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SUMMARY

This report outlines the framework for the damage model that should be applied in the project. The intended readership of the report is project partners who will be assessing flood damage in the different case study cities.

The model outlined in the report deals with direct tangible damage, and indirect tangible and intangible damage will be described in detail in other deliverables.

This report outlines the general principles that should be adhered to in assessing flood damage. Recommendations are provided on the appropriate scale of modelling that should be adopted. The report then goes on to outline the categories of assets that should be considered in assessing direct tangible damage. The report also provides recommendations on the data that should be sought to estimate the value of the assets at risk and the damage functions, which relate to the characteristics of the flooding.

Finally, the report concludes with recommendations on how to estimate the Expected Annual Damage.

An appendix is included, which provides the technical details of the modelling tool that has been developed on a trial site in Dhaka in Bangladesh. This tool can be applied on a GIS software platform. The details of the algorithms have been provided so that they can be applied in different software packages, if necessary. The tool will be updated as further progress is made

Contents

1 Introduction

One of the key tasks in the CORFU project is the development of the flood damage model (T3.3). The aim of this model is to combine all the different impacts that arise from flooding, including the direct damage that is caused by the contact of floodwater with residential and non-residential property and their contents, the indirect impacts, such as the disruption to businesses and transport networks, and intangible impacts such as the health and social costs of flooding. An earlier deliverable (D3.1) has reviewed the literature on flood impact estimation methods, and discussed some of the advantages and disadvantages of these methods.

The objective of this report is to outline the flood damage model that will be applied in the CORFU project. Each case-study city is unique, insomuch as their combination of socio-economic, climatic, topographic and political factors are different. The availability of flood damage data will also vary from city to city. For these reasons, it is not possible to define a single flood damage model. This model is, therefore, not intended to be prescriptive, but will describe general principles, that should be applied in the CORFU project.

The intended readership of this report is the members of the project team who will be applying this model in the different case study cities. This report serves as the part of the Adapted Damage Assessment model prototype (D3.3). The proposed model will remain open for discussion among the Project Partners before the model is finalised. This report is not intended to be excessively technical. A report detailing the technical details, including the software and algorithms employed as attached as an Appendix (Appendix A).

The overarching aim of the CORFU project is to improve the flood resilience of cities, by developing and investigating the effectiveness of different resilience strategies. Therefore, the damage model should be developed with this objective in mind. If the model cannot measure the effectiveness of different resilience measures, then it would not be fit for purpose.

This report will focus on ex-ante damage estimation, meaning that estimates are made of the impact of future hypothetical events. This is in contrast to ex-post damage estimates, which studies the impacts from events that have occurred. Of course, there is a strong relationship between the two, in that ex-post estimates are often used to provide the evidence base for ex-ante damage estimates.

The CORFU damage model will comprise three damage model components:

- Direct tangible damage
- Indirect tangible damage
- Intangible damage

This report deals with the direct tangible damage component. The latter two components will be described in deliverables D3.4 and D3.5.

Key principles and recommendations in this report will be highlighted in bold text.

2 Key principles of impact or damage assessment

At the heart of the CORFU project is the need to construct a unified damage model or modelling framework. The key principles behind the damage assessment need to be considered carefully. There has been much discussion in the literature on the correct principles that should be applied in any damage estimation study (Merz et al., 2010, Messner et al., 2007, Rose, 2004). These general principles will be discussed in this section.

Defining the point of departure for the impact assessment is an essential starting point. Often, two approaches are considered: a financial and an economic viewpoint. The financial viewpoint will take into consideration the losses incurred to individual households or businesses. Insurance companies might well be interested in taking a financial viewpoint, and investigating the total financial burden caused by a flood. An economic viewpoint takes a broader perspective, considering as it does the net change in welfare to a country or a region. The reason for this is quite simple and this contrast can be explained by a simple example. If a business loses trade because of flooding, it will suffer a financial loss. However, in a perfect economy, the trade lost by one firm would be gained by another firm, so that there is no net loss in trade. A financial perspective will consider the loss of business without compensating for the gain in trade by the rival business. Taking an economic perspective, there is no loss to the national economy (assuming the substitute company is in the same country).

Cochrane (2004) makes the same distinction, but adds the difference between a national and a regional perspective. To take an example, within a regional perspective, gains can arise from aid or compensation that comes from the national government. These gains do not exist if a national perspective is taken.

In the CORFU project, an economic approach should be taken at the city scale. We are therefore interested in the net welfare change to the city as a whole.

Something that arises frequently in discussions in the literature is the concept of double counting. Messner et al (2007) state it is important to recognise that stocks and flows are often “two sides of the same coin”. The value of something can be represented in two ways. On the one hand, its value is represented by its scarcity price. On the other hand, the good can be considered as a capital good, which can be used to generate a flow of income over time. A very obvious example of this is a piece of machinery used in manufacturing. **A simple rule that should be adhered to is to never sum up stock and flow values for one object** (Merz et al., 2010).

Further to this idea of avoiding double counting is to ensure that the categories that are considered are clearly delineated. Within this report, each category will be clearly outlined, ensuring that the categories are mutually exclusive and comprehensive as reasonably possible (Bockarjova, 2007).

A further issue outlined by several authors is the need to use depreciated costs for an object rather than the full replacement costs (Merz et al., 2010). These depreciated values reflect the value lost at the time of flooding rather than as if the objects were new. **In this project, depreciated costs should be applied rather than full replacement costs.**

It is important to define the clear temporal and spatial scales and boundaries of the study. This is strongly related to the point made earlier about the economic point of departure.

Finally, a key issue is the definition of damage. In the CORFU project, flood damage is defined as "loss of life, loss of value of elements at risk (buildings, inventories, infrastructure, goods, cultural and ecological assets) compared to pre-flood conditions and loss of production caused by a flood." This is the same definition as developed in the FLOODsite project (Messner et al., 2007, Glossary).

3 Direct Tangible Damage Model Component

3.1 Introduction

Direct tangible damage can be defined as the "damage caused by direct contact with flood water that can be readily quantified in monetary terms". It is the most studied type of damage. Indeed, many studies in the literature only include direct tangible damage (Apel et al., 2004, Oliveri and Santoro, 2000, Tang et al., 1992). It is usually considered to be a function of the flooded depth, although other factors are often taken into account.

The European funded project FLOODsite produced guidelines for the estimation of flood damage (Messner et al., 2007). These guidelines were developed for Europe, and their applicability to the Asian case-study cities may be limited. However, they provide a good starting point for discussing the development of flood damage estimation methodologies, without the need to reinvent the guidelines. The FLOODsite report begins by describing four steps in the assessment of direct tangible flood damage:

1) **Selection of an appropriate approach, which depends on:**
    a. The spatial scale
    b. The objective of the study
    c. The availability of resources
    d. The availability of pre-existing data
2) **Choice of the direct, tangible damage categories to consider;**
3) **Gathering the necessary information, which includes:**
    a. Inundation characteristics
    b. Land use data
    c. Value of assets at risk
    d. Damage functions
4) **Calculation and presentation of the expected results.**

At each of these steps, the modeller or analyst will have to make choices. These steps and the choices faced by the modeller will be discussed in more detail in the following sections, with some advice. Before this is done, it is necessary to outline some key principles that should be followed when conducting the flood damage assessment.

3.2 Selection of an appropriate approach

Perhaps the most difficult choice facing the modeller is the selection of an appropriate approach and methodology. The discussion of the exact methodology that can be chosen will be discussed in detail in Section 3.4. At this point, these guidelines will consider a distinction between three approaches: a micro, a meso and a macro approach (Merz et al., 2010). This distinction relates to the scale of the objects that are being considered. A micro study will focus on the individual elements at risk, e.g. individual buildings or infrastructure units. Meso-scale studies involve a level of aggregation, and will investigate entities such as land-use units (i.e. residential, commercial). Finally, macro-scale studies will look at larger non-homogenous units, such as municipalities or districts.

The choice the modeller makes will depend on the answers to four questions:

a) What is the spatial scale of the study? Is it local, regional, national, or even international?
b) What is the study's objective?
c) What resources (in terms of time and money) are available for the study?
d) What pre-existing data exists? What kind of data is it?

These questions and their implications are discussed in the following subsections.

3.2.1 What is the spatial scale of the study?

Flood damage or impact assessments can be carried out for areas that range widely in size. Starting at the largest scale, that is the national or international scale, studies have been carried out to investigate the potential flood risk of entire countries or transboundary areas. As an example of the first case, the Risk Assessment for Flood and Coastal Defence for Strategic Planning (RASP) investigated the flood risk in the entire UK (Hall et al., 2003). In Central Europe, there are several large rivers that cross national borders. Two notable examples are the River Rhine and the River Danube. Flood studies such as the Rhine Atlas (IKSR, 2001, Quoted in Messner et al., 2007) investigated flood risk in countries including Germany and Switzerland.

At a smaller scale, there are studies that investigated the flood risk on a regional scale. An example of such a study is that conducted in North-Rhine Westphalia (a federal state in Germany) quoted by Messner et al. (2007).

