a few techniques will briefly be discussed.

In a Japanese case-study, an equation was used to estimate the damage to rice paddies, as a function of a fixed cost per ton of rice multiplied by the tonnage per square kilometre, with a damage function (between 0 and 100%) applied as a function of the inundation depth (Kazama et al., 2009). The empirical data used to estimate the damage curves were taken from Ministry of Land, Infrastructure, Transport and Tourism.

In the UK, agricultural damages are estimated from assessing the impact of flooding on agricultural productivity, defining the impact of flooding upon that productivity, and then expressing the difference in a monetary value (Penning-Rowsell et al., 2005b).

Data on the flood/inundation characteristics

Finally, data are required on the inundation characteristics. This can come from flood risk mapping. Depending on the damage function used, the common characteristics that are required are flood extent, depth, and velocity. This data is usually obtained from hydraulic modelling studies and will not be discussed further.

Development and Application of models

Estimates of the direct tangible damage caused by flooding have been made for a number of years in different geographic settings, and there is not space to discuss the methods that have been applied. A few techniques will be discussed briefly.

In the UK, stage-damage curves were developed by Penning-Rowsell and Chatterton (1977) for a variety of property types. These stage-damage curves have been revised as part of the Multi-coloured Manual (MCM) (or the shorter Multi-coloured Handbook). The stage-damage curves are based on synthetic data, and use absolute damage functions, so there is no need to calculate the total value of assets at risk. As mentioned in an earlier section, the model uses an object-oriented database of property types to define the land-use types.

As well as considering the effect of stage on the flood damage, some account is taken for the flood duration in the MCM. These losses are adjusted depending on whether there are flood warnings, and the estimated damage is adjusted on the basis of whether the lead times are greater than or less than eight hours (Penning-Rowsell et al., 2005b). Figure 2 shows the classic method of estimating the Average Annual Flood Loss by combining the probability of a flood with its discharge, and thus with the flooded depth. This is further combined with the depth-damage curve to produce a relationship between the probability of the flood and the probability of the damage. By integrating this relationship, the average annual loss is calculated.

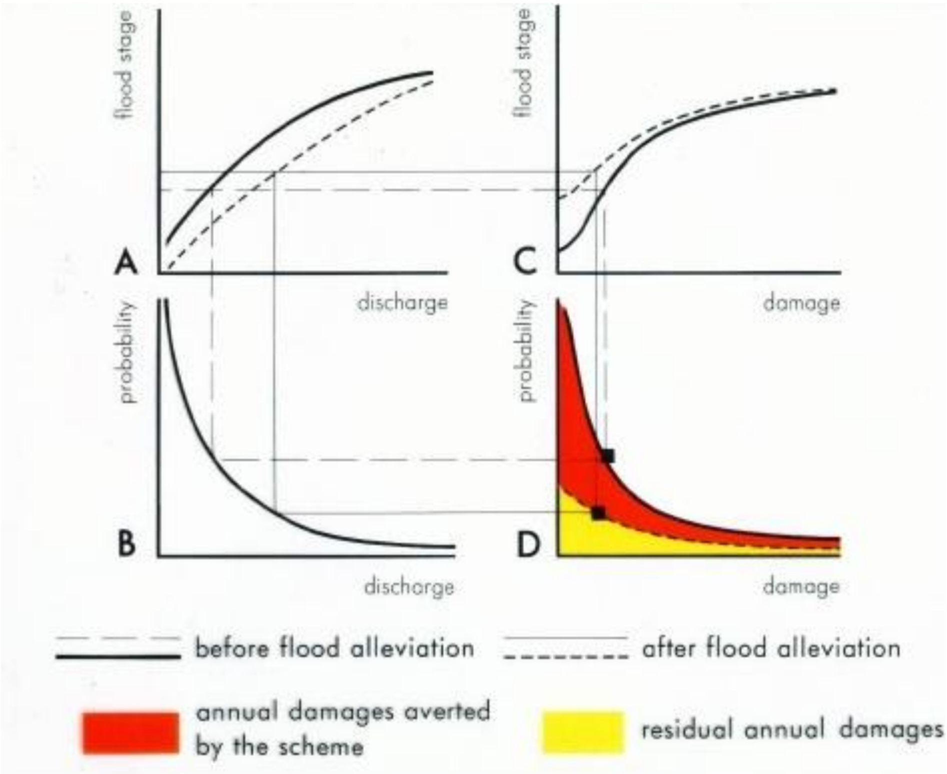

Figure 2 - Calculation of Annual Average Flood Losses (from the Multicoloured Handbook)

Research in the UK on damage to infrastructure is limited, but the MCM states that damage to utilities and communications was equal to 20% of the total economic losses, but there is no greater consideration than this in the methodology at present.

In the Netherlands, the standard method developed nationally uses depth-damage curves in a way similar to that of the UK (Kok et al., 2004). However, in addition to applying these depth-damage curves to residential and commercial properties, curves are applied for infrastructure such as roads and gas and water mains.

Dutta et al (2001) developed a model that attempted to consider urban, rural and infrastructure damage for a catchment in Japan. The ex-ante estimates were compared with a real flooding event from September 1996, but only for the urban damage, for which ex-post damage surveys were available. The ex-ante estimates were found to be between 30-40% higher than the ex-post estimates, although the authors argued that a significant proportion of this was due to the greater simulated flooded extent than observed.

In Germany, two models have been developed by a team in Germany, known as FLEMOps (Flood Loss Estimation MOdel for the private sector) and FLEMOcs (Flood Loss Estimation MOdel for the commercial sector. FLEMOps, despite its name, considers the damage to residential property, and relies on empirically derived relative damage functions. FLEMOps makes use of five variables in determining the relative damage functions; the water depth, building type, building quality (defined as high, medium or low), contamination of the flood water, and the level of private precaution (defined as none, good, or very good). FLEMOcs uses functions that are based on water depth, sector and company size as well as precaution and contamination (Kreibich et al., 2010).

2.3 Indirect tangible damage

As mentioned, indirect tangible damage is caused by disruptions to linkages within the economy. They are more complicated to estimate than direct tangible damage. Cochrane (2004) argued that there are six categories of methods used to model indirect damage caused by flooding.

- Linear programming models which provide guidance as to the optimal allocation of scarce post-event production capacity;
- Post-event economic surveys;
- Econometric models reflecting historical trading patterns (and thus unable to take shocks into account);
- Input-output (I-O) models, as demand driven models that reflect an accounting stance of an economy;
- Computable General Equilibrium (CGE) models, as an extension of input-output models taking into account price and quantity effects;
- Hybrid models (computational algorithms) addressing supply shocks, post event supply constraints and time phased reconstruction.

This section of the review will focus on three techniques that appear frequently in the literature on indirect damage estimation; simple empirical methods (derived from post-even surveys), input-output modelling, and Computable General Equilibrium models. Econometric models will be discussed very briefly. Before this is mentioned, there is a view that the direct damage is indicative of the magnitude and severity of any flooding, and therefore indirect damages do not require the same attention (Kreibich, personal communication).

Simple empirical methods

It is noted by James and Lee (1971) that indirect tangible damage could be estimated as a fixed proportion of the estimated direct tangible damage. They argued that this could be justified for practical reasons, but this is a rather simplistic method. Penning-Rowsell and Parker (1987) studied some cases where the indirect damage, as a percentage of direct losses, ranged from 21% for a study in Bristol, to 93% for a study in Chesil. In the study on St Maartens, indirect damage was simply estimated as a fixed proportion of the direct damage (Vojinovic et al., 2008). Fixed percentages of 15%, 35% and 45% were applied to residential, commercial and industrial properties. The key advantage of such a method is its simplicity.

The key disadvantage is that results from previous events might not be transferable to other events.

Other examples where this approach have been taken is in Australia with the ANUFLOOD model developed by the Queensland Government (Natural Resources and Mines, 2002) where the indirect residential damage is taken as 15% of the direct residential damage, and the indirect commercial damage is taken as 55% of the direct commercial damage. In the Rapid Appraisal Method developed by the Victorian State Government, it is recommended to estimate indirect damage as 30% of the direct damage, although rates such as 20 per cent might be more appropriate for rural regions with relatively low populations while 45 per cent might be more appropriate for flood events affecting urban centres with a substantial tourism sector (Victorian Department of Natural Resources and Environment, 2000).

Within the UK, indirect tangible losses are accounted for in a number of ways. Firstly, on the basis of empirical studies, emergency costs are assumed to be 10.7% of the direct property damage. Indirect losses to transport are estimated using extensive techniques that consider the additional travel time and costs.

In addition, research carried out on Louisiana has shown that indirect losses would increase nonlinearly, when the direct losses exceed $50bn, and therefore the linear assumption would not be valid. More complex methods are needed to assess the indirect damage from flooding, and two of these methods are discussed in the following sections.

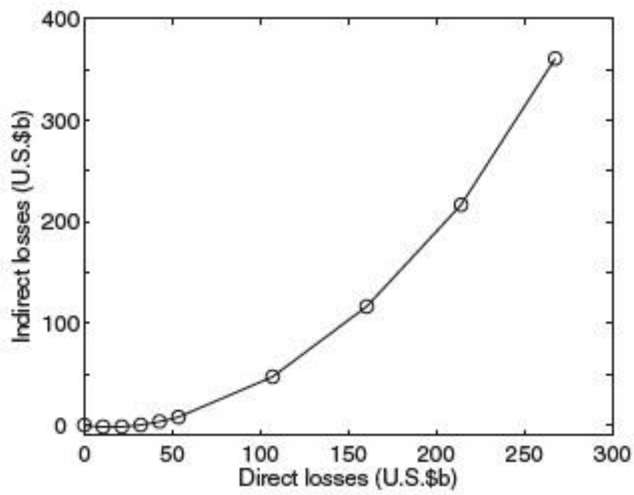

Figure 3 - Non-linearity of indirect losses in study from Louisiana (from Hallegatte et al 2008)

In addition to the simple empirical methods applied above, it is worth noting the methodology applied in the Netherlands where depth-damage curves are applied to estimate indirect flood damage.

Econometric models

Econometric models have been used to assess the impacts of disasters. For example, Ellson et al (1984) used such a model to investigate the potential losses from earthquakes in Charleston in South Carolina in the US. However, there has been limited use of such models in the field of flood risk management.

Input-output (I-O) modelling

Input-output (I-O) modelling is a method used to understand linkages in an economy. I-O modelling has a long history, dating back in some form to the *Tableau Economique* of the eighteenth century. However, in more recent history, work by Wassily Leontief in the 1930s and 1940s led to the development of its modern theory and application (Leontief, 1936), and an overview of the modelling framework is provided by Kowalewski (2009).

The I-O modelling framework rests upon the idea of an economy as a system, where industries receive inputs from other industries, and producing outputs which feed into other industries. I-O models are described as static, linear models of all purchases and sales between sectors of an economy, based on the technical relations of production. Their focus on production interdependencies makes them especially well suited to examining how damage in some sectors can ripple through the economy.

Because of the prominence of input-output modelling throughout economics, in fields such as forecasting, or structural analysis of an economy, I-O tables are commonly produced. For example in the UK, I-O tables are regularly produced, dividing the economy into 123 industries.

The following section describes the technical basis of the static input-output model, however, this section can be overlooked, and more detail can be found in equations can be skipped.

