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Global flood depth-damage functions

Methodology and the database with guidelines

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Abstract

Assessing potential damage of flood events is an important component in flood risk management. Determining direct flood damage is commonly done using depth-damage curves, which denote the flood damage that would occur at specific water depths per asset or per land-use class. Many countries have developed flood damage models using depth-damage curves based on analysis of past flood events and on expert judgement. However, the fact that such damage curves are not available for all regions hampers damage assessments in some areas. Moreover, due to different methodologies employed for various damage models in different countries, damage assessments cannot be directly compared with each other, obstructing also supra-national flood damage assessments.

To address these problems a globally consistent database of depth-damage curves has been developed. This dataset contains damage curves depicting fractional damage as a function of water depth as well as the relevant maximum damage values for a variety of assets and land use classes. Based on an extensive literature survey normalised damage curves have been developed for each continent, while differentiation in flood damage between countries is established by determining maximum damage values at the country scale. These maximum damage values are based on construction cost surveys from multinational construction companies, which provide a coherent set of detailed building cost data across dozens of countries. A consistent set of maximum flood damage values for all countries was computed using statistical regressions with socio-economic World Development Indicators. Further, based on insights from the literature survey, guidance is also given on how the damage curves and maximum damage values can be adjusted for specific local circumstances, such as urban vs. rural locations or use of specific building material. This dataset can be used for consistent supra-national scale flood damage assessments, and guide assessment in countries where no damage model is currently available.

1 Introduction

1.1 Project motive

The main objective of the Directorate General Joint Research Centre (DG JRC) is to provide science-based support to the policy process. In particular, the climate and energy policy areas are partly covered by Directorate C on Energy, Transport and Climate. Regarding climate policy, the JRC has coordinated the PESETA projects (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) with the objective to make a consistent multi-sectoral assessment of the impacts of climate change in Europe throughout the 21st century.

Under Action 4 of the EU Strategy on Adaptation to Climate Change, the JRC will work on estimating the implications of climate change, and undertake a comprehensive review of what global climate change will mean for the EU. That simulation exercise requires conducting a series of sector-specific climate impact assessments. One of those areas relates to riverine and coastal floods.

Economic damages due to floods are one of the main climate impact categories. Several studies have assessed flood damages at the local (e.g., Bouwer et al. (2010)) to regional scales (e.g. Linde et al. (2011)), whereas fewer studies have performed continental flood damage assessments (e.g. Feyen et al. (2012), Rojas et al. (2013), Jongman et al. (2014)). Recently, also global flood impacts assessment tools have been developed (Hirabayashi et al. (2013), Ward et al. (2013), Arnell and Gosling (2014)). Such assessments, however, are currently limited in evaluating the impacts from flooding due to the absence of a comprehensive global database of flood damage functions that can translate flood water levels into direct economic damage. There are various local-to-regional damage models available, especially for Europe and the US, but for most other world regions little information is available on the relation between the occurrence of the physical event and the consequent economic implications.

1.2 The report and the database

This publication consists of the report and the accompanying database. The report provides detailed description of the methodology applied to construct the flood depth-damage functions. Also, a set of guidelines is developed to facilitate use of the accompanying database of functions. The database is provided in a separate spreadsheet format.

The presented depth-damage functions are provided for 214 countries for the following damage categories:

- Residential buildings,
- Commerce,
- Industry,
- Transport,
- Infrastructure, and
- Agriculture.

Because the data used in this study comprise both fluvial and marine flooding, the damage functions constructed are not associated with specific type of floods and they can at first be used for the damage assessment of a generic inundation event.

1.3 Structure of the report

The report consists of five chapters and a set of appendices. Chapter 2 documents the methodology applied to perform the literature review and to collect the relevant data, followed by documentation of the data processing in order to derive the country-specific depth-damage functions for the impact categories. The derived damage functions and the corresponding maximum damage values are presented and discussed in Chapter 3, while Chapter 4 demonstrates an approach to determine an uncertainty associated with the damage functions and the maximum damage values.

The instructions and guidelines on use of the damage functions are set out in Chapter 5.

The flood depth damage-functions are provided in the accompanying spreadsheet file (MS Excel). The database collects the fractional damage functions which allow to determine the percentage of the asset being damaged at specific flood depth, as well as the associated maximum damage values which, when used with the fractional damage functions, allow to assess value of damage.

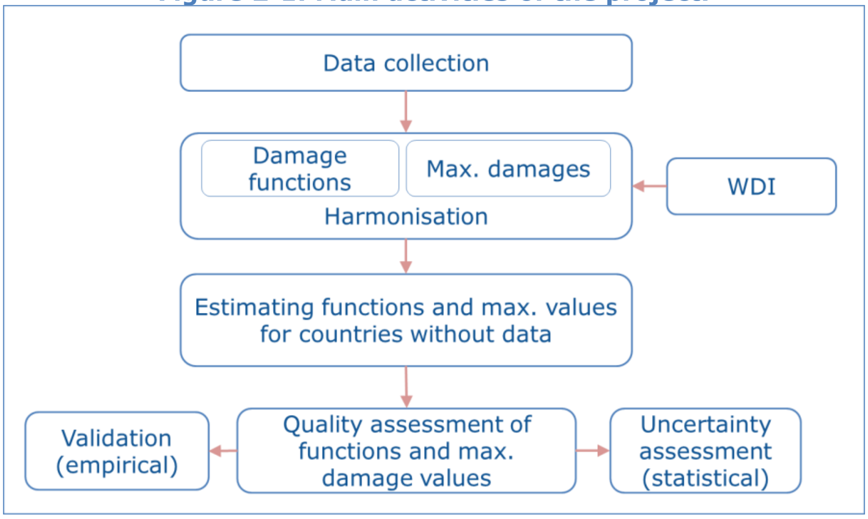
2 Method

2.1 Introduction

This chapter documents the methodology applied for the literature review and collection of the relevant data and, subsequently, it documents the process of derivation of the country-specific depth-damage functions for the impact categories.

Figure 2-1 shows a flowchart of the project's activities, which are subsequently briefly overviewed.

Figure 2-1: Main activities of the project.



A short enumeration of the project activities:

1. Data collection:
   - Review of literature on flood damage data (damage functions and maximum damage values);
   - Recording of the country-specific quantitative data;
2. Flood depth-damage functions:
   - Normalization (when necessary) to fit the full 0-1 range of the damage factor;
   - Derivation of continental damage functions per land-use class;
   - Construction of generic global damage curves for agriculture and roads from limited data;
3. Maximum damage values:
   - Harmonisation of the damage values to 2010 price level and to Euros;
   - Adjustment of the maximum damage values where the damage functions were normalised;
   - Harmonisation of the construction costs values based on regression analysis to extend the data to countries without known maximum damage values for residential, commercial and industrial buildings;
   - Computation of the maximum damage values based on value added (agriculture) and European data (infrastructure);
4. Uncertainty and validation:
   - Estimated for the damage functions and for the maximum damage values for residential, commercial and industrial buildings;
   - Compared the registered damage to damage calculated using the methods described in this report for flood events in New York City (USA) and Jakarta (Indonesia).

2.2 Data collection

The quantitative data used for constructing the flood damage functions was collected from literature identified in the literature review process, as well as from various sources available at HKV consultants and VU University.

2.2.1 Approach

The literature search has been carried out to collect numerical values for damage functions and maximum damage values. The search focussed on data for countries and regions outside Europe because the European countries have been investigated extensively for the report on European Damage Function in 2007 (Huizinga, 2007). No publications on significant improvements related to the European damage functions were found, however the data for the damage class "Transport" was included, as this was a new additional damage class for this research.

Search strings were submitted to Internet search engines Google and Bing. At least the following search words and combinations of thereof were submitted in the different languages:

English:

- Flooding, damage, function, inundation, stage, depth.

German:

- Überschwemmung, Schaden, Funktion, Inundation, Flut, Hochwasser, Tiefe.

French:

- Inondation, dommage, fonction, base de donnee, crue, profondeur.

Spanish:

- Inundación, daños, funciones de daño, profundidad.

Portugese:

- inundação, damages, funções de dano, profundidade.

The results were further filtered on the geographic relevance and, based on available references in relevant reports, new additional documents were searched for. The identified publications were screened for quantitative information on flood damage calculation.

2.2.2 Findings

The literature search produced a considerable amount of detailed information. Table 2-1 below shows those countries for which quantitative information about flood damage calculation was found.

Table 2-1: Quantitative damage data available from literature.

Continent	***Country***
Asia	Bangladesh Cambodia China India Indonesia Japan Laos Pakistan Philippines Taiwan Thailand Vietnam
Africa	Malawi Mozambique Nigeria South-Africa
North America	USA Canada
Central and South-America	Argentina Bolivia Brazil Colombia El Salvador Guatemala Haiti Mexico St. Maarten continental
Oceania	Australia New Zealand
Europe	Belgium Czech Republic Denmark France Germany Hungary Norway Sweden Switzerland The Netherlands United Kingdom

The amount of identified data was rather large for the countries and continents with a damage assessment 'tradition', like the USA, Australia, Taiwan, Japan and South Africa. However, in particular for the African continent (except South Africa), the information found was not equally distributed over the continent and concentrated for the sub-Saharan Africa only. This might be due to the fact that floods do not occur very frequently in the Sahara and in the countries north of it. For Europe there were no significant new contributions found in literature since the report of Huizinga in 2007.

2.3 Conversion of maximum damage values to Euro

2.3.1 Correction for inflation

Each collected maximum damage value has to be representative for the price-level of the selected recent year for all data available, set to year 2010. This means that price level values for earlier years have to be corrected for inflation, which was achieved by using Consumer Price Index (CPI). The CPI reflects changes in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The price-level update is based on global CPI information from World Bank (2015).

Correction is performed using the following equation:

$$max.\ damage_{2010} = max.\ damage_{year\ of\ issue} * (CPI^{2010}) / (CPI^{year\ of\ issue})$$

where:

$max\ damage_{year\ of\ issue}$	= maximum damage in year of issue
$max\ damage_{2010}$	= maximum damage for price level 2010
$CPI^{year\ of\ issue}$	= CPI for year of issue
CPI^{2010}	= CPI for 2010

2.3.2 Conversion of reported local currency to Euro

The reported maximum damage values have been converted to Euro using the following exchange rates for the year 2010 (mean annual value).

Table 2-2: Currencies' values for 2010 [€], mean annual value.[4]

Country (currency)	The currency value in Euros
South Africa (Rand)	0.105
US (Dollar)	0.77
Bangladesh (Taka)	0.011
India (Rupees)	0.0165
Thailand (Bhat)	0.024
Indonesia (Rupiah)	0.0000832
Vietnam (Dong)	0.00004
China (Yuan)	0.115
Taiwan (Dollar)	0.024
Japan (Yen)	0.0088
Brazil (Real)	0.44
Mexico (Peso)	0.061
Australia (Dollar)	0.72

2.3.3 Example of the update process

Suppose we have a maximum damage value of 150 000 Taka (Bangladesh) in 1992. This value is updated to Euros at price level 2010 by the following approach:

Example:

- Step 1: convert Taka 1992 to Taka 2010 using CPI: 150 000 * 100/36 = 416 666 Taka
- Step 2: convert Taka 2010 to Euro (2010) using an annual average exchange rate: 416 666 * 0.011 = 4 583 Euro

[4] Sourced from: www.oanda.com/currency/historical-rates, and www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-idr.en.html#

2.4 Approach to determinate continent specific curves per damage class

In this study the damage fractions in the damage curves are intended to span from zero (no damage) to one (maximum damage). The collected data, however, do not always follow this behaviour. If share of the damage does not reach one at a water depth of 6 meters the damage functions are normalised. Normalisation in the context of this study means that the damage factors were recomputed to range from zero to one[5]. This normalisation was undertaken in parallel with adjustment of the maximum damage for the normalised functions. The normalisation allowed assuring validity of taking a mean value of all damage curves to represent the 'average' continental curve. By additionally calculating a sample standard deviation for each flood depth an indication of uncertainty in maximum damage values was obtained (see also section 4.1).

Damage curves have been produced per damage class (residential, commerce, industry, transport, roads, railroads, agriculture) for each continent separately (Africa, Asia, North-America, South/Central-America, Oceania and Europe).

As there are only limited sources for the damage functions of the classes 'Infrastructure/roads' and 'Agriculture', a discussion on creating global generic curves for these damage classes is included in section 5.4.

2.5 Approach to determinate national maximum damage values per damage class

In order to translate flood water level to damage, the damage curves need an associated national maximum damage values (presented in Chapter 3). However, the literature does not provide data on maximum damage values for all countries and damage classes. Therefore, a consistent process of determining maximum damage values is developed to allow for non-biased comparison of the damage between different countries[6]. The process differs between some damage classes due to extent and type of data available; an overview is provided below.

2.5.1 Residential buildings, commerce and industry

For damage classes *residential buildings*, *commerce* and *industry*, the national maximum damage values were derived from regression analysis of damage values identified in the literature review[7] and values from international surveys of construction costs versus globally available national parameters from the World Bank (World Development Indicators), such as GDP per capita.

Initially, a large set of national socio-economic parameters was used, such as indicators in the World Development Indicators database[8]. Included indicators were: Gross Domestic Product (GDP), Purchasing Power Parity (PPP), population density, agricultural value, land use and/or geology, market exchange rates, labour costs, dependency on natural resources, national income inequality, building style (archetypes per

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[5] The exception is the USA where literature suggests there is damage present already at a value just above zero flood depth due to houses being built with basements.

[6] For examples see Jongman et al. 2012 or De Moel and Aerts, 2011

[7] The average maximum damage per continent has been calculated after removing apparent extreme values. Extremes were removed after visual and common sense inspection of the distribution of the values mimicking the Median Average Deviation for unsymmetrical distributions.

[8] http://data.worldbank.org/indicator

country/continent), governmental regulations, yield per hectare, insurance penetration, etcetera.

Regressions were performed at the global scale, to include as wide a range of indicator values as possible in the analysis. As stated, two sets of maximum damage values were tested:

- Maximum damages derived from the different national damage models identified in the literature review, and
- Construction cost values from international surveys.

The latter one is not commonly used in damage modelling, but has the potential advantage of a consistent methodology (in terms of baseline building and assessment procedure) across countries as opposed to national damage models.

This methodology resulted in a set of formulas in which a specific subset of globally available national indicators can be used to calculate the maximum damage for a specific damage class in a specific country.

2.5.2 Infrastructure

The number of available maximum damage values from literature is small and the values are not always comparable due to different ways of determining the maximum damage. Therefore, in this study we use values from the European study (Huizinga, 2007) as the average maximum damage value. This approach is elaborated in section 3.3.2.

2.5.3 Agriculture

For agriculture the damage is related to a loss in output when the yield is destroyed by floods. Therefore, the value added in US$ per hectare has been used as the proxy for the maximum damage value. From the WDI the agricultural land per country (km^2) and agriculture value added (US$) were used. This approach is elaborated in section 3.3.3.

3 Results

3.1 Introduction

The collected data have been recorded for five continents: Africa, Asia, Oceania, North America, South and Central America. The data for Europe was collected and processed in a separate study (Huizinga, 2007) and the summary figures are provided in Appendix F. The damage functions in the accompanying database cover countries in all six continents. The data was collected for damage classes: Residential buildings, Commerce buildings, Industry buildings, Transport, Infrastructure (roads), and Agriculture.

The rest of this section overviews the damage functions and maximum damage values per damage class for each continent.

3.2 Damage curves

This section presents the literature review findings on the flood depth-damage curves, as well as the constructed average continental damage functions. The results are presented per damage class.

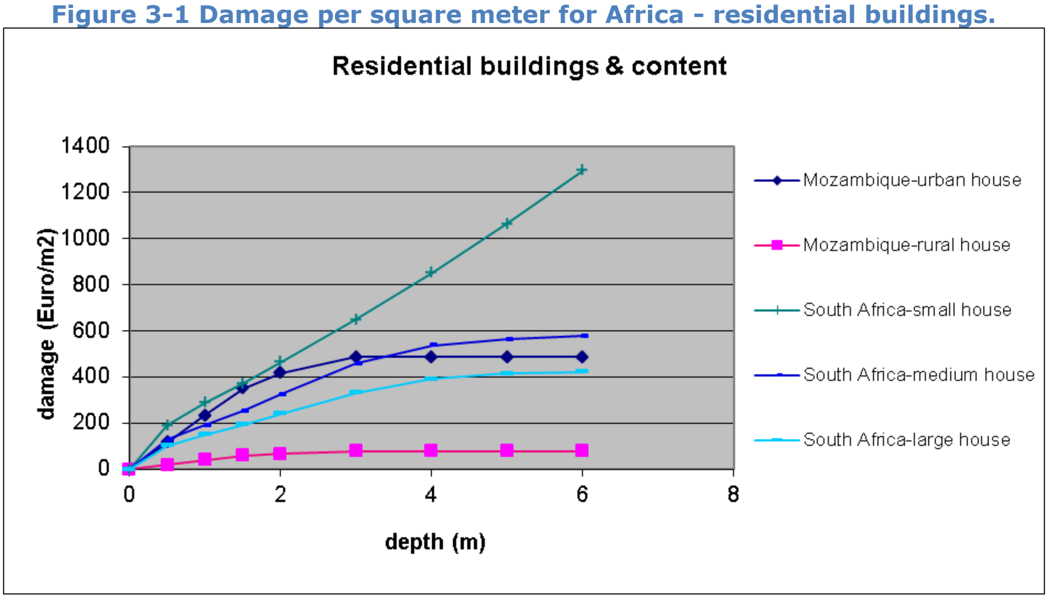
In all figures the 'average' continental function is shown as a red line; the related European function is shown as a yellow line. This is done to facilitate comparison to the earlier study by Huizinga (2007) for Europe.

3.2.1 Residential buildings

The residential buildings including content damage values all have inventory included. The results are shown below.

Africa:

Figure 3-1 Damage per square meter for Africa - residential buildings.



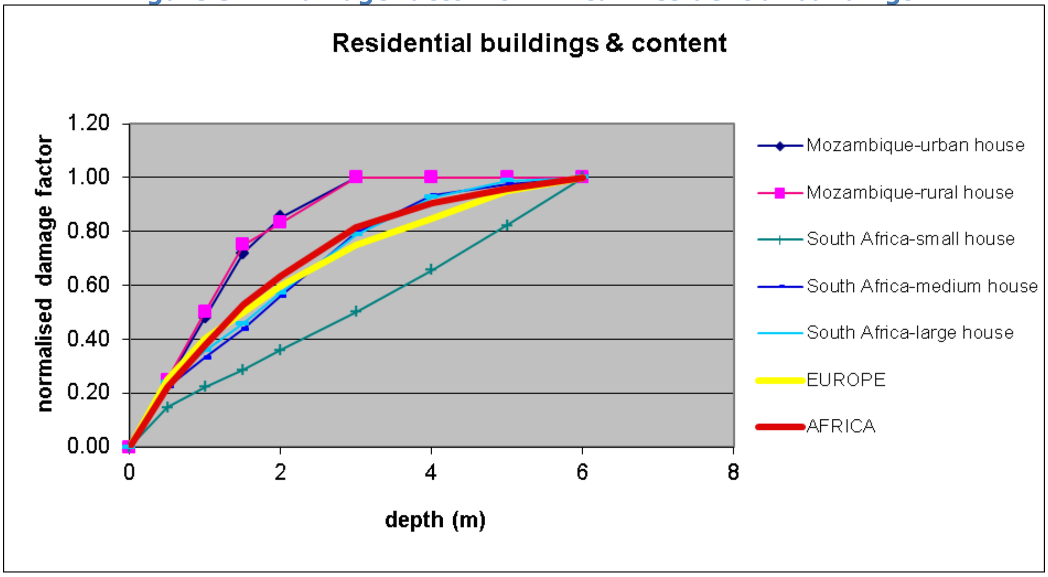
The countries in Figure 3-1 comprise South Africa (small house, medium house, large house) and Mozambique (urban house, rural house). Relative large differences exist in the figure as the local and national assessment methods may differ. The small South African house has the highest value per square meter, while the rural house in

Mozambique has the lowest value per square meter. The three remaining house types in Mozambique and South Africa have more or less equal maximum damage values.

The average maximum damage value for the class residential buildings including inventory at 6 meters water depth is 495 €/m^2 (2010) compared to 750 €/m^2 (2007) in Europe.

The normalised damage functions are shown on Figure 3-2. The damage factors in the recorded individual functions do not always range from 0 to 1, so they have been normalised to end on 1.

Figure 3-2: Damage factor for Africa - residential buildings.



As can be seen the shape of the damage factor for South Africa and Europe is nearly identical (at maximum only 10% difference at 3 meters flood depth).

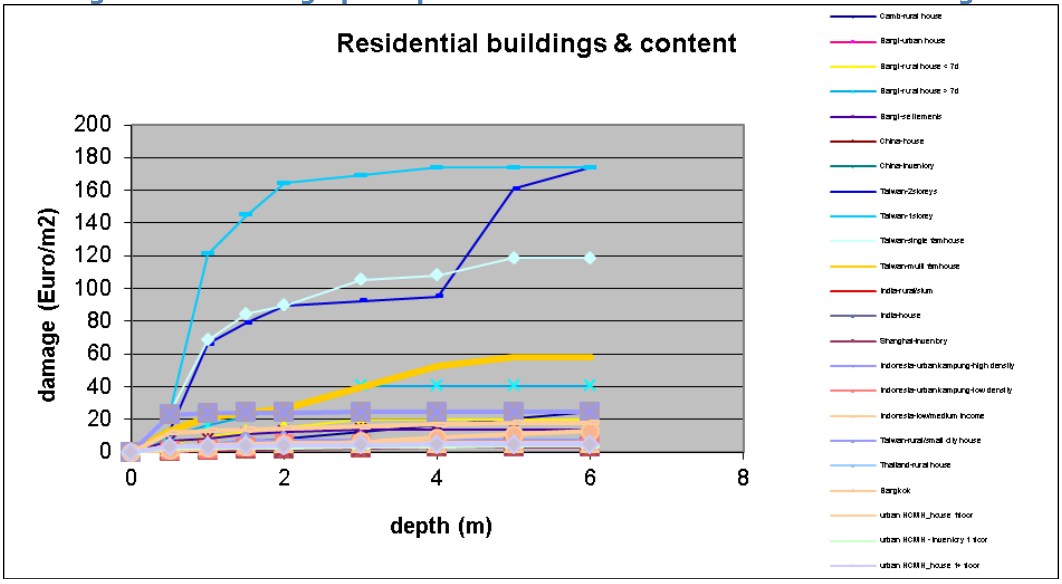
Based on the collected data a new 'average' damage function for residential buildings is constructed.

Table 3-1: Average continental damage function for Africa - residential buildings.

Water depth (m)	***Damage factor***
0	0
0.5	0.22
1	0.38
1.5	0.53
2	0.64
3	0.82
4	0.90
5	0.96
6	1.00

Asia:

Figure 3-3: Damage per square meter for Asia - residential buildings.



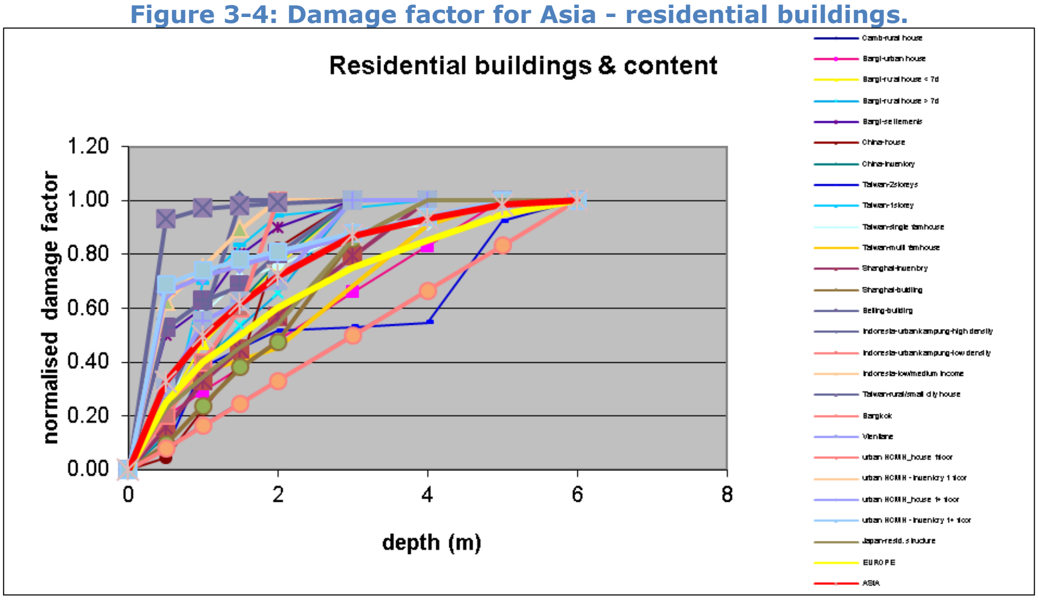
The countries in the figure comprise Bangladesh, Cambodia, Taiwan, China, Indonesia, Thailand, Vietnam, Laos and Japan. The functions for Shanghai and Beijing have been removed as the maximum damage went up to 2611 €/m^2 (2010) for Shanghai and 984 €/m^2 (2010) for Beijing. Large differences exist in the figure, as the sources come from many different countries and definition of maximum damage may be different (for example urban fabric versus individual buildings).

The third highest maximum damages are found in Taiwan with functions running up to maxima of 100-180 €/m^2 (2010). The rest of the functions have a maximum damage varying between 2-100 €/m^2 (2010). These countries are: Bangladesh, Cambodia, Indonesia, Thailand, Vietnam and Laos.

The average maximum damage for Asia is 111 €/m^2 (2010) compared to 750 €/m^2 (2007) in Europe.

The relative damage functions are shown below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-4: Damage factor for Asia - residential buildings.



As can be seen the shape of the damage factor for Asia and Europe is quite similar.

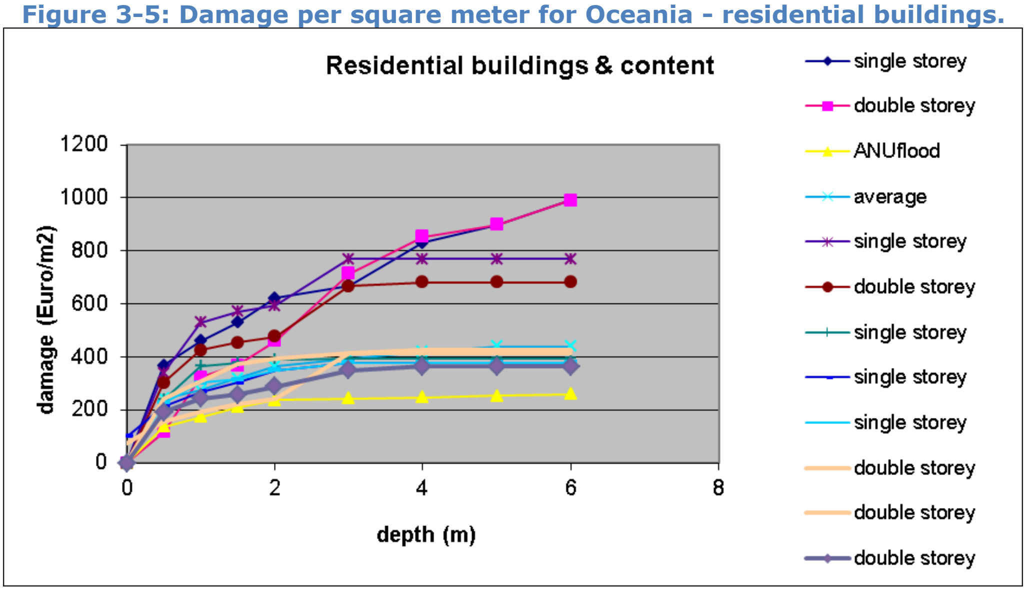
Based on the collected data a new 'average' damage function for residential buildings is made.

Table 3-2: Average continental damage function for Asia - residential buildings.

Water depth (m)	***Damage factor***
0	0
0.5	0.33
1	0.49
1.5	0.62
2	0.72
3	0.87
4	0.93
5	0.98
6	1.00

Oceania:

Figure 3-5: Damage per square meter for Oceania - residential buildings.

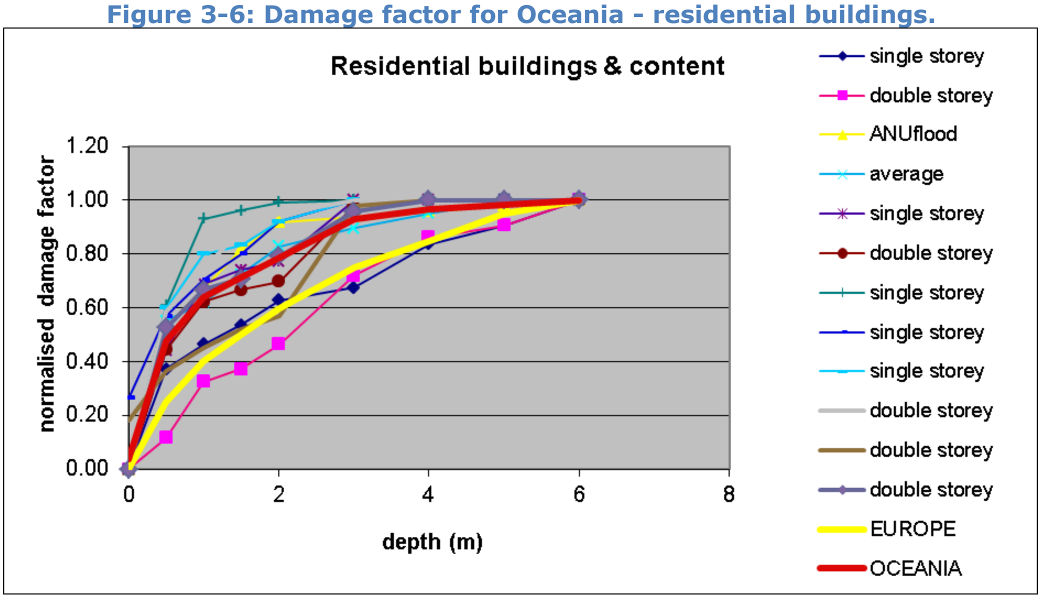


The countries in Figure 3-5 comprise Australia only. In the figure the maximum damage values range from 200 – 1000 €/m^2 (2010). For the New Zealand the methodologies developed in Australia are being used.

The average maximum damage for Oceania is 541 €/m^2 (2010) compared to 750 €/m^2 (2007) in Europe.

The relative damage functions are shown below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-6: Damage factor for Oceania - residential buildings.



As can be seen the shape of the damage factor for Oceania and Europe is not similar, as the function for Oceania is steeper until 2 meter water depth. Nearly maximum damage is there after water depth has become 3 meters or more. This may be due to the fact that in Australia there are more houses with only one floor.

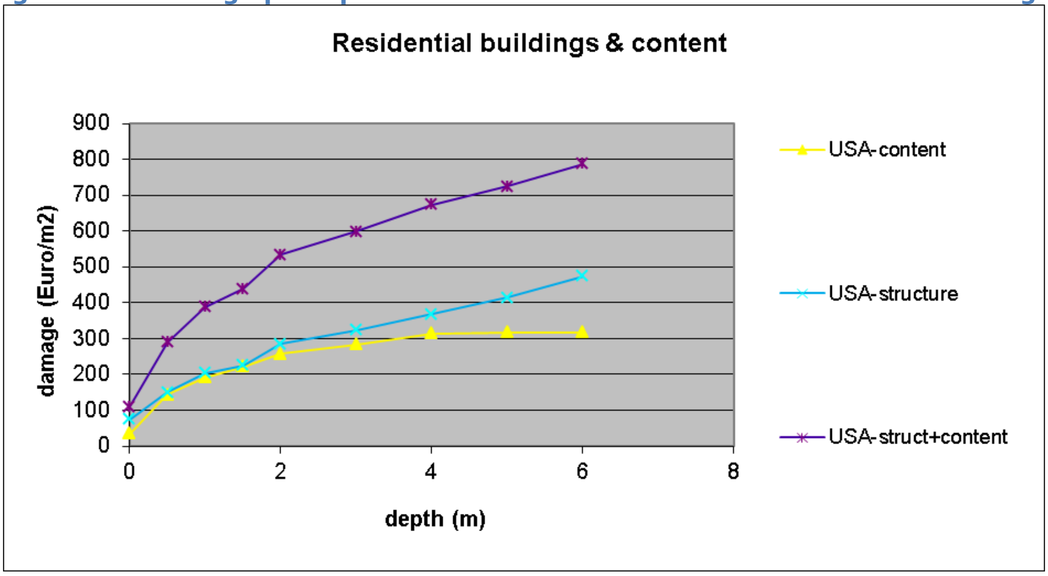
Based on the collected data a new 'average' damage function for residential buildings is developed.

Table 3-3: Average continental damage function for Oceania - residential buildings.

Water depth (m)	***Damage factor***
0	0.04
0.5	0.48
1	0.64
1.5	0.71
2	0.79
3	0.93
4	0.97
5	0.98
6	1.00

North America:

Figure 3-7: Damage per square meter for North America - residential buildings.