Finally, studies can focus on smaller areas, such as cities or areas within cities. In the UK, studies are conducted using methods described in the Multicoloured Manual to assess the potential benefits of constructing single flood defence measures (Penning-Rowsell et al., 2005). Ryu et al (2007) used this approach to develop a methodology to consider the risk of sewer flooding on a property-by-property basis.

In the CORFU project, for direct tangible damages, we are interested in scales that range from individual buildings up to the city scale. During the project meetings, four scales within the city have been discussed: city, district, block, and parcel[1]. Within several of the case study cities, sub-areas of special interest have been selected. For example, within Barcelona, the Ravel district has been selected as a study area. Wilhemsburg is a low-lying area in Hamburg, which has experienced major flooding in recent history. In Beijing, the Yizhuang New Town area will be investigated. Yizhuang New Town is one of six satellite towns that are being constructed, as part of Beijing's Urban Development Plan. In WP1, future scenarios that use the results of urban growth models will be considered. To accomplish this, it is likely that the entire city will be considered.

3.2.2 What is the objective of the study?

Although each city may well have separate objectives, the CORFU project has a unifying theme. The overall aim of the CORFU project is to develop and investigate flood resilience strategies that can be implemented on the city scale. This means that the results from the project will need sufficiently accurate so that statements about the cost-effectiveness of various flood resilience strategies can be made.

3.2.3 How much time and money is available to carry out the study?

This question is dictated by the funding and staffing of the study. This will vary between case-study cities and the project partners. Generally, the more resources (such as time and money) that are available, the more detailed and in-depth the study can be.

3.2.4 What existing data is available? What kind of data is it?

Despite the answers to these previous three questions, the modeller's choice of approach will be constrained and directed by the availability of data. It is clear from the preliminary work in each of the case study cities that the availability of data varies greatly. The data available to the modeller will have important consequences for the modeller in terms of the precise steps taken to assess the damage, and this will be considered in greater detail in Section 3.4. However, at this point, it will be sufficient to discuss the question of data as it relates to its scale and its structure.

A small digression is useful at this stage. Merz et al (2010) state that there are three steps in the calculation of direct tangible damage. These should not be confused as yet with the four steps outlined in the FLOODsite report.

1. <u>Classification</u> of the elements at risk by pooling them into homogeneous classes.
2. <u>Exposure analysis</u> and <u>asset assessment</u> by describing the number and type of elements at risk and by estimating their asset value
3. <u>Susceptibility analysis</u> by relating the relative damage of the elements at risk to the flood impact.

Steps 2 and 3 can be combined, as will be described later in these guidelines. In order to carry out these steps, data will be required on the number and types of assets, and on their value that is at risk from flooding. The question at this stage is whether the data that exists can be related to either single objects that are at risk (i.e. buildings), or whether the data is somehow aggregated into larger units (blocks or districts).

[1] See Minutes of meeting held at University of Exeter, 3rd to 4th March 2011, CORFU_WP3_Meeting_Exeter_3-4_March_2011_MINUTES.pdf

3.2.5 How these questions affect the choice of approach

The first three questions are in many ways asking a larger question, which is about how much detail is desired in the study. The more detail that is desired from the study, the finer the scale of the approach will be. The fourth question relates to the data that is available, and in a way, the detail that can be achieved. It may be that no matter the answers to the first three questions, the modeller is forced to adopt a broader approach than desired. The modeller will have to find a compromise between the detail that is desired, and the detail that is achievable.

Using the terminology used by Merz et al (2010), these questions bring the modeller to a decision over whether to use a macro, a meso or a micro-scale approach. In the CORFU project, either micro or meso-scale approaches should be adopted. The precise decision will depend on the data availability. As will be discussed, if data is available for both building-use and asset values on a building by building level, a micro approach will be appropriate. Alternatively, if the data is only available in an aggregated form, a meso approach will be suitable. Figure 1, taken from the FLOODsite presents this information in flowchart form. The distinction in that figure between, for example, Macro 1 and Macro 2 is not necessary here, but relates to the specific methods used in various European countries.

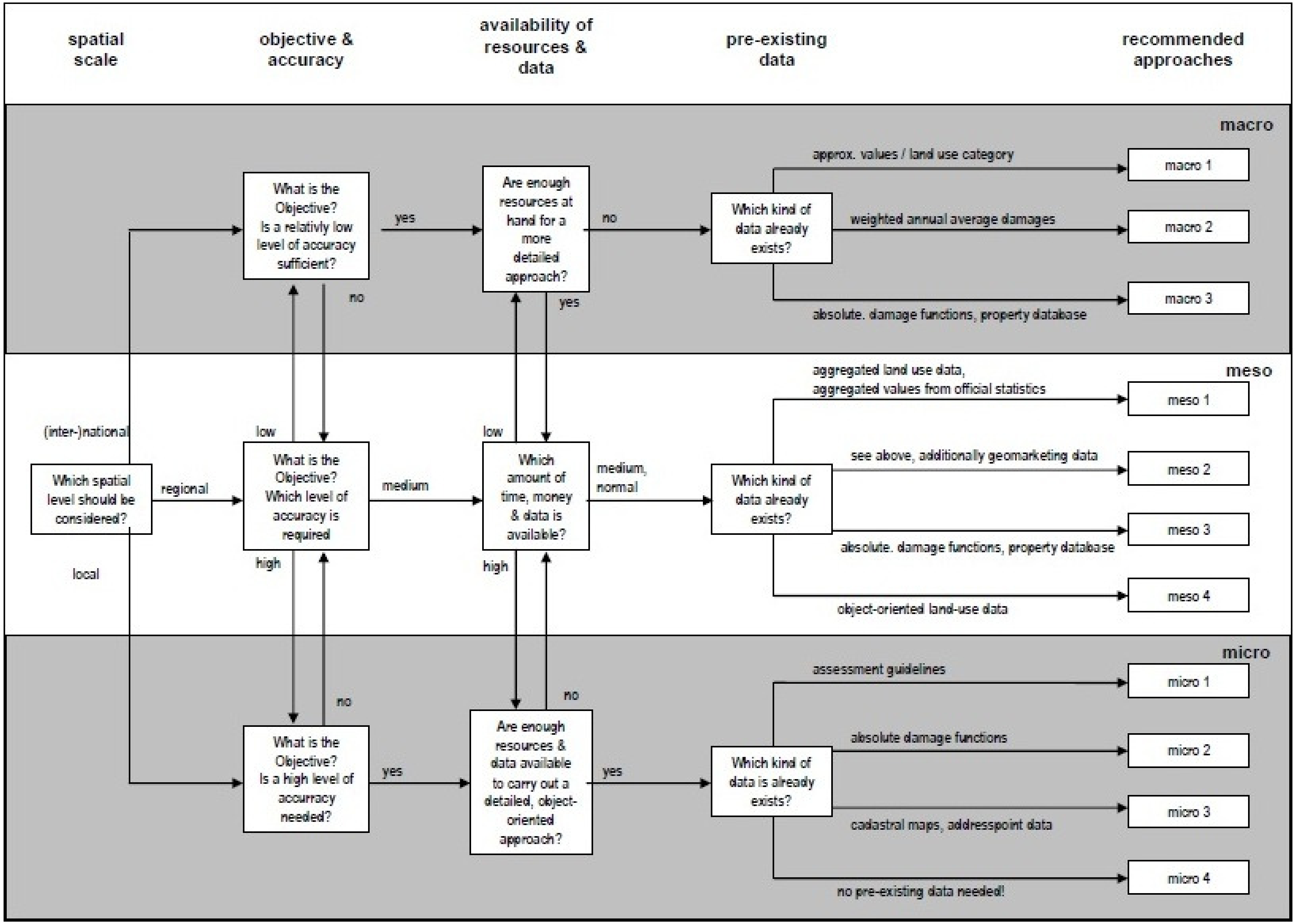

Figure 1 - Selecting an appropriate approach (From Messner et al 2007)

3.3 Choice of the direct, tangible damage categories to consider

To quantify flood damage, it is important to decide upon the categories of flood damage that will be considered. The flood damage classification should meet two requirements.

Firstly, the flood damage categories should cover as much of the damage that could be reasonably expected to occur. For example, only considering residential property will mean that important categories like industry being ignored. However, to take another example, it may not be necessary to consider agricultural damage in urban areas. In considering the categories, some thought should be given to the flood flow routes.

Secondly, when classifying the objects at risk, the categories should be sufficiently detailed to allow a differentiation between the various objects. A balance should be struck between, on one hand, selecting groups that are reasonably homogeneous, and on the other hand, matching the number of categories with the resources (time and money) and data available to assess them. To take an example, residential property is a heterogeneous group, ranging from flats to detached houses, which are variable in size and value. It would therefore be reasonable to subdivide the broader category of residential property. However, there may not be sufficient data, or it may not provide any additional information to differentiate between flats that were constructed in the 1980s and the 1990s, to give an example.

The choice of categories may well depend on the approach (macro, meso or micro outlined in Section 3.2.5).