Technical description of model

A distinction needs to be made between intermediate and final demand. If a demand is intermediate, the output from a previous sector would be expected to be processed further. For example, a motor manufacturing firm will need metals or plastics in various forms that will be further processed to produce motor parts. However, the car itself would be a final product, and thus represent a final demand. A very simple example is as follows. Imagine an economy with three sectors; Sector 1, Sector 2, and Sector 3. These could be agriculture, manufacturing, and services. Sector 1 purchases outputs from the three sectors, and these totals are denoted z_{11}, z_{21}, and z_{31}. These purchases can be presented in the following column vector.

$$\begin{bmatrix} z_{11} \\ z_{21} \\ z_{31} \end{bmatrix}$$

If demand vectors from each sectors are placed alongside each other, the intermediate output from each sector can be summed as

$$x_1 = z_{11} + z_{12} + z_{13} \qquad \textbf{(2-1)}$$

These can be combined in the following table.

		Purchasing sector			Total
		1	2	3	
Selling sector	1	z_{11}	z_{12}	z_{13}	$x_1 = \sum_{j=1,..3} z_{1j}$
	2	z_{21}	z_{22}	z_{23}	$x_2 = \sum_{j=1,..3} z_{2j}$
	3	z_{31}	z_{32}	z_{33}	$x_3 = \sum_{j=1,..3} z_{3j}$
	Total	$\sum_{i=1,..3} z_{i1}$	$\sum_{i=1,..3} z_{12}$	$\sum_{i=1,..3} z_{i3}$	$x = \sum_{j=1,...,3}^{i=1,...3} z_{ij}$

The table shown above can be put in a matrix form, but whereas above the table describes the absolute measure of inputs and outputs, coefficients a_{ij} can be used to define the relationship in relative terms, which could remain static while the magnitude of the inputs and outputs changed. The values of the coefficients are described in the following equation.

$$a_{ij} = \frac{z_{ij}}{\sum_{j=1,\ldots,3}^{i=1,\ldots3} z_{ij}} = \frac{z_{ij}}{x_j} \qquad \textbf{(2-2)}$$

The matrix of these coefficients form a matrix **A**, where

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

Having considered the intermediate inputs and outputs, there is a final demand, where the outputs are not expected to be used for further processing. This demand is created by households or government agencies for example. Equation (2-1 is altered so that the output from one sector is equivalent to

$$x_1 = z_{11} + z_{12} + z_{13} + f_1 \qquad \textbf{(2-3)}$$

where $f_1$in this case represents the demand from sector 1. Combining the matrix representation of the coefficients, and including this demand (known as exogeneous),

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{f} \qquad \textbf{(2-4)}$$

where $\boldsymbol{x}$ represents the sector outputs in vector form, and $\boldsymbol{f}$ represents the vector of the final demand. This can rearranged, in the following form

$$(\boldsymbol{1} - \boldsymbol{A})\boldsymbol{x} = \boldsymbol{f} \qquad \textbf{(2-5)}$$

or

$$\boldsymbol{x} = (\boldsymbol{1} - \boldsymbol{A})^{-\boldsymbol{1}}\boldsymbol{f} \qquad \textbf{(2-6)}$$

The matrix $(\boldsymbol{1} - \boldsymbol{A})^{-1}$ is known as the Leontief Inverse, or the multiplier matrix, and describes how changes in final consumption can 'ripple' through the economy, in what is known as a demand-driven model.

The use of I-O models in impact assessment

The Adaptive Regional Input-Output model has been used to assess the indirect impact of flooding on the wider economy following Hurricane Katrina in Louisiana (Hallegatte, 2008). This model was developed to overcome some of the limitations that had existed in previous I-O modelling studies. Firstly, the model takes into account the sector production capacities and both forward and backward propagations with the economy. The basic I-O model had typically only considered backward propagations, given a change in the final demand. Secondly, the model introduced the ability to model adaptive behaviours. For this study, National Input-Output tables were obtained from the US Bureau of Economic Analysis for 15 sectors. These were then adjusted to produce regional input-output tables for the state of Louisiana. Parameters were required that describe overproduction, adaptation and for demand and price responses. These were calibrated with a combination of data from previous events (the Landfall of Hurricane Andrew in 1992, and the Northridge Earthquake of 1994, as well as other events from the 2004 hurricane season), as well as ad-hoc expert choice.

The study assumed that the direct damage was $107bn, and that the total damage was $149bn. The total economic damage was estimated to be 139% of the direct losses, so that the economic amplification ratio was equal to 1.39 (defined as the ratio of the overall production loss due to an event to its direct costs).

This model has also been applied to a case study in Copenhagen (Hallegatte et al., 2011) and in Mumbai in India (Ranger et al., 2011). This latter study will be discussed in more detail in Section 4.5.

This type of input-output model might be referred to by Cochrane (2004) as a hybrid model, as it incorporates the use of input-output tables, but extends it. A further example of a hybrid model is the HAZUS model developed by the US Federal Emergency Management Agency and the National Institute of Building Sciences.

In a study on the Netherlands, bi-regional I-O models were used to assess the vulnerability of a region, and to identify the economic ‘hot-spots’ (Van der Veen and Logtmeijer, 2005).

An input-output model has been developed at the Hamburg Weltwirtshafts Institut (HWWI) and this model is described below. This model is a static, open model, in the sense that time is not explicitly modelled. This model has certain data requirements. Input-output tables are required, as well as data on the number of employees in different sectors in the region. A parameter is required that defines the behaviour of regional imports in the model. The model than can make estimates of the impacts, if there are changes to the sector outputs or the final demand, as a result of a shock.

Up to date, this model has not been used to assess the impact of floods, and so there is significant uncertainty over whether this model is able to produce reliable results.

There are various advantage and disadvantages to using I-O methods. They are relatively easy to manage, and their implementation is less time consuming than some models, such as Computable General Equilibrium models (discussed below). However, according to Kowalewski (2009), they have several shortcomings. They are based on a microeconomic, consistent and closed framework, and so they can only lead to a limited impact analysis. For example, allocation effects of policy measures are not considered. In the standard form, the cyclical connection between income and expenditure as well as the economic links between the markets of the region are neglected. They assume an entirely elastic supply-side in the economy, and in addition, they assume a constant return to scale, and no technological progress

Overall, I-O models are useful tools that enable the analysis of regional economic interdependencies, and they are being used regularly in studies of flood impacts. The construction of a regional I-O table poses one of the biggest challenges. I-O tables may be only found (if at all) for nations, and therefore some form of disaggregation is required, which requires some assumptions.

They are technically inferior to some models (which will be discussed in a subsequent section of the report), especially when it comes to long-run analysis. They typically show a static picture of the economy, and does not take into account price or substitution effects, nor do they include technological progress and economies of scale.

Computational General Equilibrium models

Computable General Equilibrium (CGE) models are based on an equation system that represents the demand for goods by consumers, the supply of goods by producers, and the equilibrium condition that supply equals demand on every market is solved simultaneously. However, the model allows for some modifications like imperfect markets and externalities. A review of CGE models and their application to the field of climate impacts, focusing on damage calculations and adaptation modelling was conducted by Döll (2009).

There are several steps in producing a GCE. Firstly agents (producers, consumers, state) and markets (food, cars) are delineated. The next step is to produce a Social Accounting Matrix which defines the flows between industries, labour, capital and households (Rose, 2004). A market type is assumed, benchmark prices are chosen, and the functional forms of supply and demand are specified. The model is then calibrated, and then policy effects are computed. Sensitivity analyses can be conducted.

Much of the work on using CGE models to assess disaster impacts have been related to earthquakes rather than floods. Rose and Liao (2005) used a CGE model to study on the resilience of the water supply system following an earthquake in Portland.

There are various advantages to using CGE models. They allow for simultaneous reactions to changes in the model. However, the calibration of the model has a poor empirical foundation.

It has been argued that that CGE models are not distinct from I-O analysis, but are rather a "more mature cousin or extension" and retains many of the advantages and overcomes some of their shortcomings (Rose, 2004). A major shortcoming is the assumption that decision-makers make optimal decisions, and that the economy is always in equilibrium. It has also been noted that the CGE model is more suitable for long-term analysis, and can underestimate impacts in the short-term (Rose and Liao, 2005). To date, their application in flood impact studies has been limited.

3 Intangible damage

The estimation of intangible damage is particularly complicated. Intangible damage cannot be easily quantified in monetary terms. It can include health impacts, psychological impacts, as well as damage to the environment. Perhaps the most prominent aspect of intangible damage is related to human health, and this section of the report begins there.

3.1 Health impacts

Floods are known to have a great impact on human health. This section of the report is divided into two sections. The first section will be a broad overview of the epidemiology of the health impacts of flooding. The second section of this report

There are two key articles that were provided much of the source information in this review. Hajat et al (2005) conducted a literature review on the health impacts of flooding in Europe, North America and Australasia. The purpose of the review was to investigate the impacts of flooding in Europe, but these other geographic areas provided additional information on industrialised developed countries.

Ahern et al (2005) performed a literature review on the epidemiological evidence on the global health impacts of flooding. This is useful, in that the study is *global*, in contrast to many of the European or localised studies discussed. The paper presents a table of the key studies that assess the relationship between flooding and health. The paper makes several conclusions. Firstly there is surprisingly little evidence base on the health effects of flooding, particularly on morbidity, and also on public health interventions. The risks are understood, but there is significant uncertainty. The risks to life are generally clear, but longer term impacts, and especially mental health impacts are often underestimated. These and location-specific infectious diseases require further study.

There are two principle types of health impacts from flooding (Hajat et al., 2005);

- Physical health effects sustained during the flood event itself or during the clean-up process, or from knock-on effects brought about by damage to major infrastructure including displacement of populations. These include injuries and the loss of life, as well as diseases linked to the flooding;
- Mental health effects, which occur as a direct consequence of the experience of being flooded, or indirectly during the restoration process, or by people proximate to the flooding.

Again, as with the tangible damage or impacts, a distinction can be made between direct and indirect health impacts. The loss of life caused by drowning would be a direct health impact, whereas the loss of life caused by an outbreak of disease following disruption to the sanitation systems might be seen as an indirect health impact.

Uscher-Pines (2007) argues for a third category, (the disaster-triggered impacts) to clarify what is meant by indirect health impacts. An indirect impact would be one which occurs within the first two weeks after a flood, in the "acute excitement and response phase". This might include the fatal injuries caused during the clean-up, or pulmonary embolisms as a result of poor shelter. The disaster-triggered deaths would then be those that occur from two weeks to a year after the event, assuming that the mortality levels would settle down to the pre-disaster levels during this period. The main objective of this scheme is to consider the long-term consequences of natural disasters over a longer period than is normally considered, i.e. those deaths that were it not for the particular disaster, would not have occurred.

Table 4 and Table 5, summarise the direct and indirect causes and implications of flooding on human health.