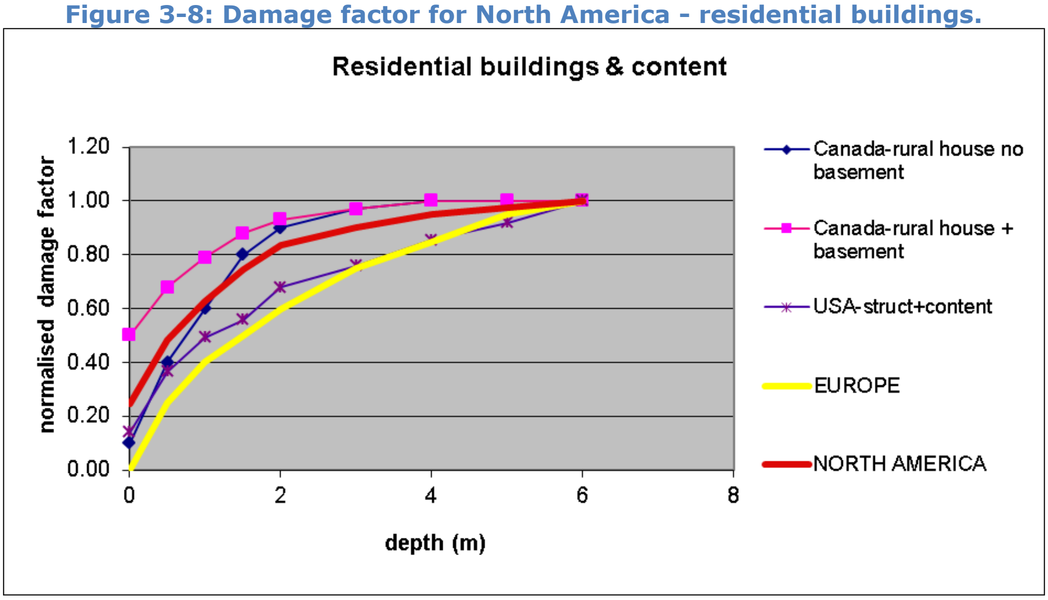


All data is from the USA and based on the HAZUS flood damage model (Scawthorn et.al., 2006a/2006b). In the Figure 3-7 above the value of houses is the sum of structure and content damage.

The average maximum damage for North America is 788 €/m^2 (2010) compared to 750 €/m^2 (2007) in Europe.

The relative damage functions are shown in Figure 3-8 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to end on 1.

Figure 3-8: Damage factor for North America - residential buildings.



As can be seen the shape of the damage functions for North-America and Europe is quite similar, with the exception of the North American functions having a positive damage factor at zero flood depth. This is due to the fact that North American flood model HAZUS provides data for different houses with - and without basements. According to literature [9] in the period 2011-2013 30% to 70% of the newly built single family residential homes in the USA were constructed with a basement.

[9] http://www.businessinsider.com and http://eyeonhousing.org

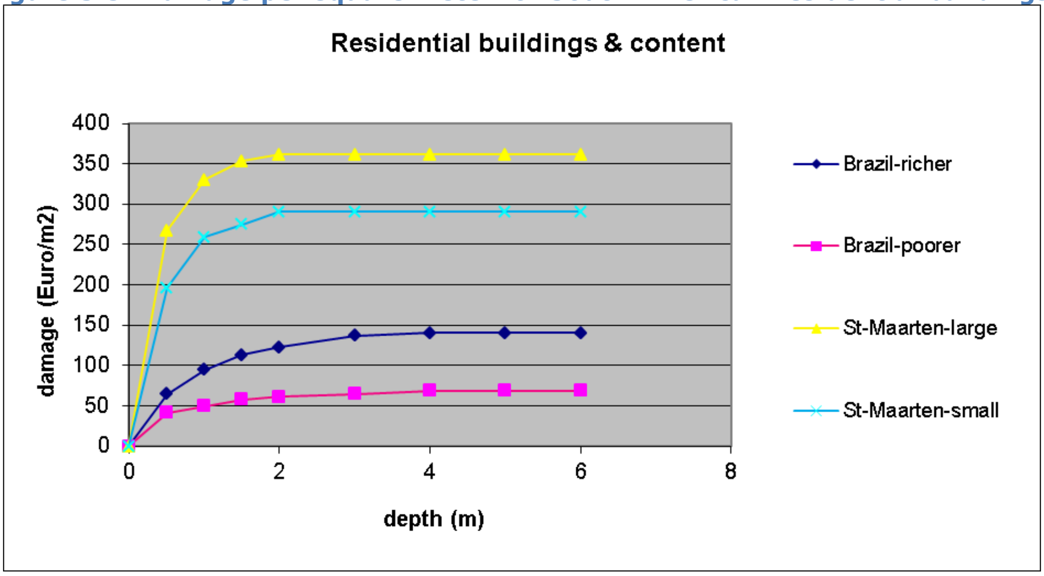
Based on the collected data a new 'average' damage function for residential buildings is made.

Table 3-4: Average continental damage function for North America - residential buildings.

Water depth (m)	*Damage factor*
0	0.20
0.5	0.44
1	0.58
1.5	0.68
2	0.78
3	0.85
4	0.92
5	0.96
6	1.00

South and Central America:

Figure 3-9: Damage per square meter for South America - residential buildings.

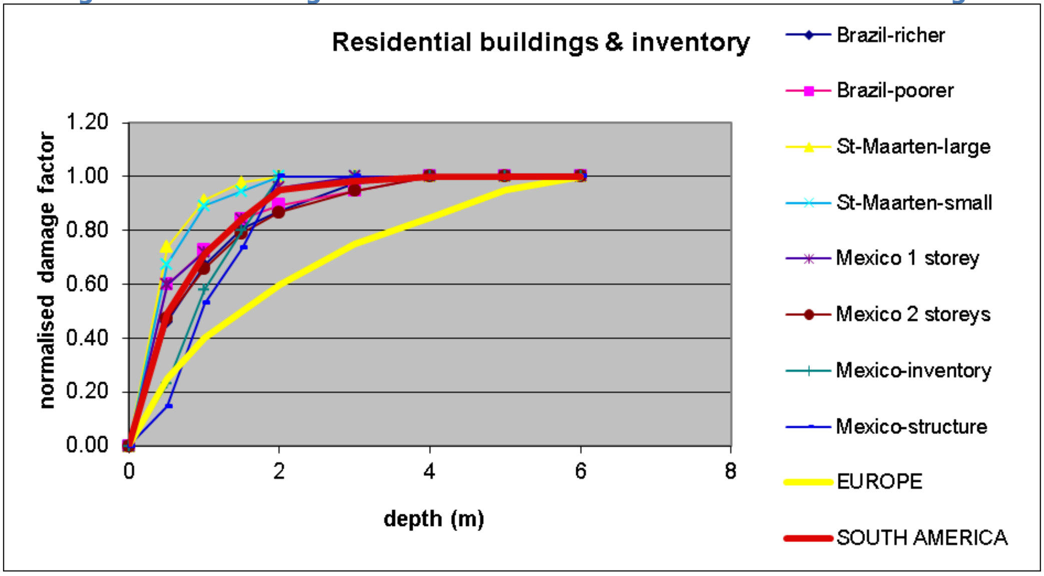


The two upper functions on Figure 3-9 are based on data from a relatively small island St Maarten (Caribbean). The two lower functions are based on data from Brazil.

The average maximum damage for South America is 215 €/m2 (2010) compared to 750 €/m2 (2007) in Europe. This value seems rather high for South America and is probably strongly biased by the relatively rich country of St Maarten. It may be a better choice to use the Brazilian value of 69 €/m2 (2010).

The relative damage functions are shown below on Figure 3-10. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-10: Damage factor for South America - residential buildings.



These functions originate from Brazil, St. Maarten and Mexico. As can be seen, the shape of the damage factor for South America and Europe is not similar, as the function for South America is much steeper in the first two meters of water depth. The South America function reaches its maximum at about 3 meters.

Based on the collected data a new 'average' damage function for residential buildings is made.

Table 3-5: Average continental damage function for South America - residential buildings.

Water depth (m)	***Damage factor***
0	0
0.5	0.49
1	0.71
1.5	0.84
2	0.95
3	0.98
4	1.00
5	1.00
6	1.00

3.2.2 Commerce

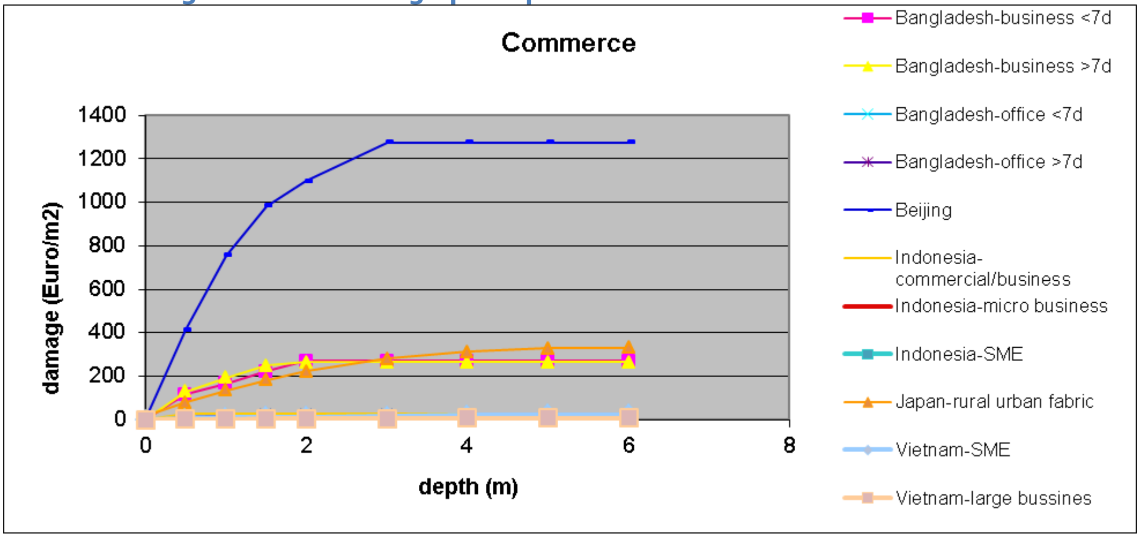
The damage type Commerce includes content maximum damage values all have inventory included. The results are shown below.

Africa:

No commerce functions are available for Africa. The average maximum damage value for the class Commerce is 621 €/m^2 (2007) in Europe.

Asia:

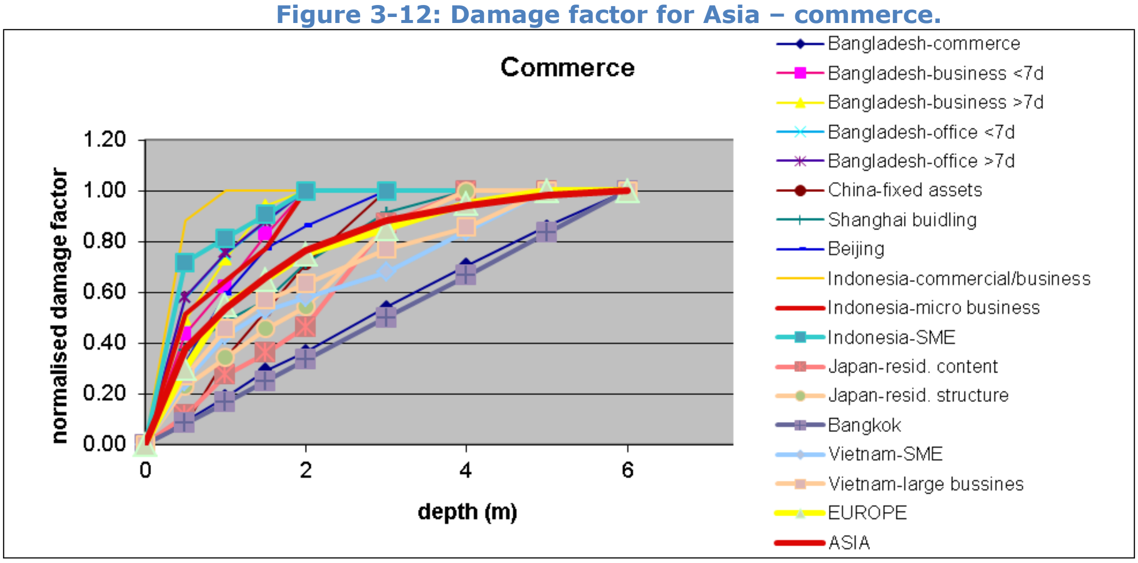
Figure 3-11: Damage per square meter for Asia — commerce.



The countries in Figure 3-11 comprise Bangladesh, China, Indonesia, Japan and Vietnam. More details can be found in the accompanying continental spreadsheets. Large differences exist in the maximum damage values, as they come from many different countries and definition of maximum damage may be different (for example urban fabric versus individual buildings). In the figure above the function for Beijing runs up to 1274 €/m^2 damage. The rest of the functions vary between 8 to 300 €/m^2 (price level 2010). The average maximum damage for Asia is 138 €/m^2 (2010) compared to 621 €/m^2 (2007) in Europe.

The relative damage functions are shown on Figure 3-12 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-12: Damage factor for Asia – commerce.



As can be seen the shape of the damage factor for Asia and Europe is quite similar.

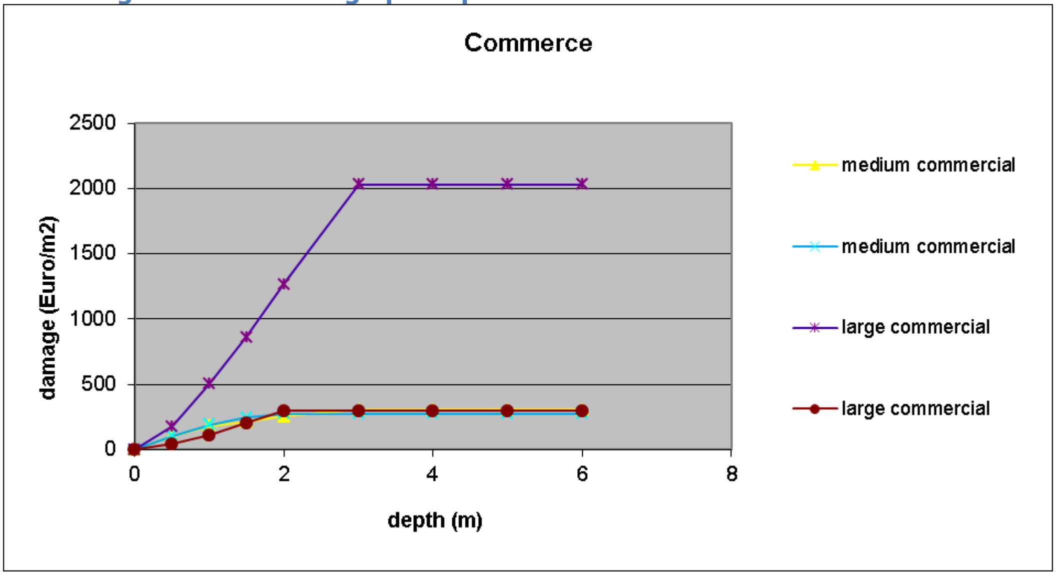
Based on the collected data a new 'average' damage function for commerce is made.

Table 3-6: Average continental damage function for Asia – commerce.

Water depth (m)	*Damage factor*
0	0
0.5	0.38
1	0.54
1.5	0.66
2	0.76
3	0.88
4	0.94
5	0.98
6	1

Oceania:

Figure 3-13: Damage per square meter for Oceania – commerce.

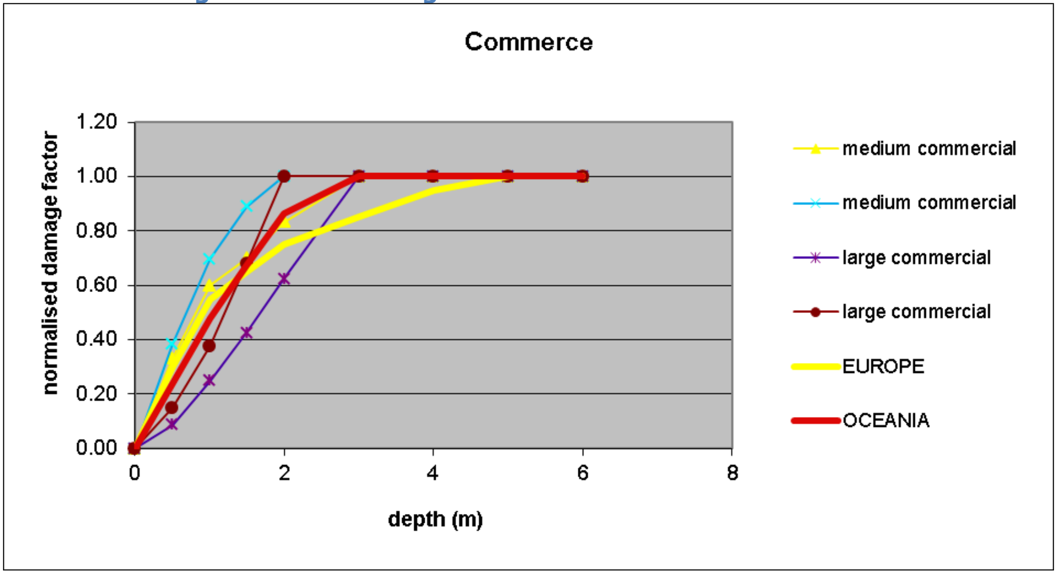


The countries in Figure 3-13 comprise Australia only, as there are no functions available for New Zealand. More details can be found in the accompanying continental spreadsheets. The function for large commercial areas runs up to 2028 €/m^2 (2010). This maximum damage value is part of a method developed by BMT (2011), and has a higher maximum damage value than the other curves being based on the ANUflood method. BMT reports the ANUflood method to underestimate calculated damage.

The average maximum damage for Oceania is 506 €/m^2 (2010) compared to 621 €/m^2 (2007) in Europe.

The relative damage functions are shown on Figure 3-14 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-14: Damage factor for Oceania – commerce.



As can be seen the shape of the damage factor for Oceania and Europe is quite similar between 0-1.5 meter water depth and from 4.5 meter water depth. In between the Oceania function reaches maximum faster than the European function does.

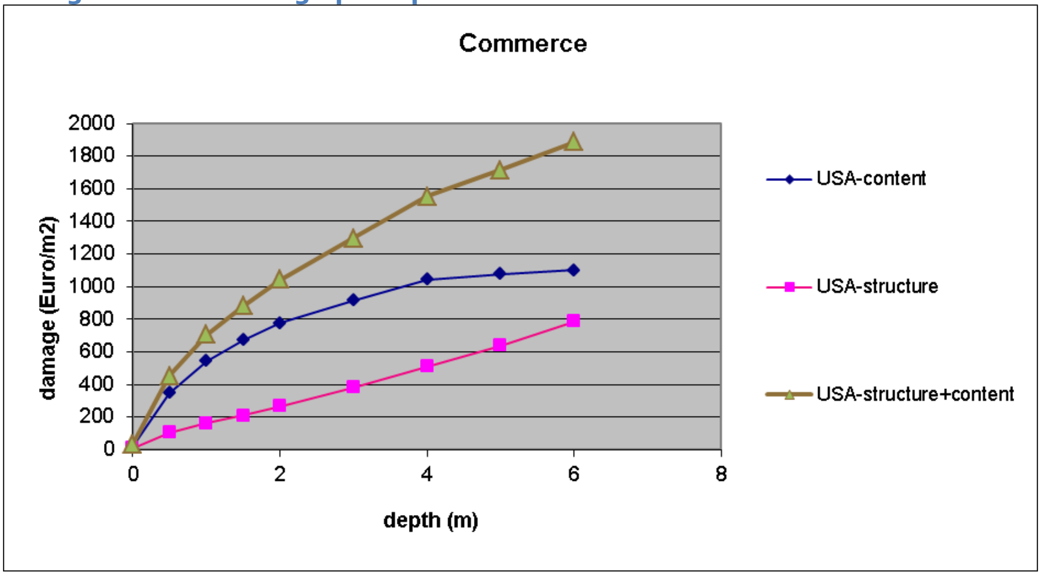
Based on the collected data a new 'average' damage function for commerce is made.

Table 3-7: Average continental damage function for Oceania – commerce.

Water depth (m)	***Damage factor***
0	0
0.5	0.24
1	0.48
1.5	0.67
2	0.86
3	1.00
4	1.00
5	1.00
6	1

North America:

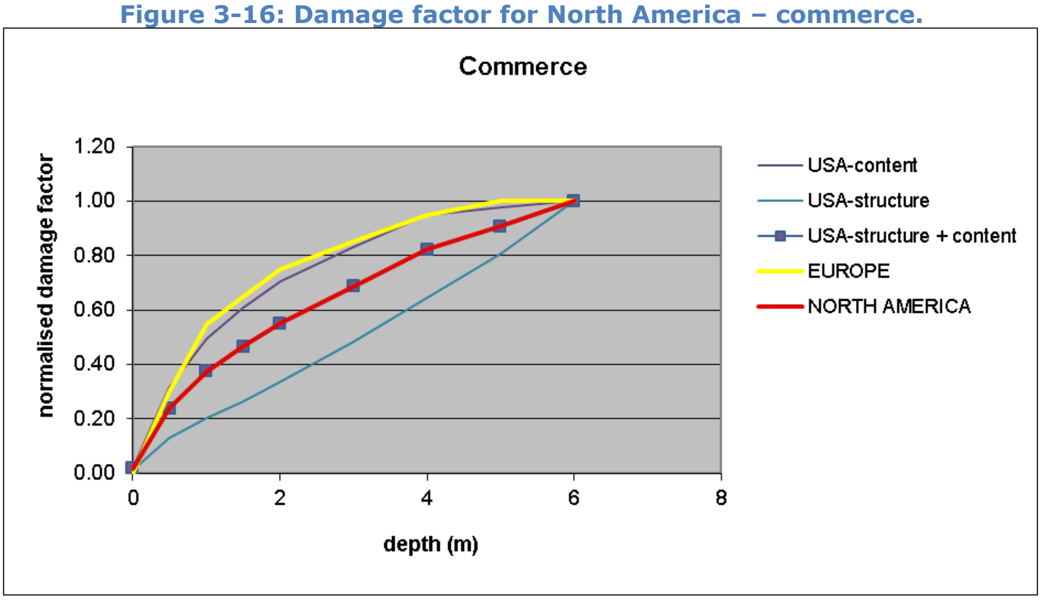
Figure 3-15: Damage per square meter for North America – commerce.



All data is from USA and based on HAZUS. In the Figure 3-15 above the total damage value is the sum of structure and content damages. The average maximum damage for North America is 1889 €/m^2 (2010) compared to 750 €/m^2 (2007) in Europe.

The relative damage functions are shown on Figure 3-16 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-16: Damage factor for North America – commerce.



As can be seen the shape of the damage factor for North America and Europe is similar to the HAZUS content function, but on the whole the European function is steeper than the North American function.

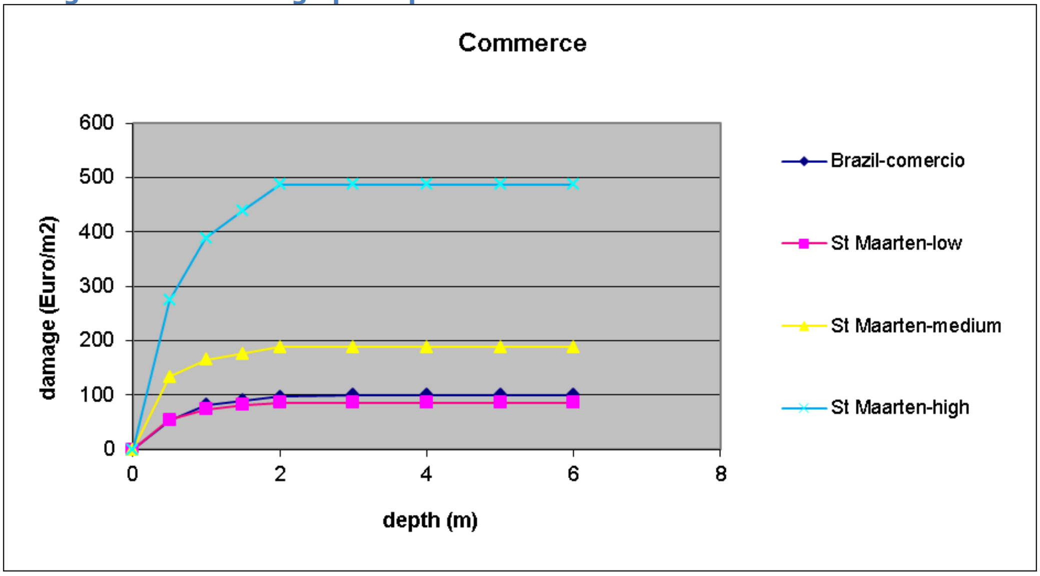
Based on the collected data a new 'average' damage function for commerce is made.

Table 3-8: Average continental damage function for North America – commerce.

Water depth (m)	Damage factor
0	0.02
0.5	0.24
1	0.37
1.5	0.47
2	0.55
3	0.69
4	0.82
5	0.91
6	1

South and Central America:

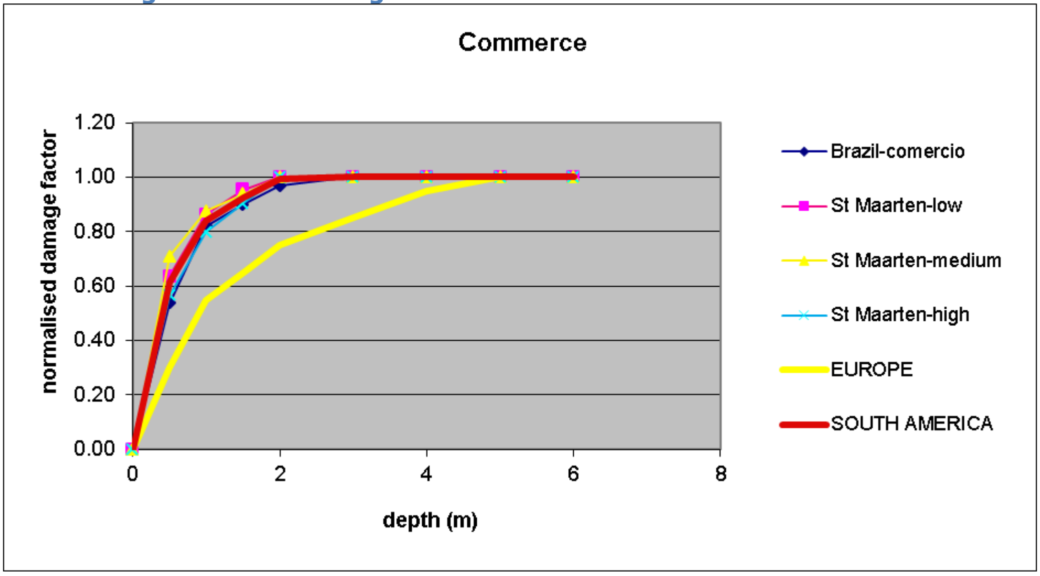
Figure 3-17: Damage per square meter for South America – commerce.



In the Figure 3-17 above the St. Maarten low, medium and high respectively represent areas of less than 100 m^2, areas between 100 and 1000 m^2 and areas above 1000 m^2. The average maximum damage for South America is 122 €/m2 (2010) compared to 750 €/m2 (2007) in Europe.

The relative damage functions are shown on Figure 3-18 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-18: Damage factor for South America – commerce.



As can be seen, the shape of the damage factor for South America and Europe is not similar, as the function for South America is much steeper in the first two meters of water depth. The South America function reaches its maximum at about 2 meters.

Based on the collected data a new 'average' damage function for commerce is made.

Table 3-9: Average continental damage function for South America – commerce.

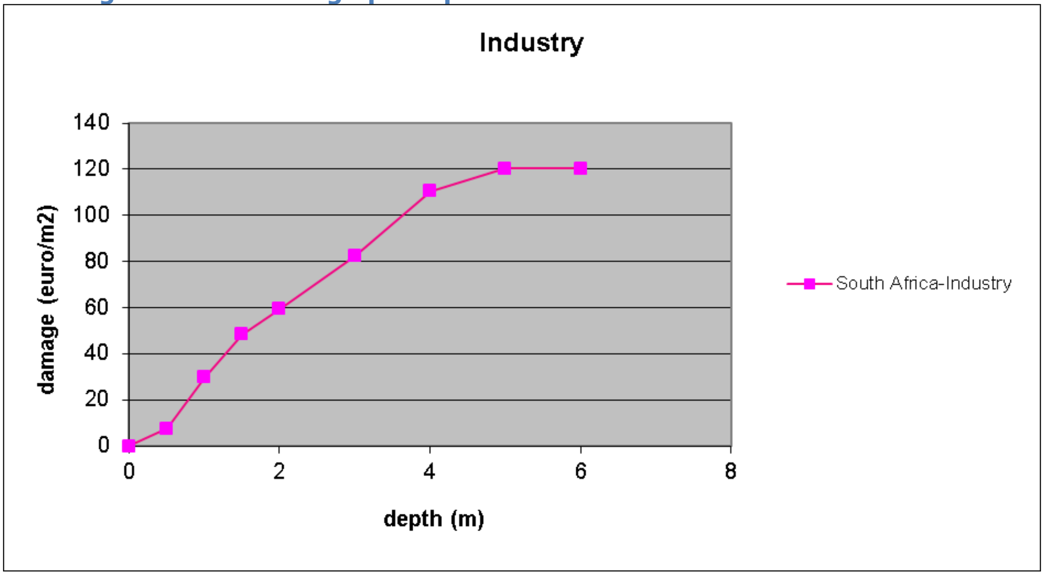
Water depth (m)	***Damage factor***
0	0
0.5	0.61
1	0.84
1.5	0.92
2	0.99
3	1.00
4	1.00
5	1.00
6	1

3.2.3 Industry

The Industry maximum damage values all have inventory included and apply to an overall industrial area (not just one specific plant or object).

Africa:

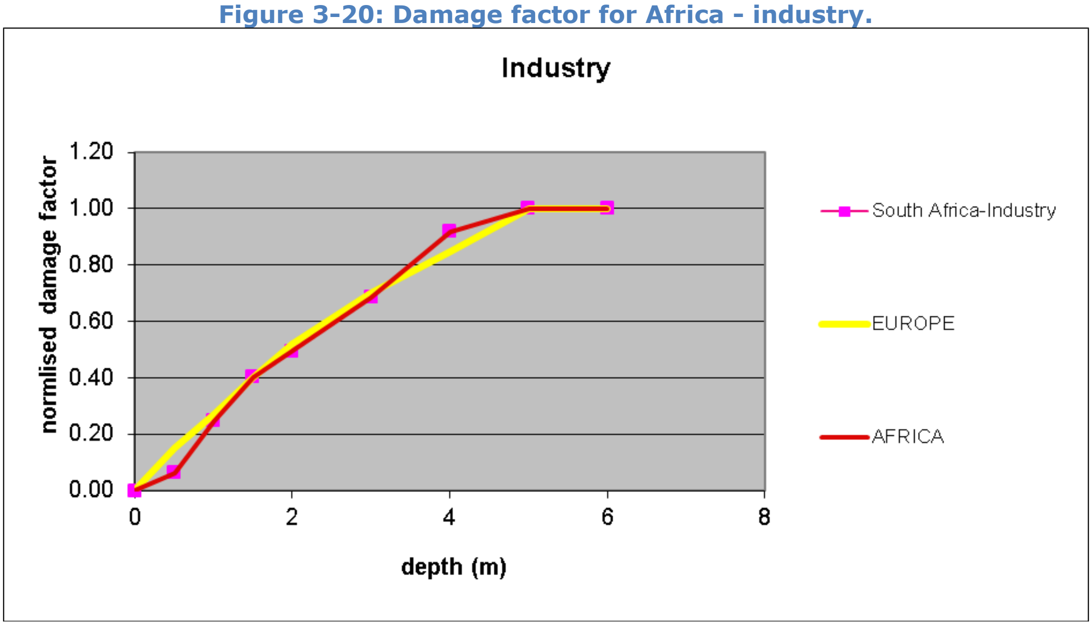
Figure 3-19: Damage per square meter for Africa - industrial area.



As there is only one function for the class 'Industry' and it's originating from South Africa, so the African average function comprises only one observation. The average maximum damage value for the class Industry is 120 €/m^2 (2010) in Africa versus 534 €/m^2 (2007) in Europe.

The relative damage functions are shown below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-20: Damage factor for Africa - industry.



The shape of the damage function is nearly identical to the European function.