These two criteria can be stated more succinctly:

1. **Top level categories should be sufficient to cover as much of the entire spectrum of flood damages as possible;**
2. **Sub-categories should be sufficiently detailed to provide reasonably homogeneous classes, without excessively disaggregating the subcategories.**

This can be represented graphically, as in Figure 2, where the top level categories span the damage ‘space’, whereas the subcategories are used to discriminate within the larger sectors to provide the required detail.

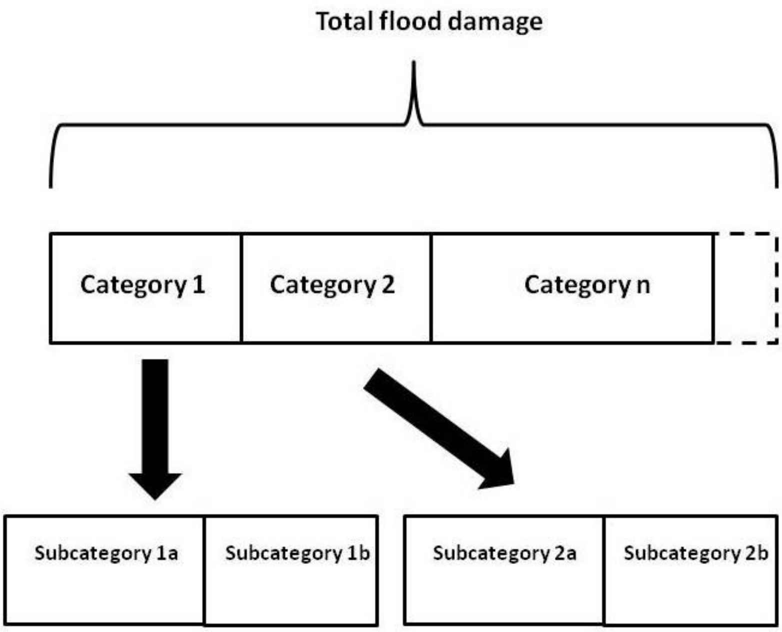

Figure 2 - Representation of damage categorisation critieria

When considering the top level categories, it may be useful to examine historical damage data. As a start, Table 1, taken from the previously quoted FLOODsite report, describes the breakdown of damage data from the 2002 floods in the German Federal State of Saxony.

Table 1 - Flood damage shares to different categories from 2002 Floods in Saxony (from Meyer and Messner, 2005)

Categories	**Subcategories**	**Share from 2002 flood (%)**
Residential properties	**TOTAL**	**33.1**
	Buildings	25.2
	Housing goods	7.8
Non-residential properties	**TOTAL**	**29.5**
	Buildings	n/a
	Machinery and equipment	n/a
	Inventories (stocks)	n/a
Technical infrastructure	**TOTAL**	**36.3**
	Streets	8.5
	Railways	13.0
	Flood defences and watercourses	10.9
	Further	3.8
Agricultural products	**TOTAL**	**1.3**
	Livestock	n/a
	Crops	n/a

The table describes the damage caused by the flooding in 4 large categories: Residential properties, non-residential properties, technical infrastructure, and agricultural products. The overwhelming majority of the damage arises from three categories: residential property, non-residential property and technical infrastructure (nearly 99%).

A further example comes from the 2007 floods that struck England. Results are presented from a study by Chatterton et al (2008) in Table 2. The totals relate to the total economic cost of flooding (see the general principles), which includes the indirect costs. The categories that clearly relate to the indirect damages have been excluded (for example, the costs of public health impacts and emergency services). Business losses have been listed to both include and exclude business interruptions. These interruptions will be considered as an indirect loss, as will be shown in a later section of this report.

Table 2 – Economic losses from Summer 2007 Floods in England (adapted from Chatterton et al., 2008)

Impact	Best estimate (£ million)	% of total
Households	1,200	38
Businesses (buildings, contents, and disruption) (buildings and contents only)	740 (580)	23 (18)
Temporary accommodation	94	3
Vehicles (motors)	80	3
Local government infrastructure (excl. roads) and non-emergency services	134	4
Utilities	325	10
Communications (roads, rail, telecom)	227	7
Agriculture	50	2

From both of these two studies, it can be seen that households (residential property) and businesses (commercial and industrial property) constitute a significant proportion of the total direct tangible impacts, as well as infrastructure (including communications and utilities). In the summer 2007 floods in England, damage to residential property was estimated to be £1.2bn, or 38% of the total damage. This compares to the Saxony study which listed the damage to residential property as 33% of the total damages.

In these two studies, agricultural losses were a small percentage of the damage. The CORFU project is focused on urban areas (cities). Although agriculture may be present in some cities, agricultural damage should be ignored.

It can be concluded that three categories should be considered: Residential properties, non-residential properties, and infrastructure.

Given these three categories that meet the first criteria, the second question of providing sufficient detail at the subcategory level is considered.

3.3.1 Residential property

Residential property as a category can be subdivided, and a few examples will be briefly mentioned. The UK's Multicoloured Manual, residential properties are subdivided firstly into detached, semi-detached or terraced houses, bungalows and flats. They are further categorised by the age of the property (e.g., pre-1919, 1914-1944, etc) and social class (they are classified as AB, C1, C2 and DE, using the commonly applied ABC1C2DE categorisation (Penning-Rowsell et al., 2010)). This results in 120 residential property subcategories. However, in contrast, in a broad scale study on Mumbai, where data was difficult to obtain, residential property was considered as a single category (Ranger et al., 2011). An intermediate example between these two extremes is quoted by Meyer and Messner (2005) and is that of a study on the River Danube in Germany, where 10 residential building types were used.

In this project, local knowledge should be used to determine the number of building classes, considering the homogeneity (or otherwise) of the residential building stock. In Mumbai, for example, it would be advisable to distinguish slums from well constructed apartment blocks. In the Ravel district in Barcelona, the residential property stock is relatively homogeneous and so fewer classes might be necessary. This will change if the scope of the study area increases to include more of the city of Barcelona.

3.3.2 Non-residential property

Non-residential property damage is also important. This might be distinguished by industrial, commercial and public sector property. Models such as FLEMOcs have assessed commercial damage to include three components (Kreibich et al., 2010). The first of these is the building structure. Secondly, there are the fixed assets, such as factory machinery, and thirdly, there are the goods or the stock or inventory stored in the commercial property.

The question arises as to an appropriate subcategorisation of non-residential property. Dutta (2003) calculated unit economic values for eight types of economic activities (mining, construction, production, electricity/gas/water, wholesale and retail sale, finance and insurance, real estate, and services). In a study in Germany, 60 economic activities were aggregated into five categories (agriculture; producing industry including construction; trade including catering and transport; corporate services including finance and renting; public and private services) (Seifert et al., 2010).

In the UK's Multicoloured Manual, 4 classes of property, described as 'bulk-classes' are considered.

- Retail;
- Warehouse;
- Office;
- Factory.

For outline studies, these 4 bulk categories are analysed with average values per category. However, for more detailed studies, such as project appraisals, they are broken down into around 40 more detailed categories. For example, under retail, categories such as restaurants, shops, banks and post offices are considered. Standard data from the Multicoloured Manual can then be applied to the different building types. However, for the most detailed studies, site surveys are recommended to improve the accuracy of the study. Other 'non-bulk' classes can be used if they can be identified using detailed knowledge of the study site.

In a very broad study on Mumbai by Ranger (2011), non-residential land-use was divided between commercial and industrial properties. Commercial properties were considered as any retail, office buildings and other high-rise buildings, with other commercial land-uses being described as industrial.

The public sector also has to be considered. This can include public office space such as municipal administration buildings and their contents. However, this can also include educational establishments such as schools and university property, as well as health and social services, ranging from small medical practices, up to large hospital facilities. In addition, cultural buildings, such as theatres, and sporting facilities might be considered in the public sector.

As with the residential sector, the subcategorisation of non-residential properties should rely on local knowledge and the availability of data, but should be sufficient to cover commercial, industrial and public sector properties.

3.3.3 Infrastructure

Infrastructure is an understudied area of direct tangible damage. Many studies have ignored it altogether, although evidence indicates that that damage to infrastructure can constitute a large proportion of the overall damage total (see Table 1).

Infrastructure as a concept is rather broad. The American Heritage Dictionary, quoted by Moteff (2004), defines infrastructure as

> "The basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons".

Within this broad definition, there are some quite different assets. On the one hand, there is technical infrastructure, which includes roads and other transport infrastructure such as airport and port facilities, as well as assets related to the supply of utilities such as water, gas and electricity, and communication infrastructure. There are also the public buildings such as schools and post offices that deliver essential functions. Assets such as hospitals might be more difficult to classify. It is largely a question of semantics under which categories such public buildings are placed. In the **CORFU project, it is recommended that only technical infrastructure should be included in this category, and hospitals, educational and public administration buildings be placed in the non-residential categories.**

Finally, the tsunami that struck Japan in March 2011 has shown how site specific the impacts from natural hazards may be, and the infrastructure categories that should be included cannot be determined a priori, but must be carefully considered using local knowledge.

We would recommend that at the very least, the categories, presented in Table 3 are considered. This will however depend on the detail on the assets at risk that are available.