Table 4 - Direct health impacts of flooding (taken from WHO (2002))

Causes	Health implications
Stream flow velocity; topographic land features; absence of warning; rapid speed of flood onset; deep floodwaters; landslides; risk behaviour; fast flowing waters carrying boulders and fallen trees	Drowning Injuries
Contact with water	Respiratory diseases; shock; hypothermia; cardiac arrest
Contact with polluted waters	Wound infections; dermatitis; conjunctivitis; gastrointestinal illnesses; ear, nose and throat infections; possible serious waterborne diseases
Increase of physical and emotional stress	Increase of susceptibility to psychosocial disturbances and cardiovascular incidents

Table 5 - Indirect health impacts of flooding (taken from WHO (2002))

Causes	Health implications
Damage to water supply systems; sewage and sewage disposal damage; Insufficient supply of drinking water; Insufficient water supply for washing	Possible waterborne infections (enterogenic E. coli, Shigella, hepatitis A, leptospirosis, giardiasis, campylobacteriosis); dermatitis and conjunctivitis
Disruption of transport systems	Food shortage; disruption of emergency response
Underground pipe disruption; dislodgment of storage tanks; overflow of toxic-waste sites; release of chemicals; disrupture of gasoline storage tanks may lead to fires	Potential acute or chronic effects of chemical pollution
Standing waters; heavy rainfalls; expanded range of vector habitats	Vector borne diseases
Rodent migration	Possible diseases caused by rodents
Disruption of social networks; loss of property, jobs and family members and friends	Possible psychosocial disturbances
Clean-up activities following floods	Electrocutions; injuries; lacerations; skin punctures
Destruction of primary food products	Food shortage
Damage to health services; disruption of "normal" health service activities	Decrease of "normal" health care services, insufficient access to medical care

Physical health impacts of flooding

Perhaps the most immediately obvious intangible damage that occurs as a result of flooding is the risk of injury, or even loss of life. Two well known examples are cited here. Hurricane Katrina, which struck Louisiana in August 2005 is estimated to have killed over 1000 people when the flood dykes were breached. To give another example, in the Campania region of Italy, approximately 160 people were killed in a flood that occurred in May 1998 (Lastoria et al., 2006).

Broadly speaking, the loss of life and injuries caused by flooding are a function of two things;

- The characteristics of the flood;
- The characteristics of the population;

The characteristics of the flood are those such as water depth, rate of rise, flood velocity and the flooded area. The characteristics of the population include the population size, and their vulnerability (e.g. is the population elderly?).

Jonkman (2008b) conducted a literature review on the methods used to estimate the loss of life due to flooding, with a particular emphasis on coastal flooding. In that study several mortality functions were quoted. For example, one study considered the mortality from typhoons in Japan. Two events were considered (Isewan Typhoon in 1959, and Typhoon Jane in 1950) and mortality functions were developed, as a function of the flooded depth, where mortality the number of deaths for a standard size of population. In Isewan Typhoon (or Typhoon Vera), there were 5238 fatalities, compared to 539 fatalities for Typhoon Jane. The mortality for a depth of 1m was 30 times greater for the Typhoon Vera, and so it is believed that other factors must have played a role. Similar empirical relationships had been developed for coastal flooding in the US (Boyd et al., 2005).

The 1953 coastal flooding of the Netherlands led to the death of approximately 1,800 people. Because of its devastating loss of life, the event has been intensively studied, and several researchers have developed explanatory models of the causes of the loss of life. Jonkman et al (2008b) quoted methods that estimated the loss of life through factors such as the flood depth, the flow velocity, whether there was warning, the rate of rise and the likelihood of collapsed buildings.

Zhai et al (2006) conducted a study in coastal regions of Japan, which related the flood fatality functions to the number of inundated houses, with empirically derived parameters.

Penning-Rowsell et al (2005a) also proposed a methodology that was developed as part of an Environment Agency study in England and Wales. Performing ex-post analyses, there is good knowledge of the number of deaths caused by flooding events in the UK and the USA. A DEFRA study (DEFRA/EA, 2006) has been developed that proposed a hazard formula for assessing risks to people, as a function of depth, velocity and a debris factor, as well as area and people vulnerability, developed with flooding from rivers, and estuaries and the sea in mind.

The methodology was developed, based on the idea that the risk to people’s life is a function of three factors.

- Flood hazard
- Area vulnerability
- People vulnerability

A Flood Hazard function is derived that is function of the expected flow velocity, the flooded depth, and a debris factor, which takes into account the probability of debris, and whether it will lead to greater hazard.

The area vulnerability score is proposed that ranges from 3 to 9, with a score of 1 to 3 given for each of three factors.

- Flood warning (1 point for an effective tried and tested scheme, whereas 3 represents no scheme)
- Speed of onset (1 point for a time that is measured in hours, and 3 points for a speed that would be measured in minutes)
- Nature of area (1 point representing multi-storey apartments, and 3 points representing bungalows and mobile homes).

Finally, a human vulnerability factor is then applied, which rates whether the population is particularly aged, or whether there is a high proportion of sick and disabled people. These factors are combined to provide an estimate of the likely deaths and injuries during a flood event.

Jonkman (2008b) begins his review by pointing out some of the event characteristics that led to the greatest loss of life.

- The flood tends to occur unexpectedly without substantial warning. Warning that allows for evacuation or time to find shelter, conversely reduces the risk of mortality;
- The possibility for shelter is very important in reducing mortality;
- The collapse of buildings used for shelter is an important determinant;
- Water depth is an important parameter;
- The combination of high water depths and rapid rise increases the risk to life;
- High flow velocities reduce the stability of people and buildings during flooding events, and increase the risk of death;
- The elderly and children are typically more vulnerable to flooding.

A new approach then proposed takes into account three general steps

- Analysis of flood characteristics, such as water depth, rise rate and flow velocity
- Estimation of the number of people exposed
- Assessment of the mortality amongst those exposed to the flood.

Figure 1 below shows the general approach to the loss of life model

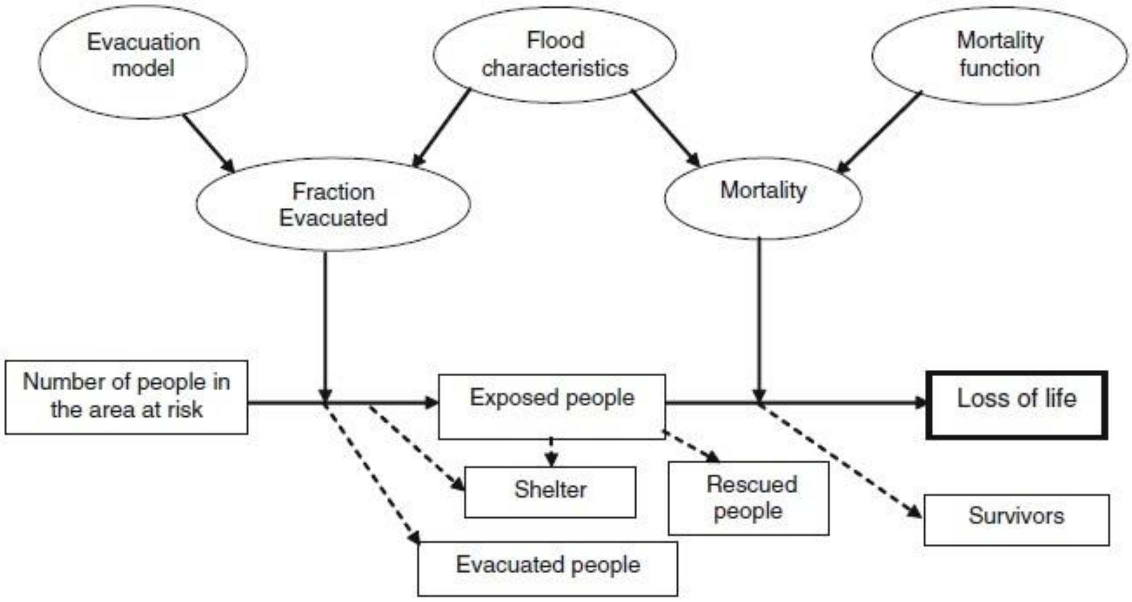

Figure 4 - General approach for the estimation of loss of life due to flooding (from Jonkman et al (2008a))

The EU Project FLOODsite extended the work of the Environment Agency's Risk to Life project and developed a methodology to map the risk of the loss of life from flooding (Priest, 2007).

Diseases

Flooding is known to be linked to the outbreak of diseases (Ahern et al., 2005). These diseases range from bacterial outbreaks such as leptospirosis and diarrhoea through to vector-borne diseases such as Malaria. Kay and Falconer (2008) have noted the growing international awareness of health risks associated with water, particularly in developing countries, and they noted that "more than half the world's hospital beds are filled by people with water-related diseases".

Ahern et al (2005) distinguished between faecal-oral diseases, vector-borne diseases and rodent-borne diseases. Faecal-oral diseases include those such as gastro-enteritis, rotavirus, diarrhoea and typhoid. All of these have been found to be linked to flooding, and are more prominent in developing countries.

There are several papers that specifically consider the impact of flooding on human health in Dhaka, Bangladesh (Harris et al., 2008). These papers have looked at the diarroeal epidemics that are linked with the flooding events. In one study, Schwartz et al (2006) noted that patients showing diarrhoea during flood periods were older, more dehydrated, and of lower socio-economic status than the patients in non-flood periods.

Vector-borne diseases are those such as malaria, which are transmitted by insects or any living carrier, such as mosquitoes. The relationship between vector-borne diseases and flooded is complex, where for example, flood waters can reduce the risk of malaria by washing away breeding sites. However, floods can lead to the collection of stagnant water, which provide breeding sites for mosquitoes. The floods in Mozambique of 2000 increased the risk of malaria by a factor of 1.5 to 2 (Kondo et al., 2002). One study showed the behaviour of malaria following flooding in Gujurat, India (Pawar et al., 2008). Other vector borne diseases include Dengue fever. A study following the 2005 flooding of Mumbai showed an increase in the incidence of Dengue Fever among children, as well as an increase in leptospirosis, a rodent borne disease (Zaki and Shanbag, 2010).

Leptospirosis is a commonly studied rodent-borne disease that is linked to flooding (Watson et al., 2007). Leptospirosis (or Weil's Disease) is a bacterial disease, caused by spiroechetes of the genus *Leptospirosa*. It is known that heavy rainfall and flooding increase the risk of leptospirosis by bringing bacteria and their animal hosts (such as rats) into contact with humans. Outbreaks following flooding have been noted in such geographically diverse areas as the Czech Republic, India, Brazil and Indonesia. Table 6 lists some incidences of outbreaks of leptospirosis linked with flooding. Leptospirosis is known to more prevalent in developing countries, but outbreaks have occurred in the USA and Japan (Lau et al., 2010).

Lau et al (2010) conducted a review on the relationship between outbreaks of the disease with flooding, and questioned whether the burden of the disease could be increased due to climate change and increased urbanisation. The areas most at risk from the increased burden would be those where multiple risk factors might coexist, such as increased flood risk, rising temperatures, overcrowding, poor sanitation, poor health care, poverty and an abundance of rats or other animal reservoirs. These factors often co-exist in urban slums, in cities such as Mumbai and Dhaka, and therefore may be at increased risk in the future. It was also argued in that review that spatiotemporal modelling using Geographical Information Systems could potentially be useful to understand the disease burden.

Kay et al (2007) argued that there is a scientific vacuum in the area of terrestrial hydraulic and catchment modelling of bacterial and other faecal pathogen concentrations. Work is currently being conducted at the Danish Hydraulics Institute, as part of a research project, to improve the modelling in urban catchments of microbial loads (Mark, 2010).

Kay and Falconer (2008) have argued for emergence of a new research agenda called *hydro-epidemiology*, which could be explored as part of the CORFU project.