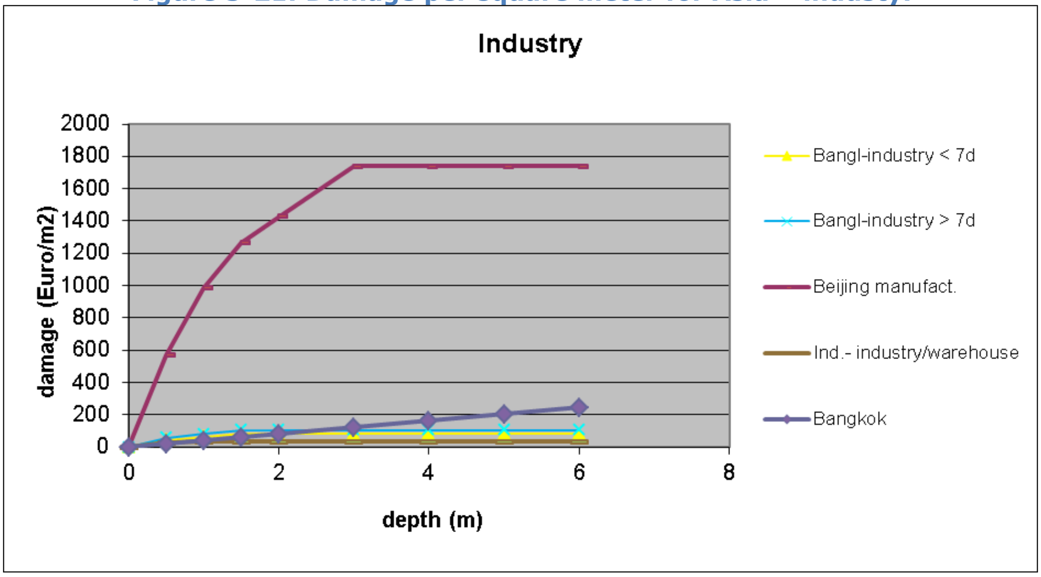
Based on the collected data a new 'average' damage function for industry is made.

Table 3-10: Average continental damage function for Africa – industry.

Water depth (m)	*Damage factor*
0	0
0.5	0.06
1	0.25
1.5	0.40
2	0.49
3	0.68
4	0.92
5	1.00
6	1

Asia:

Figure 3-21: Damage per square meter for Asia – industy.

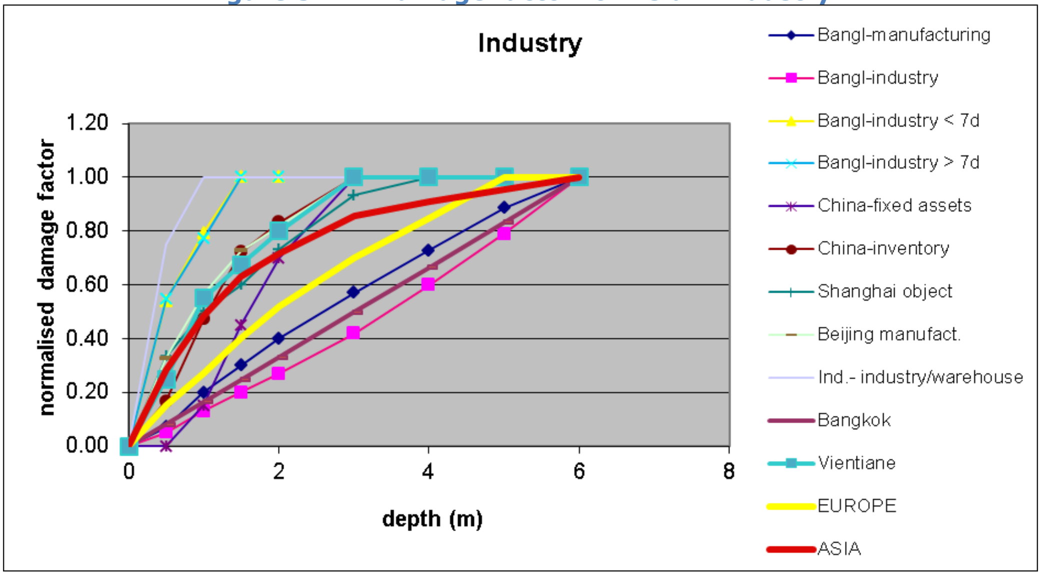


The countries in the Figure 3-21 comprise Bangladesh (industry flooded less than 7 days, industry flooded more than 7 days), China (Beijing manufacturing), Indonesia (industry/warehouse) and Thailand (Bangkok). More details can be found in the accompanying continental spreadsheets. The function for Beijing runs up to 1741 €/m^2 (2010). The rest of the functions vary between 80 – 245 €/m^2 (2010) in Bangladesh, Indonesia and Thailand.

The average maximum damage value for the class 'Industry' is 114 €/m^2 (2010) in Asia versus 534 €/m^2 (2007) in Europe.

The relative damage functions are shown on Figure 3-22 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-22: Damage factor for Asia – industry.



The shape of the damage function is not identical to the European function, as the Asian function is much steeper until 1.5 meters water depth. After 4 meters the difference becomes very small.

Based on the collected data a new 'average' damage function for industry is made.

Table 3-11: Average continental damage function for Asia – industry.

Water depth (m)	*Damage factor*
0	0
0.5	0.28
1	0.48
1.5	0.63
2	0.72
3	0.86
4	0.91
5	0.96
6	1

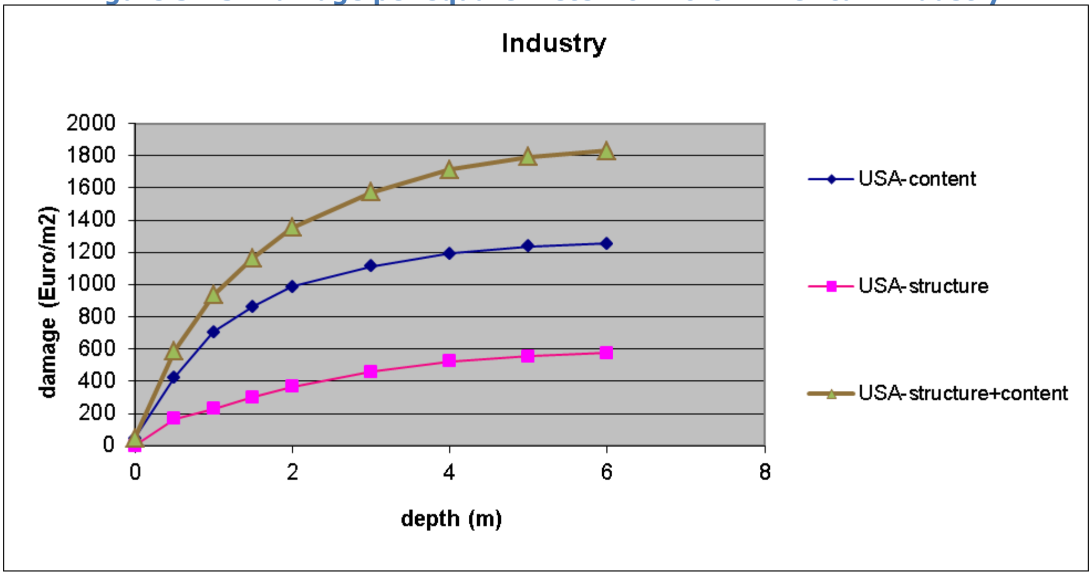
Oceania:

No industry functions available for Oceania.

The average maximum damage value for the class 'Commerce' is 534 €/m^2 (2007) in Europe.

North America:

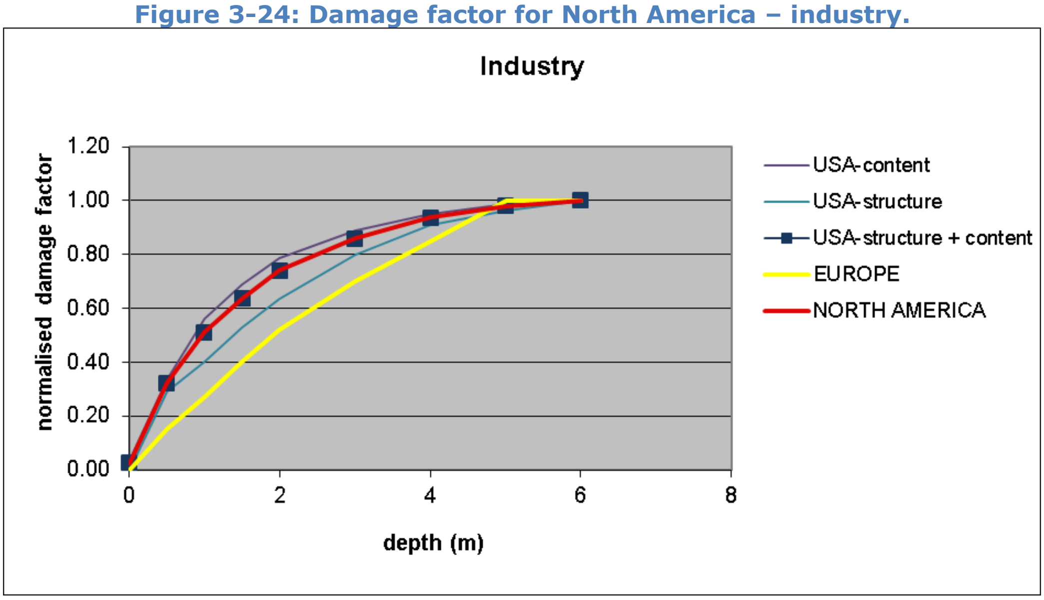
Figure 3-23: Damage per square meter for North America – industry.



All data is from USA and based on HAZUS. In the Figure 3-23 above the value of rural house is the sum of structure and content. The average maximum damage for North America is 1830 €/m^2 (2010) compared to 534 €/m^2 (2007) in Europe.

The relative damage functions are shown on Figure 3-24 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-24: Damage factor for North America – industry.



As can be seen the shape of the damage factor for North America is steeper than the European function until 5 meters of water depth. After 5 meters the functions align.

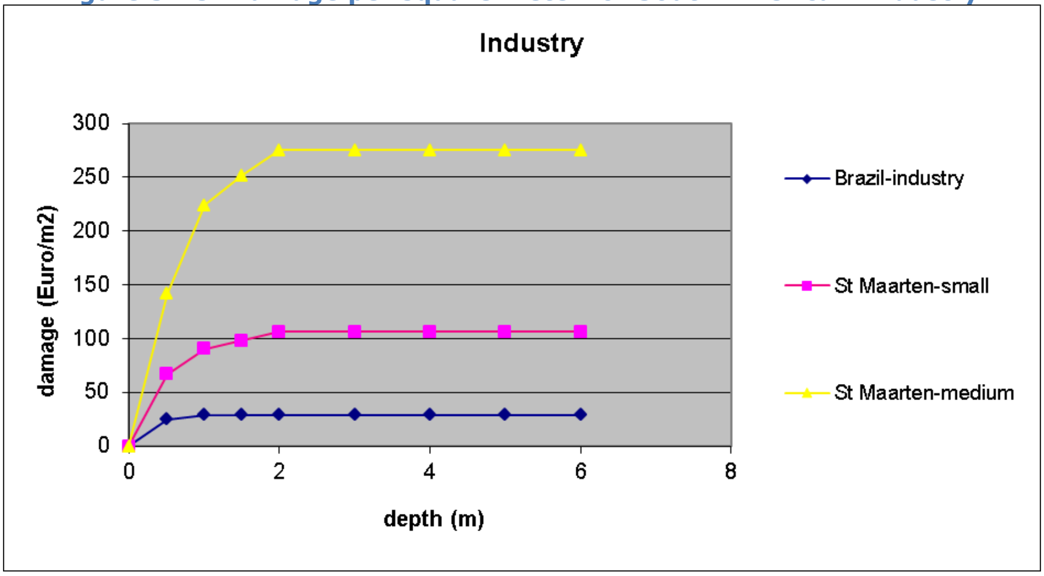
Based on the collected data a new 'average' damage function for commerce is made.

Table 3-12: Average continental damage function for North America – industry.

Water depth (m)	*Damage factor*
0	0.02
0.5	0.31
1	0.48
1.5	0.61
2	0.71
3	0.84
4	0.93
5	0.98
6	1

South and Central America:

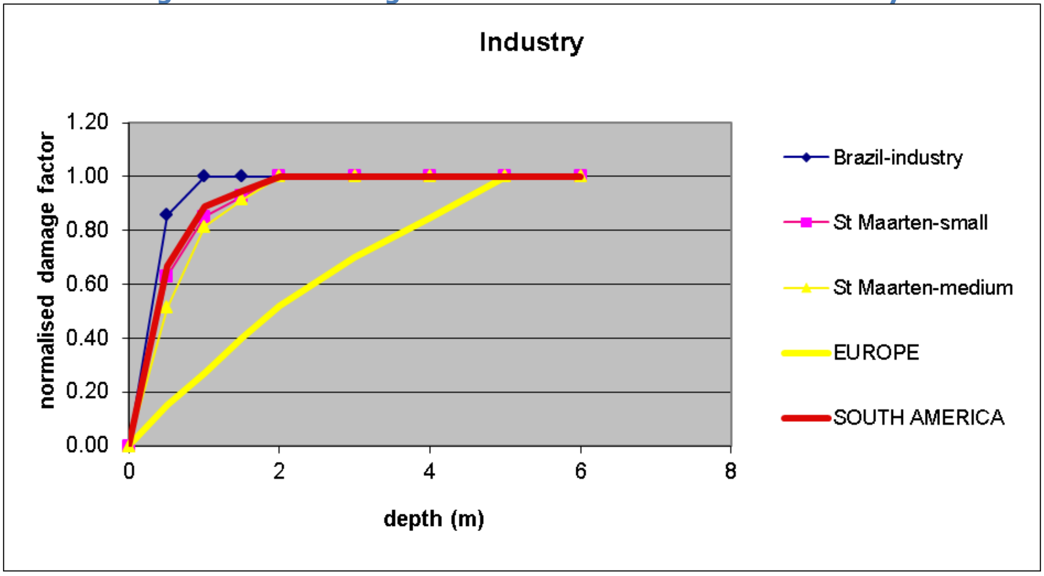
Figure 3-25: Damage per square meter for South America – industry.



The lowest function originates from Brazil. The two higher functions (small :<100m^2 and medium:100-1000m^2) originate from St. Maarten (small Caribbean island depending on tourism). The average maximum damage for South America is 137 €/m^2 (2010) compared to 534 €/m^2 (2007) in Europe. Given the lower value of 29 €/m^2 for Brazil, this value seems more appropriate to apply in South America as St. Maarten has an estimated GDP/cap in 2008 of nearly 15 000US$ compared to Brazil having a GDP/cap of 8700US$.

The relative damage functions are shown on Figure 3-26 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-26: Damage factor for South America – industry.



The shape of the damage factor for South America is much steeper than the European function. At two meters of water depth this function reaches its maximum value.

Based on the collected data a new 'average' damage function for commerce is made.

Table 3-13: Average continental damage function for South America – industry.

Water depth (m)	***Damage factor***
0	0
0.5	0.67
1	0.89
1.5	0.95
2	1.00
3	1.00
4	1.00
5	1.00
6	1

3.2.4 Transport

The results for Transport are shown below.

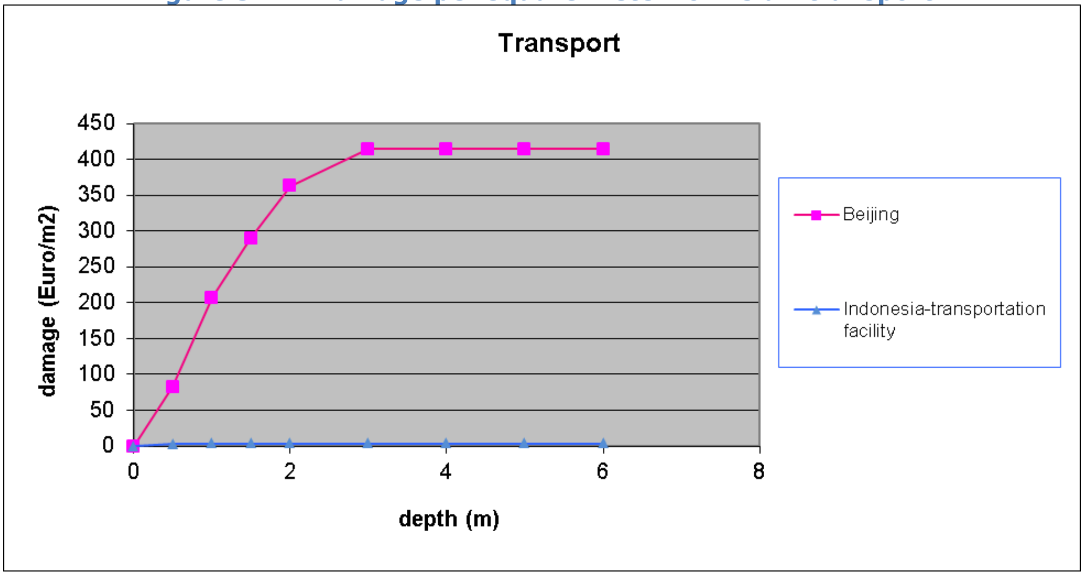
Africa:

No Transport functions available for Africa.

The average maximum damage value for the class 'Transport' is 751 €/m^2 (2010) in Europe.

Asia:

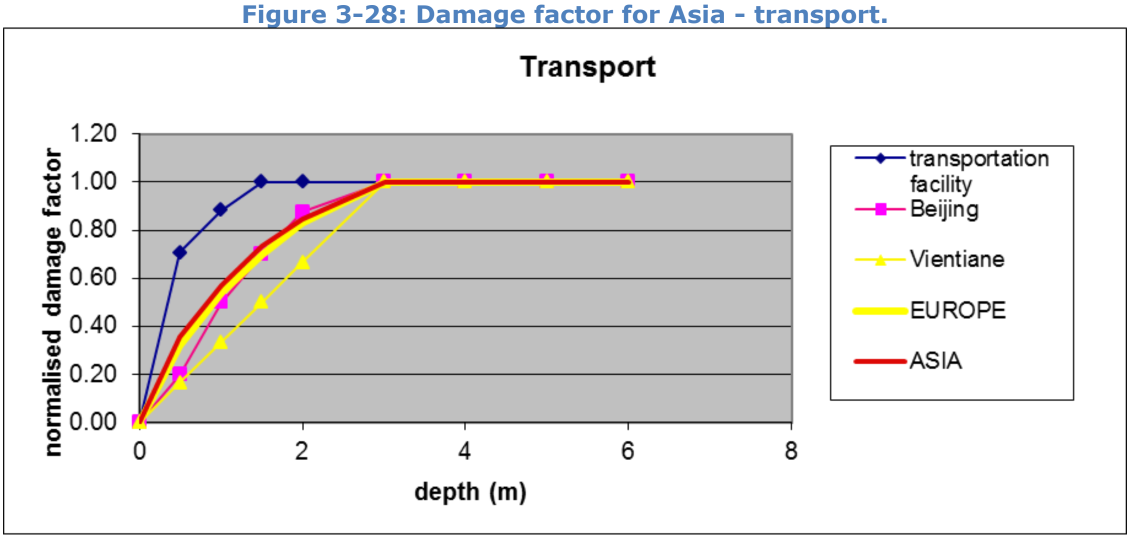
Figure 3-27: Damage per square meter for Asia - transport.



The countries in the Figure 3-27 comprise China (Beijing) and Indonesia (transportation facility). More details can be found in the accompanying continental spreadsheets. The function from Beijing runs up to about 414 €/m^2 (2010). The lowest maximum damage from Indonesia is 22 €/m^2 (2010). The average maximum damage value for the class 'Transport' is 209 €/m^2 (2010) in Asia versus 751 €/m^2 (2010) in Europe.

The relative damage functions are shown on Figure 3-28 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-28: Damage factor for Asia - transport.



The shape of the damage function is fully identical to the European function.

Based on the collected data a new 'average' damage function for transport is made.

Table 3-14: Average continental damage function for Asia - transport.

Water depth (m)	*Damage factor*
0	0
0.5	0.36
1	0.57
1.5	0.73
2	0.85
3	1.00
4	1.00
5	1.00
6	1

Oceania:

No Transport damage functions available for Oceania.

The average maximum damage value for the class 'Transport' is 751 €/m^2 (2010) in Europe.

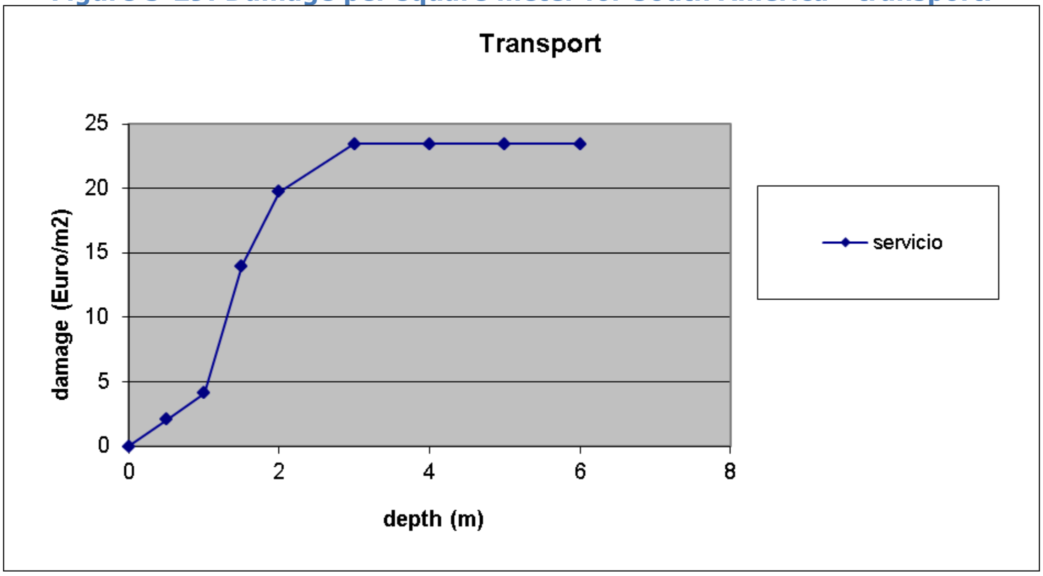
North America:

No Transport damage functions available for North America.

The average maximum damage value for the class 'Transport' is 751 €/m^2 (2010) in Europe.

South and Central America:

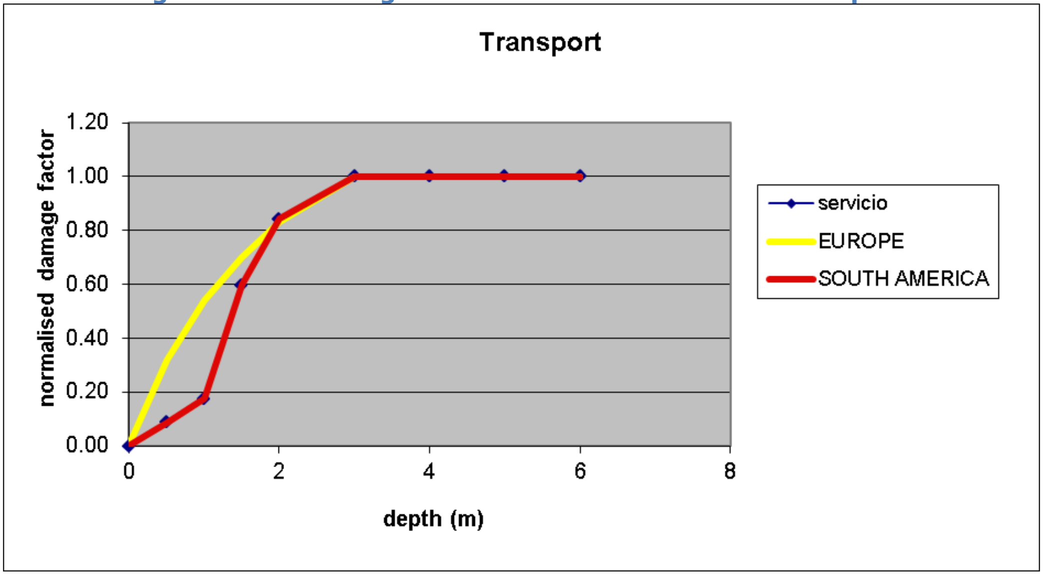
Figure 3-29: Damage per square meter for South America - transport.



The damage function in the Figure 3-29 originates from Brazil. More details can be found in the accompanying continental spreadsheets. The function from Brazil runs up to about 23 €/m^2 (2010). The average maximum damage value for the class 'Transport' is 23 €/m^2 (2010) in South America versus 751 €/m^2 (2010) in Europe.

The relative damage functions are shown below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-30: Damage factor for South America - transport.



The shape of the damage function is nearly identical to the European function from 2 meter flood depth.

Based on the collected data a new 'average' damage function for transport is made.

Table 3-15: Average continental damage function for South America - transport.

Water depth (m)	***Damage factor***
0	0
0.5	0.09
1	0.18
1.5	0.60
2	0.84
3	1.00
4	1.00
5	1.00
6	1

3.2.5 Infrastructure

The results for Infrastructure are shown below. The adopted unit is, the most often reported, meters.

Africa:

No damage functions for infrastructure were found for Africa. Reported maximum damages for Mozambique were repair costs for national roads 1069 €/m (2010) and repair costs for national railways 203 €/m (2010). The average maximum damage value at 6 meter water depth is 24 €/m^2 in Europe.

This large damage costs for infrastructure in Mozambique may be assigned to the fact that the damage for Mozambique is reported per damaged kilometre, while in many sources the maximum damage is reported for all flooded kilometres of road and track.

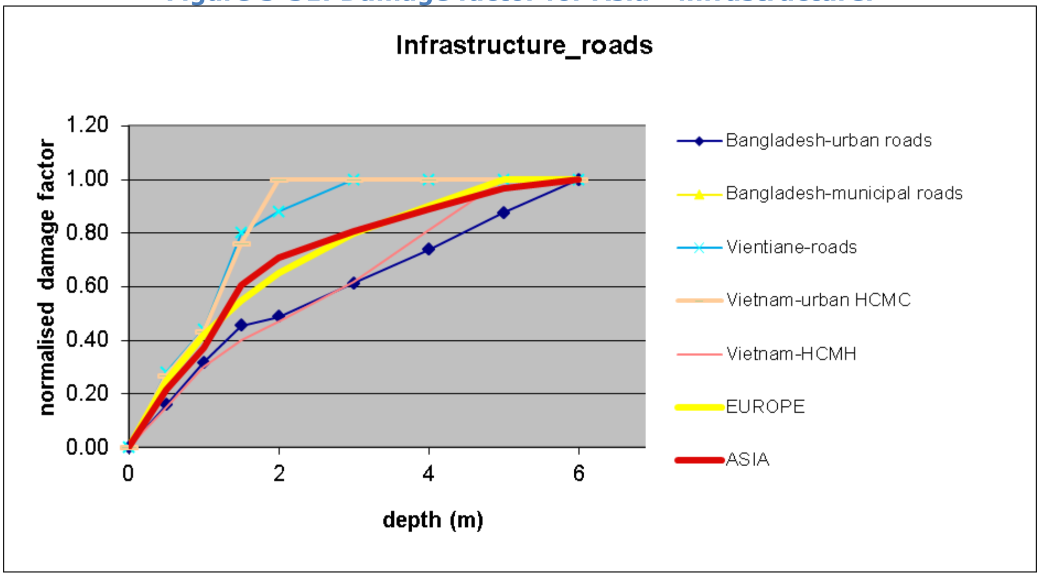
Asia:

Values for maximum damage in combination with damage functions have been found for Laos and Vietnam only. Therefore no figure on actual damage is presented here. However, from Vietnam a cost per meter of road is reported to be about 1 €/m in Ho Chi Minh City, assuming a width of 4 meters to convert from m^2 to m units. From Bangladesh it is reported that the repair cost per meter of road are about 10 €/m. For Shanghai a value of 48 €/m is reported.

The average maximum damage value in Europe is 24 €/m^2 and the calculated average value of 17 €/m for Asia.

The relative damage functions are shown on Figure 3-31 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-31: Damage factor for Asia - infrastructure.



The shape of the damage function is almost identical to the European function.

Based on the collected data a new 'average' damage function for transport is made.

Table 3-16: Average continental damage function for Asia – infrastructure.

Water depth (m)	*Damage factor*
0	0
0.5	0.25
1	0.42
1.5	0.55
2	0.65
3	0.80
4	0.90
5	1.00
6	1

Oceania:

No Infrastructure damage functions available for Oceania.

The average maximum damage value for the class 'Infrastructure' is 29 €/m (2010) for Oceania compared to 24 €/m^2 (2007) in Europe.

North America:

No Infrastructure damage functions available for North America.

The average maximum damage value for the class 'Infrastructure' is 158 €/m (2010) for North America compared to 24 €/m^2 (2007) in Europe. In this case the extreme values have been left out as they deal with kilometres of damage roads instead of kilometres of flooded roads.

The value of various other infrastructural items are described by HAZUS. These are shown in the Table below.

Table 3-17: Additional data for North America - infrastructure.

item	***value (Euro)***
Railway track	1179 per m
Powerstation LV	7 857 142 per item
Powerstation MV	15 714 285 per item
Powerstation HV	39 285 714 per item
Powerplant S	78 571 428 per item
Powerplant M+L	392 857 142 per item

South and Central America:

No Infrastructure damage functions available for Oceania.

No maximum damage values available for South and Central America. The average maximum damage value in Europe is 24 €/m^2.

3.2.6 Agriculture

Brémond et al. (2013) have considered the most influential parameters on direct damage to agriculture. The flood parameters that can be used to construct damage functions for agriculture are the seasonality of the flood, water depth, duration, current velocity, deposits, contamination by pollution, and salinity of water.

The most important flood parameter considered in the damage functions for agriculture in this study is flood depth. It is concluded by Bremond that this is generally a parameter used to assess damage to farm buildings and their contents when these are taken into account (Blanc et al., 2010). However, in this study buildings and infrastructure are assessed separately from agricultural crops.

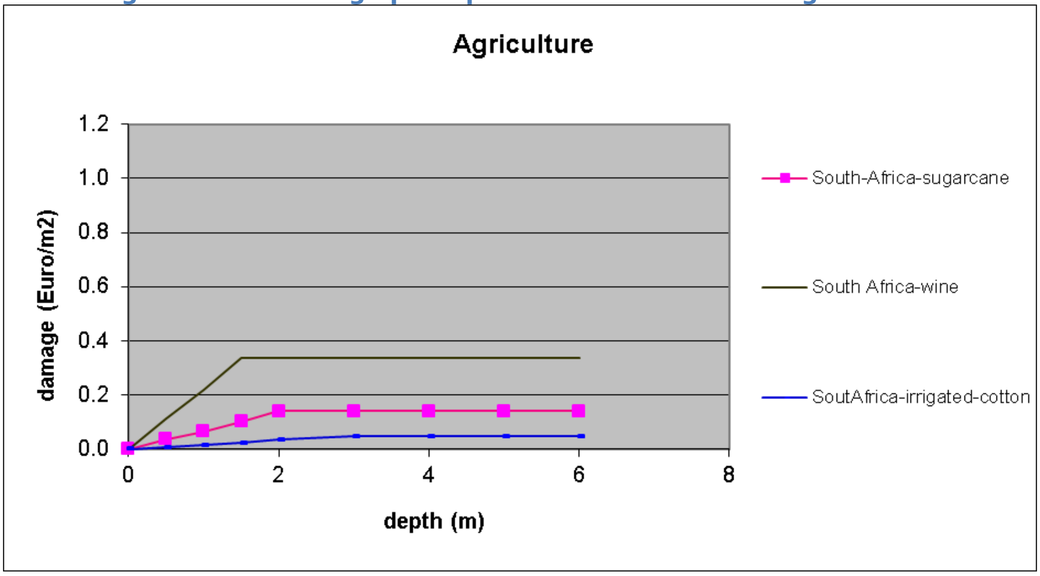
Seasonality is also considered to be one of the most influential parameters to assess crop damage. Nevertheless, Bremond concludes that this parameter is hard to use as it varies to crop, hemisphere and latitude. We do not include this parameter in this study.

The third important parameter is flood duration to assess damage to crops and to plant material. The usual unit used is the number of days of submersion.

The other parameters are being evaluated as much less influential as the first three mentioned above.

Africa:

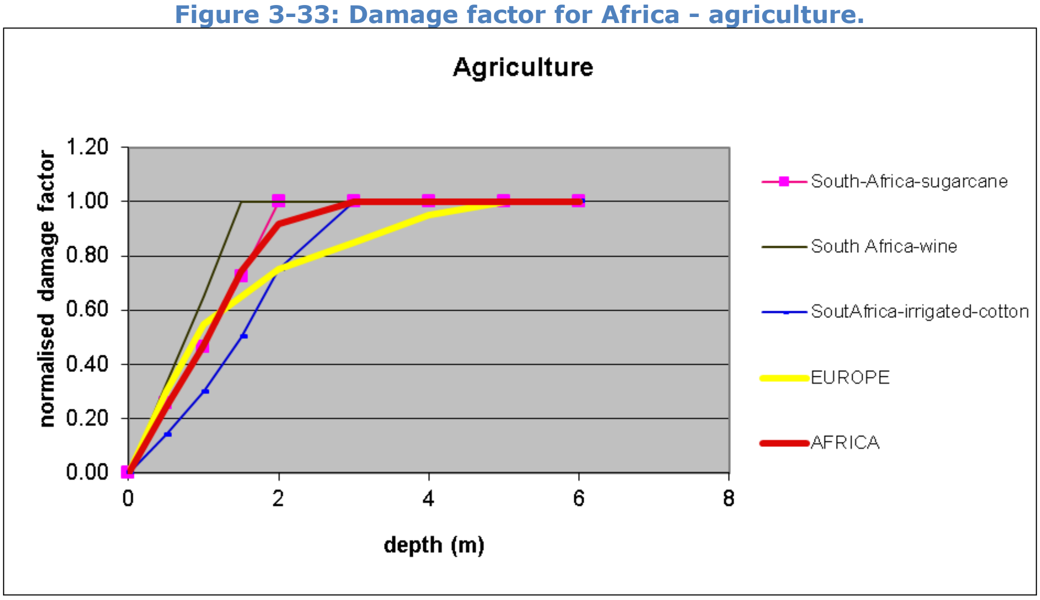
Figure 3-32: Damage per square meter for Africa - agriculture.