Table 3 - Tangible damage categories

Larger categories	Subcategories	Subcategories
Residential properties	Site specific, but to include where relevant • Flats/apartments • Terraced housing • Detached housing If possible, these properties should be distinguished by age, social class and building materials	Structural damage Household goods Vehicles
Non-residential properties	Site specific, to include where relevant • Commercial and industrial properties • Public administration • Educational establishments • Health facilities, to include hospitals	Structural damage Fixed assets (inc. vehicles) Stock
Technical infrastructure	Site specific, to include where relevant • Road and transport infrastructure • Water services infrastructure • Power generation and supply • Communications infrastructure • Flood defence infrastructure	Structural damage

3.4 Gathering the necessary information

The next step in the estimation of direct tangible damage is the collection of the data. This step (or collection of steps) will be highly dependent on the data that are available, which is highly variable between the cities. In some cities, either the data do not exist, or there are restrictions that limit their availability.

The data types that the modeller must consider are as follows:

- Inundation characteristics;
- Land-use data;
- Asset value data and relative damage functions OR absolute damage functions;

These will be discussed in the following sections.

3.4.1 Inundation characteristics

The damage caused by flooding has been linked to many different inundation parameters over the course of the study. These include the extent of the flooding, the flooded depth, the flow velocity, the flooded duration, the time of its occurrence, and the debris load. The most commonly used characteristic is flooded depth, which has led to the development and use of depth-damage curves (which will be discussed in a following section), alongside the extent of flooding.

There have been studies where only flood extent was considered. However, this is only really suitable for broad-scale modelling. For example, in one study, Ranger (2011) investigated the potential damage from flooding in Mumbai. Information on the damage functions was based on published government estimates, insured losses and typical insurance vulnerability curves. These functions provided mean damage ratios, although a wide range was noted to incorporate the uncertainty.

However, work by Merz et al (2004) has shown that flooded depth can explain only a small part of the variability in damage to residential property, having studied the German HOWAS database on damage to residential properties. A further study by Kreibich et al (2009) showed the influence of different impact parameters on flood damage.

Table 4 - Influence of impact parameters on damage (taken from Kreibich et al, 2009)

Impact parameters[2]	Damage types				
	Structural damage of residential buildings	Structural damage of road infrastructure	Monetary loss to residential buildings	Monetary loss to toad infrastructure and companies	Business interruption and disruption duration
Flow velocity	NO	STRONG	WEAK	NO	NO
Water depth	STRONG	MEDIUM	MEDIUM	NO	MEDIUM
Energy head	STRONG	MEDIUM	MEDIUM	NO	WEAK
Indicator for flow force	WEAK	STRONG	WEAK	NO	NO
Intensity	WEAK	STRONG	WEAK	NO	WEAK

The use of depth and extent are recommended in the FLOODsite report as the absolute minimum to characterise the inundation properties, although for flash flood areas, velocities may be important and should be considered.

For the CORFU project, flooded extent and depth should be considered at the very least. Where flood velocities are likely to be important e.g. in flash flood areas, velocity should be considered where possible. Information on flood duration should be collected if possible, although this will become more important when indirect damages (and business interruptions) are considered.

[2] Energy head is the total energy from the Bernoulli Equation. The indicator for flow force is taken as the product of depth and velocity squared. Intensity is defined as the product of water depth and flow velocity.

These inundation characteristics will be derived from hydraulic modelling results. In the CORFU project, it is assumed that coupled 1D/2D surface flood models will be used (principally in conjunction with DHI software), and so these model outputs (from WP2) will be the principal source of this data. However, in the case of some case-study cities, different modelling packages may be used. It is understood that Barcelona will use Infoworks software. The important point is that the modelling conducted in this study should be able to provide information on the extent of flooding in a dynamic manner, so characteristics such as the time of inundation and flow velocity can be considered. Even if all these properties are not used in assessing the direct tangible damages, they will become useful in estimating the indirect and intangible impacts.

3.4.2 Land-use data

In the literature review, the parameters that affect the damage caused by flooding were labelled as either 'impact' parameters or 'resistance' parameters. The impact parameters relate to the characteristics of the inundation. The resistance parameters relate to the objects themselves that are at risk of flooding. The next few steps are about gathering information on the objects at risk, including their number, their distribution, their value, and their susceptibility to flood damage.

Obtaining and analyzing land-use data is the next step in assessing the objects that are at risk. Land-use data can come in a variety of formats from various sources.

Information can be gathered by field survey (primary data) or from pre-existing sources (secondary data). Data can be object oriented, or aggregated. Categories can range from between two to one hundred. This should be matched with the asset values or damage functions.

A) Object-oriented land-use data

Object-oriented land-use data can be derived from primary or secondary data. An example of primary land-use data would be to conduct a field survey, going from house to house, as recommended in the UK's Multi-coloured Manual for detailed project appraisals. For each property, its location is collected, along with its category (in the case of the Multi-Coloured Manual, with residential properties split between five building types, by six age categories and by four social classes, and the non-residential properties divided by ten business sectors and its subcategories. The ground area of non-residential properties is recorded, and for all properties, the altitude of the threshold of flooding is documented).

Object-oriented land-use data can also be derived from secondary sources. One example is the **National Property Dataset** used in the UK which uses address-point data, although the classification is not as detailed as recommended for primary data, and only average floor areas are assumed for non-residential properties (and residential properties are not differentiated at all). A second example is **Cadastral maps**. A cadastral map locates each property in the form of a discrete ground area. An example of this is the **ALK** (Automaisierte Liegenschaftskarte) used in Germany, used in the MERK project in Schleswig-Holstein.

B) Aggregated land-used data

Aggregated land-use data is almost always secondary. These data sources aggregate properties or areas to area of more or less homogeneous use. Two examples of this data follow. Firstly, the **CORINE Land Cover** (CLC) project provides information for all EU member states, derived from satellite information. 44 categories in three hierarchy levels are used, although in urban areas, this differentiation is low. This data was used for a study on the River Rhine (IKSR 2001), although only six categories were identified (settlement, industry, traffic, agricultural areas, forest, and other). More detailed examples of aggregated land-use data include the **ATKIS-DLM** database (Germany), the **CBS** land-use data (Netherlands), and the **UPD** Land-used data (Czech Republic).

C) Other data

Geomarketing data can be used to integrate other socio-economic information. These data do not typically come from government sources of data, but can come from commercial providers. This type of data is incorporated into the standard method in the Netherlands. Other data can be used from sources such as Google maps or Google Street View to distinguish the building use.

Table 5 summarises the range of possible land-use data sources.

Table 5 - Sources of land-use data (adapted from Messner et al, 2007)

Source	Types	Resolution/structure
Primary	Field surveys	Object oriented, single properties
Secondary	Address point data	Object oriented: address points
	Cadastral maps	Object oriented: ground flood areas
	Detailed aggregated data	Aggregated: blocks of similar use
	Low detail aggregated data	Aggregated: areas > 25ha
	Geomarketing data	Postcode areas, election districts

For the CORFU project, as much object-oriented data as possible should be used, although it is understood that aggregated data may be available, which would be necessary for considering larger areas within a city, and when investigating future scenarios, in conjunction with the Urban Growth Models from WP1.

3.4.3 Value of assets at risk and damage functions

Obtaining the value of the assets at risk, and the associated damage functions is one of the most difficult parts of the damage estimation modelling work in WP3. An inventory of the existing damage functions has been made, and it is clear that for many of the case-study cities, flood damage functions do not already exist. To make the studies even more difficult, there is little historical data on the total damage caused from historical floods with the detail required to enable the empirical derivation of damage functions.

Firstly, the types of damage functions are briefly discussed. There are two approaches to estimating flood damage to assets and their contents. The first is to estimate the total value of the assets at risk, and apply **relative damage functions** to these as a function of the inundation characteristics. The second method is to use **absolute damage functions**, and therefore, the value of the assets at risk need not be calculated, but are incorporated into the absolute damage functions. This section will briefly describe either the value of the assets at risk and the relative damage functions, and the absolute damage functions.

When estimating these values for the purpose of assessing impact to the wider economy, it is important to remember that **depreciated values** are used. However, for some financial assessments, and in the case of insurance studies, **full replacement costs** can be applied.