Psychological impacts of flooding

Mental health impacts should be separated from other health impacts, mainly because the knowledge of these impacts is less than for those other areas, and their relationship with flooding is particularly complex. According to (Hajat et al., 2005) the studies are hampered by the varying definitions of outcomes used. Some are focused on post-traumatic stress disorder (PTSD) as a specific entity, while some use standard instruments such as the General Health Questionnaire, which does not give a specific diagnosis.

Table 6 - Incidence of leptospirosis outbreaks linked to flooding (from Lau et al, 2010)

Country, Region	Year	Flooding Event
Mumbai, India	2005	944mm in 24hr resulted in an eight fold rise in the number of cases compared with the previous 4 years.
Laos	2006	Flooding associated with seropositivity for the disease with an odds ratio of 2.12
Puerto Rico	1996	Leptospirosis diagnosed in 6% of non-dengue febrile illnesses pre-hurricane versus 24% of non-dengue febrile illnesses post-hurricane
Kerala, India	2002	Peak in leptospirosis observed 7-10 days after heavy rainfall
Indonesia	2002	Outbreak following massive flooding in Jakarta in Janaury 2002
Italy	2002	Devastating flooding in suburban area resulted in 6.8% seroconversion (development of specific antibodies in blood serum) rate for leptospirosis
Nicaragua	1995	Epidemic of leptospiros following sever rainfall and flooding. Greater than 5000mm of rainfall, where annual average of 1300mm
New Caledonia	2008	High rainfall and flooding associated with La Nina. Epidemic of leptospirosis in 138 people, with incidence rate of 500 per 100,000 in Bourail region.

Post-traumatic stress disorder (PTSD) is defined as “arising after a stressful event of an exceptionally threatening or catastrophic nature and is characterised by intrusive memories, avoidance of circumstances associated with the stressor, sleep disturbances, irritability and anger, lack of concentration and excessive vigilance". It is the most commonly studied and probably the most frequent psychological disorder that occurs after traumatic events and natural disasters. A review of its epidemiology was conducted by Galea et al (2005), using studies from 1980 to 2003. The prevalence of PTSD related to natural disasters was found to range between 5 to 60%, with most of the studies showing numbers towards the lower end of this range. The review demonstrated that the biggest risk factor for developing PTSD during a natural disaster was the extent of the exposure, and therefore injured people, for example, are significantly more likely to develop PTSD. Approximate figures from the review suggested that the prevalence among direct victims of disasters is at 30-40%, 10-20% among rescue workers, and 5-10% in the general population. Other risk factors included gender (women are shown to be more likely to suffer from PTSD), pre-existing psychological disorders and low social support.

More specifically related to flooding, studies quoted by Ahern et al (2005) have shown a prevalence of 22% of PTSD during the 1993 Midwest floods, or 19% among flood victims of the 1997 Central Valley Floods in California. However, studies are limited in some cases by the fact that some of the results from these studies are self-reported. A study in India (Telles et al., 2009), showed older people were more prone to PTSD than the younger population.

A meta-analysis of the risk-factors that are linked to PTSD caused by traumatic events was conducted by Brewin et al (2000). The analysis showed similar factors were linked with a higher prevalence of PTSD, including age, education, previous trauma and psychiatric history, as well as the severity of the trauma and the lack of social support.

Huang et al (2010) studied post-traumatic stress disorder among people in flood-hit areas in the Hunan Province in China, and developed what they claimed to be the first predictive model of PTSD using a risk-score model among flood victims in a large population. Nearly 30,000 individuals were selected for the study, of whom 25,500 participated (87% response rate). 70% of the sample was used to develop the predictive model, with the remaining 30% used to test the model's predictive skill. The prediction model used 7 variables:

- Age
- Gender
- Education level
- Type of flood (soaked flood (drainage related), collapsed embankment (river) flood, or flash flood).
- Severity of flood
- Flood experience
- Mental status before flood

These variables were used to develop a risk score, and individuals with a score higher than a certain threshold were then diagnosed as potential sufferers. The model has a positive predictive value of 23%, and a negative predictive value of 98% (for a threshold of 67.5 although this was a function of the threshold. As the threshold increased, the Positive Predictive Value increased, while the Negative Predictive Value[1] decreased), showing that the model had some predictive value. There were several limitations of the study. Firstly, because the survey was taken after the flooding, recall and information bias could be present. Secondly, the sufferers of PTSD were not diagnosed by trained psychologists, and so their diagnosis might not have been accurate.

Verger et al (2003) developed indicators for the cumulative exposure to a flooding incident in south-eastern France in 1992, and assessed its association with the incidences of PTSD five years later. The researchers found a strong exposure-effect relationship, and argued that such studies could be used to develop a greater predictive understanding of the impact of flooding on mental health.

Other psychological disorders are known to affect people affected by flooding include anxiety and depression. Most of the studies on the effects of these disorders are from wealthier countries, although a study quoted by Ahern et al (2005) focused on Bangladesh. Among 162 children aged 2 to 9 years old, 16 children were found to be very aggressive post-flood, in contrast to no reports before the flood. The prevalence of bed-wetting increased from 16% to 40%.

Ahern et al (2005) conclude that the mental health impacts of flooding, especially the long-term impacts, and their principal causes, have been inadequately researched, even in high-income settings. A study in Lewes, UK, following the floods of 1998, demonstrated a four-fold increase in psychological distress among flood-affected people (Reacher et al., 2004). An unquantified increase in visits to doctors with mental health problems was noted in Nimes, following the floods of 1988 (Duclos et al., 1991).

The vulnerability of the population to these health impacts is clearly important and is briefly discussed in the following section.

Social Vulnerability

There is a discussion in the literature over the precise meaning of vulnerability in the context of flooding. In addition, there is the need to distinguish between ‘vulnerability’ and ‘deprivation’. To give an example, the elderly may be vulnerable to flooding, but not materially deprived.

[1] The Positive Predictive Value (PPV) is a measure of the ability of the method or technique to correctly identify true. The Negative Predictive Value (NPV) is a measure of the ability to measure true negatives

The Social Flood Vulnerability Index (SFVI) was developed for the UK as a measure of the coping capacity of the flood affected population, and includes indicators such as the number of elderly people, lone parents as well as people with pre-existing health and financial deprivation problems (Tapsell et al., 2002). This approach has been used on several case studies in the UK, in Salford and in Maidenhead. However, this work is limited to the UK, and the factors that give rise to social vulnerability may be significantly different in the other case study cities considered in this project.

A similar index was proposed by Lekuthai and Vongvisesomjai (2001) who introduced a "Anxiety-Productivity and Income Interrelationship Approach", or API approach. However, this approach attempts to quantify intangible damage in monetary terms. It does this by relating flood depth to anxiety, anxiety to productivity, and productivity to income. Finally, it is able to produce a relationship between flood depth and loss of income. The equations used to estimate these relationships are based on survey data. Although this study was conducted in Thailand, the techniques have been applied to St Maartens in the Dutch Antilles (Vojinovic et al., 2008).

3.2 Quantification of health impacts

Although it is evident from these studies that the health impacts of flooding are significant, it would be useful to be able to quantify the health impacts of flooding. This section of the report considers how the health impacts of flooding can be best be quantified.

There are three techniques that can be applied to quantify the health impacts of flooding.

- Firstly, direct measurements of the changes to the health of the population could be made. For example, the number of fatalities, injuries and numbers of the infections that either have occurred in an ex-post evaluation, or could be expected, in an ex-ante evaluation.
- Secondly, indirect measurements of the health impacts on the population could be made. Two common measurements that will be discussed are the Quality Adjusted Life Year (QALY) and the Disability Adjusted Life Year (DALY). These two measures attempt to make an estimate of the change in health levels of summed over the life (or the expected remaining life) of a person, which can then be aggregated over the population.
- Thirdly, and most controversially, the health impacts could be quantified in monetary terms. However, there may be ethical concerns with these methods, where some may feel uncomfortable placing a monetary value, for example, on a human life.

Direct measures of health impacts

There are a number of simple measurements that can be made directly, to make an ex-post evaluation of the health impacts of flooding. Public bodies typically make records of the number of fatalities and injuries during and in the aftermath of a flood event. Records are also typically made of the outbreaks of diseases that occur. Some examples have been described in Sections 0 to 0 above.

For the ex-ante estimation of the quantification of the physical outputs of diseases there are several approaches that can be considered. There are two broad methods to produce ex-ante estimates. The first of these methods is to use data from previous estimates, or to extrapolate from them. In one study, for example, Fewtrell and Kay (2008) attempted to estimate the health impacts from flooding in the UK. To do so, they used statistics from earlier studies to estimate the baseline incidence and the relative risk of some certain health-related problems linked to flooding. For example, following work by Reacher et al (2004), psychological distress had a baseline incidence of 15.5%, flooding produced a Relative Risk of 4.1, leading to an incidence rate of 63.6%. The results are presented in the following table.

Table 7 - Baseline incidence rates and Relative Risks of health impacts (adapted from Fewtrell and Kay, 2008)

Disease	Baseline incidence	Relative Risk
Asthma	0.076	3.1
Gastroenteritis illness	0.02	2.36
Earache	0.001	2.2
Psychological distress	0.155	4.1

A second approach is to undertake some modelling studies to estimate the impact. For example, several studies have developed models that estimate the risk of the loss of life or injury, depending upon such parameters as the flow depth and velocity, as well as the characteristics of the population. Some of the methods that have been employed were described in Section 0.

QALYs and DALYs

The second approach is to use some indirect measurement of the health impact of flooding on the affected population. Two metrics, used to measure the loss of perfect health, appear frequently in the literature on health impact assessments. These are the Quality Adjusted Life Years (QALY) and the Disability Adjusted Life Year (DALY).

The Quality Adjusted Life Year (QALY) was developed in the 1960s by economists, operations researchers, and psychologists, primarily for use in cost-effectiveness analysis (Gold et al., 2002). Its function is to combine the number of years of life that are added to an individual by a certain medical intervention, with a measure of the quality of those years (using a scale where 1 is a year of perfect health, decreasing to zero as the health deteriorates).

A related, but more relevant metric used in health impact assessment is the Disability Adjusted Life Year (DALY). In a sense, it is the obverse of a QALY, as its aim is to quantify the health that is lost, by either some disease or disaster. The DALY has been adopted by the World Health Organisation as a metric to assess the burden of diseases, injuries and risk factors on human populations (Murray and Acharya, 1997). The DALY is described as combining the "time lived with a disability and the time lost due to premature mortality". Years lost from premature mortality are estimated with respect to a standard expectation of life at each age. Years lived with disability are translated into an equivalent time loss by using a set of weights which reflect reduction in functional capacity, with higher weights corresponding to a greater reduction (Anand and Hanson, 1997). DALYs have been applied in studies such as Pruss et al (2002), which estimated the disease burden from water, sanitation, and hygiene to be 5.7% of the total disease burden (in DALYs) occurring worldwide, taking into account such diseases as diarroea and schistosomiasis.

The DALY is not a universally accepted measure, and there has been criticism of some of the assumptions used in its formulation. For example, Anand and Hanson (1997) argued that

- There is no account taken for other important socio-economic factors, such as wealth, which does affect the ‘burden’ felt by an individual.
- The weighted age-function, which values one year of a mid-age person rather than that of a child or an older person
- Discounting factors are used so that one person’s life may be worth more than five people in fifty years time.

Some of these criticisms have been rebutted by Murray and Acharya (1997), who state that functions within the DALY framework can be adjusted to recalibrate the value placed on different lives at different stages. However, it remains the case the DALY is not universally accepted within the health assessment field (Nygaard, 2000).