The countries in the Figure 3-32 comprise South Africa only. The differences in the figure are small between the various crops. Wine has by far the highest maximum damage per square meter, while other crops show less difference. In Mozambique the damage is 0.10 €/m^2 for maize and rice. The average maximum damage value for the damage class 'Agriculture' is 0.16 €/m^2 (2010) compared to 0.77 €/m^2 (2007) in Europe.

The relative damage functions are shown in Figure 3-33 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-33: Damage factor for Africa - agriculture.



The average function for Africa deviates from the European function. However, this difference becomes significant after the flooding depth exceeds 1 meter.

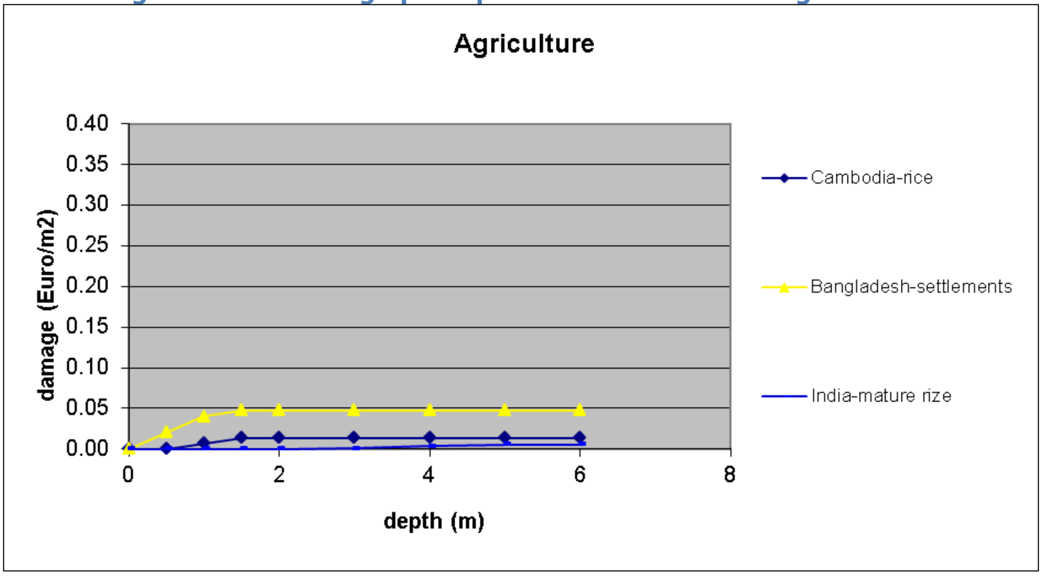
Based on the collected data a new 'average' damage function for agriculture is made.

Table 3-18: Average continental damage function for Africa - agriculture.

Water depth (m)	*Damage factor*
0	0
0.5	0.24
1	0.47
1.5	0.74
2	0.92
3	1.00
4	1.00
5	1.00
6	1

Asia:

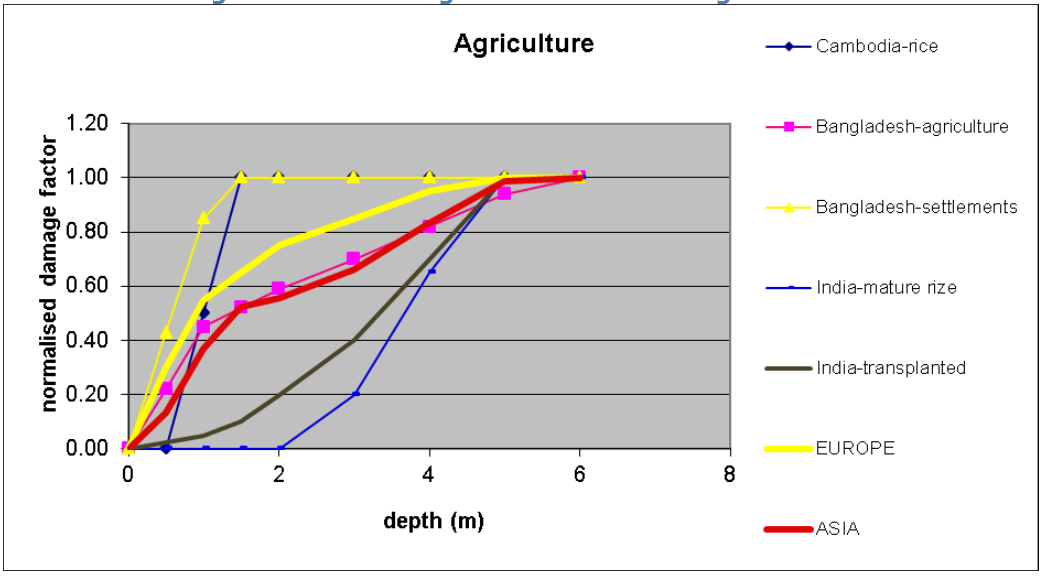
Figure 3-34: Damage per square meter for Asia – agriculture.



The differences in the Figure 3-34 are relatively small. The upper function in the figure above comes from Bangladesh and runs up to about 0.05 €/m^2 (2010). The two lower functions come from Cambodia and India and vary between 0.01 – 0.02 €/m^2 (2010). The average maximum damage value for the class 'Agriculture' is 0.02 €/m^2 (2010) in Asia compared to 0.77 €/m^2 (2007) in Europe.

The relative damage functions are shown on Figure 3-35 below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-35: Damage factor for Asia - agriculture.



The shape of the Asian damage function for agriculture is not identical to the European function, as the Asian function is less steep until about 2 meters water depth. This may be due to the fact that rice (one of the main crops in Asia) is grown in water. After 5 meters the differences becomes small.

Based on the collected data a new 'average' damage function for agriculture is made.

Table 3-19: Average continental damage function for Asia - agriculture.

Water depth (m)	*Damage factor*
0	0
0.5	0.17
1	0.37
1.5	0.51
2	0.56
3	0.69
4	0.83
5	0.97
6	1

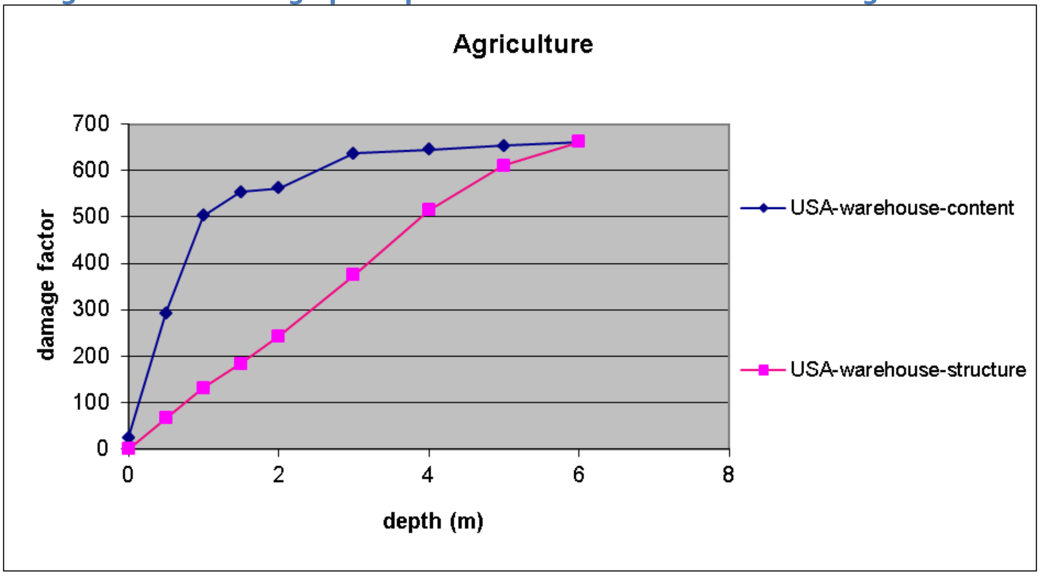
Oceania:

No Agriculture damage functions available for Oceania.

The average maximum damage value for the class 'Agriculture' is 4.85 €/m^2 (range 0.003-19 €/m^2) (2010) in Oceania compared to 0.77 €/m^2 (2007) in Europe.

North America:

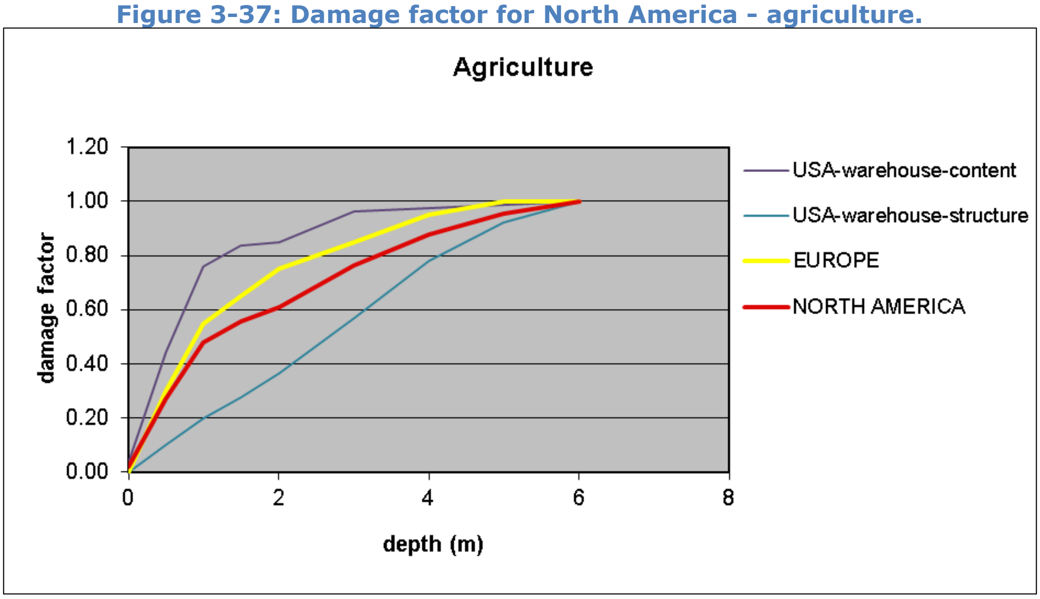
Figure 3-36: Damage per square meter for North America – agriculture.



All data is from USA and based on HAZUS. In the Figure 3-36 above the value of warehouse is the sum of structure and content. The average maximum damage for North America is 1324 €/m^2 (2010) compared to 0.77 €/m^2 (2007) in Europe. This difference is huge and may be contributed to the fact that HAZUS additionally includes damage to farms (buildings) and warehouses.

The relative damage functions are shown below. The recorded individual functions are not always running from 0 to 1, so they have been normalised to always end on 1.

Figure 3-37: Damage factor for North America - agriculture.



As can be seen the shape of the damage factor for North America and the European function is nearly identical.

Based on the collected data a new 'average' damage function for agriculture is made.

Table 3-20: Average continental damage function for North America - agriculture.

Water depth (m)	*Damage factor*
0	0.02
0.5	0.27
1	0.48
1.5	0.56
2	0.61
3	0.76
4	0.88
5	0.95
6	1

South and Central America:

No Infrastructure damage functions available for South and Central America.

No maximum damage values available for South and Central America. The average maximum damage value in Europe is 0.77 €/m^2.

3.2.7 Damage function shape analysis: an example

It was investigated if variations in the degree of damage at a specific flood depth can be associated with other known characteristics of the flooded site. For example if, at a given depth level, there exists a consistent difference in damage between the urban and rural areas. The analysis aimed to find a significant statistical relation between the curvature of the damage functions and control variables like WDI-parameters (for example GDP per capita).

As an initial reconnaissance two different possibilities were investigated for the damage class residential buildings:

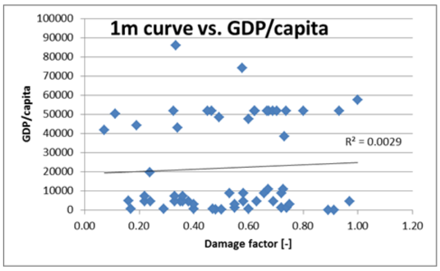
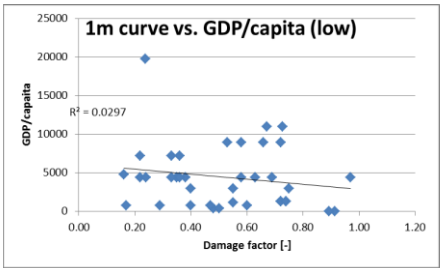
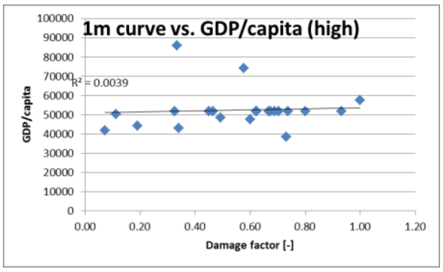
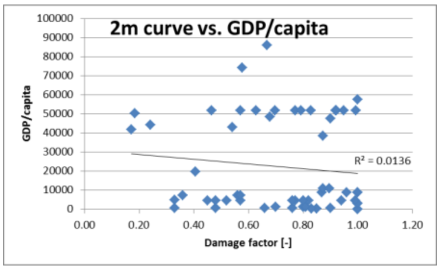
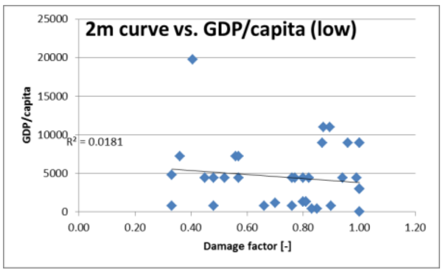
1. individual functions for all available countries versus GDP per capita,
2. averaged national functions for all available countries versus GDP per capita

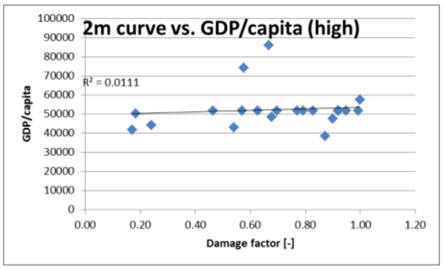
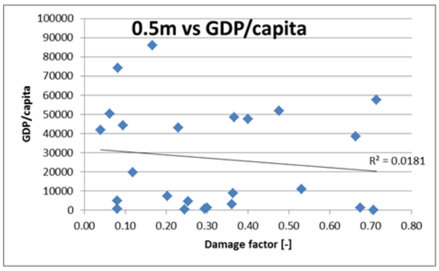
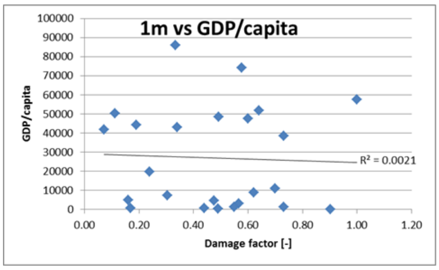
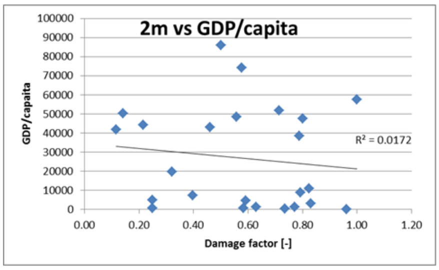
The results of the calculations are presented in Figure 3-38 below.

Included are two flood levels (1.0 and 2.0m) for the case including all individual functions and three flood levels (0.5, 1.0 and 2.0m) for case dealing with country averaged functions.

The goodness of fit value (R^2) was observed for different combinations of the indicators, as well as for subsets of the data (eg developed vs developing countries). Also the fit with the only one curve per country versus GDP per capita was checked.

Figure 3-38: Analysis of the relationship between the curvature of the damage curves and the regional characteristics.

Graphical represenatation	***Description***
	○ flood depth 1 m ○ damage factor vs GDP/capita ○ all collected functions ○ **all countries** ○ R^2 = 0.0029
	○ flood depth 1 m ○ damage factor vs GDP/capita ○ all collected functions ○ **poor countries** (note Y-axis range) ○ R^2 = 0.0297
	○ flood depth 1 m ○ damage factor vs GDP/capita ○ all collected functions ○ **rich countries** (note Y-axis range) ○ R^2 = 0.0039
	○ flood depth 2 m ○ damage factor vs GDP/capita ○ all collected functions ○ **all countries** (note Y-axis range) ○ R^2 = 0.0136
	○ flood depth 2 m ○ damage factor vs GDP/capita ○ all collected functions ○ **poor countries** (note Y-axis range) ○ R^2 = 0.0136

Graphical represenatation	*Description*
	○ flood depth 2 m ○ damage factor vs GDP/capita ○ all collected functions ○ **rich countries** (note Y-axis range) ○ R^2 = 0.0136
	○ flood depth 0.5 m ○ damage factor vs GDP/capita ○ country average functions ○ R^2 = 0.0181
	○ flood depth 0.5 m ○ damage factor vs GDP/capita ○ country average functions ○ R^2 = 0.0021
	○ flood depth 0.5 m ○ damage factor vs GDP/capita ○ country average functions ○ R^2 = 0.0029

The results on Figure 3-38 show a cloud without detectable (linear) relation, with R^2 nearly zero. There is also little indication of significant correlation for other WDI indicators or for industrial/commercial damage classes. It probably takes more detail to explain the damage factor at various flood depths than simple application of GDP per capita, however, the detailed data is not available to pursue the investigation at this stage.

3.3 Maximum damage values

Maximum damage values for the various classes are described in section 3.2 and are summarized in the Table 3-21 below. The values are for price level 2010, except for Europe, which represents price level 2007. The values in the Table below are the continental-average maximum damage values.

Table 3-21: Average maximum damage value per continent [Euro/m^2 – 2010].

Damage class	***Africa***	***Asia***	***Oceania***	***N America***	***SC America***	***Europe***
Residential buildings	495	111	541	788	215	750
Commerce	-	138	506	<u>*1889*</u>	213	621
Industry	120	114	-	<u>*1830*</u>	137	534
Transport	-	209	-	-	-	751
Roads	<u>*267*</u>	4	7	39	-	24
Agriculture	0.12	0.03	4.85	<u>*662*</u>	-	0.77

The values which are considered as requiring further research (they show considerably higher values than other countries) are presented in underlined italic font.

The data can also be presented as national maximum damage values, as collected in the following Table 3-22.

Table 3-22: Average maximum damage value per country [Euro/m^2 – 2010].

Damage class:	***Residential***	***Commerce***	***Industry***	***Transport***	***Infrastructure***	***Agriculture***
Africa						
Mozambique	283				267	0.1
South Africa	765		120			0.18
Asia						
Cambodia	24					0.01
Bangladesh	25	144	92		2.5	0.05
China	984	*1274*	*1741*	*414*	*12*	
Taiwan	131					
India						0.01
Indonesia	6	29	27	4		8
Thailand	1		245			0.02
Laos						
Vietnam	7	15			0.25	0.1
Japan		332				
Oceania						
Australia	541	506			7	4.8
North America						
Canada						
USA	788	*1889*	*1830*		39	662
Central and South America						
Brazil	105	90	29	23		
St. Maarten	326	254	191			
Europe						
Belgium	792					0.55
Czech Republic		130	130			
Denmark	259					
France		261	257			
Germany	526	362	203			
Hungary						
Netherlands	717	106	106	691	60	1.55
Norway	729	1254	1254		14	
Switzerland					12	
United Kingdom	1475	1615	1255	812	11	0.2

It is clear from Table 3-21 and Table 3-22 that the maximum damage values are strongly varying between countries and between continents per damage class. This relates to different assumptions and definitions in reported cases.

It is for this reason that alternative approach has been developed to define maximum damage values for the classes residential, commercial and industrial buildings, agriculture and roads. The alternative approach is elaborated in the next sections.

3.3.1 Residential, commercial and industrial buildings

In this section, country specific maximum damage values for residential, commercial and industrial buildings are calculated. With damage curves differentiated per continent, these maximum damage values will be used to calculate country-specific damage values (also within the same continent).

From the literature review (section 2.2), the damage curves have been derived per continent (section 3.1). Many of the literature sources also provide maximum damage values. There are, however, two reasons why maximum damage values from the literature review should not be used directly:

1. maximum damage values are not available for every country, and
2. maximum damage values show a significant variation.

This second point can be due to various reasons, for instance: object vs. land use; unknown objects size; various types of residential, commercial, industrial objects used (e.g. rural house, apartment, various quality of buildings, offices, warehouses, stores, factories, etc.); different ways of determining a maximum damage figure by different sources; based on a damage factor ranging to one or not; inclusion of basements; etc.

As a result, there are significant differences between maximum damages from different national models making it difficult to form them into a consistent global dataset.

Therefore, in this study, a different approach based on regression analysis of the construction costs is used in order to generate a consistent global set of maximum damage values for buildings. In order to derive maximum damage estimates, the following steps have been followed in the next three sub-sections:

1. Identification of construction costs of buildings (various types) for as many countries as possible (section 3.3.1.1);
2. Calculation of construction costs for typical residential, commercial and industrial buildings using average building stock as weighing between building types (section 3.3.1.2)
3. Regression analyses to extrapolate construction costs to all countries based on socio-economic parameters from World Development Indicators (WDI) (section 3.3.1.3).

3.3.1.1 Construction cost of buildings

International construction cost surveys form a source of information for damage in terms of reconstruction costs. International construction costs are available for many different countries and classes, including residential, commercial and industrial buildings.

In the literature three sources have been found: Turner & Townsend (2013), Gardiner & Theobald (2012), and EC Harris (2010, 2012). For the purpose of this study, construction costs for residential, commercial and industrial buildings are required.

Turner & Townsend (2013), EC Harris (2010) and Gardiner & Theobald (2012) provide construction costs per m^2 for different types of buildings for many countries, and EC Harris (2012) provides a range of index numbers related to different building types. More detailed information can be found in the following Table 3-23.

Table 3-23: Details of sources for construction costs of different building types.

Turner & Townsend (2013)	
23 countries	Australia, Brazil, Canada, China, Germany, Hong Kong, India, Ireland, Japan, Malaysia, Netherlands, Oman, Poland, Qatar, Russia, Singapore, South Africa, South Korea, UAE, Uganda, UK, US, Vietnam
27 building types	○ Airports: domestic terminal, low-cost carrier ○ Carparks: above ground, below ground ○ Commercial: Offices, CBD up to 20 floors, CBD prestige

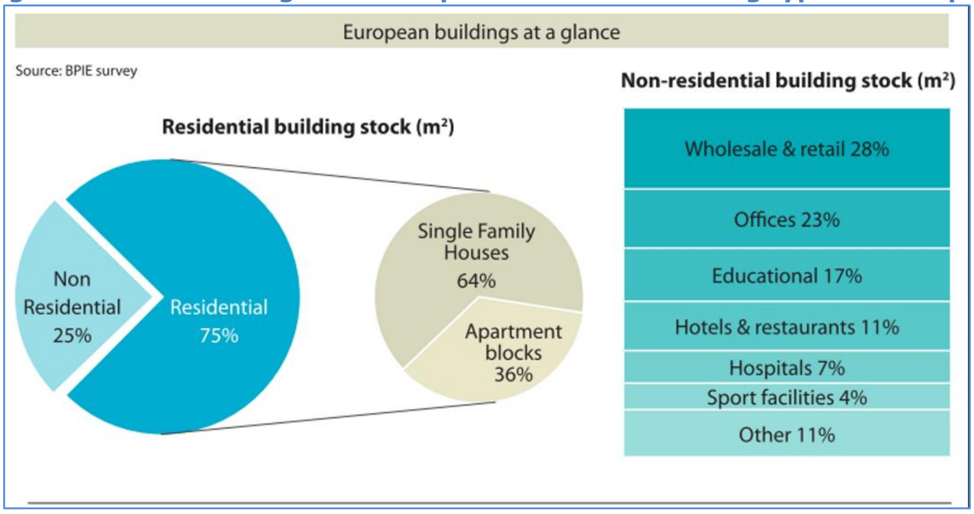
	- Education: School, University - Hospitals: day centre, regional hospital, general hospital - Hotels: 3-star, 5-star, resort style - Industrial: warehouse/factory, warehouse/distribution, high-tech/lab - Residential: individual detached, individual prestige, townhouse, apartments, apartments high rise, aged care/affordable units
Gardiner & Theobald (2012)	
32 countries	Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Romania, Slovakia, Spain, Sweden, Switzerland, United Kingdom, China, Hong Kong, India, Indonesia, Kenya, South Africa, Sri Lanka, Turkey, UAE, Ukraine, USA
8 building types Incl. low and high estimate per building	- City centre heated office - City centre air-conditioned office - Factories, warehouse, industrial - Business park - High-rise apartments - Shopping centre - High quality city hotel - Suburban hotel
EC Harris (2010)	
51 Countries	Austria, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Latvia, Macedonia, Netherlands, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Spain, Sweden, Switzerland, Turkey, UK, Ukraine, Abu Dhabi, Bahrain, Oman, Qatar, Saudi Arabia, China, Hong Kong, Indonesia, Malaysia, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Cameroon, Egypt, Ghana, South Africa, Australia, Canada, New Zealand, USA
48 building types with high and low estimates per type	- Industry: Industrial Units (shell only); Purpose Build Industrial units (incl. services); High bay distribution units; Chilled distribution warehouses. - Offices: Traditional low rise offices; Business Park development; High rise offices; Medium rise offices; Office fit out; Office refurbishment. - Retail: Underground car parks; Multi storey car parks; Supermarkets – shell only; Supermarket – fitting out; Retail warehouses; Shop units; Shopping centres – retail areas; Shopping centres – landlords back-up; Shopping centres – malls. - Health: General hospitals; Health centres; Old people's homes; Nursing homes / hospices. - Leisure: Restaurants – shells; Restaurant / Food court; Theatres; Multi-screen cinemas; Sports / leisure centres; Swimming / leisure pools; Community centres. - Education: Schools (primary and secondary) - Residential: Houses – social; Houses – speculative private estate; Houses – private high quality; Houses – luxury; Apartments – social; Apartments – private high standard; Apartments – private luxury; Sheltered housing; Students' residences. - Hotels: Hotels – budget; Hotels – mid market (low); Hotels – mid market (top); Hotels – luxury.
EC Harris (2012)	
53 Countries	Austria, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, France, Germany, Greece, Hungary, Italy, Latvia, Macedonia, Netherlands, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK, Ukraine, Qatar, Saudi Arabia, UAE, Algeria, Ghana, Morocco, Tunisia, South Africa, China, Hong Kong, India, Indonesia, Japan, Macau, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand, Vietnam, Australia, Canada, New Zealand, USA
Range of index based on 44 building types	Index based on the UK=100

From the sources identified, EC Harris (2010) and Turner & Townsend (2013) provide information on all three categories and, correspondingly, will be used in the analyses. Gardiner and Theobald (2013) has not been used because it does not include data for regular residential buildings (only for high-rise apartment buildings) and EC Harris (2012) has not been used as no absolute figures are given.

3.3.1.2 Building stock as weighting criterion

In order to derive average building cost estimates for generic residential, commercial and industrial buildings, the detailed construction cost estimates from EC Harris (2010) and Turner & Townsend (2013) have been aggregated into a single estimate for a commercial building. For the weighting criterion use has been made of studies on building stocks in Europe (BPIE, 2011) and the United States (Deru et al, 2011). These studies were related to estimating energy consumption and give estimates in terms of the percentage of floor space of different building types (see Figure 3-39). Note that these studies show that there is considerable variation between countries. For example, the percentage of single family houses in Europe is on average 64%, but most countries fall in a range between 50% and 80% (i.e. +/- 15%).

Figure 3-39: Percentage of floor space of various building types in Europe.



source: BPIE (2011)

As both studies yielded comparable results in terms of percentages of floor space between different types of buildings, these findings have been used to derive weights for aggregating the data from the construction cost surveys presented in Table 3-24 below. For industrial buildings, almost equal weights have been used between the (couple of) industrial building types present as no information on industrial building stock was found.

Table 3-24: Generic weights for different building types.

Residential %		***Commercial (non-residential) %***	
Single Family	65	Shops/malls	15
Apartments	35	Warehouse/storage	15
		Offices	25
		Education	15
		Hotels/Restaurants	10
		Hospitals	5
		Other (public/sport)	15

3.3.1.3 Regression analysis

The construction cost surveys of EC Harris (2010) and Turner & Townsend (2013) report on building costs per m^2 of different types of residential, industrial and commercial buildings in a consistent way, covering dozens of countries. They form an excellent source to derive a consistent set of maximum damage estimates. The process covered the following steps:

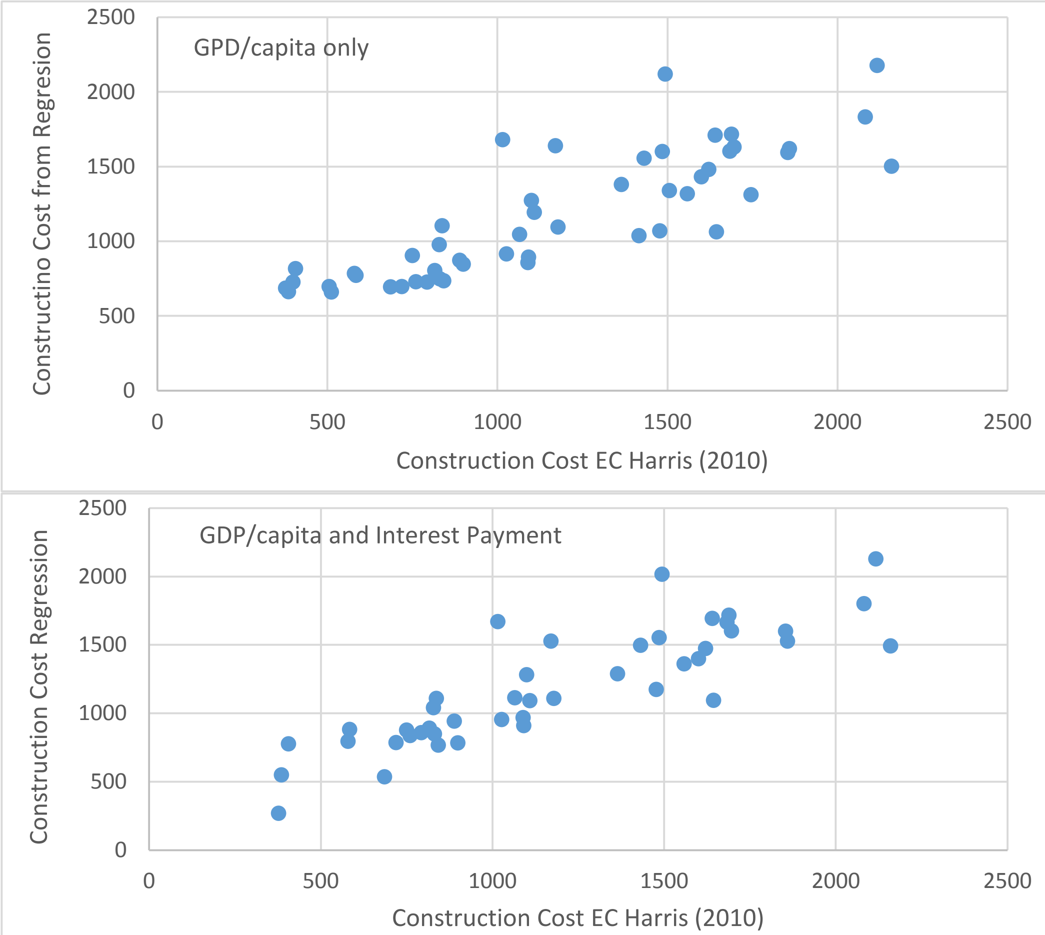
Correlations

Correlation coefficients are calculated for all combinations of WDI indicators (1300+) and the three construction costs of both EC Harris and Turner & Townsend (separately to avoid overlap issues). This shows that usually between 150-200 WDI indicators correlate significantly with the construction costs. However, in many cases the indicators are very similar (many variations on GDP, GNI) or auto-correlated. Some interesting indicators are identified, such as *Interest payments (% of expense)*, *Net official flows from UN agencies, UNDP (current US$)*, or *Deposit interest rates*.