If a relative damage approach is taken, the value of the assets at risk must be calculated. The value of the assets at risk can be obtained from several sources, and these are listed below.

a) Aggregated data from 'official' statistics

Examples of this include national accounts, which can provide information on gross and net value of fixed assets based on residential and non-residential buildings (Eurostat) in national, regional, or municipal levels. It is possible to disaggregate national or regional data to municipalities on the basis of the number of employees or population. However, this type of data is only suitable for macro-scale modelling. Such data on the value of assets may be available from insurance companies, although this data can be difficult to obtain.

b) Disaggregation to land-use units

For finer scale studies (meso or micro), the estimation at a municipality or region level is not sufficient. However, spatial modelling can be conducted to disaggregate such data to land-use units. A study on the River Mulde in Saxony in Germany investigated different disaggregation techniques, and estimated their accuracy (Wunsch et al., 2009) and found the choice of method had significant effects on the results, leading to a significant uncertainty in the final damage estimates. The results can be presented on unit areas (i.e. the value per square metre). Inaccuracy is an inherent potential problem with these methods and care must be taken. This is likely to be a greater problem when object-oriented land-use data is used (i.e. individual buildings). Such disaggregation is generally not recommended for such data.

c) Approximate values per land use unit from other studies

For macro scale modelling, data on the value of assets can be transferred from studies in other areas, although this must be done with care. This is only generally recommended for large scale studies with relatively lower precision requirements.

d) Object-oriented assessment of building values

For more detailed studies, the determination of object oriented asset values is sensible. For residential buildings, typical market prices are often published. Data can be collected from official statistics or from real estate agents, if the former are not available. Standard construction costs for different property types can also be collected. For example, in Germany, there are official guidelines on the assessments of buildings (Normalherstellungskosten, NHK, quoted in Messner et al., 2007).

e) Object-oriented assessment of property components

For even more detailed studies, the methodology in the UK's Multi-Coloured Manual can be followed. For 100 types of residential properties, expert judgement is used to calculate a typical inventory. A similar approach is conducted for non-residential property. A further example of this approach is the FLORETO method developed by TUHH in Hamburg (Manojlovic et al., 2010). These approaches involve constructing information on the assets from the bottom up, by considering the fixtures and fittings for individual properties.

The next step is then to estimate the damage functions, and there are two broad (although not exclusive) approaches to this. Firstly, there is the **empirical** approach which uses historical data to develop the relationship between the inundation characteristics and the damage. The other approach is **synthetic**. Some authors have differed slightly on the meaning of this term. On the one hand, Merz et al (2010) have described this approach as being developed by applying "what-if" scenarios. On the other hand, Edmund Penning-Rowsell, quoted in Messner et al (2007, Chapter 4) states that a synthetic approach does not mean that it is artificial, but rather that it involves the synthesis of all data, including historical data. Merz argues that the synthetic approach and the empirical approach can be combined, whereas Penning-Rowsell would see this as a synthetic approach, with the empirical and synthetic approaches being mutually exclusive. This minor difference is largely semantic, but for the purposes of the CORFU project, it would be clearer if we distinguished the purely synthetic approach which relied on "what-if" analyses, from the empirical approach, and call the mixed class an empirical-synthetic approach, as per Merz et al (2010).

The empirical approach has been used in multiple studies and relies on the existence of reliable historical flood damage data. Examples of such studies include work in Brazil (Nascimento et al., 2007) which used a reference flood event from 2000, work in Japan (Dutta et al., 2003), or the work in Germany (Merz et al., 2004).

If such empirical data exists, it should be used, even if in conjunction with a synthetic approach. Such damage data can be collected either from official agencies, or from insurance companies.

In contrast, the purely synthetic approach has been used in the UK's Multi-coloured Manual, where expertise was used to build a database of absolute damage curves for over 100 building types.

In one study, Neubert et al (2009) described a model used to investigate flood damages in Germany. The model uses an Urban-Structural-Type (UST) approach. USTs are built-up areas with homogeneous characteristics, including formations of buildings and open spaces. The UST can be linked to a building typology, where buildings can be grouped by age and type. They can be detected and described by drawing polygons around areas of typical areas. Examples include single family homes, multi-unit residential buildings. Synthetic water level building damage relationships were developed based on refurbishment costs. This method is both high-resolution and described as bottom-up. This approach requires significant effort, and therefore, this approach is only suitable for small areas.

The work conducted at the Technical University of Hamburg is highly relevant here where synthetic-empirical damage functions have been developed using a knowledge of the typical building types (Manojlovic et al., 2010). This synthetic information data can come from expert advice such as from loss-adjustors, or from insurance data, or even working with construction companies to obtain estimates of the refurbishment costs. Standard building typologies can be assessed by considering their typical contents and building materials. These typical buildings can then be represented in a GIS format so that they come be overlain with the results from hydraulic modelling.

Estimation of damage to vehicles is important. In the literature, damage to vehicles has been assessed with the use of damage functions. In the US, damage to vehicles has been assessed using depth-damage curves (Scawthorn et al., 2006b), where different relative damage functions have been developed for cars, light trucks and heavy trucks. A certain number of vehicles per head of population can be calculated, and relative curves were developed. Because of the nature of vehicles, such functions might be easily transferable. Similar functions have been used in the Netherlands in the Dutch Standard Model and in Germany with the MERK model.

Assessing the damage for infrastructure is difficult. Unless empirical data exists, synthetic approaches, similar to those used for residential and non-residential properties, must be used. Refurbishment costs could be obtained from the agencies that manage and operate these facilities. In the US, costs for the repair or replacement of water supply networks are needed to ascertain the flood damage (Scawthorn et al., 2006a, Scawthorn et al., 2006b).

To take a further example, replacement costs for roads can be obtained from transport ministries. It was shown by Kreibich et al (2009) that flow velocity was strongly linked to structural damage to roads, and so velocity rather than depth might be the more appropriate variable to use. Damage costs for roads and other railways should be quoted per unit length, rather than area. This approach is followed, for example, in Queensland, Australia (Natural Resources and Mines, 2002).

For very specific assets such as hospitals, local knowledge or use of official statistics will be vital in assessing their value. It is not possible to prescribe a method here.

Damage functions and assets values can be transferred from one area to another. This may well be advisable for large scale (macro or meso) studies were no local data exists, and there are strong similarities between the two study areas. It is also more advisable to transfer relative damage functions, as these are independent of the asset values. This point is made by Merz et al (2004).

For the CORFU project, the development of the damage data will be highly dependent on the data that exists. Its quality and reliability should be considered, so that the data is not used, merely because it exists.

3.5 Calculation of Expected Annual Damage

Up to this point, the estimation of flood damage has been implicitly considered for modelling based on single events. Expected Annual Damage (EAD), sometimes referred to as the Mean Annual Damage or Average Annual Damage, is a commonly used measure of flood risk, which is a function of the consequences of a range of events and their likelihoods. It can be simply stated as “the average damage per year that would occur in a particular area, as a result of flooding, over a very long period of time” (State Government of Victoria 2010).

EAD can be expressed in mathematical terms, and is shown with the following formulation (Samuels et al. 2009):

$$E(X) = \int_0^\infty x f(x) dx$$

In this formulation, x is a continuous variable that represents flood damage, and $f(x)$ is the continuous probability density function of flood damage.

Another way of presenting the probability is to treat it as the probability that it will be exceeded in a year, known as its annual exceedance probability.

$$F_X(x) = \int_x^\infty f_x(u) du$$

With this formulation, EAD can be expressed as

$$EAD = \int_0^1 D(F) dF$$

where $D(F)$ is the damage as a function of the annual exceedance probability, F.

It is however, impossible to precisely define the relationship between the probability of some flooding event and the damage it would cause. In practice, the calculation of EAD requires some sampling of the damage function. This can be achieved by estimating the damage for a range of events and scenarios. With a selection of events, EAD becomes the area under the sampled flood-damage annual exceedance probability curve (Arnell 1989). This is shown in Figure 3. Deliberately, the damage-probability curve shown here does not meet the axes. In practical terms, events will be selected that either have a low (but non-zero) exceedance probability, or a higher exceedance probability, that has causes little (but non-zero) damage. This is the most straightforward and commonly applied definition of EAD and it could be recommended in the CORFU project.

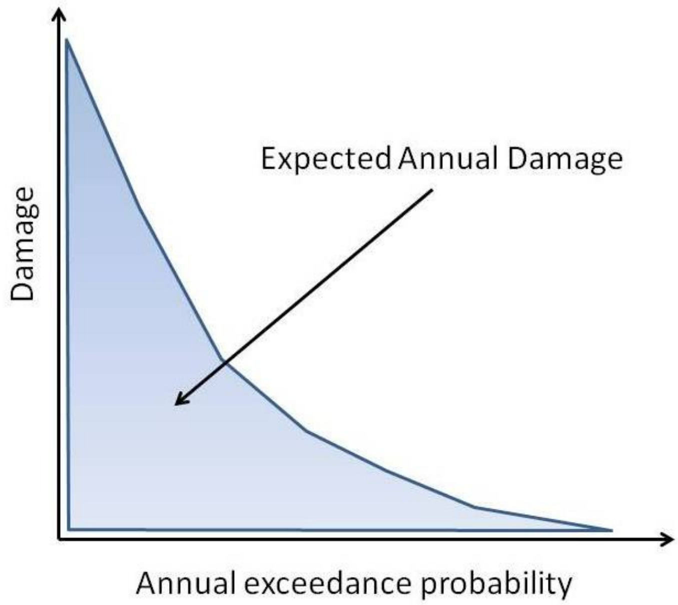

Figure 3 - Expected Annual Damage

There is little advice in the literature on the how many flood events to sample when calculating the EAD, and what their range of probabilities should be.

It is recommended as part of the CORFU project that *at least* three flood events are used to estimate the EAD, although the more that are used, the more reliable the results will be. When selecting the range of events, it should be noted that the calculation is typically dominated by the mid-range events, rather than the extreme events at the extremes. The largest flooding event (with the lowest exceedance probability) chosen should represent a rare event, which produces significant flood damage. At the other end of the scale, a relatively more frequent event should be selected that leads to a minimal level of flood damage.