The DALY has been used within the UK to assess the health risk from flooding (Fewtrell et al., 2008). This study considered the health impacts of pluvial flooding in the UK. This study categorised health impacts into three groups:

- Mortality and injuries
- Infection; and
- Mental health effects.

The study demonstrated that, in the UK case study, the greatest impacts on human health were related to mental health problems, something also noted in the review by Ahern et al (2005). However, this may not be the case in developing countries where the risk of disease outbreak is known to be greater. This framework of using DALYs to estimate the burden of disease from flooding could be extended within the CORFU project, and applied to the various case studies.

3.3 Monetisation of intangible impacts

Much of the focus on intangible damage has been on health impacts, although there are other intangible impacts such as environmental or recreational impacts which fall under the category of intangible damage. They are not easily monetised, there have been attempts in the literature to place a price on them. Firstly this report will focus on human health impacts

Placing a value on human life and health

Mishan (1971), discussed the range of methods that can be used to incorporate the value of life into cost-benefit analyses:

1. Discounting to the present the person's future earnings (known as a gross output approach);
2. Discounting to the present the loss of money accrued to *others only* as a result of a person's death (known as a net output approach). This can be thought of as a more refined version of the first approach;
3. Taking a social approach, and assess the number of additional or reduced deaths due to investment decisions;
4. The insurance principle, where it is considered how much a person is willing to pay in insurance premiums combined with the probability of his or her death.

These approaches have been developed further, and methods of assessing the value of human life can be placed into two categories. The first of these categories is known as a human capital approach, in which it explores the income in some way that is lost following a mortality. The second approach uses concepts known as the Willingness To Pay (WTP), or the Willingness to Accept (WTA). WTP or WTA can be estimated using either revealed or expressed (or stated) preference surveys.

There are some who criticise of putting a monetary value on a human life (Ackerman and Heinzerling, 2004). They argued that a human life is simply beyond valuation, although that it not to say the value of a human life is infinite.

Human Capital Approach

One approach is to estimate the lost future income (discounted to present), referred to as a gross output method, or to estimate the loss amount of money accrued to other as a result of a person's death (approach 2. above).

In the first approach, the person's income is summed (and discounted over their expected remaining lifetime (had they not died), whereas for the second approach, their income generated minus the expenditure that passes to others is summed. The first method is criticised by some, who argue that the method implicitly relies on the idea that it is an appropriate economic policy to maximise Gross National Product (GNP). However, in its favour, it does readily enable the calculation of the "value" of a life. The second method is deemed more reasonable, in that it considers the economic benefit to society of a life as a whole. However, it can lead to the conclusion that the premature death of someone's life, whose net output was negative, such as a retired or unemployed person, would be a benefit to society. It is also criticised for taking no account of the feelings of the person's decedents.

An ethical problem with this approach is that wealthier people who earn more, are valued more than either the less well off or the retired or ill. This method also ignores the intrinsic value of life.

Willingness to Pay or Willingness to Accept

This second class of methods relies on the idea that a person or persons are willing to pay some amount to reduce the risk of death or injury, or are willing to accept some amount , to face a higher risk of death or injury.

A problem with this model is that they can assume a linearity relation between the value of life, probability of death and the premium that should be paid. For example, assume a man is willing to be paid $100,000 to do a job where the risk of death is 25%, suggesting a value of his life of $400,000. However, it is implausible to suggest he would go to a certain death for $500,000. A further criticism is that the insurance premium is the value one would want to accrue to others on his death (perhaps his family), but does not necessarily state how he values his own life for its own sake. Take the example of a bachelor with no family, he may have no desire to take out insurance, but will value his own life to some degree.

Values from WTP or WTA methods can be derived from Revealed or Express Preference studies. These are described below.

Expressed or stated preference methods

Expressed or stated preference rely the idea of directly asking people how much they would be willing to pay, either in insurance premiums or indirectly for flood defences, for example, to reduce the risk of death or injury. These are often conducted through a methodology called *Contingent Valuation*.

Fischer at al (1989) applied this concept to estimating the value of a human life, and concluded that empirical studies indicated a range for the value-per-statistical-life estimates of $1.6m to $8.5m (in 1986 US Dollars). A study conducted by DEFRA and the Environment Agency in England and Wales, based on a WTP concept, suggested a £200 value per household per year as representing the benefits of a reduced risk of flooding (DEFRA and EA, 2004).

Revealed preference methods

Expressed preference methods are contrasted with *Revealed Preference* techniques, where the one's valuation of their life and health is estimated by observing their decisions in relation to other markets. For example, one might be willing to pay more for a house, if it were identical to another but with reduced flood risk. There have been fewer studies into estimating the value of human life with revealed preference methods. However, they have been used to study the value of other intangible impacts such as environmental losses, and these are briefly discussed in the next section.

Valuing other intangible impacts

As with estimating human life, expressed preference techniques can be used to estimate the value of other intangible impacts such as the loss of environmental or cultural benefits. However, revealed preference techniques have been more widely applied.

In a meta-study, Daniel et al (2009) considered the difference in house prices to assess the value of flood risk. This is known as a *hedonic pricing* method. They concluded that the results were highly variable, but estimated that ncrease in the probability of flood risk of 0.01 in a year is associated to a difference in transaction price of an otherwise similar house of –0.6%. This study does not explicitly estimate the health impacts of flooding however, but rather the value of being flood free. The problem with this kind of estimation is identifying precisely what the risk is that is being estimated.

A further method is the *replacement cost* method. For example, wetlands damaged in a flood can be rehabilitated, but there is a cost associated with this rehabilitation. However, this method is unlikely to uncover the true cost of the method.

The *production cost* method can investigate the economic benefit derived from a resource, such as through tourism, or perhaps through the market price of fish that might be caught in a lake or river. A related method is the *substitute* or *proxy* method uses the value of some substitute good that is closely linked with the damaged resource.

Finally, a method that has been applied to valuing the benefit derived from some environmental benefit is the travel cost approach. Through calculating the amount that people are prepared to spend to travel to the environmental amenity, the benefit of the amenity can be estimated.

Other techniques of incorporating intangible damage in an impact assessment

If, as some authors have suggested, it is not feasible to adequately monetise the losses to human health, it may be necessary to adopt a multi-criteria decision scheme. The different criteria (e.g. monetary losses, health losses) can be weighted in importance, using weighting processes such as simple additive, pairwise comparison, simple weighted average, ordered weighted average, spatial ordered weighted average (SOWA) or fuzzy additive weighted processes (Yager, 1988, Makropoulos and Butler, 2006).

4 Work in the case study areas

This section of the report will describe in detail some of the damage estimates that have been conducted in or near to the case study cities. This work has principally been derived from work with our case study partners.

4.1 Barcelona

Barcelona, and the Catalonia region in general, has a long history of being affected by flooding, with records stretching back to the Middle Ages (Barrera et al., 2005). A list of some of these events is presented in Table 8.

Table 8 - Damage estimates from flood events in Barcelona

Date	Max. Intensity (mm/h)	Total Precipitation (mm)	Discharge (m^3/s)	Economic loss (million €)	Deaths
October 1907	-	-	1500 (Martorell)	-	29
October 1940	-	-	2200 (Martorell)	0,7	300
September 1962	110 (1 h)	250	1550 (Martorell)	16	815
September 1971	82 (4 h)	400	1630 (Martorell)	42	19
November 1982	17 (24 h)	556	1600 (Martorell)	270	14
June 2000	100 (1 h)	225	1100 (Castellbell i el Vilar)	65	5

There are three broad approaches to estimating flood impacts in Barcelona.

INUNCAT methodology

The first of these is known as INUNCAT, a Flood Risk Management Plan that describes a methodology to assess the level of flood risk at a municipality level, and was developed by the Catalan Water Agency (ACA). It consists of a methodology to assess the flood hazard (together with River Area Planning PEFCAT (ACA, 2005), which is framed in the European Water Framework Directive (2000/60/CE)) and vulnerability, obtaining a level risk of each Catalan municipality.

In the frame of the INUNCAT plan, the flood hazard is obtained using hydraulic and hydrologic models that allow to determine the flood delimitation areas regarding different return periods (T=50, T=100 and T=500). For each of the cells (1x1 m in the Llobregat basin (south-west of Barcelona)) the flood water depth is given.

The vulnerability to flood events depends on several variables, such as the flood water depth, water velocity, debris concentration and duration of the event.
Depending on the flood risk level of each municipality, the creation of a Municipal Action Program (PAM) is set as compulsory, recommended or not needed. Most of the municipalities (501 out of 946) of Catalonia (including Barcelona), must have a PAM for flood events, as shown in Figure 5.

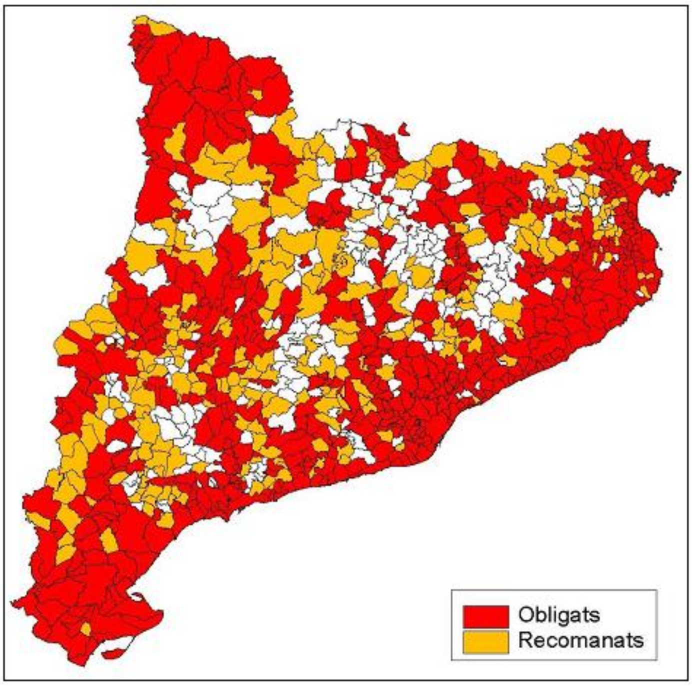

Figure 5 - Map showing municipalities where Action Plans are compulsory (red) and recommende (orange)

The direct tangible costs, are separated in three different categories:

- Loss assessment;
- Population in the affected area;
- The length of road affected

The loss assessment for different land uses are obtained differently. In the case of urban land use, the damages are calculated with damage-depth curves, using the same methodology as in the USA or Great Britain. However, it uses a relative damage function, where the proportion of damage to the property is assessed.