Regression analyses

In the subsequent regression analyses it is found that GDP per capita alone explains most of the variance. Some combinations add significant extra explained variation, for instance including *Interest Payments.* However, the increase is not large (R^2 increased from 0.704 to 0.736). More importantly, regression plots show that particularly at lower construction cost levels (i.e. in poorer countries) applying GDP and *Interest Payments* results in a better fit, as shown on Figure 3-40.

Figure 3-40: Plots comparing the regression results of regression with only GDP/capita (top panel) and regression using both GDP/capita and Interest Payment (bottom panel).



However, whilst such combined regression analyses yields better results, the spatial coverage in terms of countries for which such WDI indicators are available is often poor. Some very promising WDI indicators are only available in 20% of the countries. As the goal is to derive estimates with a global coverage, it is desirable to use only indicators with (near-) global coverage.

<u>Power function fit</u>

Using only GDP per capita as the explaining factor for construction costs results in overestimations of construction costs in poorer countries having low construction costs (Figure 3-40).

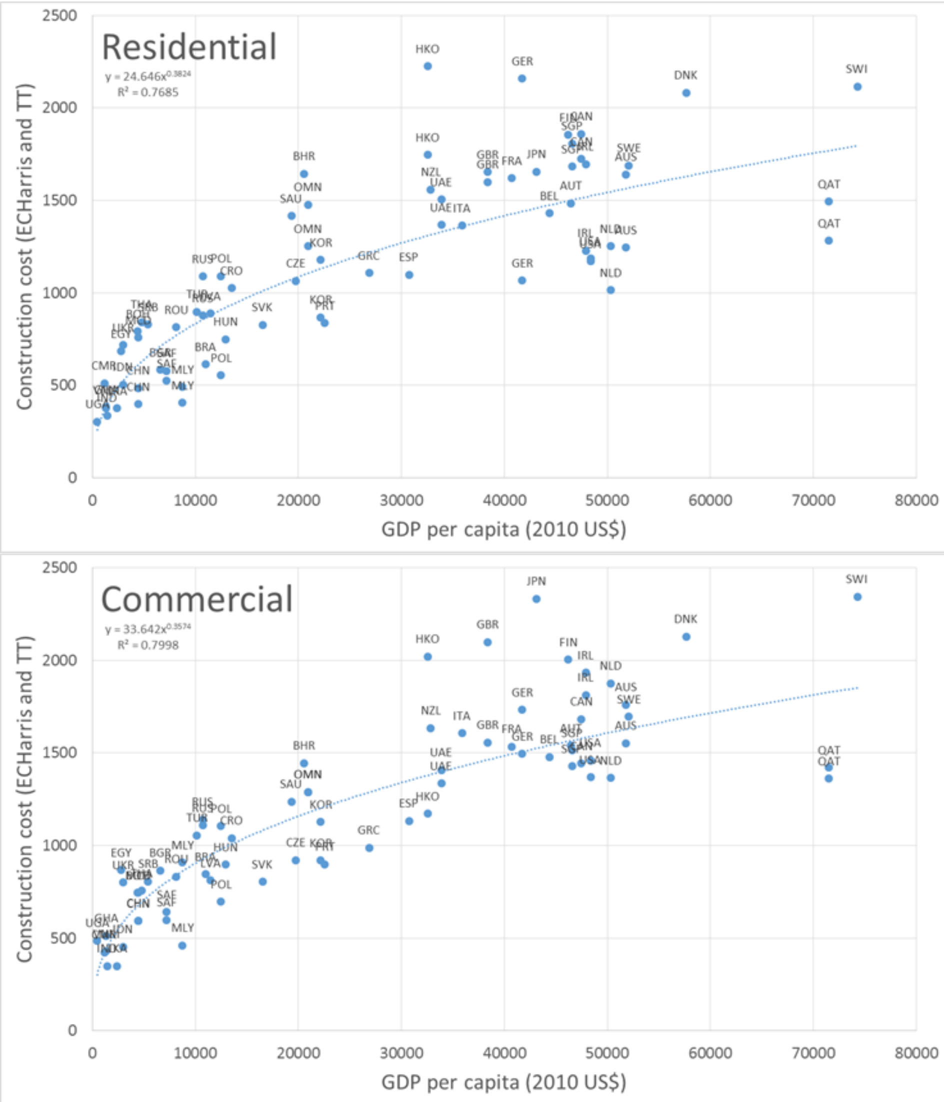
To overcome this issue, non-linear functions were fitted in order to see if such functions would improve results. This was done on the combined datasets of EC Harris (2010) and Turner & Townsend (2013), where overlapping countries were treated as two separate data points (with the same GDP per capita), resulting in just over 70 data points (Figure 3-41).

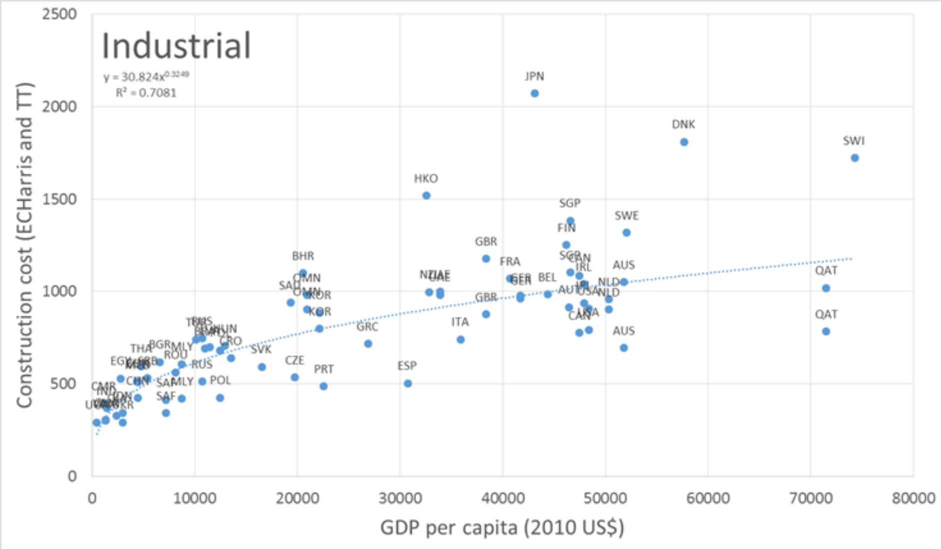
Eventually, power-functions with exponents smaller than one yielded the best results, resulting in substantially higher R^2 values as compared to linear regression. For example the R^2 value in case of residential buildings increased from 0.64 for linear fit to 0.77 for the power function fit. The results of the power function fit are shown below in Table 3-25 and in Figure 3-41.

Table 3-25: Power law functions ($y = ax^b$) for the three building classes; with y corresponding to construction cost in Euro/m2 (2010), x to GDP/capita in US$ (2010), and *a* and *b* being the coefficients of the fit.

Class	***a***	***b***	R^2
Residential	24.1	0.385	0.77
Commercial	33.6	0.357	0.80
Industrial	30.8	0.325	0.71

Figure 3-41: Power function fits for residential(a), commercial(b) and industrial (c) construction costs [Euro/m^2, 2010]





Using the fitted power functions, maximum damages can be calculated for all countries having a known GDP per capita.

<u>Discussion</u>

Overall, the fit is quite good, with R^2 values above 0.75. Nevertheless, there is clearly some spread around the fit. To possibly reduce the observed variation, it was explored whether grouping of countries would be possible, based on some other socio-economic indicator (such as the percentage of urbanisation).

At first sight, no specific groups of countries stand out above and below the current fit. For instance, Qatar (QAT) is clearly below the fit, whereas other Middle Eastern countries (United Arab Emirates, Bahrein, Saudi Arabia) are on or clearly above the fit. The same goes for other 'logical' groups such as Eastern European or North-western European countries. It is also clear that in some cases the double entries for a single country (i.e. construction costs estimated from two different sources, resulting in two data points) can be considerably apart (i.e. Germany and Poland).

To systematically see if a factor can be found to create different groups for differentiated fits, the relative difference of each data point with the fit has been estimated (similar to the error estimation). This relative difference has correspondingly been used to calculate correlation coefficients with all WDI indicators. Indicators for which a relatively high correlation coefficient was calculated, and had a reasonable sample size, were then investigated to see whether differentiated fits would make sense.

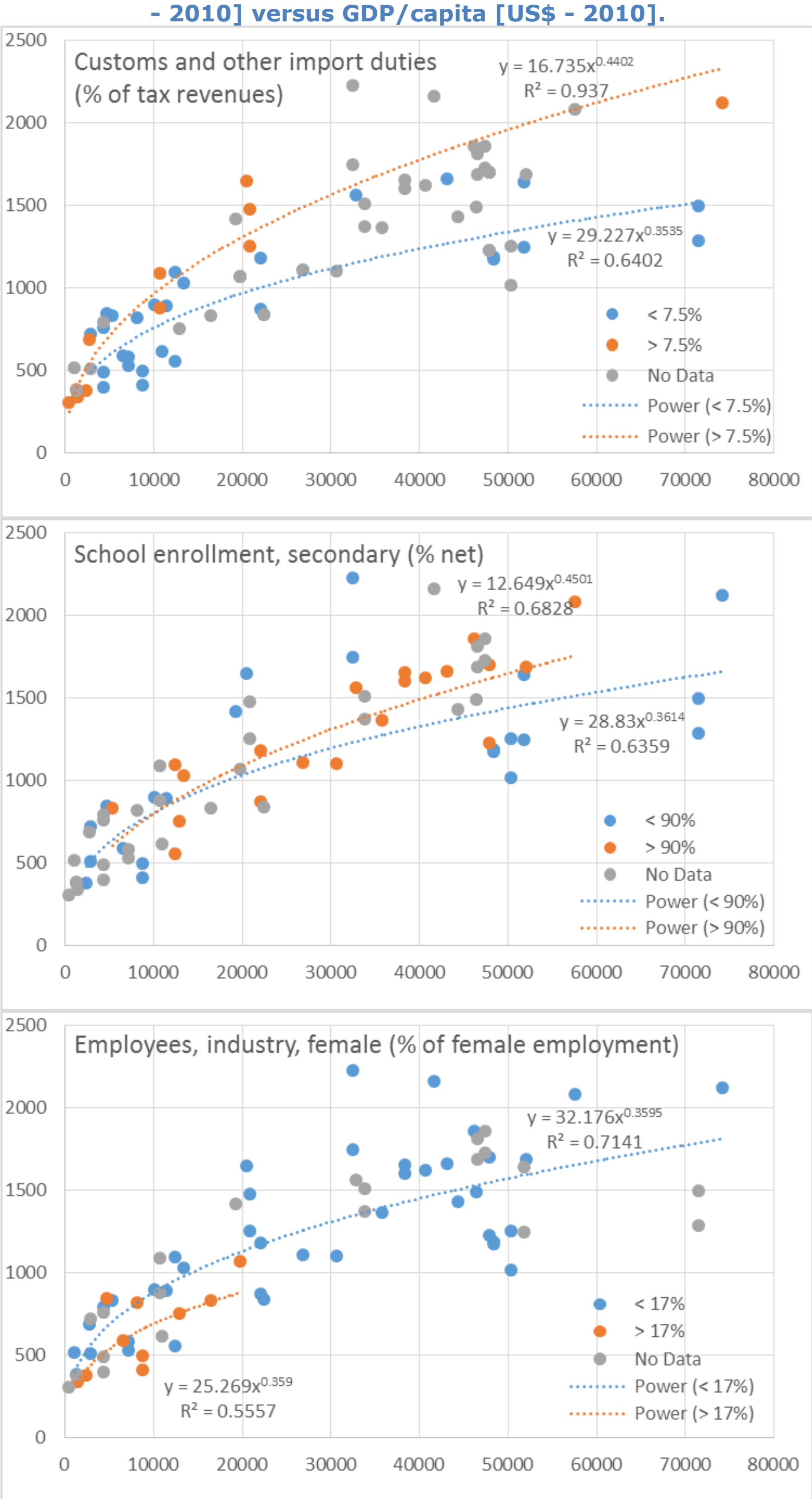
WDI indicators explored for this were:

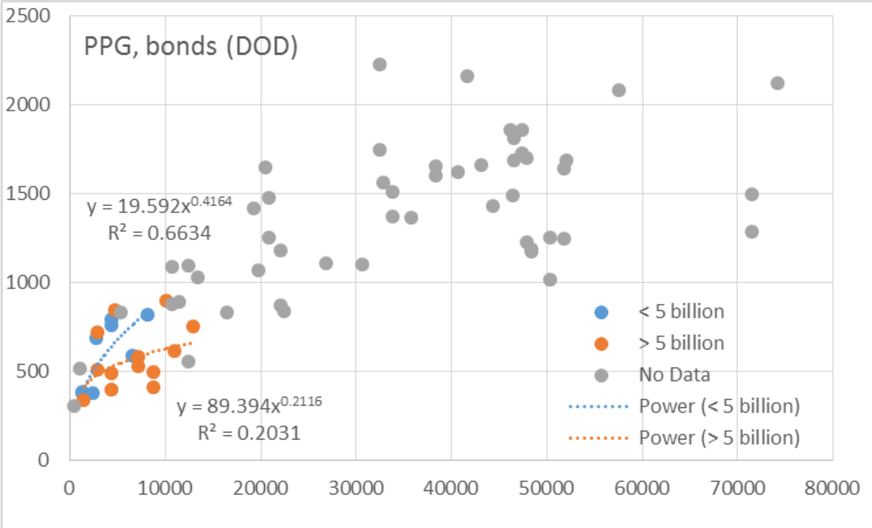
- Tariff rate, applied, weighted mean, manufactured products (%)
- Percentage Urban (%)
- PPG, bonds (DOD, current US$)
- Employees, industry, female (% of female employment)
- School enrolment, secondary (% net)
- Customs and other import duties (% tax revenues)

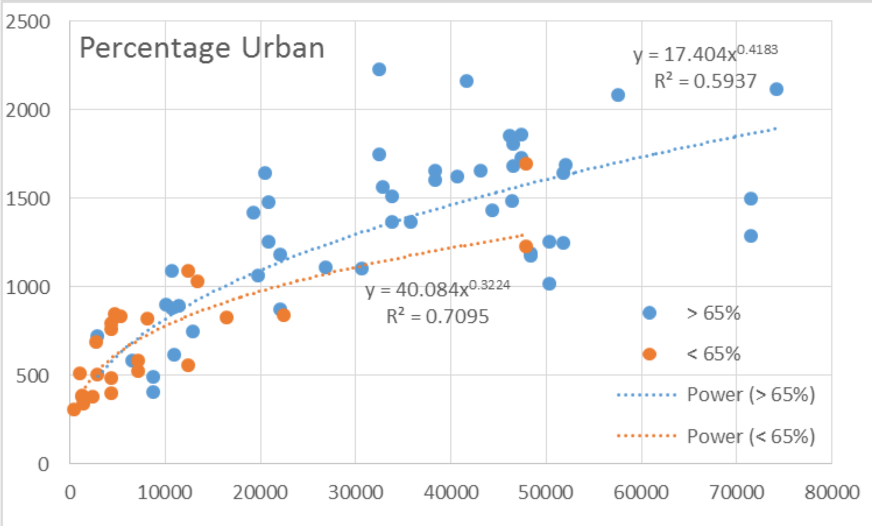
Using these indicators, the residential fit (top graph on Figure 3-41) has been split in two groups in order to investigate if the samples of the data would estimate improved fits. Graphically, this would result in a group that is clustered above the fit-line, and a group that would be clustered below the fit-line.

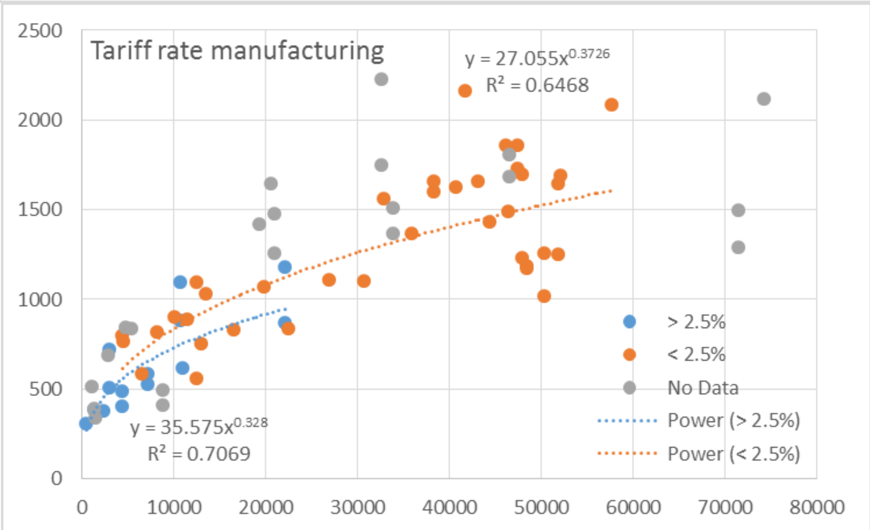
Results for splitting are included in Figure 3-42 below.

Figure 3-42: Splitting the construction costs for residential construction costs [Euro/m^2 - 2010] versus GDP/capita [US$ - 2010].









Unfortunately, there was no improved fit to be found for any indicator. In all cases, except for the 'Customs and other import duties' the R^2 of the power function fits for the individual groups were lower than for all the data (i.e. below 0.77). For the 'Customs and other import duties' indicator, one of the two fits was better but the other one was lower. Coupled with the relatively large amount of countries with no data (grey dots), an approach differentiating countries using these indicators would not improve the overall results.

3.3.1.4 From construction costs to maximum damage

Various adjustments are necessary in order to compute the maximum damage values from the construction costs; these are described in the following sub-sections.

Depreciated Values

Construction costs need to be adjusted in order to reflect maximum flood damages, as these are related to reconstruction costs and for most analyses depreciated values (i.e. current remaining value instead of new value) are needed, rather than replacement values (Merz et al., 2010). The translation from replacement costs to depreciated value is done using a conversion factor of 0.60, based on World Bank (2000), Frenkel & John (2002), Messner et al. (2007) and Penning-Rowsell et al. (2010), who quote values of 0.63 (Mozambique, Germany) and 0.5 (UK rule of thumb). Note that for some purposes it is better to use full reconstruction costs, for instance when an individual company is studied (Messner et al., 2007), or for insurers in case the policies in the contracts which are based on replacement costs which should be paid out. Therefore, the conversion factor in the accompanying Excel file is set as an adjustable parameter.

Contents and Inventory

The construction costs data only refers to the costs related to the building itself (including fittings and such). However, flood damage also comprises damage to the content of the buildings. In various national models, use is made of percentages of the building damage for damage to contents or inventory. For instance, the HAZUS model uses damage values of 50% for residential contents, ~100% for commercial contents, and ~150% for industrial contents (Scawthorne et al., 2006; FEMA, 2013: Table 14.6). Several other studies also suggest that residential content is roughly half of the value of the building structure (De Moel et al., 2014; Kok et al. 2005; Vanneuville et al. 2006; Penning-Rowsell et al. 2010). For a global methodology, we will therefore use the following percentages for maximum damage to contents/inventory (Table 3-26). In the accompanying spreadsheet, these numbers are adjustable by the user to allow for maximum flexibility and future knowledge on this subject to be easily integrated.

Table 3-26: Contents damage as % of building damage.

Class	***Contents damage*** *(as % of building damage)*
Residential	50
Commercial	100
Industrial	150

Object vs. land-use

The derived maximum damage values relate to individual objects and their content. However, in many studies, especially when working at a large scale/low resolution, there is no spatial information on actual building footprints, but rather information on land-use (e.g. residential land use, comprising houses, but also the open spaces in between). To account for this, an estimate of the density of buildings is necessary (ratio of the area of actual building footprints over the total area). Generally, the density is accepted to range between 20% and 30%, though this can vary of course between downtown (higher density) and more rural residential areas.

Undamageable part

Comparing the maximum damage estimates with those of studies around the globe and the previous EU study (section 4.2.1) shows that for buildings build of more water resistant material (i.e. concrete, bricks) there seems to be a substantial part of the construction costs that will never be damaged. Correspondingly, many functions asymptote to e.g. 60%, indicating a 40% portion that is undamageable and should thus not be included in the maximum damage estimate used in the flood damage assessment.

3.3.2 Infrastructure

From the literature review, maximum damage values for infrastructure have been recorded per continent (section 3.1). The number of available maximum damage values is rather low (about 10 individual recorded values over all continents) and varying strongly due to different methods of determining maximum damage, as illustrated in Table 3-27.

Table 3-27: Countries having maximum damage values for Infrastructure (roads) damage class.

Continent / country	***Euro/m^2 (2010)***
Africa	
Mozambique	267
Asia	
Bangladesh	2.5
China	12
Vietnam	0.25
Oceania	
Australia	7
North America	
USA	39
Central and South America	
none	
Europe	
average	24

As a result, there are significant biases between maximum damages from different national models making it difficult to form them into a consistent global dataset.

Therefore, this study applies values from the European study (Huizinga, 2007) because the average maximum damage value reported by Huizinga has an identical magnitude of values compared to the USA and China. Moreover, the specifications of the European average are well known.

The average value in Europe is 24 Euro/m^2 for five countries with a long established track-record on damage assessment. These countries are: United Kingdom, Germany, Netherlands, Belgium and France. The price level of the reported maximum damage value is 2007.

The procedure applied to update the maximum damage value for roads in Europe is:

1. Convert maximum damage value to price level 2010 by applying average CPI increase of the five countries (World Bank, 2014)
2. Calculate GDP/capita (2010) in UDS2015 by calculating average GDP/capita 2010 for the five different countries - World Bank website (2015).

Table 3-28: Update factors considering European maximum damage values for roads.

Country	***CPI (2010/2007)***	***GDP/capita (2010)***
	-	**US$ (2015)**
UK	1/0.92	38 293
Germany	1/0.95	41 788
Netherlands	1/0.95	50 341
Belgium	1/0.94	44 283
France	1/0.96	40 706
average	1.0595	43 082

The maximum damage to be used for roads is 25.2 Euro/m2 corresponding to a GDP/capita of 43 082 US$.

If the GDP/capita of a country under consideration is known, than the maximum damage can be recalculated according to the GDP/capita(2015)-ratio of the global maximum damage value and the national value.

3.3.3 Agriculture

For the determination of maximum damage values to agricultural crops a different approach has been devised. Agricultural crop damage is related to a loss in output when crops are destroyed by the flood[10].

Therefore, the methodology is based on the value added is calculated per hectare. From the World Development Indicators (WDI) the following two variables have been extracted for all (214) countries, and the years 2008–2012:

- Agricultural land (sq. km)
- Agriculture, value added (current US$)

Subsequently, the VA per hectare was calculated, and an average of the five years was computed to minimise a single-year deviations. The resulting values for the Value Added (US$) per hectare (VA/ha) are given in Appendix A.

<u>Value added per hectare</u>

Of the 214 countries 37 do not have values, which relates mainly to very small countries like Andorra, Bahrain, Kosovo, pacific islands, etc. The agricultural VA/ha ranges between 9 US$ (Mongolia) to 122 070 US$ (Singapore). Most numbers ranged in the order of a couple of hundred to a couple of thousand US$.

Table 3-29 shows the highest VA/ha countries:

[10] Agricultural buildings and infrastructure are considered separately, not as part of the damage class *Agriculture*.

Table 3-29: Countries showing the highest value addition per hectare in agriculture.

Country	***VA/ha (US$)***	***ha (2008-2012)***
Singapore	122070	7
Bermuda	59263	7
Hong Kong SAR, China	25346	51
Malta	14201	99
Japan	13841	45880
Korea, Rep.	13788	17858
Maldives	13205	70
Bahamas, The	11789	142
Brunei Darussalam	8630	118
Egypt, Arab Rep.	7892	36358
Seychelles	7411	30
Netherlands	7261	18984
Israel	6588	5199
United Arab Emirates	6020	4258
Aruba	5602	20
Norway	5416	10069

Two countries stand out with very high VA/ha: Singapore and Bermuda. These countries have a very small area devoted to agriculture. Singapore, for instance, mainly grows high-value fruits (e.g. mangos) and flowers (e.g. orchids). As a result, the value per hectare is relatively high as compared to other countries which produce bulk food like grains. Correspondingly, these values will be taken as calculated.

3.4 Conclusions and recommendations

In this chapter the damage functions and the corresponding maximum damage values for various damage categories have been described.

Continental damage functions are average functions of all normalized available functions per continent identified from the literature review. Continent specific functions should be used for all countries within a continent.

It is recommended to use (average) maximum damage values from the literature review when performing damage calculations within a country. This can be for a country with known maximum damage values or a country with maximum damage values derived from the continental maximum damage average. In the latter case the derivation can be based on scaling the maximum continental damage value with the GDP ratio of the continent and the GDP of the country under consideration (Huizinga 2007).

At the global scale, the maximum damage values from the literature review show significant variation. This can be due to various reasons, for instance: object vs. land use; unknown objects size; various types of residential, commercial, industrial objects used (e.g. rural house, apartment, various quality of buildings, offices, warehouses, stores, factories, etc.); different ways of determining a maximum damage by different sources; based on a damage factor ranging to one or not; inclusion of basements; etc. As a result, there are significant biases between maximum damages from different national models making it difficult to form them into a consistent global dataset. Therefore it is no advisable to compare damage assessment results for different countries based on maximum damage values taken from literature.

An alternative approach has been developed in order to overcome these problems and generate a consistent global set of maximum damage values for various damage classes. The datasets containing maximum damage values based on construction costs, agricultural yield per hectare and infrastructure in Europe are best suited to be used when performing and comparing damage assessments internationally (for example when comparing the effects of flooding coastal cities).

4 Uncertainty and validation

Uncertainty in damage estimation draws on several factors, including:

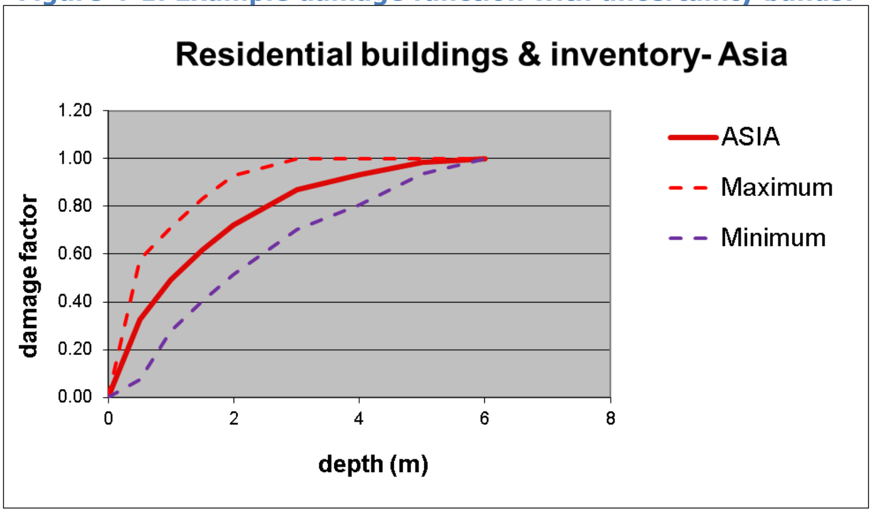
1. Uncertainty in the damage functions;
2. Uncertainty in maximum damage values;
3. Uncertainty in the (observed or calculated) flood extent and flood depth;
4. Uncertainty in the modelled land use.

This chapter addresses the first three items, as land use data is not provided.

4.1 Uncertainty in damage functions

Continental damage functions are designed by taking the average of all normalised damage functions on a continent from the literature review. The uncertainty in the continental damage functions can be described using function specific uncertainty bands, based on the sample standard deviation of its constituting functions. An example is given for Asia in Figure 4-1.

Figure 4-1: Example damage function with uncertainty bands.



In the above Figure the red solid line represents the continental average damage function based on all normalized Asian damage functions. The dashed red line is the average value plus one standard deviation and the dashed purple line is the average value minus one standard deviation. As all normalized functions in Asia have a damage factor of zero at zero meter flood depth and a damage factor of one at six meter flood depth, the calculated standard deviation of the damage factor at these points is zero.

4.2 Uncertainty in maximum damage

The first part of this section compares the maximum damage estimates based on the regression analysis with maximum damage values from the literature survey of global damage models, while in the second part of this sections uncertainty bands are formalized based on the fit of the regression of construction costs.

Comparison with the literature

Comparison with the non-European studies

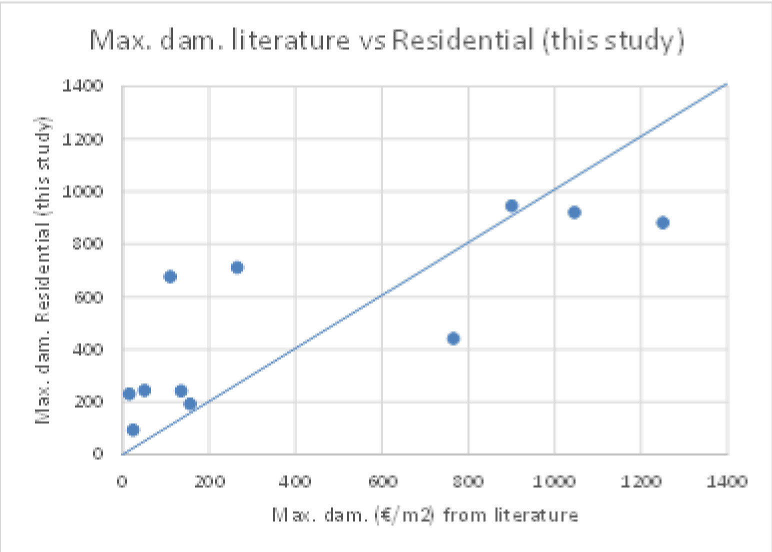
Table 4-1 below compares the maximum damage for class *residential* from various studies with the estimated maximum damage using the power fit. As different studies have different baselines (building, land-use, with/without content) the appropriate value from the estimated maximum damage values was chosen. Also some information from the studies has been added: up to what fraction the curves reach, up to what water depth, and the basis on which the maximum damage was determined by the study. Comparison of the numbers shows that the estimated numbers are often higher than compared to the numbers from the literature survey, which, however, is not consistent across the board. Australia and USA are for instance very similar to the estimated value, and Japan appears underestimated.

Table 4-1: Recorded maximum damage values from literature versus reconstruction costs based values.

		Base	Estimated	Literature	Max fraction	Max depth	Type data	Source
Africa			€/m2	€/m2				
	Mozambique	Building (incl.)	193	156	n.a.	n.a.	Post-flood estimation	World Bank, 2000
	South Africa	Building	442	765	n.a.	5.4	Earlier, emperical studies	Villier et al. 2007
Asia								
	Cambodia	Building (incl.)	245	50	n.a.	n.a.	Estimation	Shresta et al, 2014
	Bangladesh	Building (incl.)	242	135	0.1 - 0.6	2.44	Based on survey	Nabiul Islam 1997
	Indonesia	Land-use based	94	24	0.6 - 0.8	2	Based on expert workshop	Budiyono 2015
	Vietnam	Building (incl.)	231	15	1	5	Based on Survey	Lasage et al., 2014
	Japan	Building	881	1250	0.6	6	Based on empirical database	Dutta et al, 2003
Oceania								
	Australia	Building (incl.)	946	900	n.a.	4	Combi old emperical data and expert judgement	Sargent, 2013
North America								
	United States	Building	921	1045	0.6	7.3	Based on empirical data US	HAZUS technical manual
SC America								
	Brazil	Building (incl.)	676	110	n.a.	2.8	Statistically derived from empirical data	Machado et al., 2005
	Sint Maarten	Building (incl.)	711	265	n.a.	2	Assigned without source	Vojinovic et al., 2008

The scatter plot (Figure 4-2) of the maximum damage underscores the variation present in the data.

Figure 4-2: Literature review max damage for residential versus estimated maximum damages.



Whilst reviewing the existing literature, it was found that there are many degrees of freedom which will cause variation. For instance, not all curves go up to 100% (see section 3.3.1.4 for the undamageable part discussion). Sargent (2013) also explicitly states that the building material of houses determines heavily the costs of reconstruction, pointing out houses with a wooden frame need to have their walls stripped out after flooding for the wood to dry. Concrete or brick walls can be expected to be much less affected (up to virtually inalterable). Also the study from Nabiul Islam (1997), based on extensive field work, shows that building material has a large effect on maximum damage values, showing a difference of about 7 times between brick and mud houses.

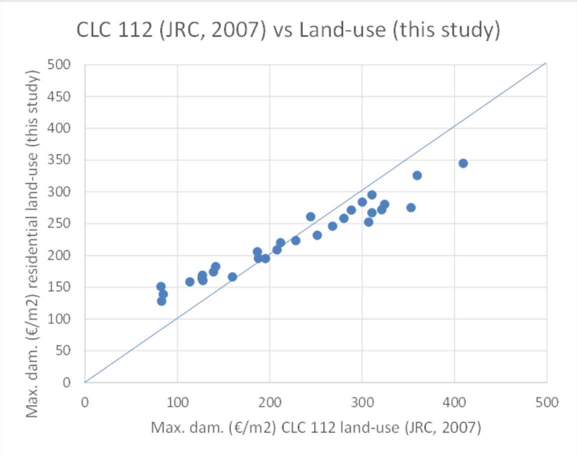
In addition, different studies are based on different ranges of water depth. Many studies do not address water depths over 3 meters. Correspondingly, any damage to the first floor above the ground floor will not be part of the value. HAZUS illustrates that there is a split in damage of about 60/40% between the first and the second floor. Hence a substantial part of the possible flood damage is not grasped when water levels do not exceed 2.5-3 meters.