It is important to be clear on what these exceedance probabilities relate to. Do they relate to the probability of the weather conditions that lead to flooding (e.g. the extreme rainfall), or do they refer to the probability of flooding itself, which may be the result of a series of infrastructure failures as well as extreme weather and antecedent conditions. The exceedance probabilities should relate the probability of the flooding itself. In the case where local extreme precipitation is the leading cause of flooding (pluvial flooding), it may be reasonable to assume that the probability of the rainfall is equal to the probability of the flooding. However, where flooding is a result of a combination of events, such as particular combinations of local rainfall and antecedent conditions, rainfall in the upstream catchment, tidal levels etc.), then this assumption is not valid. Therefore, the events that lead to flooding in the case study areas should be considered carefully, and the flooding probabilities determined accordingly.

Once the events have been chosen and the corresponding flood maps have been produced, the calculation of EAD can be performed using the CORFU Flood Damage Assessment Tool. The tool links multiple flood maps with their corresponding exceedance probabilities through a text file, and then performs the damage calculations for each flood map. The tool finally performs the integration of the damage-probability function to provide EAD estimates.

4 Indirect and Intangible Damage Model Components

This deliverable focuses on the guidelines for direct tangible damage assessment. Methodologies for the assessment of other components of damage and their use within CORFU case studies are described elsewhere:

- Impacts of flooding on traffic (indirect tangible damage) and application of the methodology in Beijing are described in deliverable D3.4 in section 3.4.1.
- Health impacts of flooding (direct intangible damage) and application of the methodology in Dhaka are described in deliverable D3.5.

5 Conclusions

The CORFU direct damage methodology can be summarised as follows.

- The CORFU project is interested in studying cities or areas within cities. Therefore, either a meso or micro-scale approach should be adopted. Whether individual buildings or land-use units is considered will depend on the availability of land-use and asset building.
- Basic economic principles should be adhered to. These include the use of depreciated costs, and the avoidance of double counting.
- The assets at risk should be subdivided into residential, non-residential and technical infrastructure. Local knowledge should be applied to develop an appropriate subcategorisation of assets. It is important not to exclude any infrastructural assets, particularly those that may be buried.
- For the development of flood damage functions, at a minimum, flood extent and depth should be considered. Such information will be obtained from the hydraulic modelling work of WP2. If empirical data is available, it should be used. However, synthetic approaches may well be necessary where such data is not available.
- Flood damage functions should be generated with a view to incorporate both structural and non-structural resilience measures.
- Expected Annual Damage should be calculated, using information from at least three different flood events, with a reasonable range of probabilities, using the CORFU Flood Damage Assessment Tool.

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APPENDICES

The CORFU flood damage assessment toolbox

1 Introduction

The WP3 in CORFU project aims to develop tools that can be applied to assess various types of flood damage. With the different data availability of each case study, the flexibility of data requirement is the main concern for the tool development. To integrate with the hydraulic modelling results from the DHI MIKE Urban software, the tools are mainly developed using python script and the ArcObjects, the geoprocessing functions within the ESRI ArcGIS software. Most of GIS software also provide similar functions with their own syntax. The python script can be easily adapted by changing the ArcObject functions to the corresponding functions in other GIS software. With the detailed explanation of the algorithm, any modeller who uses different GIS software can easily implement the same functions on other platforms.

Some algorithms applied herein are difficult or inefficient to implement under the GIS environment, hence, separate executable programs are developed to provide those functions. The standard GIS data format is adopted as the inputs and the outputs of the standalone executable programs so the data can be easily imported or exported in GIS software.

This document will report the general method and the guideline to use the tools. A journal paper that describes the technical issues that we've experienced during model development has been submitted to the Environmental Modelling and Software. The draft manuscript is attached in the Appendix.

2 Methodology

The input for calculating direct tangible flood damage includes h**azard characteristic, components at risk and damage functions**. The hazard characteristic can be (a) flood depth, (b) flood velocity, (c) concentration of contamination, etc. The components at risk can be (a) building uses, (b) land cover classes from urban growth model, (c) population density, etc. The damage functions can be for (a) depth and damage, (b) velocity and safety, (c) dose and response, etc.

The direct tangible damage assessment includes the residential properties, non-residential properties, technical infrastructure, vehicle & cars, and agricultural damage (Messner et al., 2009). The depth-damage curve is used to represent the flood damage of a specific land use type based on the flood depth. For the case that flood duration is taken into account, more than one curve could be applied to the same land use type.

In the following approach, the residential and non-residential property damage are merged as building content damage, assuming that the depth-damage curves (DDCs) are available for both types of properties. The damage to vehicles can be reflected in the DDCs or to be assessed separately, depending on the condition of case study. The individual tool for assessing the vehicle damage will be developed later. The technical infrastructure such as transportation network and flood defences will also require a separate model for assessment. The agricultural products are neither included in the study. Figure 1 shows the data requirement for calculating building content damage. The minimum data requirement for the model includes the maximum flood depth, the land uses and the DDCs.

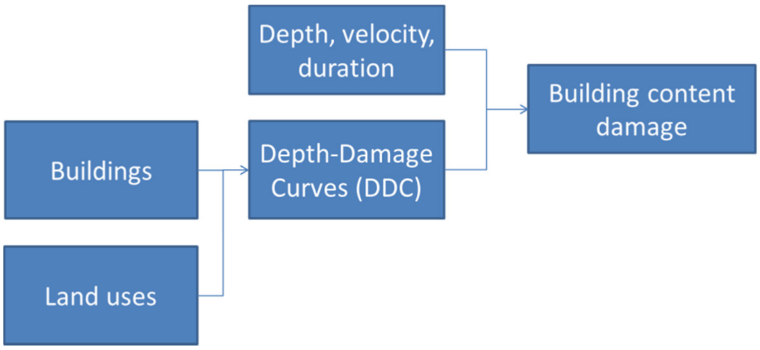

Figure 4 The data requirement for building content damage assessment

If the statistic information about building and land uses are only available in block or district levels (ex. 30% area of a district is residential, 20% is commercial, etc.), a simplified approach would be used. Assuming the buildings and land use distributions within a block or a district are homogenous, the weighted damage function of each block or district can be determined. Then, the tool can be used to assess the total damage in block or district level[3].

The same model can also be used for assessing the health impact. The assessment of health impact in building level may not be available (neither appropriate). It would be more sensible to look at the block or district level. We can adopt the demographic information to build up the Contamination-Health Impact curve for each block or district, then, estimate the health impact in the area.

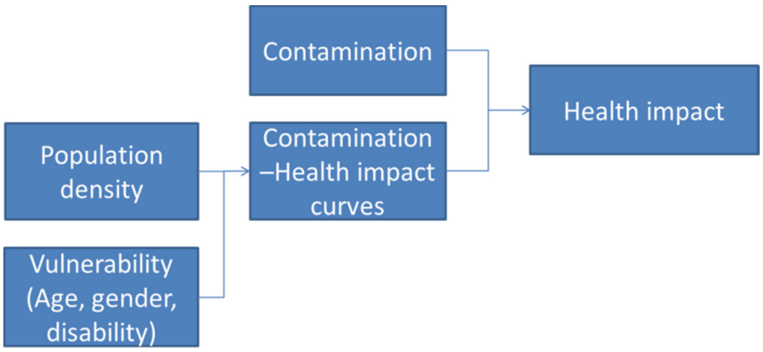

Figure 5 The data requirement for health impact assessment

2.1 Input data availability

The characteristic data often have two types of data format, i.e. irregular mesh (polygons) or regular grid. For various combinations of data input, different methods can be applied to determine direct flood damage, which are described as following.

2.1.1 For irregular mesh of hydraulic modelling

For hydraulic modelling that uses irregular mesh, the output would be in polygon format. In this case, buildings are often considered as solid blocks that runoff cannot flow through such that no flood depth inside a building is available. A post-processing algorithm is required to assign a flood

[3] If other spatial information is available from other sources such as Google map, it might be used to refine the spatial distribution of the aggregated information. For example, the green areas in a city can be easily identified from the Google map. Then, the building distribution would be confined to the non-green areas. However, it would require an additional tool for the analysis.

depth value to each building. Since a building has a unique flood depth value, the flood damage can be estimated by combining the land use of building and damage function.
If each building only single major land use type, the damage can be estimated using the damage function corresponding to the specific land use and the unit for the damage function should be per building. If the damage function per unit area is used, then, the input information should include the areas of buildings.
If each building may contains several different land use types (Barcelona case), the damage estimation should include the components of various land use. The combination of different land use type may vary from building to building such that it would be difficult to define the damage function for each building for its specific combination of land use. Therefore, to simplify the input, the damage functions per unit area are used together with the areas of different land use types in a building to estimate the damage of each building.