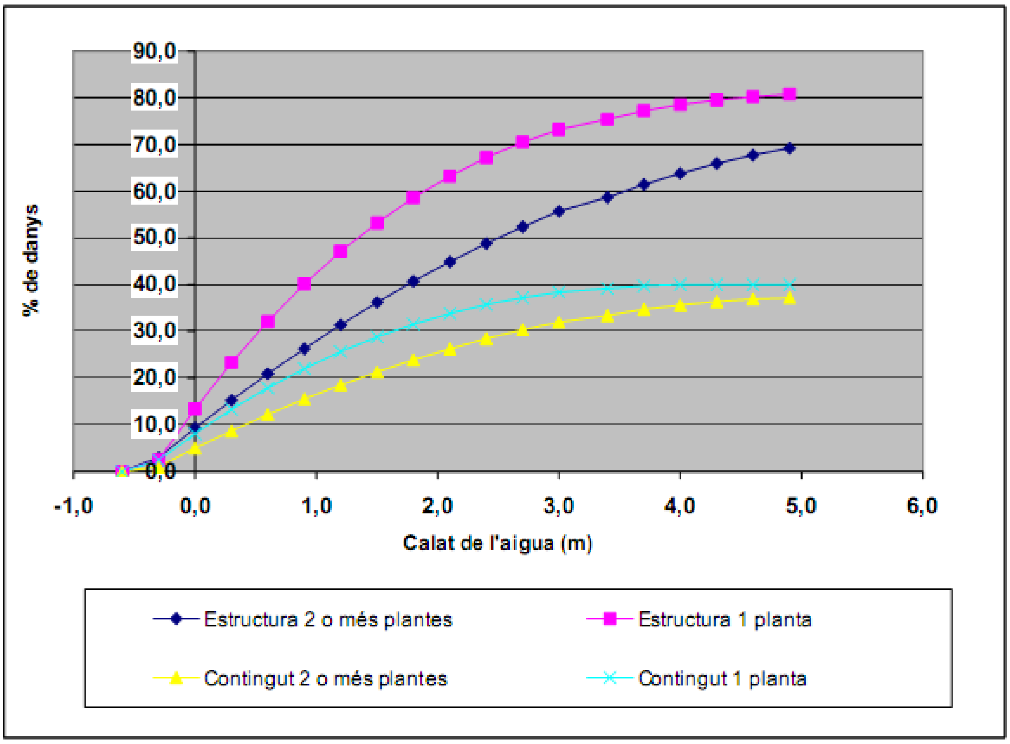

Figure 6 - Damage curves used in INUNCAT plan

Depending on the typology and kind of building studied, different curves are used, as well as different value is given to the structure, as it can be seen in the next table. In addition, the damages of the goods contained in the building are considered as half of the monetary value of the structure.

Table 9 - Monetary value given to the structures of different kinds of buildings

Typology	Cost (€/m^2)
Apartments	606,79
Average income home	653,01
Two-story house	529,46

For industrial and commercial land use categories, the same methodology is used, but a single value has been established: 346.5 €/m^2 and the coefficient for the goods contained in the building is 1.07.

In camp sites, these two values are 117€/m^2 and 1.07 and, for rural areas, the value given depends on the land cover:

Table 10 - Monetary value given to the different kinds of land cover

Type of crops	Dry	Irrigated
Cerals (€/Ha)	356,9	553,9
Fruit trees (€/Ha)	2168,4	4713,3
Vineyard (€/Ha)	2253,2	2880,9

The measurement of the population that lives in affected areas is done by using, for each municipality, data from the last population census, together with the flood hazard curves for different return periods.

According to the affected roads, a threshold of 0.3m of water depth has been established, and all the km with a higher water depth have been considered as affected.

By doing all this in Barcelona, the potential damage values obtained are as follows:

- Damages: €10.2m
- 21,000 people affected
- 5km of road flooded

In the INUNCAT plan, this qualifies as a high level of risk is detected, and therefore it is required to obtain a Municipal Action Program.

Indirect tangible damages, and intangible damages are not included in the INUNCAT methodology.

SW0801 methodology

The SW0801 project (Medium & long term strategies to manage flooding events in urban and peri-urban areas) is framed in the R+i Alliance funding program, a genuine management tool to target research on water and environment. Leaders in the water sector currently participate in this very active network to shape, finance and manage research programmes.

This project aims to develop a methodology for flood risk assessment in urban and peri-urban areas, focused on different types of floods. Flood risk must be determined in order to obtain the impacts or damages of a given rainfall. This methodology has been tested in the

Barcelona area, in the Raval district, a very impervious area with a several vulnerable elements such as schools, hospitals, and emergency highway or avenues.

In this case study, only human vulnerability was taken into account, considering that goods and properties are uniformly distributed on the analyzed domain and the related potential economic damages should be uniform, too. It is done that way, due to the type of analyzed flooding, characterized by low flow depths and high flow velocity, making possible to classify the infrastructures as low vulnerable respect to the surcharged sewer floods and urban flash floods generated by the exceeding runoff not captured by the sewer network.

However, vulnerability is high in terms of people exposition due to the high demographic density and the presence of several buildings that can suppose a high concentration of people.

For all these reasons the vulnerability level of the analyzed domain for the current scenario was represented through the elaboration of a specific map showing the following vulnerable elements:

- Cultural and education buildings
- Hospital and sanitary buildings
- Municipal markets
- Retirement homes
- Main roads
- Underground roadways and tunnels

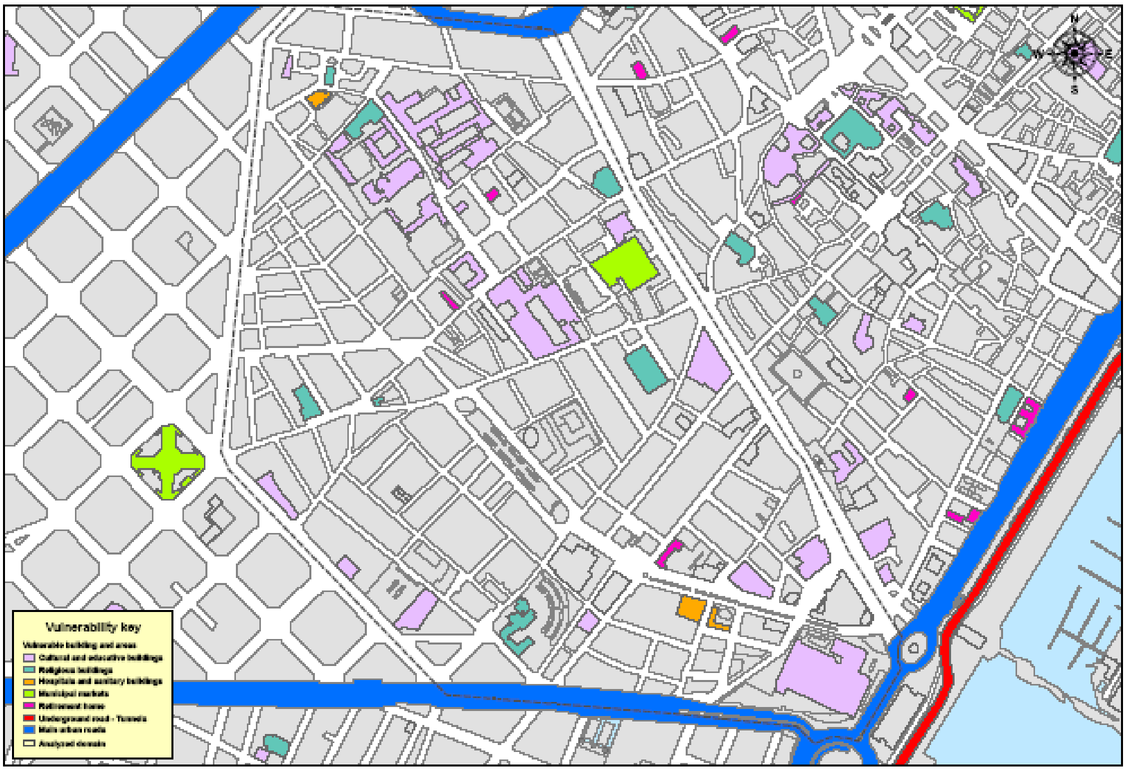

Figure 7 - Vulnerable elements in the analyzed domain for the current scenario

In order to evaluate the vulnerability of the analyzed domain, it is necessary to take into account the population component, considering the following people constraints:

- Density of people with critical age (less than 15 years old or more than 65 years old);
- Density of foreign people;
- General population density.

Thresholds are set to define low, medium and high vulnerability, as in the following tables.

Table 11 - Thresholds of vulnerability

Category	Vulnerability		
	Low threshold	**Medium thresholds**	**High thresholds**
People aged < 14 or > 65	< 33%	33% < X ≤ 50%	> 50%
Density of foreign nationals	< 33%	33% < X ≤ 50%	> 50%
Population density	≤ 1273 / km^2	1,273<X≤16,000 / km^2	> 16000 / km^2

This thresholds were deduced from the medium density of Barcelona (16000 inhabitants) and the definition of the National Institute of Statistics of urban area defined as a group of minimum 10 houses in a distance less than 200 m (equivalent to 1273 inhabitants per km^2).

Then values of 1, 2 and 3 were given, respectively to low, medium and high vulnerability, and for the assessment of the final human vulnerability, the maximum values were selected for each sub-district.

With all this, a final map of vulnerability was obtained, where in this particular case, almost all the region is rated with a high vulnerability value (3), as it can be seen in the next figure.

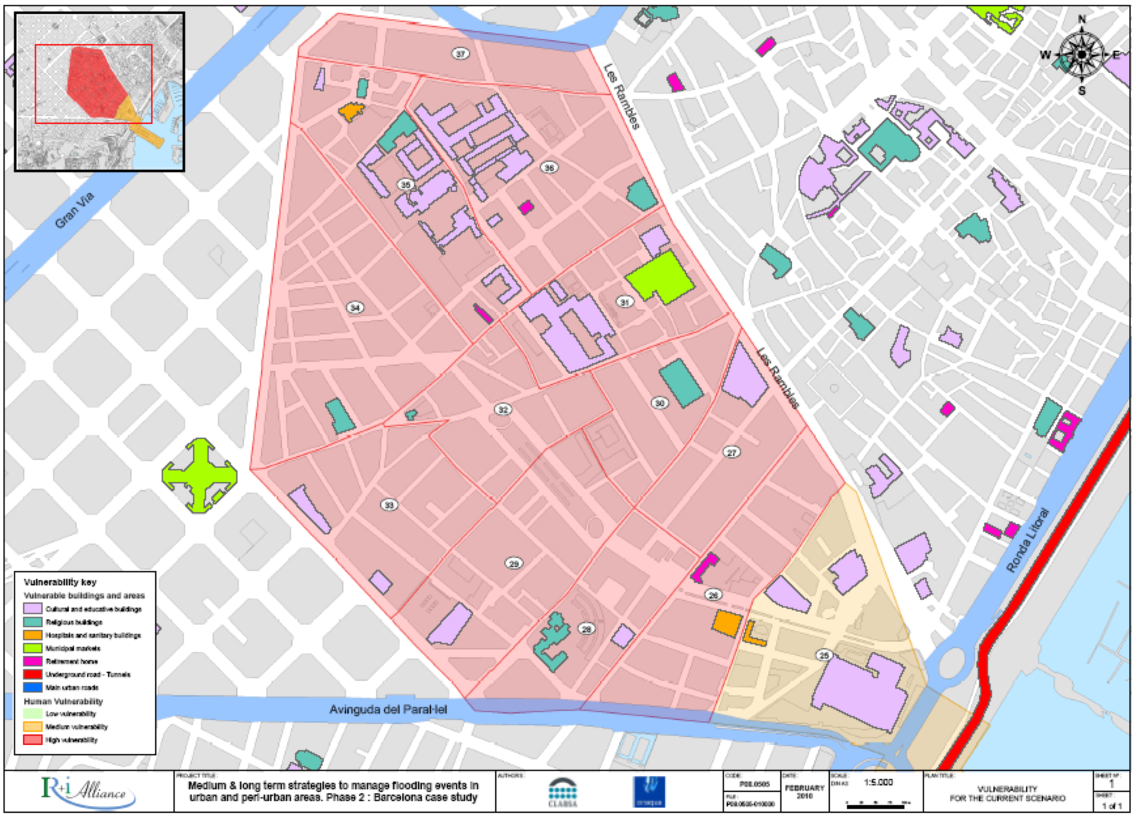

Figure 8 - Vulnerability mapping in Barcelona

ACA simplified methodology

From a draft report framed in the PEFCAT plan, a simplified methodology of flood risk assessment on singular points was created in 2008 by the Catalan Water Agency (ACA). It consisted on different tables where a weighed value was given to each of the categories, and then, by multiplying the different variables (intensity, probability, vulnerability, etc.), a final value for each point is obtained, and classified as high, medium or low risk.