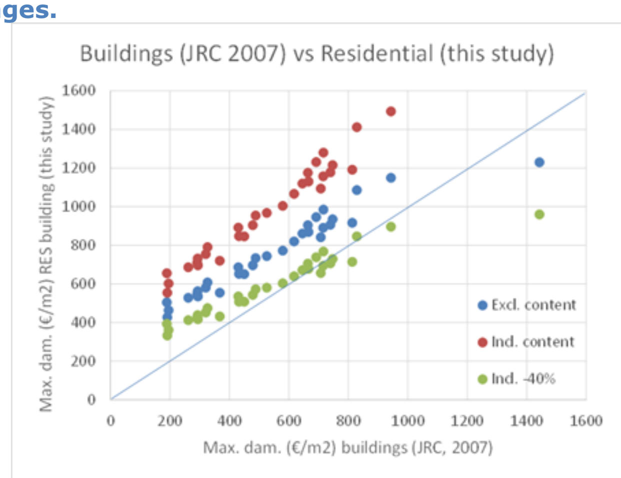
Lastly, different studies are based on data with different socio-economic backgrounds. Some studies are based on (dense) urban areas, but other studies have targeted more rural areas (usually accompanied by less resistant building material; Nabiul Islam, 1997) or informal settlements (uncontrolled urban sprawl, with much lower building standards; Budiyono et al., 2014). Also within urban fabric houses of different socio-economic classes can be distinguished (as shown by Machado et al. 2005). All these factors affect the maximum damage estimates in individual studies, complicating direct comparisons.

Comparison with the European countries

The estimated maximum damage values have also been compared with the results from the study by Huizinga (2007) on European flood damage functions. Estimates of building damage from 2007 and those of CORINE class 112 (urban fabric) have been compared to the 'land-use' estimates from the regression analysis. The results are shown the scatter plots below.

Figure 4-3: Literature review max damage for residential versus calculated maximum damages.





Both plots are based on the same dataset, only in the left plot the two extremes from the right plot have been left out.

The results usually line up very well, which can be attributed to the fact that both are based on GDP/capita. However, in absolute terms the maximum damage for buildings is considerably higher for the estimates based on the construction costs as opposed to the 2007 study. For the land-use based estimates the agreement seems much better, but this is probably due to the fact that the land-use estimates are based on 20% building area, where the CLC-112 estimate is based on almost 50% residential. This overestimation could be the result of an inalterable part of the construction cost for European buildings. When a 40% inalterable portion is taken into account (based on many curves going up to 60% damage), there is actually good correspondence between the 2007 study and this study.

Conclusion

The estimated maximum damage values are based on full construction costs of urban houses. Whilst this provides a consistent solid basis for damage estimation, these figures are often relatively high for flood damage studies. In countries where houses are primarily constructed by very resistant material, this will give an overestimation as even in very dramatic situations not everything needs to be reconstructed (i.e. in many European countries). On the other hand, in countries where a large proportion of the building stock is not urban and may consist of less resilient material or lower building standards, there may not be an inalterable part (i.e. maximum damage equals reconstruction costs without inalterable part), but the (re-) construction costs (and thus maximum damage) will be lower because of the lower grade material and standards. Therefore, some extra modifiers have been included in the Database for the user to fine-tune the damage assessment towards the study-specific conditions. It is advised to use a non-damageable portion of around 40% as a basis for urban settings around the globe.

Uncertainty in maximum damage estimates

The uncertainty presented in the estimates of maximum damages has been assessed by comparing the estimated construction cost values with the original construction cost values[11]. As maximum damage estimates relate linearly with these construction costs, relative errors herein can also directly be applied on the maximum damage estimates.

Uncertainty in construction cost

In total, there are 72 industrial or 73 residential/commercial unique construction costs from the combined datasets of EC Harris (2010) and Turner & Townsend (2013). These can directly be compared to the construction costs estimated using the derived power function fit. For this, the difference of each data point with its original has been calculated using the following formula: *Estimated/Original-1*. The resulting differences have been summarized in Table 4-2 and the results for residential buildings are visualized in Figure 4-4.

Table 4-2: Summary of the differences between the estimated and original construction costs.

Class	*Average difference*	*Standard deviation of difference*	*5%*	*95%*
Residential	0.03	0.27	-0.28	0.53
Commercial	0.02	0.22	-0.31	0.35
Industrial	0.03	0.26	-0.3	0.53

As can be noted in Table 4-2, the average difference is slightly above zero, indicating a small overestimation. Histograms of this difference (Figure 4-5) also show that this

[11] As the unique number of construction costs for industrial, residential and commercial are each over 70, it was assumed that excluding a sample from estimation and then comparing against the estimated values should have little added value.

difference is not completely normal distributed, but rather skewed to the right (except for commercial, which is quite close to a normal distribution). Correspondingly, using standard deviations as an indicator for the uncertainty can lead to errors (specifically underestimations at the lower end). Therefore, we will describe the uncertainty in the estimated construction cost (and thus in maximum damage) using an interval with percentiles. Using the 5% and 95% percentiles a 90% confidence range can be given using the values in Table 4-2.

Figure 4-4: Plot of estimated vs original construction costs for residential buildings.

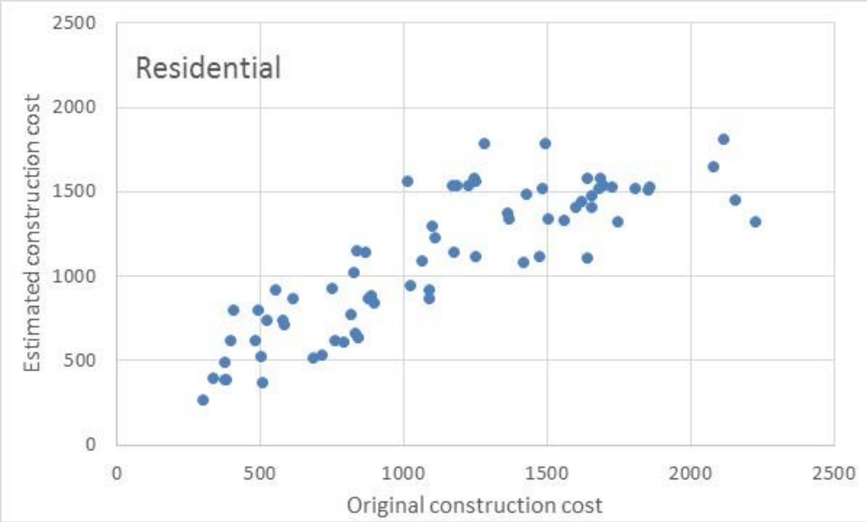
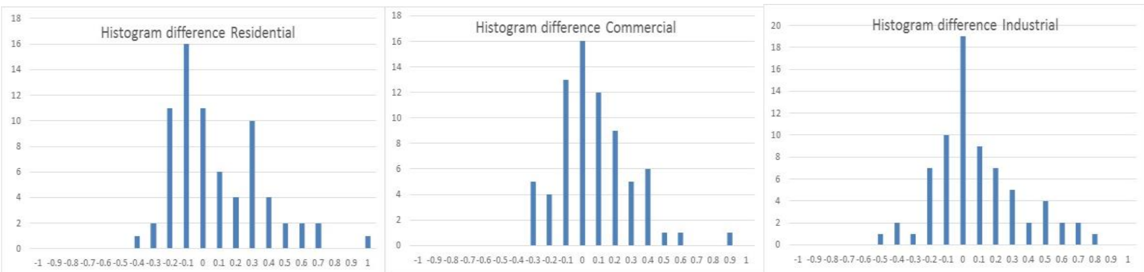


Figure 4-5: Histograms of the differences between the estimated and original construction costs of all three classes.



4.3 Validation using historical flood events

4.3.1 Introduction

Several sources provide data on flood events all over the world. Examples are the Dartmouth Flood Observatory (http://floodobservatory.colorado.edu), Copernicus-Emergency Management Service (http://emergency.copernicus.eu) and UNOSAT from the UN: http://www.unitar.org/unosat).

These organisations provide detailed maps showing delineated flood areas. This section explored feasibility of using this data in conjunction with other sources of information to validate the depth depth-damage functions and maximum damage functions that have been developed in the current study.

Depth damage functions represent the relation between hydraulic parameters (at least water depth) and economic damage of certain types of assets. Thus, the following information is needed to verify damage functions by a particular flood event:

1. Exposure (number of assets and its asset values);
2. Maximum flood depth (pattern of the maximum flood depth variation over the full flood extent);
3. Recorded damage (reported total damage of the flooded area).

4.3.2 Data sources to provide validation information

This paragraph describes the information needed to perform validation more in detail.

Exposure

The number of affected buildings, infrastructure, or other assets can be found by analysing satellite images. However, the flood duration may range from days to months and the flood extent may shift geographically during this period. This means that one needs many satellite images to cover the full flooding period. The type of assets must be known to assign the correct damage functions. This cannot be derived from satellite images alone, detailed GIS data must be available for the area under consideration.

Maximum flood depth

Maximum flood depth cannot be derived from satellite images, as there is no one-to-one relationship between flood extent and flood depth, let alone maximum flood depth and flood extent (Huizinga et al., 2005).

To determine the flood extent and the local maximum flood depth, usually satellite images and field observations are used together to validate a hydraulic model. After validation, the model can be used to determine the maximum flood extent and local maximum flood depth. The development of a hydraulic model is time-consuming and needs a lot of expertise.

This means that for an accurate determination of maximum flood extent and maximum flood depth one needs to combine data from different sources in case of flood events or have to develop a hydraulic model. This holds both for small events with a short duration (hours) and for large events with a long duration (months).

Recorded damage

Data on recorded damage is nowadays readily available on the internet. However, this data is often geographically scattered or too general.

Available recorded data on flood events (including satellite maps) are not easily converted into information that can be used to validate damage estimation models. It requires considerable effort to construct maps containing maximum flood depth and maximum flood extent based on available information. Usually this information is applied to calibrate a hydraulic flood model. After validation of a hydraulic model, maps on maximum local flood depth and maximum flood extent can be generated.

4.3.3 Validation studies

As accurate spatial data is still not available on a global scale, this section focuses on several sites to test the performance of the developed global damage functions and maximum damage values.

The first validation site chosen in the New York City (USA) with focus on the damage induced by storm Sandy in 2012. Detailed information is available on the flood extent and the total damage is well recorded.

As a second test site is Jakarta (Indonesia), as a hydrologic model of the floods in 2007 is available from HKV. Also the damaged area is rather confined and there is a damage assessment available.

4.3.3.1 Hurricane Sandy in New York City

In 2012 hurricane Sandy hit New York and New Jersey, causing billions of dollars damage, mainly due to flooding (Blake et al., 2013). Around the same time, Aerts et al. (2014) developed a flood risk model for New York City based on HAZUS using 549 synthetic storms to calculate risk (dollar/year). This gives an opportunity to compare the global damage functions (curves and maximum damages) both against a more detailed model (Aerts et al., 2014), as well as against observed damage (Sandy, 2012).

The New York City damage model is based on HAZUS, which uses building counts of 33 different building types (including 11 residential, 10 commercial and 6 industrial types) with separate curves and maximum damages. Aerts et al. (2014) used this model to estimate flood damage and risk for 549 storms with varying probabilities. As a validation check, this has also been done with a single curve and maximum damage for each building class (including content). Namely: 829 €/m^2, 1144 €/m^2 and 923 €/m^2 for residential, commercial and industrial buildings respectively (including a 40% inalterable part). As this method is object based, also the average footprint size had to be established for every class, which can vary quite a bit (see Aerts et al., 2014; supplementary information), especially for residential buildings. For this, the average size of RES1 and RES3a, making up 78% of all buildings, has been used (185 m^2).

In addition, a flood extent of flooding caused by Hurricane Sandy (unpublished) has been used to calculate the damage in order to be able to compare this to the observed damage. Information on observed damages is from the official state estimates which have been the basis for the congressional aid.

Validation results

Table 4-3 below shows recalculated damage versus assessed damage based on regression values for the USA, including the uncertainty range based on the statistical uncertainty in the fit of GDP vs construction costs. The values from EC Harris / Turner&Townsend were not applied directly since the performance of the global approach was to be verified. It is known that the value from the regression overestimates with respect to the original data on construction costs.

Table 4-3: Comparison of the developed JRC Global curves with a more detailed model (Hazus; Aerts et al., 2014); and with observed damages related to hurricane Sandy.

Damage class	***Aerts et al. (2014) (million €/yr)***	***JRC Global (million €/yr)***	***Sandy (billion €)*** [12]	***JRC Global (billion €)***
Residential	22.3	39.8 *(28.6 – 60.8)*	3.6	5.3 *(3.8 – 8.1)*
Commerical	18.7	50.8 *(35.1 – 68.6)*	5.6	5.6 *(3.9 – 7.6)*
Industrial	3.4	8.7 *(6.1 - 13.3)*		1.6 *(1.1 – 2.4)*
Total	44.4	99.2 *(69.8 – 142.7)*	9.3	12.5 *(8.8 – 18.1)*

As can be seen, the global curves overestimate damage in the NYC. The risk calculation is about two times larger as compared to the more detailed HAZUS calculations of Aerts et al. (2014). Also when looking at the uncertainty range, the lower end is still above estimates of Aerts et al. (2014), though the order of magnitude is similar. The comparison with the damage sustained by Hurricane Sandy is, however, much closer to each other. The calculation using the global curves is still higher than the observed damage, but it does fall within the uncertainty range (at the lower end).

Given the uncertainties present in damage, the order of magnitude is correct though. Jongman et al. (2011) show that for two cases model estimates of various models ranging from underestimates of 15 times, up to overestimates of 2.5 times. The results of the global curves fall within this range. This difference can be the result of various causes. For instance, the construction cost for residential buildings estimated for the United States is overestimated by about 30% with respect to the original construction cost, which translates directly into an overestimates in maximum damage. As stated above we used regression values since the performance of the global approach numbers was to be verified.

4.3.3.2 Flood in Jakarta

This section considers validation based on a major flood that occurred in Jakarta in 2007. Heavy rainfall recorded on 2nd and 4th February led to extremely high water levels up to 10.6 m in the downstream Ciliwung river as reported by Brinkman et.al. (2007). Jovel (2007) estimated the damage to be Rp 5 185 billion (563 million USD, 433 million EUR).

The 2007 Jakarta flood damage was recalculated using damage functions and maximum damage values developed in this study by Kosters (2015). Kosters used Asian damage functions and corrected Asian average maximum damage values to compute Indonesia-specific maximum damage values. The correction allowed calculating the Indonesia-specific values by using the country's GDP per capita and the average GDP per capita for Asia.

The extent and land use of the flooded area was based on the Open Street Map (OSM). To deal with significant share of missing land use information within the city limits on the OSM, Kosters introduced a 'no-data' land use category, and assumed the same composition of the land use categories as in the known part of the flooded urban area.

The values are shown in the Table 4-4.

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[12] *Note that original values have been recalculated to Euros (using 2010 conversion factor of 0.77). The residential number relates to damage quoted for 'Housing', and the commercial/industrial number relates to damage quoted for 'Business' and 'Health'. See:* http://www.governor.ny.gov/sites/governor.ny.gov/files/archive/assets/documents/sandyimpactsummary.pdf

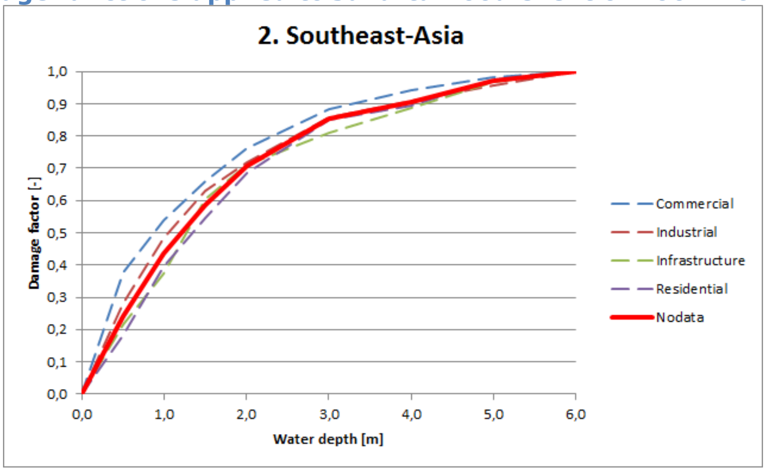
Table 4-4: Maximum damage values for Jakarta recomputed based on maximum damage values for Asia.

Land use category	***Based on all data [€/m²]***	***With outliers removed [€/m²]***
Residential	29,194.00	97.80
Commercial	1,850.60	241.40
Industrial	440.80	115.90
Infrastructure	57.70	57.70
Agriculture	0.92	0.92
'no-data' layer	16,837.00	127.00

source: Kosters(2015)

The maximum damage values were applied to fractional damage functions for Asia. The functions are replicated on Figure 4-6:

Figure 4-6: Damage functions applied to Jakarta flood event of 2007 from this report



Validation results

The damage from 2007 Jakarta flooding based on methods developed in this report were calculated by Kosters (2015) to amount to 415 million Euro (price level 2010). This is very close to the estimated damage of 433 million Euro (price level 2007) as estimated by Jovel.

The category specific contributions together with uncertainty range (section 4.2) are presented in Table 4-5.

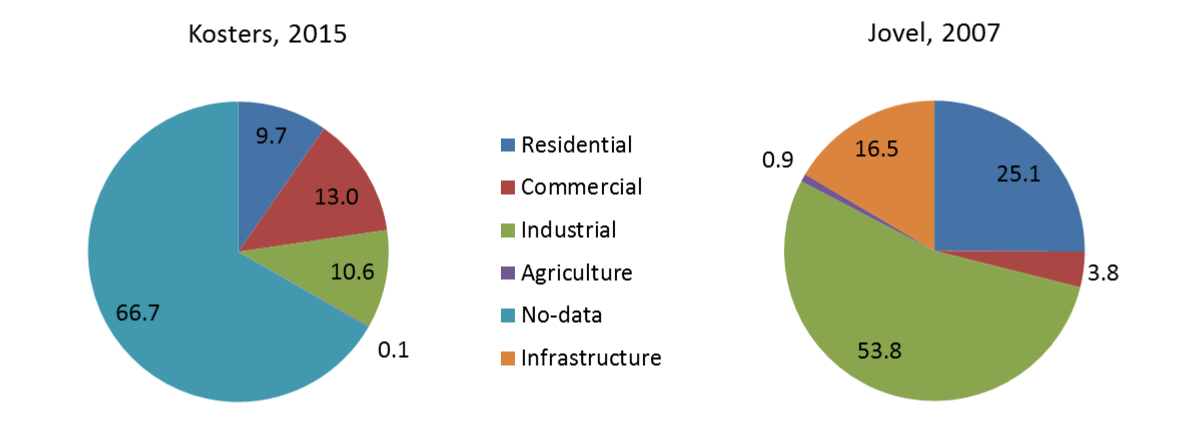
Table 4-5: Total damage values by land use category for Jakarta 2007 flood event.

Land use category	***Damage [million €]***	***Damage uncertainty interval [million €]***
Residential	40.1	28.9 - 61.4
Commercial	54.0	37.3 – 72.9
Industrial	43.9	30.7 – 67.1
Agriculture	0.4	unknown
No-data	276.6	194.5 – 406.6
Total	414.6	291.8 – 608.4

source: Kosters(2015)

Comparison of the composition of damage between different land use categories by Jovel (2007) and Kosters (2015) are shown in Figure 4-7.

Figure 4-7: Comparison of damage distribution [%] for Jakarta 2007 flood between Kosters (2015) and Jovel (2007).



There is large contribution from the 'no-data' category in Koster's estimates which make a direct comparison difficult. Looking at the known data only, it can be concluded that the calculated relative contribution of commerce is much larger for Kosters, while the relative contribution of industry is calculated to be much smaller.

5 Guidelines

This chapter provides guidelines on how to use the accompanying database of the depth-damage functions and the maximum damage functions.

The relevant data is contained in the accompanying spreadsheets (Excel):

Global flood depth-damage functions.xlsx

5.1 Maximum damage values

The spreadsheet contains depth damage functions (one worksheet) and the maximum damage values (one worksheet for each of the six impact categories). A Quick Start Guide is outlined in the initial worksheet of the file.

The spreadsheet allows for adjustment of parameters for the three types of buildings (residential, commercial and industrial) to account for additional information that a user could have regarding the site considered. The parameters' values are specified in the input form - an example of the input screen is presented in Figure 5-1.

Figure 5-1: Worksheet MaxDamage-Adjustment in the Excel spreadsheet on Global Maximum Damages.

Automatic adjustment

The parameters' values specified via this tab are automatically reflected in the maximum damage values for buildings (residential, commercial and industrial) computed in this spreadsheet. The parameters' entry cells are highlighted.

1. Construction Cost vs. Depreciated Value			**2. Max Damage Content/Inventory**		
Conversion factor (multiply with CC to get DV)			*Conversion factor (multiply with maximum damage building)*		
RES	0.6	*(default = 0.6)*	**RES**	0.5	*(default = 0.5)*
COM	0.6	*(default = 0.6)*	**COM**	1	*(default = 1.0)*
IND	0.6	*(default = 0.6)*	**IND**	1.5	*(default = 1.5)*
3. Building vs Land-Use			**4. Building area vs Object**		
Percentage of area covered by building footprint			*Average building footprint in m2 per object (e.g. house)*		
RES	0.2	*(based on Flanders, Koks et al., 2014)*	**RES**	100	*(varies considerably)*
COM	0.3	*(based on Flanders, Koks et al., 2014)*	**COM**	200	*(varies considerably)*
IND	0.3	*(based on Flanders, Koks et al., 2014)*	**IND**	500	*(varies considerably)*
5. Undamageable part			**6. Damage adjustment**		
Percentage that is regarded never to be damaged by a flood			*In case of less expensive material (multiply with maximum damage building)*		
RES	0.4	*(in case of resilient building material)*	**RES**	1	
COM	0.4	*(in case of resilient building material)*	**COM**	1	
IND	0.4	*(in case of resilient building material)*	**IND**	1	

The same worksheet, '*MaxDamage-Adjustment*', also provides additional information which can be used to calculate, for example, confidence intervals or make additional adjustment with respect to, eg material used. These additional manipulations, however, would need to be undertaken manually by a user.

The next section provides additional information and guidelines potentially useful in process of fine-tuning the maximum damage values.

5.2 Further differentiations in maximum damages

This section provides some guidance for modellers on how to adjust the global maximum damage values to more local situations in case such information is known.

The damage functions developed within this research are primarily determined for urban environments as the underlying data on maximum damages is derived from construction cost surveys which mainly concern costs of urban types of buildings (as opposed to more rural buildings or traditional building materials). Nevertheless, the inventory of damage models shows a wide variety of information related to different types of buildings (e.g. mud vs. brick buildings) and different environments (e.g. rural vs. urban environments). Also if exposure data allows for differentiation between different types of build environment (e.g. urban vs. rural, slums, different building materials), it may be very worthwhile to use different maximum damage values.

5.2.1 Building material

Most buildings around the world are built of relatively resistant material such as bricks or concrete. This is also what the construction costs are based on. However, in various locations (often more rural) houses can be built of local material such as mud with thatched roofs. Some studies from Asia explicitly differentiated different building materials. For instance, Nabiul Islam (1997) investigated 5 building types differentiating building material for floors and walls in a generally rural setting. The total value of the house and the content (recalculated into 2010 euros) can be found in Table 5-1.

Table 5-1: Values per m^2 for buildings with different building types in Indonesia and their relative relation between these types.

Building type (floor | wall)	***Total value per m^2 (2010 euro)***	***Factor***
Brick | Brick	135	1
Brick | Corrugate	83	0.61
Mud | CI sheet	73	0.54
Mud | Thatched	34	0.25
Mud | Mud	27	0.2

source: Nabiul Islam (1997)

A difference in value between a fully brick building and a complete mud building is about a factor of 5. Note that this is not just because of more expansive material, but also because the value of contents in a brick building is usually higher than those of a mud building due to a generally better socio-economic status of the inhabitants.

It should be noted that not only the value may be different between different building materials, but also the vulnerability (i.e. the shape of the damage curve) can be expected to be different. Maiti (2007), for instance, differentiated two main building types in rural India based on material: a mud dwelling with straw roof and a concrete building. Whilst no values were assigned to these building types, it is noted by Maiti that mud buildings are expected to suffer total loss damage already from about 1m water depth (Maiti, 2007), much sooner than compared to concrete buildings. This is in line with the damage function from the CAPRA database (Central American Probabilistic Risk Assessment), where functions for mud buildings reach 100% around 1.5 meter. Moreover, the CAPRA functions for concrete and masonry buildings reach 60%, confirming the 'undamageable' part of around 40% for buildings build of resistant material.

5.2.2 Formal vs. informal

In developed areas, urban regions are relatively heterogeneous with respect to building types and materials, with possible exception of high-rise buildings in down-town areas, but these are usually still of the same resistant material. In developing regions there may be considerable areas consisting of non-planned neighbourhoods with simple dwellings constructed by inhabitants. Such informal neighbourhoods, or even slums, have typically considerably lower values per house/dwelling (and arguably a higher vulnerability). Hack (2014) quotes a study by the OECD (Hallegatte, 2010) stating that values of slums are about nine times lower as compared to regular houses. Budiyono et al. (2014) finds values for formal urban land-use (planned houses) that are about 2.5 times higher as compared to more informal settlements (kampungs): 342 $k/ha as opposed to 130-155 $k/ha. As these numbers concern areas of land-use (as opposed to only buildings), this also inherently includes the higher density of houses in informal neighbourhoods, which are typically much more dense. When assuming a density that is about three times higher (30% area covered by buildings in formal neighbourhoods and 90% in informal neighbourhoods), the difference in value would increase up to almost 8 times. Overall, it can thus be stated that houses/dwellings in informal areas have a value about 8 times lower as compared to formal area (which is the basis of this study). There will, however, not be an undamageable portion of the buildings in informal areas.

5.2.3 Urban vs. Rural

As many studies from the inventory are at a case-study level, they address a specific region. This can for instance be a specific city or urban region, but can also be a more rural region. A study by the World Bank (2000) on flooding in Mozambique addressed both, allowing for a consistent comparison. There it is estimated that the (depreciated) reconstruction value for an urban household is about $2500 per building ($600 structural, rest content and vehicles), whilst for rural residential this is about $400 per building ($250 structure, $150 content). This would result in difference of a factor 6 in maximum damage between urban and rural houses (including content). This assumes, however, that the size of the houses is also the same. When acknowledging that rural houses are also comparatively smaller (linked for instance to the socio-economic status of the inhabitants), then this factor is reduced. When assuming that rural houses are about half the size of urban houses, this difference in value per m^2 becomes a factor 3.

5.2.4 Impact on people

The previous paragraphs show that maximum damages in rural regions are expected to be lower as compared to urban regions and lower for lower grade building material. However, the impact on the people, whilst lower in monetary value, may be relatively higher as the coping capacity may be inferior (e.g. access to insurance, savings, higher percentage of annual income lost). This can be accounted for when going to a non-monetary impact metric (i.e. percentage of annual income lost), or by adjusting net present value calculations for socio-economic status. However, this reduces the use for monetary cost-benefit analyses, but may still be very informative from a prioritization point of view.

5.3 Area versus objects in damage modelling

The database as described in the previous paragraph also contains information on the area versus object approach of global maximum damages.

For residential, commercial and industrial damage classes the following maximum damage values are presented:

1. Building based;
2. Land use based;
3. Object based.

The first type of damage value represents maximum damage per square meter for buildings if the footprint of individual buildings is used for damage calculation.

The second represents maximum damage per square meter for buildings if land-use maps are used containing a mixture of houses, roads and empty space between individual buildings.

The last damage value presented is applied when only house locations are known. In this case a building having "general" characteristics will be applied.

5.4 Generic global curves for agriculture and infrastructure

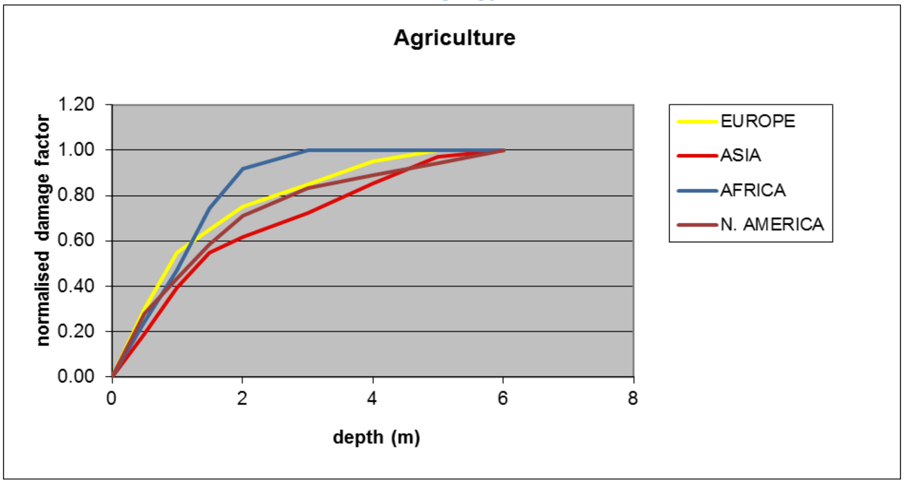
Damage functions for infrastructure and agricultural crops are available for Asia, Europe, Africa (agriculture only) and North America (agriculture only) but not for Oceania and South America.

It would be convenient to have one generic global applicable function for agriculture and one generic global applicable function for infrastructure for all continents. This is feasible as the data shows that the total share of both agriculture and infrastructure in total damage is limited and the available functions are rather close.

5.4.1 Agriculture

In the Figure 5-2 below the various continental damage functions for agriculture from Asia, Europe, North-America and Africa are shown.

Figure 5-2: Damage functions for Agricultural crops in Europe, Africa, Asia and North-America.



From the figure it is clear that the shape of the curves for agricultural crops are roughly equivalent, the African curve being the most deviant, but originating from only one source.

If damage to agricultural crops is in most flood events limited compared to total (recorded) damage, then it is allowed to apply one global function. Even if a flooded area is mainly agricultural, damage to buildings contributes much more to the total damage. The share of agriculture in total recorded damage is shown in the table below.

Table 5-2: Share of agriculture damage in total direct damage for several major flood events.

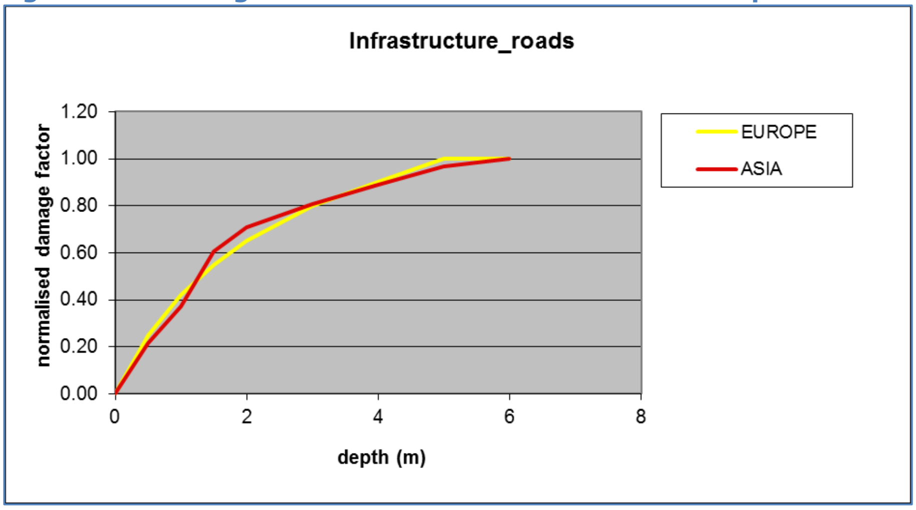
Event	***Description***	***Total damage***	***Damage to agricultural crops***	
		x 10^6	***x 10^6***	***share in total***
Maas 1995 (Huizinga, 2002)	medium scale rural & urban area	€94	€8.7	9%
Saxony 2002 (Floodsite, 2006)	large scale rural & urban area	-	-	1.3%
Thailand 2011 (Worldbank, 2012)	large scale rural & urban area	$46 500	$1 300	2.7%
Jakarta 2007 (Jovel, 2007)	large scale urban area	€433	€4	0.9%

It can be concluded that the contribution of agriculture damage in total damage is limited in the observed cases. This suggests that applying one global average function is acceptable.

5.4.2 Roads

In Figure 5-3 below the continental damage functions for infrastructure-roads from Asia and Europe are shown.

Figure 5-3: Damage functions for Infrastructure in Europe and Asia.



Both the two curves are quite similar. If the share of these individual damage categories is restricted in the total (recorded) damage, then it they can be represented by one global function. The share of both individual damage categories in total damage is shown in Table 5-3 with recorded data from validation sites and literature.