2.1.2 Regular gird hydraulic modelling that takes building height into account

In this case, neither flood depth inside a building is available from modelling result. A post-processing algorithm is required to select the flood depth from raster output data and assign it to a building. Since a building has a unique flood depth value, the flood damage can be estimated by combining the land use of building and damage function (per building), which has been described in above section.
For the above two modelling approaches, the selection of representative depth of each building would be an important issue, especially for a large building with several entrances at different elevations.

2.1.3 Regular gird hydraulic modelling with bare DEM

When the bare DEM is applied to hydraulic modelling, a building often contains more than one grid cell. Using a single value to describe a building would have the above-mentioned problem for selecting the representative value. Another approach is using the damage functions per unit area to calculate the damage inside buildings. The approach requires a building land use raster for damage estimation, which results in a new issue: the resolution for assessment.
The building land use raster can be the same resolution to the hydraulic modelling. However, if the resolution is too coarse, then, the estimation would be less accurate. When a coarse resolution is used, the conversion from polygon to raster may introduce errors because the building boundaries do not align with the cell boundaries. Hence, a buffer is applied to ensure all the building areas are covered for estimation, and a building mask is required to avoid the extra building areas introduced due to the use of coarse resolution.

2.1.4 Regular gird hydraulic modelling with bare DEM and lacks of detailed building information, or detailed building information is inappropriate (e.g. demographic data for health risk)

If the land use zoning is available (in the case, should be regional zoning polygon), the assessment is recommended to use the resolution of hydraulic modelling. The land use zoning polygons are converted into raster for estimation. The damage functions will represent the homogenous attribute for the large land use zone.

3 CORFU damage assessment tool

The tools are designed to simplify the process for damage assessment. Users can choice an appropriate tool based on the purpose for analysis and the input data type. A GUI dialogue box will ask for the required input data and allow the user to change some parameters for modelling. Then, the whole algorithm will be executed and the final result will be added to the GIS windows automatically.

The toolbox contains four categories of tools, the Raster, Vector, Barcelona and other tools.

3.1 Hazard to Damage (Raster version)

The tool calculates direct content damage based on the flood depth raster and the building land use polygons. The two datasets are in different format such that the polygons are converted into raster format for combined analysing, and the results are integrated back to polygon format.

3.1.1 Inputs

3.1.1.1 Workspace

The workspace is the folder where scripts and executable programs are saved. All the permanent modelling results will be saved in Workspace as well. A scratch folder “Temp” will be created under the Workspace for saving Intermediate results.

3.1.1.2 Hazard characteristic

The toolbox takes the maximum hazard characteristic information in raster format as the input, which can be directly from DHI MIKE Urban modelling results. The hazard characteristic can be flood depth, flood velocity, concentration of contamination, etc. Together with their corresponding damage functions (see below), the damage can be evaluated.

3.1.1.3 Components at risk

The components at risk represent the spatial variation of damage functions. The components can be land use types, land cover types obtained from urban growth model, or population densities of districts, and the data can in either polygon or raster format.

When a polygon shapefile is used, it should include two fields in the attribute table: “Index” and “Landuse”. The “Index” is a unique value to each polygon that will be used to sum up the damage from computed raster file for cells within the same polygon. The “Landuse” refers to the damage functions to be used for calculation.

When the raster is used, the raster value should refer to the damage functions to be used for calculation. However, when the land cover classes obtained from the urban growth model are used as the raster, a pre-processing is required to generate the damage functions for different land cover types.

If the component polygon data do not include land use information, it should be overlapped with land use data to generate the required information. The direct conversion from land use data to raster may include the non- component areas. It will depend on the definition of damage functions.

3.1.1.4 Damage functions

The damage functions are required for calculating the flood damage and must be specified in a text file. The details of the file is described as following:

"*" can be used as comment line indicator. For a set of damage function, it starts with a line that has "DF" at the beginning. The "DF" is followed by the index (Curve_ID, integer), Name and of damage function curve, and comments. The damage function contains a series of hazard-damage data. The Curve_ID should correspond to the index of land use.

The users can use as many points as needed to define the data. The program will recognise a new set of damage function when it reads a new "DF" indicator. The hazard values of a damage function are suggested to increase monotony. Otherwise, the program will use the first damage value for calculation.

The current example adopts the damage function data from "The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques-2010 (Multi-Coloured Manual)", Middlesex University, UK.

Land use type	**Corresponding category in MCM**
Residential	Residential sector average, Shorter than 12 h
Industrial	Factory/Works/Mill
City Centre	High Street Shop
Highly built-up area	Flat
Technical	Computer Centres (Hi-Tech)
Runway	Miscellaneous (Weighted mean)
Parking	Miscellaneous (Weighted mean)
Sport	Sports and Leisure centres
Recreation	Sports and Leisure centres
Cemetery, Churchyard	Cemetery/Crematorium

3.1.1.5 UG land cover

If "UG land cover" is selected, it indicates that the "Components at risk" is the land cover obtained from urban growth model. In this case, the "Reality UGM Correlation" (See 3.8) should be run in advance to get the relationship between land cover and buildings such that new damage functions for UGM land covers will be created and used.

3.1.1.6 EAD configuration file

If provided, the tool will calculate the EAD using the events and probability provided in the given configuration file.

The limit of the GUI in the ArcToolbox will result in a complex dialog if all the flood depth files and their corresponding return period are included. Therefore, an external text file (default name: EAD_Configure.txt) will simply the input interface. The EAD configuration text file includes two columns, i.e., the flood depth filename, and its corresponding return period. The return period can be defined in any order, the script and external program will sort out the return period and present the results in ascending order.

3.1.1.7 Cellsize for calculations

The default setting for the analysing cell size is the resolution of hydraulic modelling results (Components at risk). However, if this resolution is too coarse, the results may not reflect the spatial variations in land-use or components. Therefore, the cells for analysing damage can have a finer

resolution than that of the hydraulic modelling results, to provide more accurate results. This, however, comes at the cost of increased computer processing time.
If a cell size value is selected that is larger than that of the hydraulic model results, this value will only be used to generate the component index and land use rasters. The damage per unit area will be calculated using the resolution of the hydraulic model results to avoid averaging of the flood depths over an analysing cell. This is important as the depth-damage functions are not linear, and averaging of the flood depths could lead to inaccuracies in the results.
The value of this cell size should be an integer fraction (e.g. 1/5 or 1/4) of the hydraulic modelling results resolution. Otherwise, some of these cells would span adjacent flood depth results cells. This again, leads to the potential for inaccuracies, as a result of averaging, and the inherent loss of information. An alternative solution to this problem would be to generate a finer raster in the "overlapped" sections, but this would lead to increased computer processing times, and so this solution is not favoured.

3.1.1.8 Mask resolution (optional)

Larger analysing cell size will result in over-estimation of component area, if a component on occupies a small portion of a cell. The mask is applied to clip out non-component areas from the analysing result to reduce the assessment error.
The value of this cell size should be an integer fraction (e.g. 1/5 or 1/4) of the hydraulic modelling results resolution. Otherwise, some of these cells would span adjacent flood depth results cells. This again, leads to the potential for inaccuracies, as a result of averaging, and the inherent loss of information.

3.1.1.9 Binary Output (optional)

The option allows the users to save the raster data in binary file format to reduce the file size. If unselected, the raster data will be saved in Ascii text format.

3.1.1.10 Hazard snapshots (optional)

Time-series of hazard snapshots from hydraulic modelling results (e.g. dfs2 file). The snapshots are used to determine the duration of hazard which is above the given threshold (L).

3.1.1.11 Snapshot interval (optional)

The interval between two snapshots (minute).

3.1.1.12 Hazard threshold (optional)

The threshold that a hazard starts to have impact. It is used to determine the calculate the duration of hazard.

3.1.1.13 Hazard duration threshold (optional)

The duration that a hazard lasts long enough to switch to a different damage function (hour), which is defined in a DV_configuration.txt.

3.1.2 Outputs

3.1.2.1 Component index raster (co_index.flt or co_index.asc)

The raster, generated by the built-in "PolygonToRaster" function of the ArcGIS geoprocessing, is the unique index of each building in the resolution of building mask, which is used to clip out non-building areas and sum up the total damage of all raster cells with the same index.

3.1.2.2 Damage function index fine raster (df_id_fine.flt or df_id_fine.asc)

The raster, generated by the built-in "PolygonToRaster" function of the ArcGIS geoprocessing, is the land use index of each building in the resolution of building mask. However, the damage calculation in such resolution would require extraordinary computing resources. Therefore, the raster is aggregated into coarsen resolution (see below).

The direct use of the "PolygonToRaster" to generate the building land use raster in coarse resolution is inappropriate because the non-building areas often dominate the area of a coarse cell. Therefore, the building land use fine raster must be created first and then aggregated to coarse raster. But the built-in "Aggregate" function of ArcGIS geoprocessing only allow the use of Maximum, Minimum, Mean of fine cell values to represent the new value in the coarse cell. It fails to describe the coarse cell using the dominating fine cell value. An external program "Aggregate.exe" is applied to select the majority of the fine cell values as the new coarse cell value.

3.1.2.3 Damage function index coarse Raster (df_id.flt or df_id.asc)

The raster, generated by the external program "Aggregate.exe", is the land use index of each building in the resolution of analysing cellsize. It is used together with the hazard characteristic and damage functions to determine the direct building content damage.