According to vulnerability, the categories created together with its values given can be seen in the following table.

Table 12 - Vulnerability factors for the ACA simplified methodology

Name	V
Life loss	16

Urban zones, vulnerable areas, industrial or commercial areas	8
Road infrastructures and other basic networks	8
Other (rural zones, cultural heritage regions, etc.)	4
Free urban systems (green areas, parking zones, etc.)	2
Agriculture and farming regions	2
Natural regions without anthropological uses	0

4.2 Hamburg

KALYPSO is an open source software package, and was developed jointly by the Hamburg University of Technology (TUHH) and Bjornsen Consulting Engineers. It comprises separate modules that permit the modelling and mapping of various facets of flood risk, including a 1D and 2D Hydrodynamic modelling, as well as damage estimation techniques. KALYPSO RISK is the module that enables the modelling of direct tangible damage. A unit loss methodology is used, that combines flooded depths, land-use types and depth-damage curves to estimate flood damage. Flood depths from different return period events can be used to estimate the Expected Annual Damage.

The main steps in using KALYPSO to estimate flood damage are as follows (Schrage et al., 2009)

- Land use on the flood-plain is categorised into standard land-use units;
- Asset values and damage functions are derived for the land-use units, on the basis of available statistical data;
- Overlay the land-use data and inundation data;
- Calculate the damage within each unit by making use of the asset values and the damage functions
- Calculate the expected average annual damage by summing the expected damage of different likelihoods, and then weighting them by their probability

TUHH has also developed a software tool called FLORETO. This allows for a more micro-scale analysis of direct tangible damage. The user can specify individual building types, the number of floors, property inventories and other variables to establish depth-damage curves.

A case study was conducted on the Wilhemsburg area of Hamburg using three approaches. The first was the rasterised medium scale standardised damage curves. The second approach was to use a physically based individual property level assessment. Thirdly, the two approaches were coupled, using physically based damage curves rather than standard damage functions for land-use types. The overall damage is obtained by aggregating damage data of the raster cells defining building types multiplied by their share in their land-use area. The results indicated an improvement by coupling the two approaches (Manojlovic et al., 2010).

4.3 Nice

The government of Alpes Maritimes (the region within which Nice lies) has developed the Floor Risk Prevention Plan in the Lower Valley of the Var (*Plan de Preventions des Risques d'Inondation de la basse vallee du Var)* on the basis of broad scale hydraulic modelling. Hazard maps are developed, which classify the zones on the basis of the damage as weak, moderate, strong and very strong, as a function of the flow velocities and the flooded depth.

Although quantified, these values go not give monetary information on the damage in Nice.

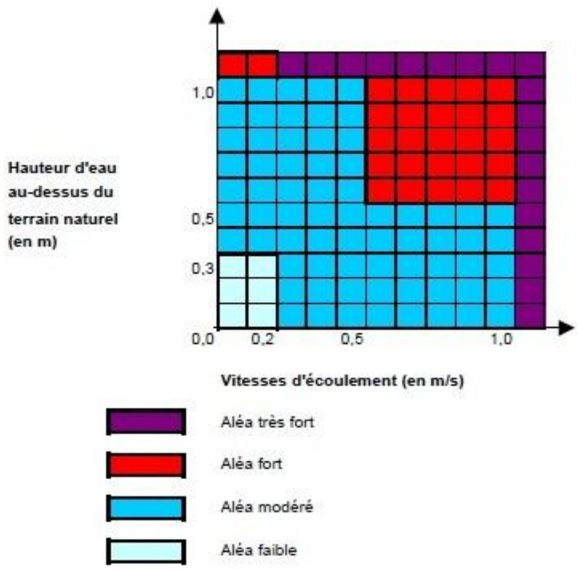

Figure 9 - Damage mapping in Nice

No damage estimates in Nice could be found.

4.4 Taipei

The estimations on flood damages are often obtained from government statistics. Some information is collected by the local government such as Taipei City Government (TCG), while as some data are reported to the authorizing departments in the central government.
Data on the direct tangible damages are collected in the following way:

1. Re-construction or recovering costs for damaged public facilities (flood defense systems, transportation networks, electricity/gas/water supply systems, etc.) are often estimated by government authorities.

2. Tax relief claims from individual households and business, collected by tax revenue office.
3. Household damage estimates are made by field surveys conducted by government investigators.

The indirect tangible damages are estimated in the following ways:

1. Cost of emergency operations (management, evacuation and rescue, shelters), estimated by the Emergency Operation Center (EOC) of TCG
2. The loss of business transactions and delay of product deliveries are reported by individual businesses to the Department of Economic Development of TCG, and to the Ministry of Economic Affairs in the central government
3. Increase in food (vegetable) prices because of supply shortages from outside of Taipei are estimated by the Council of Agriculture in the central government.
4. Tourism losses are reported by the travel agencies, hotels, and tourism industries to the Ministry of Transportation and Communication in the central government.
5. Aftermath cleansing costs are estimated by the TCG

Intangible impacts, including health impacts (both physical and mental) are estimated in the following ways:

1. Statistics on the loss of life, injuries and the missing are collected by the EOC of TCG
2. Clinics and hospitals records are reported to the Department of Health, TCG

All of these damages are then collected by the EOC from the various government departments. The final detailed figures are collected by:

1. Field investigations by the Department of Civil Affairs;
2. Tax relief claims from victims by the Department of Finance;
3. Business losses from the Department of Economic Development;
4. Road and drainage recovery costs by the Department of Public Works;
5. Deaths and injuries by the Department of Health;
6. Water supply systems repairs by the Taipei Water Company;
7. Rapid transit system damage and losses are collected by the Department of Rapid Transit System and Taipei Rapid Transportation Corporation.

Other than these estimates made by municipal government, some flood damages are estimated in the national scale by the departments of central government (flood defense facility, highway agency, airport, agriculture and business).

Some households are not liable for paying income tax, and the damages caused to those people are not included in the tax relief claims. Other deficiencies for the collected ex-post damage data include the fact that the damages are collected immediately after the event, using simplified methods. Systematic guidelines for estimating the flood damages more precisely is required.

The central government and TCG are highly involved with the flood damage estimation. The databases are stored in different government departments, collected via the above-mentioned methods.

Our colleagues in the NTU and NCDR have been involved in several studies of flood damage estimation and flood insurance planning. They may hold some useful information that we can apply to the CORFU case study.

In a study, the economic losses are loss of life over a period from 1991 to 2001 were quoted (Teng et al., 2006).

Table 13 - Economic losses in Taipei from 1991 to 2001 (from Teng et al, 2006)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Loss of life	31	15	36	28	35	73	28	17	54	89	178
Economic damages (US $m)	32.4	22.9	26.2	15.1	13.8	19.4	24.2	33.7	28.8	36.1	55.7

However, there have been several investigations with computer modelling to develop damage estimates.Research by Shaw(2005a) showed that the damage caused by Typhoon Nari was affected by socio-economic factors such as human vulnerability. For example, the number of years that one had lived in the same area reduced flood damage. There were also some differences noted when comparing the number of times a person had been flooded before. The paper concluded that these factors should be taken into consideration when estimating flood damages.

There have been several academic studies into flood damage estimation in Taiwan, that have largely focused on the direct tangible damages. Chang (2009) developed depth-damage curves for the industrial and commercial sectors in Taiwan, using data from Typhoon Nari that struck Taiwan in 2001. Kang et al. (2005) developed depth-damage curves for residential areas in Taipei, using socio-economic data such as persons per household, building characteristics, and indoor decorations, furniture and appliances for Taipei. For example, information on the percentage of households that possessed dishwashers or televisions were used in the development of the stage-damage curves. It was suggested in this study that the information derived for Taipei could be adjusted and applied to other cities, using such information as land values and taxation data.

Finally, research was conducted by Su et al (2005) into using a grid-based flood damage model. The model was developing using aggregated census data, rather than parcel data to estimate the damages. The benefit of this approach was that the data handling is more practical, although there is the potential that the estimates are less accurate. The model was applied to Shih-Jr City.

No ex-ante methods to estimate intangible damages were found in the literature.

4.5 Mumbai

No formal techniques have been used to estimate flood damages in Mumbai. However, flood damages in the past have been estimated by personal interview of various head or senior officials of organizations; information available with Government during flood and informal sources like newspapers.

Watson Hawksley International Ltd had adopted a following simplistic approach of estimation of flood loss while preparing master plan for Greater Bombay storm drainage and sewer rehabilitation (BRIMSTOWAD Project, 1993). They investigated several factors

- Number of Establishment affected by flooding
- Average loss per establishment (based on actual observation and probability of occurrence of flood per year).

Ex-post estimates of the impacts from the 2005 Flood

On 26th July 2005, extremely high rainfall totals were recorded in Mumbai and the surrounding area. In 24 hours, from 8.30am on the 26th July, 944mm of rain was recorded at the Santa Cruz meteorological station to the south of the City. At least 419 people (and 15,000 cattle) were killed as a result of the ensuing flash floods and landslides in the Mumbai municipal area, and another 216 as a result of flood-related illnesses. Over 100 000 residential and commercial establishments and 30 000 vehicles were damaged (Gupta, 2007).

Water levels rose rapidly, and much of the transport networks was submerged. Road traffic was immobilized, low-lying areas in the city were heavily flooded, with the poor being the worst affected, although no social groups were unaffected. Basic services were damaged, with no electricity in Mumbai, telephone services were disrupted. Access to information was limited, causing greater difficulties. The Western and Central Railways did not run their local services for a number of days, and all the long-distance trains run by the Central Railways were cancelled. The national and international flights at the Sahar and Santacruz airports were disrupted for a number of days (Government of Maharashtra, 2006).

A substantial number of buildings were damaged: 175,000 residential buildings were partially damaged, damaged while 2,000 were fully damaged and 40 000 commercial establishments suffered heavy losses. Some 30 000 vehicles were damaged and 850 buses of the Mumbai Transport were damaged. The following table, taken from the report by the Govenrent of Maharashtra (the Indian state within which Mumbai is situated) in million rupees shows the losses from the 2005 event.

In Mumbai, reports of diseases were made, and listed in the following table.

Table 14 - Hospital admissions following the 2005 floods

Name of the disease	**Admission in the last 24 hours**	**Total admissions since 29th July**	**Number of deaths**
Gastroenteritis	154	1318	1
Hepatitis	27	194	--
Enteric fever, typhoid	5	53	--
Malaria	62	406	2
Dengue	5	49	--
Leptospirosis	56	197	10
Fever (unknown cause)	597	1,044	45
Total	906	3,261	57

Table 15 - Total losses in the Mumbai 2005 floods

Nature of losses	Total losses (Bn Rupees)
Infrastructure losses	10
Livestock losses	1
Housing losses	3
Loss of crops	6

Export losses	8
Total losses	28

Insured losses in Mumbai were as follows. It can be seen that the insured losses are only a small proportion of the estimated total losses.