Table 5-3: Share of infrastructure damage in total direct damage for several flood events.

Event	*Description*	*Total damage x 10^6*	*Infrastructure damage x 10^6*	*Infrastructure damage share in total*
Eilenburg (Jongman et al, 2012)	small scale urban area	€218	€109	50%
Carlisle (Jongman et al, 2012)	small scale urban area	€535	€64	12%
Maas 1995 (Huizinga, 2002)	large scale rural & urban area	€94	€4.3	4%
New York Sandy http://www.governor.ny.gov	large scale urban area	$41 885	$7348	18%
Jakarta 2007 (Jovel, 2007)	large scale urban area	€433	€71	16.5%

Most flood events show that the contribution of damage to roads to total damage is about 4-18%. Rural areas have lower damage to roads than urban areas.

The flooding in Eilenburg shows highest contribution of infrastructure damage of all presented cases. The reason for this high damage is the collapse of a large bridge. As a collapse cannot be captured in flood depth damage functions, this case should not be considered.

From Table 5-3 it can be concluded that the contribution of road damage in total damage is considerably higher than for agriculture. However, there are only two damage functions available and they are very alike. This suggests that applying one global average function is acceptable.

5.4.3 Conclusion

From the results above it may be concluded that application of one global function for agriculture and on global function for infrastructure is justifiable.

Global applicable functions for agriculture and infrastructure are shown below: these are based on the average of available continental functions.

Table 5-4: Global applicable flood damage functions for agriculture and infrastructure.

Water depth (m)	***Generic Global Functions (fractional damage)***	
	Agriculture	**Infrastructure**
0	0.00	0.00
0.5	0.23	0.22
1	0.39	0.43
1.5	0.55	0.58
2	0.65	0.67
3	0.78	0.79
4	0.87	0.89
5	0.96	0.97
6	1.00	1.00

5.5 Spatial data

Damage functions are derived for different damage classes. In order to perform analyses with these functions, they need to be applied in conjunction with spatial data containing these classes. Currently, global datasets do not differentiate very well between residential, commercial, industrial and transport classes. They are usually aggregated in a single urban fabric class.

Some type of downscaling or land-use accounting technique is necessary to downscale this urban class into the desired classes. This would result in maps giving a percentage of residential/commercial/industrial/etc. land use in a single cell. This could be based on country-level economic information, such as the percentage of commerce and industry to national GDP (as is available in the WDI, or Eurostat). However, type of activity is not directly tied to land surface. Therefore, this relation would need to be determined in areas where there is information on different urban land uses, such as Europe (with the Corine land cover dataset). Using this relation, the share of various urban land use types to the total urban land cover can then be extrapolated over the globe.

Subsequently, a translation needs to be made from a generic land use (e.g. residential), to the area covered by buildings related to that land use as the damage functions are based on buildings. Here, information on urban density, as is being estimated by the Global Human Settlement Layer that is developed by JRC, can be used.

Overall, various sources of information would ideally be combined into a global dataset with a spatial resolution that is still workable (e.g. 1km), but with sub-cell in formation in the form of percentage of a certain land use or cumulative length (unit: meters) of road and railroad network in that particular cell.

Key input data for such a dataset includes:

- GlobCover[13] (to differentiate agriculture, nature and urban);
- OpenStreetMap[14] (for length of roads and data on residential, commercial- and industrial categories and areas (20- 50% coverage of urban area in Asia according to Kosters (2015);

[13] http://geoserver.isciences.com:8080/geonetwork/srv/en/metadata.show?id=228

- Railroad dataset (for length of railroad)[15];
- Global Human Settlement Layer[16] (for percentage urban/urban densities);
- Eurostat (for downscaling urban);
- World Development Indicators (for downscaling urban);
- CORINE land cover (for downscaling urban area).

The development of such a global spatial dataset will involve significant harmonization of data and analyses for downscaling urban land use and falls outside the scope of the current project.

14 http://www.openstreetmap.org

15 http://www.openrailwaymap.org

16 http://ghslsys.jrc.ec.europa.eu

References

Asian Development Bank (ADB), 2010.Strengthening the Resilience of Water Sector in Khulna to Climate Change. Manila: ADB. Technical Assistance Partner's Report. Project Number: 42469-01 – August 2010

ADB, 2013. Japan: Supporting Investments in Water-Related Disaster Management. Technical Assistance Partner's Report. Project Number: 7276 - June 2013. International Centre for Water Hazard and Risk Management under the auspices of UNESCO (ICHARM). Asian Development Bank.

Adedeji,O. H. , Odufuwa,B. O. & O. H. Adebayo, 2012. Building Capabilities for Flood Disaster and Hazard Preparedness and Risk Reduction in Nigeria: Need for Spatial Planning and Land Management. Journal of Sustainable Development in Africa, Vol. 14, No. 1, 2012, pp. 45-58.

Anonymous, 2004. Year 3 Report to the International Joint Commission. Report for International Lake Ontario-St. Lawrence River Study Board.

Apel, H., Thieken, A.H., Merz, B. & G. Blöschl, 2004.Flood risk assessment and associated uncertainty. Natural Hazards and Earth System Sciences (2004) 4: 295-308. SRef-ID: 1684-9981/nhess/2004-4-295

Apel, H., Aronica, G. T., Kreibich, H. & A.H. Thieken, 2009. Flood risk assessments - How detailed do we need to be? Nat. Hazards, 49(1), 79-98, 2009.

Arnell, N.W. & S.N. Gosling, 2014. The impacts of climate change on river flood risk at the global scale. Climatic Change. DOI 10.1007/s10584-014-1084-5

Asaduzzaman,M., Enamul Haque, A.K., Nabiul Islam,K.M. , Qamar Munir, M. , Roddick,S., Roberts,E. & A Hasemann, 2013. Loss & Damage - Assessing the Risk of Loss and Damage Associated with the Adverse Effects of Climate Change in Bangladesh. CDKN, International Centre for Climate Change and Development (ICCCAD), German Watch, MCI, United Nations University (UNU-EHS).

Barbosa, F. de Assis dos Reis, 2006. Medidas de proteção e controle de inundações urbanas na bacia do rio Mamanguape/PB. Dissertação de Mestrado apresentada à Universidade Federal da Paraíba para obtenção do grau de Mestre.

Baró-Suárez, J.E., Díaz-Delgado,C., Calderón-Aragón,G., Esteller-Alberich, M.V. & E. Cadena-Vargas, 2011. Costo más probable de daños por inundación en zonas habitacionales de México. Tecnología y Ciencias del Agua, vol. II, núm. 3, julio-septiembre, 2011, pp. 201-218. Instituto Mexicano de Tecnología del Agua - Morelos, México

Barros, V., 2005. Global Climate Change and the Coastal Areas of the Río de la Plata. A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. LA 26 CIMA/Faculty of Sciences, University of Buenos Aires, Buenos Aires, Argentina.

Barton,C., Viney, E., Heinrich, L, & M. Turnley, 2003. The Reality Of Determining Flood Damages. 2003 NSW Floodplain Management Authorities Annual Conference - Flood Mitigation Without the Barriers.

Bello, O.D. (red), 2014. Handbook for disaster assessment. Unigted Nations & ECLAC.

Berning, C., Viljoen, M. F., & L.A. Du Plessis, 2000. Loss functions for sugar-cane: Depth and duration of inundation as determinants of extent of flood damage. Water SA, 26, 527-530, 2000.

Bitrán, D., 2001. Características del impacto socioeconómico de los principales desastres ocurridos en México en el período 1980-99. Centro nacional de prevención de desastres 1ª edición, octubre, 2001. CI/EES-23102001 ISBN: 970-628-591-1.

Blake, E.S., Kimberlain, T.B., Berg, R.J., Cangialosi, J.P. and Beven, J.L. (2013). Tropical cyclone report hurricane Sandy (AL182012) 22 – 29October 2012. National Hurricane Center. http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf

BMT, 2001. Belongil Creek Floodplain Risk Management Study and Plan - Discussion Paper 2: Flood Damages Assessment. Byron Shire Council

BMT, 2012a. Ballina floodplain risk management study, Exhibition Version - Volume 1 January 2012-01-12

BMT, 2012b. Ballina floodplain risk management study,Appendix E: Flood Damages Methodology Exhibition Version - Volume 1 January 2012-01-12

Booysen, H.J., Viljoen, M.F., & G.T. de Villiers, 1999. Methodology for the calculation of industrial flood damage and its application to an industry in Vereeniging. Water SA, 25, 41-46.

Bormudoi,A., Fowze,J.S.M., Hazarika,M.K., Samarakoon,L., Gunasekara,K., Kabir,S.M.H. & S.A. Mustofa, 2011. Rapid flood damage estimation: a case study at Chandpur, Bangladesh. 3rd International Conference on Water & Flood Management (ICWFM-2011).

BPIE, 2011. Europe's Buildings under the Microscope - a country by country review of the energy performance of buildings. Buildings Performance Institute Europe. http://www.bpie.eu/eu_buildings_under_microscope.html

Brémond, P., Grelot, F. & A.L. Agenais, 2013. Review Article: economic evaluation of flood damage to agriculture - review and analysis of existing methods. Natural Hazards and Earth System Sciences, European Geosciences Union (EGU), 2013, 13, p. 2493 - p. 2512.

Briene, M., S. Koppert, et al. 2002. Financiële onderbouwing kengetallen hoogwater-schade (in Dutch). Rotterdam, the Netherlands, Netherlands Economic Institute (NEI).

Brinkman,J. & M. Hartman, 2008. Jakarta flood hazard mapping framework, World Bank Report (unpublished). Deltares & HKV consultants.

BTE, 2001a. Economic costs of natural disasters. Report 103. Bureau of Transport Economics.

BTE, 2001b. Flood damage in Tamworth. Working paper 48. Bureau of Transport Economics.

Bubeck, P., 2008. Memo: Flood Damage Evaluation Methods

Bubeck, P., de Moel, H., Bouwer, L. M., & J. C. J. H. Aerts, 2011. How reliable are projections of future flood damage? Nat. Hazards Earth Syst. Sci., 11, 3293-3306, doi:10.5194/nhess-11-3293-2011, 2011.

Budiyono Y, Aerts JCJH, Brinkman JJ, Marfai MA and Ward P, 2015. Flood risk assessment for delta mega-cities: a case study of Jakarte. Natural Hazards 75, pp. 389-413.

Chang, L.F. & M.D. Su, 2007. Using the geographically weighted regression to modify the residential flood damage function. World Environmental and Water Resources Congress 2007: Restoring Our Natural Habitat.

Chang,L.F., Lin,C.H. & M.D. Su, 2008. Application of geographic weighted regression to establish flood-damage functions reflecting spatial variation. ISSN 0378-4738 = Water SA Vol. 34 No. 2 April 2008

Chatterton, J., Viavattene, C., Morris, J., Penning-Rowsell, E., and S. Tapsell, 2010. The Costs of the Summer 2007 Floods in England. Tech. rep., Environment Agency, 2010.

Chaua, V.N., Cassells, S. & J. Holland, 2014. Measuring direct losses to rice production from extreme flood events in Quang Nam province, Vietnam Institute of Agriculture and Environment, Massey University

Chen, A.S., Hammond,M.J., Djordjevic, S. & D. Butler, 2013a. Flood damage assessment for urban growth scenarios. International Conference on Flood Resilience: Experiences in Asia and Europe. 5-7 September 2013, Exeter, United Kingdom

Chen, A.S., Hammond,M.J., Djordjevic, S. & D. Butler, 2013b. Flood damage assessment for urban growth scenarios – Presentation. International Conference on Flood Resilience: Experiences in Asia and Europe. 5-7 September 2013, Exeter, United Kingdom

Cheng, X., 2011. Evolving trend of Flood Risk in China - Presentation. China-UK Bilateral International Workshop on Flood Management. IWHR, Beijing China, December 1, 2011

Chinh, D.T. & H. Kreibich, 2012. Flood loss assessment in Can Tho City, Vietnam. – Poster German Research Centre for Geosciences (GFZ) on EGU 2012 conference.

Ciscar, J.C., 2009. Climate change impacts in Europe - Final report of the PESETA research Project. JRC-European Commission. EUR 24093 EN.

Da Silva, A.M.R., Freire, B.G.A., Abrao, P.B.& R.Cuevas, 2011. Custos das Enchentes Urbanas. Escola Politecnica da Universidade de Sao Paulo - Departamento de Engenharia Hidraulica e Ambiental

Dahm. R., Dirks, F., Visch, J. van d, Diermanse, F., Mens, M. & L.P. Ho, 2014. Robust cost-benefit analysis to assess urban flood risk management: a case study on Ho Chi Minh City. 13th International Conference on Urban Drainage, Sarawak, Malaysia, 7-12 September 2014

Deltares, 2009. Best Practise Guidelines for Integrated Flood Risk Management for Basin Development Planning. The Flood Management and Mitigation Programme, Component 2: Structural Measures & Flood Proofing in the Lower Mekong Basin. Mekong River Commission.

Depettris, C.A., Mendiondo, E.M., Neiff, J.J., & H. Rohrmann, 2000. Flood defence strategy at the confluence of the Parana-Paraguay Rivers. In: F. Tönsmann & M. Koch -River Flood Defence-, Herkules Vg, Kassel, Germany.

Deru M., Field, K., Studer, D., Benne, K., Griffith, B., Torcellini, P., Liu, B., Halverson M., Winiarski D., Rosenberg M., Yazdanian M., Huang J. and D. Crawley, 2005. U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. Technical Report NREL/TP-5500-46861. National Renewable Energy Laboratory.

Diaz-Delgado, C., Baro-Suarez, J., Bedolla Lara, S. & J.C. Diaz Espiritu, 2011. Estimacion de costos de danos directos por inundacion en zonas habiticionales con empleo de curva costo versus altura de agua alcanzada: caso de estudio Valle de Chalco Solidaridad, Estado de Mexico - No further information.

Du Plessis, L.A. & M.F. Viljoen, 1997. Die ontwikkeling van vloedskadefunksies vir die landbousektor in die Benede-Oranjerivier,Water SA, 23, 209-216, 1997 (in Afrikaans).

Du Plessis, L.A. & M.F. Viljoen, 1998. Calculation of the secondary effects of floods in the lower Orange River area - A GIS approach, Water SA, 25, 197–203, 1999.

Dutta, D & S Herath, 2001. A GIS Based Flood Loss Estimation Modeling in Japan. INCEDE, IIS, The University of Tokyo, Tokyo, Japan

Dutta D, Herath S, Musiake K, 2003. A mathematical model for flood loss estimation. Journal of Hydrology 277, pp. 24-49.

EC Harris, 2010. International buildings costs worldwide | may 2010. EC Harris Built Asset Consultancy.

EC Harris Research , 2013. International construction cost report: a change of pace. Arcadis.

Ericksen, N., 1986. ANUflood in New Zealand: Part 1. Approaches to urban flood-loss reduction in New Zealand. CRES Working paper 1986/2 - ISBN 0 86740 197 4 - ISSN: 0313-7414

Eleuterio, J., Martinez, D., and A. Rozan,2010. Developing a GIS tool to assess potential damage of future floods, Risk Analysis VII, Algarve, Portugal, 2010,

Eleuterio, J.,Rozan, A. & R. Mosé, 2014. Propagation of hydraulic modelling uncertainty on damage estimates. 6thInternational Conference on flood management, Sao Paulo - Brazil

Eurostat, 2005. Eurostat yearbook 2005: Europe in figures. Office for Official Publications of the European Communities. Luxembourg.

Eurostat, 2007. Regional GDP per inhabitant in the EU27. Eurostat News Release. 23/2007 - 19 February 2007. Office for Official Publications of the European Communities. Luxembourg.

EMA, 2002. Disaster loss assessment guidelines. Emergency Management Australia - Manual 27

FEMA, 2013. Multi-hazard loss estimation methodology HAZUS-MH - Flood Model Technical Manual. Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, Washington D.C. Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, Washington D.C. http://www.fema.gov/media-library-data/20130726-1820-25045-8814/hzmh2_1_fl_um.pdf

Förster,S., Kuhlmann, B., Lindenschmidt, K.E. & A. Bronstert1, 2008. Assessing flood risk for a rural detention area. Nat. Hazards Earth Syst. Sci., 8, 311-322, 2008

Freebairn, D. & S. Vocea, 2007. Floodplain infrastructure. Sub-project 3. Latural Solutions Environmental Consultants PTY ltd

Frenkel M and John KD (2002). Volkswirtschaftliche Gesamtrechnung [System of National Accounts], 5. Auflage (quoted in Messner et al., 2007)

Fuentes Mariles, O.A., De Luna Cruz, F. & L. Vélez Morales, 2012. Análisis de vulnerabilidad, peligro y riesgo en una zona de planicie de inundación al sur de México. XXII Congreso Nacional De Hidráulica - Acapulco, Guerrero, México, Noviembre 2012

Gardiner & Theobald, 2012. International construction costs survey. Euro version.

Gaspard, G., 2005. Flood loss estimate model: recasting flood disaster assessment and mitigation for Haiti, the case of Gonaives. A Thesis Submitted in Partial Fulfillment of the Requirements for the Master of Science Degree. Faculté d'Agronomie et de Médecine Vétérinaire, University of Haiti State.

GHD, 2014a. Burnett River Floodplain Action Plan - Preliminary Options Assessment Report Report for Bundaberg Regional Council

GHD, 2014b. Burnett River Floodplain Action Plan-Appendix_A. Report for Bundaberg Regional Council

Genovese,E., 2006. A methodological approach to land use-base flood damage assessment in urban areas: Prague case study European Commission - JRC.

Green, C., Viavattene, C. & P. Thompson, 2011. Guidance for assessing flood losses - CONHAZ Report. No. D6.1. WP6 report - Middlesex University.

Guha-Sapir, D. & R. Below, 2002. The quality and accuracy of disaster data - a comparative analyses of three global data sets. Working paper for the Disaster Management Facility, The World Bank, CRED, Brussels, 2002.

Hack,A., Schitzenhofer, K.,Sturmlechner, M.& M. Szinetár, 2014. Quantifying impacts of flood risk. Report in the context of the lecture "Environmental Risk Analysis and Management". University of Natural Resources and Life Sciences, Vienna.

Hammond,M.J., Chen,A.S., Djordjevic,S., Butler,D., Khan,D.M., Rahman,S.M.M., Haque,A.K. E. & O. Mark, 2012. The development of a flood damage assessment tool for urban areas.

Hammond, M.J., Chen, A.S., Djordjevic,S., Butler,D. & O.Mark, 2013. Urban flood impact assessment: A state-of-the-art review.

Hammond, M.J., Chen, A.S., Butler,D., & S. Djordjevic, 2014. Flood Damage Model Guidelines CORFU: WP3 Impact Assessment: WP3/D3.3/d1

HAZUS manual: http://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

Huizinga, J, 2002. Damage Model River Meuse - SSM-IVM. September 2002 (in Dutch)

Huizinga, H.J., Barneveld, H.J., Vermeulen, C.J.M., Solheim I. & S. Solbø, 2005. On-line flood mapping using spaceborne SAR-images, waterlevel deduction techniques and GIS-based flooding models in the river Rhine. In: Floods, from Defence to Management – Van Alphen, van Beek & Taal (eds). Taylor & Francis Group, London

Huizinga, H.J., 2007. Flood damage functions for EU member states. Technical Report, HKV Consultants. Implemented in the framework of the contract #382441-F1SC awarded by the European Commission - Joint Research Centre.

FEMA, 2009. HAZUS-MR4 Technical manual. Federal Emergency Management Agency (FEMA)

Herath, S., 2003. Flood damage estimation of an urban catchment using Remote Sening and GIS. International Training Program on Total Disaster Risk Management - 10-13 June 2003.

Herath, S. & Y. Wang, 2010. Incorporating wind damage in potential flood loss estimation. Institute for Sustainability and Peace, United Nations University

Honert, R.C.van den & J. McAneney, 2011. The 2011 Brisbane Floods: causes, impacts and implications. Water 2011, 3, 1149-1173; doi:10.3390/w3041149

Huizinga, H.J., 2007. Flood damage functions for EU member states. Technical Report, HKV Consultants. Implemented in the framework of the contract #382441-F1SC awarded by the European Commission - Joint Research Centre.

Jha, A.K., Bloch, R. & J. Lamond, 2011. Cities and Flooding - A guide to integrated urban flood risk management for the 21st century. The World Bank & GDFRR.

Jongman, B., Kreibich, H., Apel, H., Barredo, J.I., Bates, P.D., Feyen, L., Gericke, A., Neal, J., Aerts, J.C.J.H. & P. J. Ward, 2012. Comparative flood damage model assessment: towards a

European approach. Nat. Hazards Earth Syst. Sci., 12, 3733-3752, 2012. doi:10.5194/nhess-12-3733-2012

Jongman, B., Ward, P.J. & J.C.J.H. Aerts, 2012. Global exposure to river and coastal flooding: Long term trends and changes. Global Environmental Change 22 (2012) 823-835

Jongman, B., 2014. Unravelling the Drivers of Flood Risk Across Spatial Scales. PhD Thesis, VU University, Amsterdam.

Jovel, R., 2007. Revisiting the 2007 Jakarta Flood Disaster: Assessment of Damage and Losses, Tech. Rep.

Kang,J.L., Su, M.D. & L.F Chang, 2005. Loss functions and framework for regional flood damage estimation in residential area. Journal of Marine Science and Technology, Vol. 13, No. 3, pp. 193-199 (2005)

Karamahmut, U., 2006. Risk Assessment for Floods Due to Precipitation Exceeding Drainage Capacity. Faculty of Civil Engineering and Geosciences - TU DElft. WL/Delft Hydraulics.

Khan, D.M., Rahman, S.M.M., Haque, A.K.E., Chen, A.S., Hammond, M.J., Djordjevic, S. & D. Butler, 2012. Flood damage assessment for Dhaka City, Bangladesh. Proceedings 2nd European Conference on FLOODrisk Management, 20th-22nd November 2012, Rotterdam, the Netherlands.

Kundzewicz, Z.W., Kanae,S., Seneviratne,SI, Handmer,J., Nicholls,N., Peduzzi,P., Mechler,R., Bouwer,L.M., Arnell,N., Machl,K., Muir-Wood,R., Brakenridge,GR, Kron,W., Benito,G., Honda,Y., Takahashi, K. & B. Sherstyukov, 2013. Flood risk and climate change: global and regional perspectives. Hydrological Sciences Journal, DOI: 10.1080/ 02626667. 2013. 857411

Ke, Q., Jonkman,S.N., Gelder, P.H.A.J.M. van & T. Rijcken, 2012. Flood damage estimation for downtown Shanghai - sensitivity analysis. Department of Hydraulic Engineering, Delft University of Technology, the Netherlands.

KGS, 2000. Red River Basin Stage-Damage Curves Update And Preparation Of Flood Damage Maps. Final Report. Report for International Joint Commission/Commision mixte internationale.

Kok M., Huizinga H.J., Vrouwenvelder, A.C.W.M. & A. Barendregt, 2005. Standard Method 2004 - Damage and Casualties caused by Flooding. Standaardmethode 2004 - schade en slachtoffers als gevolg van overstromingen. DWW-2005-005, RWS Dienst Weg- en Waterbouwkunde

Kok, M., Huizinga H.J., Vrouwenvelder A.C.W.M., & E. v/d Braak, 2005. Standaardmethode2005 - Schade en Slachtoffers als gevolg van overstromingen. Rijkswaterstaat DWW, Delft. (in Dutch)

Kosters, A., 2015. Flood risk assessment for urban areas in Asia. BsC thesis report- Delft University of Technology. Faculty of civil engineering and geosciences.

Lasage,R., Veldkamp, T.I.E., Moel, H. de, Van, T.C., Phi, H.L., Vellinga, P. & J.C.J.H. Aerts, 2014. Assessment of the effectiveness of flood adaptation strategies for HCMC. Nat. Hazards Earth Syst. Sci., 14, 1441–1457, 2014 www.nat-hazards-earth-syst-sci.net/14/1441/2014/ doi:10.5194/nhess-14-1441-2014

Leenders, J.K., Wagemaker, J., Roelevink, A., Rientjes, T.HM. & G. Parodi, 2010. Development of a damage and casualties tool for river floods in northern Thailand.

Lehman, 2012. Central Valley Flood Protection Plan. Attachment 8F: Flood Damage Analysis. Report for 2012 Central Valley Flood Protection Plan - State of California.

Lekuthai,A. & S. Vongvisessomjai, 2001. Intangible Flood Damage Quantification. Water Resources Management 15: 343-362, 2001.

Liu,Y., Zhou, J., 2013. Case study of flood damage assesment of YIZHUANG Beijng.- Presentation.

Liu,Y., Zhou, J., Song, L., Zou, Q., Guo, J. & Y. Wang, 2014. Efficient GIS-based model-driven method for flood risk management and its application in central China. Nat. Hazards Earth Syst. Sci., 14, 331-346, 2014. doi:10.5194/nhess-14-331-2014

Machado, M.L., Nascimento,N., Baptista,M., Goncalves,M., Silva,A., CostadeLima,J., Dias,R., Silva,A., Machado,E. & W.Fernandes, 2005. Curvas de danos de inundação versus profundidade de submersão: desenvolvimento de metodologia. REGA Vol. 2, no. 1, p. 35-52, jan./jun. 2005.

Maiti, S., 2007. Defining a Flood Risk Assessment Procedure using Community Based Approach with Integration of Remote Sensing and GIS - Based on the 2003 Orissa Flood. Thesis IIRS - India & ITC - the Netherlands.

Merz, B., Kreibich, H., Thieken, A. & R. Schmidtke, 2004. Estimation uncertainty of direct monetary flood damage to buildings. Natural Hazards and Earth System Sciences, 4, 153-163.

Merz, B., Kreibich, H., Schwarze, R. & A. Thieken, 2010. Assessment of economic flood damage. Natural Hazards and Earth System Sciences, 10, 1697-1724. doi:10.5194/nhess-10-1697-2010

Messner F., Penning-Rowsell E., Green C., Meyer V., Tunstall S. & Veen A. v/d, 2006. Guidelines for Socio-economic Flood Damage Evaluation. FLOODsite Project Report

Messner, F.,Penning-Rowsell, E., Green, C., Meyer,V., Tunstall, S., & A. van der Veen, 2007. Evaluating flood damages: guidance and recommendations on principles and methods. FLOODSite Consortium. Report T09-06-01

Meyer, V. & F. Messner, 2005. National Flood Damage Evaluation Methods. A review of applied methods in England, the Netherlands, the Czech Republic and Germany. UFZ discussion papers 13/2005.

Middelmann-Fernandez, M.H., 2010. Flood damage estimation beyond stage^damage functions: an Australian example. J Flood Risk Management 3 (2010) 88-96.

MLIT, 2005. Manual for Economic Appraisal of Flood Control Projects (in Japanese).

Moel, H. de, Vliet, M. van & J.C.J.H. Aerts, 2013. Evaluating the effect of flood damage-reducing measures: a case study of the unembanked area of Rotterdam, the Netherlands. Reg Environ Change. DOI 10.1007/s10113-013-0420-z

Moel, H. de, Vliet, M. van & Aerts, J.C.J.H. (2014). Evaluating the effect of flood damage-reducing measures: a case study of the unembanked area of Rotterdam, the Netherlands.Regional Environmental Change 14(3), 895-908. doi:10.1007/s10113-013-0420-z

Morrison, T. & S. Molino, 2012. Hawkesbury-Nepean Flood Damages Assessment: Final Report. Molino Stewart Pty Ltd - Report for Infrastructure NSW.

Nabul Islam, K.M., 1997. The impacts of flooding and methods of assessment in urban areas of Bangladesh. Ph.D. thesis, Flood Hazard Research Centre, Middlesex University, UK.

Newcomb & Whittington, 2011. Flood Damages Assessment.Oct 2011 (Parts 6 - App). BMT/WBM

Nguyen, P. & A. Green, 2012. Damage Assessment in a large River Basin: The Mekong Experience - presentation. UNFCCC Regional expert meeting on loss and damages Bangkok-Thailand 27-29 August 2012. Mekong River Commission.

Maiti, S., 2007. Defining a Flood Risk Assessment Procedure using community based approach with integration of Remote Sening and GIS. Based on the 2003 Orissa flood. Master Thesis. International Institute for Geo-infromation Science and Earth Observation.

Merz, B., Kreibich, H., Thieken. A. & R. Schmidtke, 2004. Estimation uncertainty of direct monetary flood damage to buildings. Natural Hazards and Earth System Sciences (2004) 4: 153-163. SRef-ID: 1684-9981/nhess/2004-4-153

Merz,B., Kreibich, H., Schwarz, R. & A. Thieken, 2010. Review article: Assessment of economic flood damage. Nat. Hazards Earth Syst. Sci., 10, 1697-1724, 2010. doi:10.5194/nhess-10-1697-2010

Molino-Stewart, 2012. Hawkesbury-Nepean Flood Damages Assessment - Final Report

MRC, 2009. Annual Mekong Flood Report 2008. Mekong River Commission.

Nascimento, N., Baptista, M., Silva, A., Machado, M.L., CostaDeLima, J., Gonçalves, M., Silva, A., Dias, R. &, É. Machado, 2006. Flood-damage curves: Methodological development for the Brazilian context. Water Practice & Technology Vol 1 No 1 © IWA Publishing 2006 doi: 10.2166/WPT.2006022

Neiff,J.J., Mendiondo,E.M. & C.A. Depettris, 2007. ENSO floods on river ecosystems: From catastrophes to myths

Newcomb & Whittington, 2011. Flood Damages Assessment. Chapter 6.

Nkeki, F.N., Henah, P.J. & V.N. Ojeh, 2013. Geospatial Techniques for the Assessment and Analysis of Flood Risk along the Niger-Benue Basin in Nigeria. Journal of Geographic Information System, 2013, 5, 123-135

Penning-Rowsell, E., Johnson, C., Tunstall, S., Tapsell, S., Morris, J., Chatterton, J.B. & C. Green, 2005. The benefits of flood and coastal risk management: A Handbook of assessment techniques. Flood Hazard Research Centre, Middlesex University Press.

Penning-Rowsell EC, Viavattene E, Pardoe J, Chatterton J, Parker D, Morris J (2010) The benefits of flood and coastal risk management: a handbook of assessment techniques - 2010. Flood Hazard Research Centre, Middlesex University Press.

Pinto,L.L.C.A., Lucci,R.M., Fadiga,F.M., Martins,J.R.S. & M.N. Alves de Miranda, 2007. Elaboração da curva risco x prejuízo para o plano de águas pluviais de Nova Friburgo - Estudo de caso. XVII Simpósio Brasileiro de Recursos Hídricos.

Ranger, N., Hallegatte, S., Bhattacharya, S., Bachu, M., Priya, S., Dhore, K., Rafique, F., Mathur. P.,Naville, N., Henriet, F., Herweijer, C., Pohit, S. & J. Corfee-Morlot, 2010. An assessment of the potential impact of climate change on flood risk in Mumbai. Climatic Change (2011) 104:139-167. DOI 10.1007/s10584-010-9979-2.

RedCross, 2013. Emergency appeal Mozambique: Floods. Revised Emergency appeal n° MDRMZ010 - GLIDE n° FL-2013-000008-MOZ - 1 March, 2013.

Sargent, D.M., 2013. Updating Residential Flood Stage-Damage Curves based on Building Cost Data. Reaching out to the Regions - SIAQ Conference, Townsville, 2013. O2 Environmental Pty Ltd.

Scawthorn,C., Blais,N., Seligson,H., Tate,E., Mifflin, E., Thomas,W., Murphy,J. & C. Jones, 2006a. HAZUS-MH Flood Loss Estimation Methodology.I: Overview and Flood Hazard Characterization. Nat. Hazards Rev., 60-71, 2006.

Scawthorn,C., Flores,P., Blais,N., Seligson,H., Tate,E., Chang,S., Mifflin,E., Thomas,W., Murphy,J., Jones,C., & M.Lawrence, 2006b. HAZUS-MH Flood Loss Estimation Methodology. II. Damage and Loss Assessment. Nat. Hazards Rev., 7(2), 72-81, 2006.

Segob-UN, 2008. Tabasco: características e impacto socioeconómico de las inundaciones provocadas a finales de Octubre y a comienzos de Noviembre de 2007 por el frente frío número 4. Secretaria de Gobernacion Mexica - UN. LC/MEX/L.864

Shrestha,B.B., Okazumi,T., Tanaka,S., Sugiura, A. & Y.Kwak, 2013. ssessment of flood hazards and vulnerability in Cambodian floodplain. ICWRER 2013 Proceedings, p629-647. doi: 10.5675/ICWRER_2013.

Shrestha,B.B., Okazumi,T., Miyamoto, M, Nabesaka,S., Tanaka,S., & A. Sugiura, 2014. Fundamental Analysis for Flood Risk Management in the Selected River Basins of Southeast Asia. Journal of Disaster ResearchVol.9No.5, 2014

Shrubsole,D.,Brooks,G., Halliday,R., Haque,E., Kumar,A., Lacroix,J., Rasid,H., Rousselle,J. & S.P.Simonovic, 2003. An assessment of flood risk management in Canada. ICLR Research. Paper Series – No. 28 - ISBN 0-9732213-6-4

Silva, A.P.M., 2006. Elaboração demanchas de inundação para o Municipio de Itajuba-utilizando-SIG. Dissertação apresentada à Universidade. Universidade Federal De Itajuba - Mestrado em Engenharia da Energia.