3.1.2.4 Hazard characteristic coarse raster (HazardMax.flt or HazardMax asc)

The raster, generated by the built-in "RasterToFloat" or "RasterToAscii" function of the ArcGIS, is in the resolution of "Cellsize for calculations".

If EAD configuration file is given, the hazard.flt or hazard.asc are renamed as HazardMax[XXX]y.flt or HazardMax [XXX]y.asc. [XXX] is the return period corresponding to the hazard characteristic file.

3.1.2.5 Damage coarse raster (Damage.flt or Damage.asc)

The raster, generated by the external program "HIA.exe", is the direct building content damage per unit area in the resolution of analysing cellsize. The reason for using external program is that the hazard characteristic could be any values that are not defined in the damage functions. Interpolation is needed to calculate the damage for a hazard characteristic between the sampling points of the damage functions.

If EAD configuration file is given, the Damage.flt or Damage.asc are renamed as Damage[XXX]y.flt or Damage[XXX]y.asc. [XXX] is the return period corresponding to the damage file. A Component_EAD.flt or Component_EAD.asc will be also generated to represent the EAD value for each cell.

The domain for the Component Damage raster grid will have the same lower left corner reference point as either the (C) damage function index raster or (D) hazard characteristic raster, whichever has a finer cell size. If the domain has a different extent from both raster grids, only the cells completely inside the common extent of all raster grids will be evaluated.

The current version of the tool assumes that all raster grids have the same lower left corner reference point. An updated version will be developed to allow different reference points in different raster grids.

3.1.2.6 Component _Damage_Sum.txt

The text file, generated by the external program “CDS.exe”, is the direct building content damage of each building. When clipping out the damage, the tool uses (A) the building index raster grid to clip out (E) the building damage raster to calculate the damage of each building. If both domains have different extents, only the cells completely inside the common extent of all raster grids will be evaluated.
The current version of the tool assumes that all raster grids have the same lower left corner reference point. An updated version will be developed to allow different reference points in different raster grids.
If EAD configuration file is given, the Component_Damage_Sum.txt is renamed as Component_Damage_Sum[XXX]y.txt as the damage for [XXX] return period of each building. The Component_EAD.txt that summarises the damage for different return period and the EAD of each building will be also generated.
For the assessment using land cover type, which doesn’t include a shapefile of component, the result will not produce the Component_Damage_Sum.txt.

3.1.2.7 Component Damage Shapefile (Component_Damage.shp)

The “Component _Damage_Sum.txt” is associated with the original building shape file to generate a new shape file “Component_Damage.shp” as the final result of the direct building content damage of each building. The shape file is automatically displayed in the ArcMap using the default legend groups “Component_Damage.lyr”.
If EAD configuration file is given, the “Component_EAD.txt” is associated with the original building shape file to generate a new shape file “Component_EAD.shp” as the final result of the direct building content damage for different return period and the EAD of each building. The shape file is automatically displayed in the ArcMap using the default legend groups “Component_EAD.lyr”.
For the assessment using land cover type, which doesn’t include a shapefile of component, the result will not produce the Component_Damage.shp.

3.1.2.8 Damage_Category_Summary.txt

The “Damage_Category_Summary.txt” is, calculated based on ‘Component_Damage.shp’, the sub-total damage of same land use or land cover type.

3.2 Hazard to Damage (Vector version)

3.2.1 Inputs

3.2.1.1 Workspace

Same as 3.1.1 (A).

3.2.1.2 Components at risk (Component Polygons)

Same as 3.1.1 (C). But, the component polygon data should include three attributes: component index, land use, and hazard characteristic.

3.2.1.3 Damage functions
Same as 3.1.1 (G). However, the unit should be damage per building. If the damage functions are defined in unit area, then the building area is required for calculating the total damage.

3.2.2 Outputs

3.2.2.1 ComponentInfo.csv
The tool first converts the dbf file that associates with the shapefile of building polygon into a csv file "ComponentInfo.csv", then it calls the external executable program "HIAV.exe" to calculate the damage.

3.2.2.2 Component _Damage_Sum.txt
The "HIAV.exe" reads the "ComponentInfo.csv" and damage functions and calculates the damage according the maximum hazard characteristic, damage function index and the corresponding damage function of each building. The results are saved as "Component_Damage_Sum.txt" as the direct building content damage of each building.

3.2.2.3 Component Damage Shapefile (Component_Damage.shp)
Same as 3.1.2 (G).

3.3 Hazard to Damage (Barcelona version)
In general, the tool is similar to "Hazard to Damage (V)" that calculates direct building content damage based on the flood depth and the building land use type. Both datasets are polygon t such that the processing can be done in vector format. The difference is that the land use information for the particular case in Barcelona. There are six land use types defined in the case study. But each building may have different combinations of the six land use types. Meanwhile, the 1st basement and further down basements may also have different combinations of land use types and flood depth.

3.3.1 Inputs

3.3.1.1 Workspace
Same as 3.1.1 (A).

3.3.1.2 Components at risk *(Component Polygons)*
The component polygon data should include the attributes: component index, areas of the six land use types on the ground floor, 1st basement and further down basement, and flood depth on the ground floor.

3.3.1.3 Damage functions
Same as 3.1.1 (G). The unit is damage per unit area. Additional three parameters C1, C2 and C3 are required to specify the multiplying factor as the flood depth on the ground floor, 1st basement and further down basement.

3.3.2 Outputs

3.3.2.1 Barcelona_Components.csv

The tool first converts the dbf file that associates with the shapefile of building polygons into a csv file "Barcelona_Components.csv", then it calls the external executable program "HIAVB.exe" to calculate the damage of each building.

3.3.2.2 Component _Damage_Sum.txt

The "HIAVB.exe" reads the "Barcelona_ Components.csv" and damage functions and calculates the damage according the maximum flood depth, land use index and the corresponding damage function of each building. The results are saved as "Component_Damage_Sum.txt" as the direct content damage of each component.

3.3.2.3 Component Damage Shapefile (Barcelona_Component_Damage.shp)

The "Component_Damage_Sum.txt" is associated with the original component shape file to generate a new shape file "Barcelona_Component_Damage.shp" as the final result of the direct building content damage of each building. The shape file is automatically displayed in the ArcMap using the default legend groups "Barcelona_Component_Damage.lyr".

3.4 Depth2EAD (Barcelona)

Same as 3.3. But the tool calculates direct building content damage of different return periods and the EAD at once.

3.4.1 Inputs

Same as 3.2.1. Additional EAD Configuration text file is required to specify the flood depth fields and their corresponding return periods.

3.4.1.1 Workspace

Same as 3.1.1 (A).

3.4.1.2 EAD Configuration

Same as 3.4.1 (A).

3.4.1.3 Buildings

Same as 3.3.1 (B). But the flood depth fields specified in the EAD Configuration files should be included in the building information.

3.4.1.4 Damage functions

Same as 3.1.1 (G).

3.4.2 Outputs

3.4.2.1 Component Damage Sum (CDSum[XXX]y.txt)

The "HIAVB-EAD.exe" reads the EAD Configuration file, "Barcelona_ Components.csv" and "DFC.txt" and calculates the damage according the maximum flood depth, land use index and the corresponding damage function of each building. The results are saved as CDSum[XXX]y.txt as the direct building content damage of each component for [XXX] return period.

3.4.2.2 Component Damage Shapefile (Barcelona_Component_Damage_[XXX]y.shp)

The "CDSum[XXX].txt" is associated with the original component shape file to generate a new shape file "Barcelona_Component_Damage_[XXX]y.shp" as the direct content damage of each component for [XXX] return period.

3.4.2.3 Barcelona_Componen _EAD.txt

The text file, generated by the external program "HIAVB-EAD.exe", is the direct building content damage for different return periods and the EAD of each building.

3.4.2.4 Component EAD Shapefile (Barcelona_Component_EAD.shp)

The "Barcelona_Component_EAD.txt" is associated with the original building shape file to generate a new shape file "Barcelona_Component_EAD.shp" as the final result of the direct building content damage for different return periods and the EAD of each building. The shape file is automatically displayed in the ArcMap using the default legend groups "Barcelona_Component_EAD.lyr".

3.5 Component damage landuse sum

This tool will calculate the sub-total damage of all land use or land cover types and produce a statistic report 'Damage_Category_Summary.txt'. See 3.1.2 (H).

3.6 Component damage sum

This tool will call the external program "CDS.exe" to sum up the damage of each component polydon from either Damage.flt or Damage.asc, and generate 'Component _Damage_Sum.txt', see 3.1.2 (F).

3.7 Component landuse area sum

This tool will calculate the sub-total area of all land use or land cover types and produce a statistic report 'Damage_LU_Summary.txt'.

3.8 Reality UGM Correlation

This tool compares the land uses in the Component.shp and the land cover raster from the urban growth model to calculate the areas and ratios of land uses in each land cover type. The results are saved as 'UGM_Area.txt' and 'UGM_Area_Ratio.txt', which are necessary when using UGM land cover types for damage assessment.

Submitted journal article

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