Table 16 - Insured losses in the Mumbai 2005 floods

Insurance type	**Total losses (Bn Rupees)**
Insurance of cars	0.3
Insurance of property	0.2
Insurance of shops	0.5-0.6
Insurance of Godowns (warehouses)	2
Total losses	3.1-3.2

An ex-ante study was conducted by Ranger et al (2011) into the potential impact of climate change on Mumbai. The study investigated the direct and economic damage that could be caused by flooding, assuming certain future carbon emission scenarios. Intangible damages were not considered. In that study, the exposure to flooding was estimated from several sources. Population was estimated using local census data. The distribution of property types was derived from the analysis of satellite data. The total insured values were taken from an existing insurance industry database (RMS India Earthquake model), to create a total insured value (TIV) of $2,960m from the residential, commercial and industrial sectors. Vulnerability was first considered using stage – relative depth-damage curves (See Section 2.1 for an explanation) for each of the three sectors (residential, commercial and industrial). However, because of the lack of good data, an *average mean damage ratio* was applied, and therefore only flood extent was taken into account. A disadvantage of this study is, therefore, if floods, as expected become deeper, the results will be underestimates, unless some adjustment is made. The data used to create the average mean damage ratio came from the July 2005 event discussed above. Data were taken from published statistics from the Dartmouth Flood Observatory and Swiss Re data (a reinsurance firm), assuming 50% of the total damage came from the Greater Mumbai area, and 70% of these losses were related to residential, commercial and industrial losses. These were also combined with insured loss data taken from RMS, as well as RMS simplified flood vulnerability curves, with estimates of the flooded depth taken from Gupta (2007). Infrastructure losses were then added, and assumed to be 40% of the combined residential, commercial and industrial direct damage.

As for the indirect damage, an Input-Output model, known as the Adaptive Regional Input-Output model was used (Hallegatte, 2008). The model has previously been discussed in Section 0. Sector-by-sector macroeconomic data from the National Council of Applied Economic Research was used, and downscaled to the Mumbai area. Several modifications were made to the model, to make it more applicable to the Mumbai area. A difficulty with the indirect losses is that it was not possible to validate these losses because of no data on the wider implications on the economy. The study did go on to consider the benefit of resilience measures, and in particular the role that insurance could play in reducing the indirect economic losses.

4.6 Dhaka, Bangladesh

The information on Dhaka comes largely from work conducted by Dr. K. M. Nabiul Islam, firstly as part of a PhD at the University of Middlesex, and from two subsequent books published on the subject.

In a study on the impacts of flooding in Bangladesh, estimates were made of the direct and indirect impacts of flooding (Islam, 2000), using unit-loss models for the direct tangible damages, and linkage models for the indirect effects. Estimates were made for river, flash and tidal floods, and it was shown that tidal flooding in Bangladesh caused the greatest damage.

An input-output model was used to estimate the indirect effects of flooding upon the economy, and it was estimated to be 61% of the direct damages.

However, there are no known formal methods that are prescribed by the government to assess flood impacts in Bangladesh.

As mentioned earlier in this report, there have been a few studies that investigated the potential for communicable diseases in Bangladesh (see Section 0).

4.7 Beijing, China

The methods for estimating flood damages in Beijing are limirted. According to our project partners, in the past 20 years, North China has been very dry with relatively few flooding events, and the reservoir on the Yongding has helped for Beijing to avoid flooding.

Normally in China, direct tangible damages are evaluated by national ex-post investigations and from loss report produced by the local government. The estimation of indirect tangible damages is very difficult.

There are some methods on flooding assessment in our work, especially in direct loss evaluation. We usually use statistic or empirical model to estimate the flooding loss, and the key factor in flooding loss evaluation is the rate of loss, it is related to the factors such as the intensity of the flooding, the submergence depth, the submergence time length etc. The rate of loss also is different that related to land use such as urban, agriculture, forest etc. The rate of loss is also related to location, and the quality of construction.
The rate of loss usually is calculated by this formula:

$$\frac{\text{the value before flood} - \text{the value after flood}}{\text{the value before flood} * \text{price index}} * 100\%$$

In China, The Department of Disaster Mitigation has conducted research on how to appraise the indirect damages caused by flooding, but the methods are not well used.

Zhang et al (2002) reviewed the techniques employed more widely in China to evaluate flood damages. With funds from the Ministry of Science and Technology of China, the National Professional and Operational Integrated System (NPOIS), which uses remote sensing technology, was developed to monitor and evaluate natural disasters, of which flooding is one of the most prevalent. Before flooding, the system is able to estimate the economic and social losses under different alternatives, based on social and economic databases. During flooding, the system dynamically monitors flooded areas, and after flooding, the system can be used to calculate the actual losses from flooding.

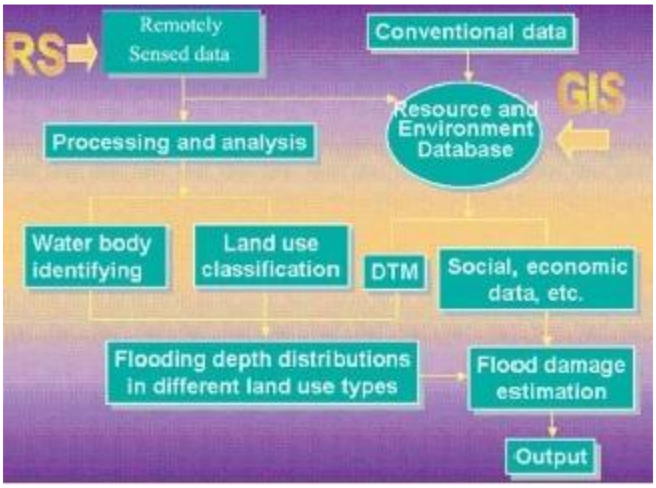

Figure 10 - Data flow in NPOIS From Zhang et al (2002)

That article notes that when flood disasters occur in China, local governments are required to report the losses to the national government, in order to receive relief funds. However, there is a tendency for these losses to be inflated. The priorities for the damage assessment are as follows.

- The area of homes submerged and the population affected;
- The area of crop land submerged and the losses;
- Damage to infrastructure, including roads, bridges and pipe lines;
- Damage to flood control works such as dykes and dams.

The techniques for the analysis are shown in the following figure.

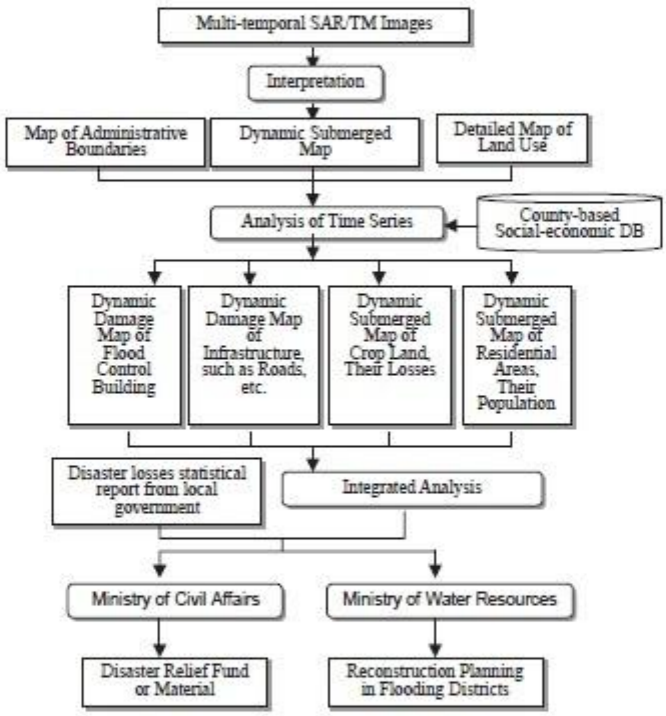

Figure 11 - From Zhang et al 2002

The system was applied to investigate widespread flooding of the River Yangtze in the summer of 1998. A flood disaster report was produced and showed that the total inundated area was 1403.2km^2. The system was able to produce estimates of the submerged areas, broken down into classes, such as wetland, grassland, urban areas and suburban residential areas.

Ni et al (2010) studied the impacts of flooding in terms of sustainability in China. Two indices were developed to evaluate the flood impacts. The first, termed the Insurance Related Flood Risk Index (IRFRI), which measures impacts in the short term. It is a function of vulnerability and the Flood Hazard Index (FHI. The second measure, the Long Term Flood Impact on Sustainability (LFIS) is a ratio of the Flood Hazard Index to the Sustainability Development Index (SDI). The techniques used were rapid assessment techniques. The SDI, developed by Sun et al (2010) uses social, economic and environmental indicators, such as GDP per capita, number of telephones per 1000 people, and forest coverage to develop indicator scores for counties and cities in China. Of 58 major cities investigated, Beijing was found to have the highest sustainability indicator score. The Flood Hazard Index was a function of the climate, geomorphology and the river network. Vulnerability was a function of the per-Capita GDP, the population density, the arable land density and the road density. The research showed the variability of these indices across China. The rapid assessment techniques were compared with work derived from an earlier PhD thesis (unavailable in English), and good agreement was found between the results. The results from the two indices demonstrated the need for both the short-term economic losses and longer term changes in sustainability to considered in flood risk management.

Broad-scale modelling was discussed by Harvey et al (2009) who described how the UK Foresight Flooding approach could be applied to the Taihu Basin in China.

In one study on the Hunan Province, a Synthetic Evaluation Model was developed to investigate the impacts of flooding in the Hunan Province (Tan et al., 2006). Data from historical floods were studied, and data on the number of casualties, the incidence of Post-Traumatic Stress Disorder, the spread of diseases, as well as the economic losses. The model was used to predict the impacts of flooding with differently ranked indicators.

5 Conclusions

This review has assessed the existing literature on flood impact assessment. From the review, several points can be highlighted.

- There has been a greater emphasis in the literature of the estimation of direct tangible damage. There are some shortcomings to these techniques, especially in reference to the impacts on infrastructure.
- There is a less developed understanding of the impacts of flooding on the wider economy, as indirect tangible damage. Indirect damage is often poorly defined, and suffer from the problem of setting the boundary of the area to be studied.
- Health impacts are as significant, if not more significant than tangible flood impacts. Diseases are thought to be a more significant problem in the developing world. Mental health impacts are even more difficult to assess than the physical impacts.
- The assessment of all impacts is made more difficult by a lack of good quality flood impact data. This leads to problems with the validation of flood damage data.
- The quantification of health impacts is difficult. The use of the DALY appears to be a useful avenue through which the impacts could be quantified. The monetising of health impacts is difficult and likely to remain so because of the value attached to human life.
- Due to the difficulty of putting a monetary value on human life, it may be that the most appropriate way of comprehensively assessing all flood impacts will be through some multi-criteria decision scheme.
- There is a need for a consistent, comprehensive framework to consider all types of damage. There is a multitude of techniques that are used in different countries or regions, and so a comparison of impacts can be difficult.
- Estimates from flood damage are uncertain. More emphasis on understanding the uncertainty surrounding these damage estimates may be necessary.

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