Silva Figueiredo, A.P., 2003. Determinação da mancha de inundação do Município de Itajubá na Enchente de Janeiro / 2000. Anais XI SBSR, Belo Horizonte, Brasil, 05 - 10 abril 2003, INPE, p. 1791 - 1794.

Singo,L.R., Kundu, P.M., Odiyo, J.O., Mathivha, F.I. & T.R. Nkuna, 2012. Flood Frequency Analysis of Annual Maximum Stream Flows for Luvuvhu River Catchment, Limpopo Province, South Africa.

Smith, D.I., 1994. Flood damage estimation - A review of urban stage-damage curves and loss functions. Water SA Vol. 20 No. 3 July 1994. ISSN 0378-4738

Solimano, A., 2005. Economic growth in Latin America in the late 20th century: evidence and interpretation. Economic Development Division. Raimundo Soto (Catholic University of Chile). United Nations - CEPAL.

Suderhsa-CH2MHILL, 2002. Manual de drenagem urbana. Região Metropolitana de Curitiba- PR. VERSÃO 1.0 - Dezembro 2002

Surminski, S., Lopez, A., Birkmann, J. & T. Welle, 2012. Current knowledge on relevant methodologies and data requirements s well as lessons learned and gaps identified at different levels, in assessing the risk of loss and damage associated with the adverse effects of climate change - Background paper. United Nations - Framework Convention on Climate Change.

Thieken, AH , Ackermann, V., Elmer, F., Kreibich, H., Kuhlmann, B., Kunert, U., Maiwald, H., Merz, B., Müller, M., Piroth, K., Schwarz, J., Schwarze, R., Seifert, I. & J Seifert, 2008. Methods for the evaluation of direct and indirect flood losses. 4 Th International Symposium on Flood Defence: Managing Flood Risk, Reliability and Vulnerability Toronto, Ontario, Canada, May 6-8, 2008.

Tiepolo, M, 2014. Flood Risk Reduction and Climate Change in Large Cities South of the Sahara. Chapter 2 in: Climate Change Vulnerability in Southern African Cities, Springer Climate, DOI: 10.1007/978-3-319-00672-7_2, Springer International Publishing Switzerland 2014.

Torterotot, J.P., 1993. Le coût des dommages dus aux inondations: Estimation et analyse des incertitudes, Thèse de doctorat, spécialité sciences et techniques de l'environnement, École Nationale des Ponts et Chaussées, Paris, 1993 (in French).

Tucci, C.E.M., 2003. Inundações e drenagem urbana.

Tucci, C.E.M., 2007. Urban Flood Management. WMO, CAP-NET.

Turner & Townsend, 2013. International construction cost survey 2012.

UN, 2005. Efectos En El Salvador De Las Lluvias Torrenciales, Tormenta Tropical Stan Y Erupción Del Volcán Ilamatepec (Santa Ana), Octubre Del 2005. Comisión Económica Para América Latina Y El Caribe - Cepal. LC/MEX/R.892.

UN, 2006. Efectos En Guatemala De Las Lluvias Torrenciales Y La Tormenta Tropical Stan, Octubre De 2005. Comisión Económica Para América Latina Y El Caribe - Cepal.

UN, 2008. Evaluacion Del Ipacto Acumulado y Adicional Ocasionado Por La Nina - Bolivia 2008. Comisión Económica Para América Latina Y El Caribe - Cepal. LC/MEX/L.863/Rev. 1.

UN, 2012. Impacto socioeconómico de las inundaciones registradas en el Estado de Tabasco de Septiembre a Noviembre de 2011. Comisión Económica Para América Latina Y El Caribe - Cepal. LC/MEX/L1064_es.

Unicef, 2013. Situation Report Unicef Mozambique - Reporting Period: February 1-2, 2013 - Flood Emergency Preparedness And Response.

URS, 2008. Flood Rapid Assessment Model (F-RAM) Development 2008. Report for State of California - Department of Water Resources - Division of Flood Management

USaid, 2002. Mozambique 1999-2000 Floods. Impact Evaluation: Resettlement Grant Activity Emergency Recovery: Agriculture and Commercial Trade (ER: ACT).

Vanneuville W, Maddens R, Collard C, Bogaert P, De Maeyer P, Antrop M (2006) Impact op mens en economie t.g.v. overstromingen bekeken in het licht van wijzigende hydraulische condities, omgevingsfactoren en klimatologische omstandigheden. MIRA/2006/02, Vakgroep Geografie, Universiteit Gent, Gent, Belgium (in Dutch)

Villiers, G. de, Viljoen, MF & H.J. Booysen, 2007. Standaard residensiële vloedskadefunksies vir Suid-Afrikaanse toestande - Standard residential flood damage functions for South African conditions. Suid-Afrikaanse Tydskrif vir Natuurwetenskap en Tegnologie, Jaargang 26 No. 1: Maart 2007. (in Afrikaans)

Vineet, J, 2010. Anatomy of a Damage Function Dispelling the Myths. –Webblog. AIR-Wordlwide: http://www.air-worldwide.com/Publications/AIR-Currents/2010/Anatomy-of-a-Damage-Function--Dispelling-the-Myths/

Vojinovic, Z., Ediriweera, J.D.W., & A.K. Fikri, 2008. An approach to the model-based spatial assessment of damages caused by urban floods. Presented at the 11th International Conference on Urban Drainage, 31st August-5th September 2008, Edinburgh, UK.

Wagenmaker, J, Leenders, J. & J. Huizinga, 2008. Economic valuation of flood damage for decision makers in the Netherlands and the Lower Mekong river basin. 6th Annual Mekong Flood Forum, 27-28 May 2008, Phnom Penh, Cambodja.

Walton, M., Kelman, I., Johnston, D. & G. Leonard, 2004. Economic impacts on New Zealand of climate change-related extreme events - Focus on freshwater floods. Report to the New Zealand Climate Change Office, July 2004.

Ward,P.J., Marfai, M.A., Yulianto, F., Hizbaron, D.R. & J.C.J.H.Aerts, 2011. Coastal inundation and damage exposure estimation: a case study for Jakarta. Nat Hazards (2011) 56:899-916. DOI 10.1007/s11069-010-9599-1

Ward,P.J., Ierland, E.C. van, Budiyono, Y., Wijayanti, P., Muis, S., Marfai, M.A., Poerbanmdono, Julina, M.M. & A. Fauzi, 2014a. Jakarta Climate Adaptation Tools (JCAT). Knowledge for Climate report number: HSINT02a

Ward,P.J., 2014b. Jakarta Climate Adaptation Tools (JCAT) - Presentation Deltas Conference Knowledge for Climate report number: HSINT02a.

Wijanti, P., Zhu, X., Hellegers, P., Budiyonoc, Y. & E.C. van Ierland, 2014. River flood damage estimation in Jakarta, Indonesia - Poster Deltas Conference. Knowledge for Climate.

World Development Indicators (WDI): http://databank.worldbank.org/data/views/variableSelection/selectvariables.aspx?source=world-development-indicators

WMO, 2013. Conducting flood loss assessments. Integtrated Floodf Management tools series - Issue 2, June 2013. World MeteorologicalOrganization / Global Water Partnership.

Worldbank, 2000. Republic of Mozambique: A Preliminary Assessment of Damage from the Flood and Cyclone Emergency of February-March 2000.

Worldbank, 2010. Economic Vulnerability and Disaster Risk Assessment in Malawi and Mozambique - Measuring Economic Risks of Droughts and Floods. WorldBank, RMSI, XXX, Global Facility For Disaster Reduction and Recovery (GFDRR).

Worldbank, 2012. Improving the assessment of disaster risks to strengthen financial resilience. A Special Joint G20 Publication by the Government of Mexico and the World Bank.

Worldbank, 2012b. Thai flood 2011. Overview. Rapid Assessment for Resilient Recovery and Reconstruction Planning.

Worldbank, 2014a. Recovery from Recurrent Floods 2000-2013 MOZAMBIQUE. Recovery Framework Case Study. August 2014. GFDRR, World Bank, UNDP, INGC.

Worldbank , 2014b.

World Development Indicators 2014.

WorldBank (2015). Consumer Price Index (CPI): http://data.worldbank.org/indicator/FP.CPI.TOTL. Accessed 28 January 2015.

Zhong,G., Liu,S., Han,C. & W. Huang, 2014. Urban Flood Maping for Jiaxing City Based on Hydrodynamic Modeling and GIS Analysis.Journal of Coastal Research, 68(sp1):168-175. 2014.

Web:

Consumer Price Index (CPI): http://data.worldbank.org/indicator/FP.CPI.TOTL. Accessed 28 january 2015

Consumer price index reflects changes in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used.

Agricultural land (%): http://data.worldbank.org/indicator/AG.LND.AGRI.ZS. Accessed 28_1_2015

Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures. Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded. Land under permanent crops is land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee, and rubber. This category includes land under flowering shrubs, fruit trees, nut trees, and vines, but excludes land under trees grown for wood or timber. Permanent pasture is land used for five or more years for forage, including natural and cultivated crops.

Agriculture_ValueAdded (% GDP): http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS. Accessed 28_1_2015

Agriculture corresponds to ISIC divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.

LandArea_sqareKilometers: http://data.worldbank.org/indicator/AG.LND.TOTL.K2. Accessed 28_1_2015

Land area is a country's total area, excluding area under inland water bodies, national claims to continental shelf, and exclusive economic zones. In most cases the definition of inland water bodies includes major rivers and lakes

GDP (current US$): http://data.worldbank.org/indicator/NY.GDP.MKTP.CD. Accessed 28_1_2015

GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars. Dollar figures for GDP are converted from domestic currencies using single year official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used.

Inflation, consumer prices (annual %): http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG. Accessed 28_1_2015

Inflation as measured by the consumer price index reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used.

Industry, value added (% of GDP): http://data.worldbank.org/indicator/NV.IND.TOTL.ZS. Accessed 28_1_2015

Industry corresponds to ISIC divisions 10-45 and includes manufacturing (ISIC divisions 15-37). It comprises value added in mining, manufacturing (also reported as a separate subgroup), construction, electricity, water, and gas. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.

United Nations Economic Commission for Europe:http://www.unece.org/stats/trends2005/environment.htm

Eurostat:http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_330765768_dad=portal&_schema=PORTAL

Natural Hazards and Earth System Sciences. http://www.copernicus.org/EGU/nhess/nhess.html

Economic and Financial Affairs department from the European Commission (ECFIN). http://ec.europa.eu/economy_finance/indicators/euroareagdp_en.htm

Emergency Events Database EM-DAT. http://www.emdat.be

Natural Disasters Database since 2001: http://naturaldisastersnews.net/

World Development Indicators (WDI): http://databank.worldbank.org/data/views/variableSelection/selectvariables.aspx?source=world-development-indicators

Appendix A: Maximum damage in agriculture

Table A-1 is based on data from the World Bank (World Bank, 2015) and JRC. An average of these five years (2008-2012) was calculated to obtain a robust estimate for 2010.

Myanmar, Haiti and Israel are based on data provided by JRC (2010 only) with respect to the share of agriculture VA in GDP (%) due to missing data in the World Bank sheet. Per country the total value addition in GDP of agriculture is divided by the total agricultural area. This results in a value of agriculture per hectare.

Table A-1: Value added per hectare in Agriculture sector.

Country	***VA/ha (US$)***	***Country***	***VA/ha (US$)***
Afghanistan	102	Lebanon	2401
Albania	1841	Lesotho	66
Algeria	349	Liberia	241
American Samoa		Libya	104
Andorra		Liechtenstein	
Angola	135	Lithuania	463
Antigua and Barbuda	2290	Luxembourg	1162
Argentina	208	Macao SAR, China	
Armenia	1032	Macedonia, FYR	840
Aruba	5602	Madagascar	57
Australia	67	Malawi	245
Austria	1744	Malaysia	3367
Azerbaijan	641	Maldives	13205
Bahamas, The	11789	Mali	85
Bahrain		Malta	14201
Bangladesh	2097	Marshall Islands	
Barbados	3860	Mauritania	14
Belarus	560	Mauritius	3681
Belgium	2586	Mexico	345
Belize	1071	Micronesia, Fed. Sts.	3256
Benin	654	Moldova	273
Bermuda	59263	Monaco	
Bhutan	510	Mongolia	9
Bolivia	58	Montenegro	646
Bosnia and Herzegovina	569	Morocco	429
Botswana	13	Mozambique	68
Brazil	347	Myanmar*	927
Brunei Darussalam	8630	Namibia	23
Bulgaria	498	Nepal	1234
Burkina Faso	261	Netherlands	7261
Burundi	350	New Caledonia	
Cabo Verde	1979	New Zealand	674
Cambodia	704	Nicaragua	295
Cameroon	562	Niger	54
Canada	366	Nigeria	1085

Country	***VA/ha (US$)***	***Country***	***VA/ha (US$)***
Cayman Islands		Northern Mariana Islands	
Central African Republic	207	Norway	5416
Chad	116	Oman	466
Channel Islands		Pakistan	1693
Chile	444	Palau	2038
China	1224	Panama	472
Colombia	438	Papua New Guinea	
Comoros	1400	Paraguay	189
Congo, Dem. Rep.	193	Peru	
Congo, Rep.	45	Philippines	2120
Costa Rica	1204	Poland	867
Cote d'Ivoire	289	Portugal	1255
Croatia	1951	Puerto Rico	3692
Cuba	406	Qatar	2275
Curacao		Romania	787
Cyprus	3805	Russian Federation	281
Czech Republic	983	Rwanda	1021
Denmark	1439	Samoa	1990
Djibouti		San Marino	
Dominica	2447	Sao Tome and Principe	782
Dominican Republic	1309	Saudi Arabia	73
Ecuador	903	Senegal	210
Egypt, Arab Rep.	7892	Serbia	725
El Salvador	1626	Seychelles	7411
Equatorial Guinea		Sierra Leone	426
Eritrea	33	Singapore	122070
Estonia	671	Sint Maarten (Dutch part)	
Ethiopia	407	Slovak Republic	1519
Faeroe Islands		Slovenia	1882
Fiji	792	Solomon Islands	
Finland	2615	Somalia	
France	1473	South Africa	85
French Polynesia		South Sudan	
Gabon	128	Spain	1214
Gambia, The	388	Sri Lanka	2365
Georgia	408	St. Kitts and Nevis	1730
Germany	1568	St. Lucia	3290
Ghana	560	St. Martin (French part)	
Greece	1089	St. Vincent and the Grenadines	4126
Greenland		Sudan	120
Grenada	3239	Suriname	4941
Guam		Swaziland	167
Guatemala	1096	Sweden	2280

Country	***VA/ha (US$)***	***Country***	***VA/ha (US$)***
Guinea	72	Switzerland	2889
Guinea-Bissau	256	Syrian Arab Republic	
Guyana	275	Tajikistan	266
Haiti*	714	Tanzania	160
Honduras	633	Thailand	1833
Hong Kong SAR, China	25346	Timor-Leste	516
Hungary	848	Togo	303
Iceland	502	Tonga	2026
India	1489	Trinidad and Tobago	2265
Indonesia	1904	Tunisia	365
Iran, Islamic Rep.		Turkey	1508
Iraq	884	Turkmenistan	103
Ireland	618	Turks and Caicos Islands	
Isle of Man		Tuvalu	4597
Israel*	6588	Uganda	265
Italy	2918	Ukraine	285
Jamaica	1665	United Arab Emirates	6020
Japan	13841	United Kingdom	850
Jordan	726	United States	416
Kazakhstan	38	Uruguay	235
Kenya	371	Uzbekistan	264
Kiribati	977	Vanuatu	819
Korea, Dem. Rep.		Venezuela, RB	827
Korea, Rep.	13788	Vietnam	2271
Kosovo		Virgin Islands (U.S.)	
Kuwait	4100	West Bank and Gaza	1760
Kyrgyz Republic	95	Yemen, Rep.	
Lao PDR	904	Zambia	90
Latvia	471	Zimbabwe	69

Appendix B: International construction costs

The information from the two applied sources on international construction costs [Euro/m^2 - 2010] has been compiled in the Table below.

Table B-2: Comparison of construction costs of EC Harris (2010) vs Turner and Townsend (2013).

	EC Harris (2010)			*Turner & Townsend (2013)*		
Country	***RES***	***COM***	***IND***	***RES***	***COM***	***IND***
Abu Dhabi	1506	1335	999			
Australia	1640	1760	1050	1246	1553	695
Austria	1485	1540	915			
Bahrain	1644	1445	1099			
Belgium	1431	1478	983			
Bosnia & Herzegovina	793	745	515			
Brazil				613	846	689
Bulgaria	584	866	618			
Cameroon	511	425	394			
Canada	1859	1444	1086	1725	1683	776
China	398	594	518	486	593	422
Croatia	1027	1041	639			
Czech Republic	1065	922	534			
Denmark	2082	2129	1810			
Egypt	685	868	529			
Finland	1854	2004	1250			
France	1621	1534	1070			
Germany	2159	1494	978	1067	1733	963
Ghana	385	512	304			
Greece	1108	989	716			
Hong Kong	1746	1173		2225	2021	1519
Hungary	750	897	705			
India				338	349	369
Indonesia	505	454	342			
Ireland	1696	1932	1040	1228	1812	937
Italy	1365	1607	740			
Japan				1656	2332	2071
Latvia	889	812	697			
Macedonia	760	746	508			
Malaysia	406	461	420	492	909	607
Netherlands	1015	1365	958	1253	1875	903
New Zealand	1559	1633	997			
Oman	1477	1289	979	1252	1289	904
Poland	1092	1105	682	554	696	424
Portugal	837	898	487			
Qatar	1494	1362	1019	1283	1420	782

	EC Harris (2010)			Turner & Townsend (2013)		
Country	***RES***	***COM***	***IND***	***RES***	***COM***	***IND***
Romania	816	832	563			
Russia	1089	1108	513	878	1141	745
Saudi Arabia	1417	1236	939			
Serbia	830	806	531			
Singapore	1683	1513	1103	1807	1428	1383
Slovakia	828	805	592			
South Africa	579	641	413	525	598	341
South Korea	1178	1128	797	869	920	886
Spain	1099	1134	503			
Sri Lanka	377	350	326			
Sweden	1688	1695	1319			
Switzerland	2117	2343	1723			
Taiwan	301	426	317			
Thailand	842	756	596			
Turkey	899	1055	739			
Uganda				304	488	292
United Arab Emirates				1367	1408	982
Ukraine	719	801	292			
United Kingdom	1600	1557	875	1655	2098	1176
USA	1171	1369	793	1186	1460	908
Vietnam				379	430	301

Appendix C: HAZUS inventory values

Below (Table C-3) the HAZUS (for the USA) content value percentage of structure value is presented.

Table C-3: Default HAZUS contents value, share of the structure value.

No.	Label	Occupancy Class	Contents Value (%)
		Residential	
1	RES1	Single Family Dwelling	50
2	RES2	Mobile Home	50
3	RES3	Multi Family Dwelling	50
4	RES4	Temporary Lodging	50
5	RES5	Institutional Dormitory	50
6	RES6	Nursing Home	50
		Commercial	
7	COM1	Retail Trade	100
8	COM2	Wholesale Trade	100
9	COM3	Personal and Repair Services	100
10	COM4	Professional/Technical/ Business Services	100
11	COM5	Banks	100
12	COM6	Hospital	150
13	COM7	Medical Office/Clinic	150
14	COM8	Entertainment & Recreation	100
15	COM9	Theaters	100
16	COM10	Parking	50
		Industrial	
17	IND1	Heavy	150
18	IND2	Light	150
19	IND3	Food/Drugs/Chemicals	150
20	IND4	Metals/Minerals Processing	150
21	IND5	High Technology	150
22	IND6	Construction	100

Appendix D: Glossary

Table D-4: Glossary terms.

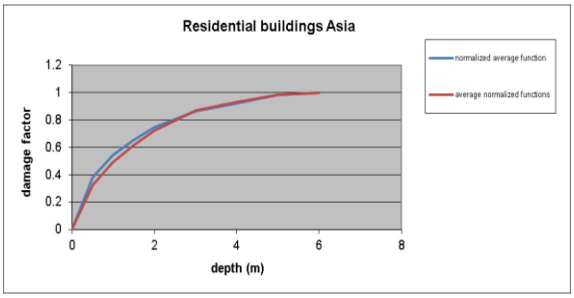
Term	***Description***
Avoidable losses	Losses that can be avoided through mitigation
Commerce	In a loss assessment context, 'commerce' refers to the retail, wholesale, service industries and the manufacturing sectors
Costs	In a loss assessment context, the resources or alternative consumption which must be sacrificed to achieve the desired end result, such as implementing mitigation.
Damage class	One of six damage classes defined as follows: 1. Residential: ○ Refers to residential buildings such as houses and apartments and their contents ○ Weighted averages based on studies of building stock are used, i.e. taking account of different sizes and quality standards of houses and apartments ○ Damage to assets in residential areas which are not residential buildings (i.e. in the public area and gardens) is not included 2. Commerce: ○ Refers to commercial buildings and their contents such as offices, schools, hospitals, hotels, shops, etc. ○ Weighted averages of the various buildings types are used based on building stock studies ○ Damage to assets in commercial areas (i.e. in the public area and vehicles) is not included 3. Industry: ○ Refers to industrial buildings and their contents such as warehouses, distribution centers, factories, laboratories, etc. ○ Weighted averages of the various building types are used based on building stock studies ○ Damage to assets in industrial areas (i.e. in the public area and vehicles) is not included 4. Transport: ○ Transport facilities ○ Maximum damage values from literature: very limited data 5. Infrastructure ○ Roads and railroads ○ Direct damage to roads and railroads as a result of contact with (fast flowing) water 6. Agriculture: ○ Based on damage resulting from flooded agricultural lands only (i.e. does not include farms, sheds, farming material, etc.) ○ Value added used as a proxy in this study
Disaster	A serious disruption to community life which threatens or causes death or injury in that community and/or damage to property which is beyond the day-to-day capacity of the prescribed statutory bodies.

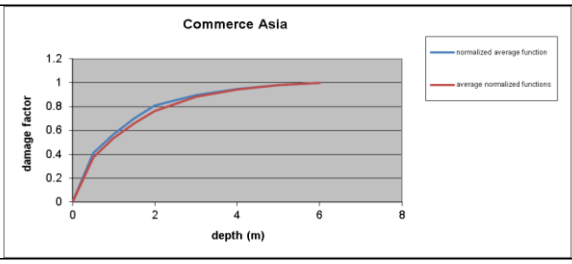
Term	*Description*
	A disaster requires special mobilisation and organisation of resources other than those normally available to those authorities.
Depth–damage	Depth–damage curves (also known as stage–damage curves) are graphical relationships of the losses expected to result at a specified depth of flood water. Such curves are typically used for housing and other structures where the stage or depth refers to depth of water inside a building and the damage refers to the damage expected from that depth of water. They may be thought of more generally as representing the relationship between hazard magnitude and loss, and can be adapted to cover other hazards.
Economic loss	See 'loss/damage'.
Financial loss	See 'loss/damage'.
Intangible loss	Items which are not normally bought or sold (such as memorabilia, lives, health and the environment) and for which, therefore, no agreement on their monetary value exists.
Loss/damage	A loss is counted if it is an economic loss, unless otherwise specified. An economic loss is a measure of the impact of the disaster on the specified economy. It is taken as being equal to the resources (expressed in time, money or intangible loss) lost by the specified area as a result of the disaster (see also 'net loss'). This is distinct from financial losses due to the disaster which are losses borne by individual enterprises as well as the other sectors. Many individual business losses do not amount to economic losses as their losses are offset by other businesses gaining the trade, or are made up over time.
Stage–damage curves	See 'depth–damage curves'
Tangible damage	Items which are normally bought or sold and which are therefore easy to assess in monetary terms.

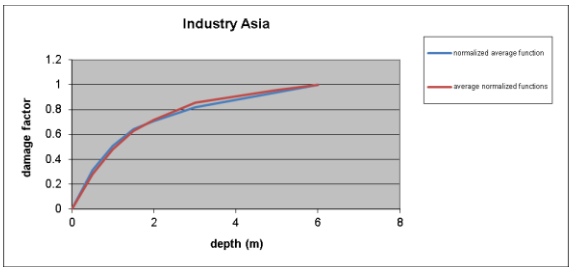
Appendix E: Averaging procedure for the damage function

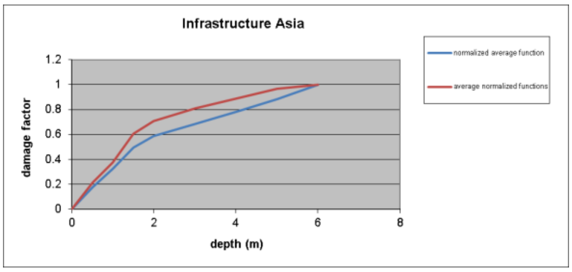
The damage functions are first normalized and then averaged. The procedure is presented on example of Asian data with the results for two options: 1) normalised average of the recorded damage functions (alternative approach) and 2) average of normalised recorded damage functions (original approach).

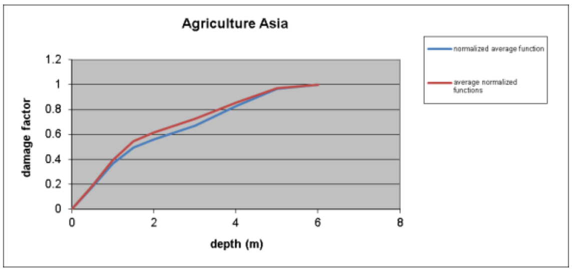
Figure E-1: damage functions for Asia, example of processing.

<table>
<tr><th>Graphical representation</th><th>Description</th></tr>
<tr><td>
</td><td>

number of functions: 25
recorded functions ranging 0-1: 13
functions are nearly identical with the normalized average function being a bit steeper between 0.5 and 2.5 meters than the average of normalized functions
</td></tr>
<tr><td>
</td><td>

number of functions: 20
recorded functions ranging 0-1: 9
functions are nearly identical with the normalized average function being a bit steeper between 0.5 and 2.5 meters than the average of normalized functions
</td></tr>
<tr><td>
</td><td>

number of functions: 11
recorded functions ranging 0-1: 5
functions are nearly identical
</td></tr>
<tr><td>
</td><td>

number of functions: 4
recorded functions ranging 0-1: 1
the average of normalized functions has higher values than normalized average function
</td></tr>
<tr><td>
</td><td>

number of functions: 8
recorded functions ranging 0-1: 5
the average of normalized functions has slightly higher values than normalized average function
</td></tr>
</table>

In the case of Industry the damage functions from both methods are nearly equal. In the case of Residential buildings and Commerce the values from the normalized average of recorded functions are a bit higher than the values from the average of normalised recorded functions. For the remaining damage categories this is reversed.

It can be observed that differences between both functions are reduced the higher the number of observations (i.e. functions). It is not straightforward to relate the observed differences to any parameter.

Both methods show different results. It is difficult to determine that one method performs better, although it seems more useful to first produce a normalised version of a function (and its corresponding maximum damage value) and average these (the original approach) and compute standard deviations, than the other way round (the alternative) without adapted maximum damage values and the ability to calculate standard deviations.

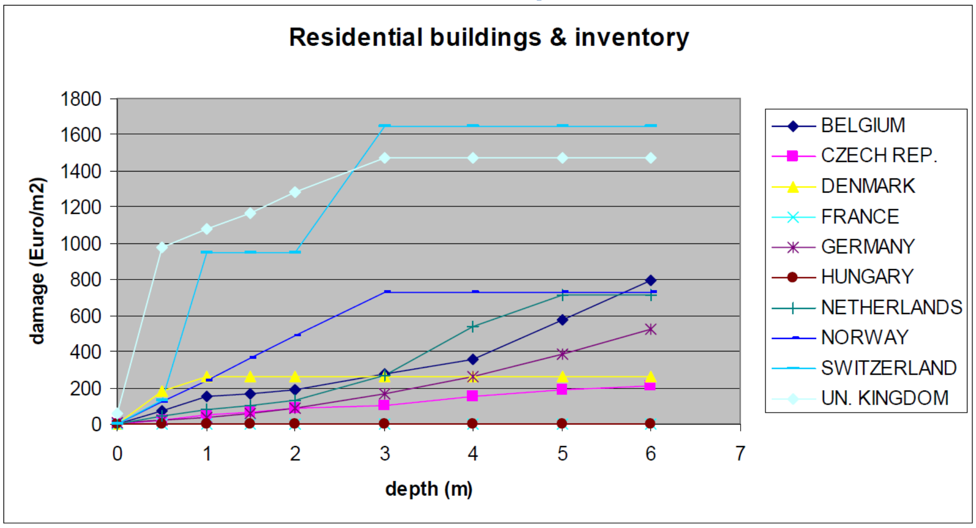
Appendix F: Damage functions for Europe

This Appendix provides extract from the previously unpublished study (Huizinga, 2007) which developed flood-damage functions for EU member states.

Residential buildings

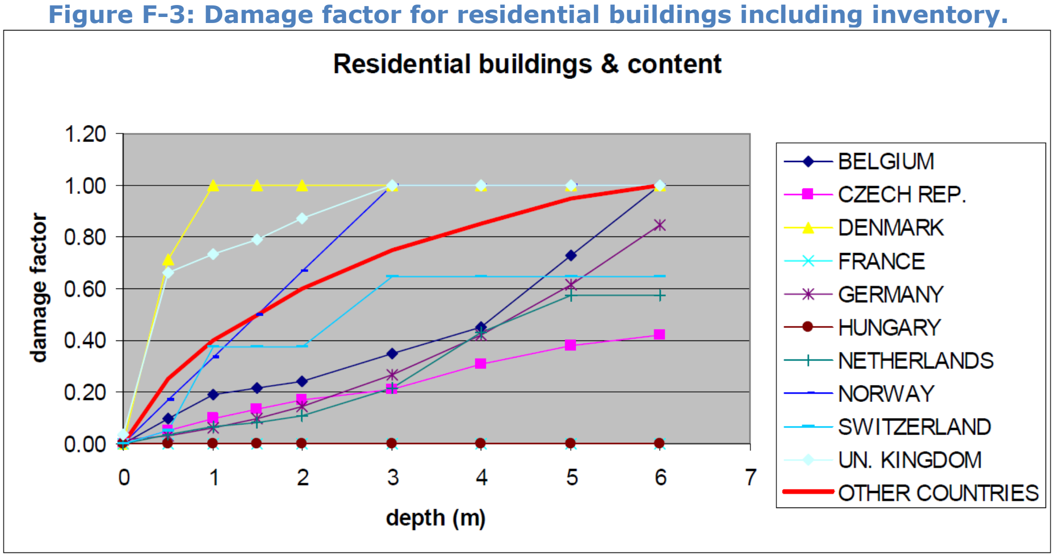
The residential buildings including inventory maximum damage values all have inventory included.

Figure F-2: Damage per square meter for residential buildings including including inventory.



Switzerland & the UK have by far the largest damage values, the rest of the explored countries have more or less equal maximum damage values. The average maximum damage value for the category residential buildings including inventory at 6m depth is 750 €/m^2.

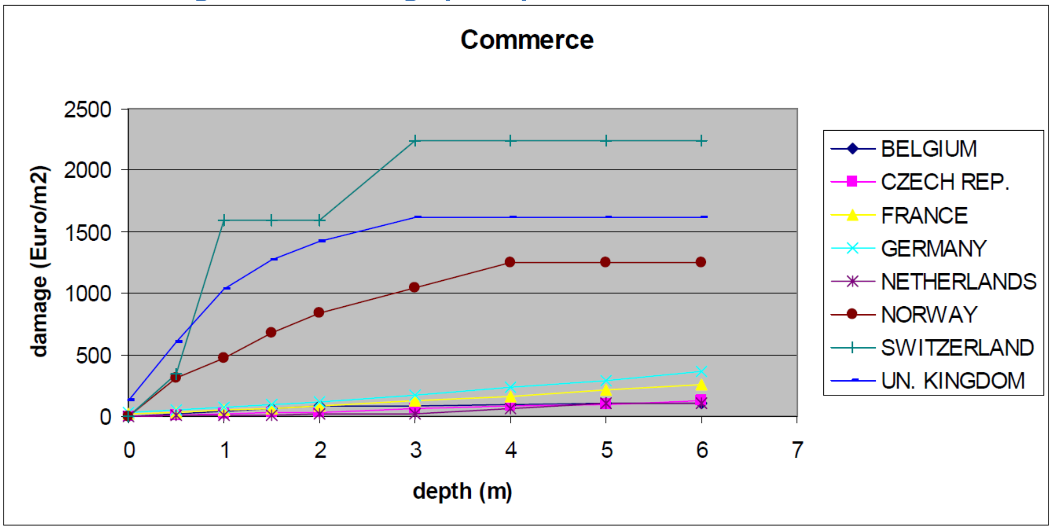
Figure F-3: Damage factor for residential buildings including inventory.



Commerce

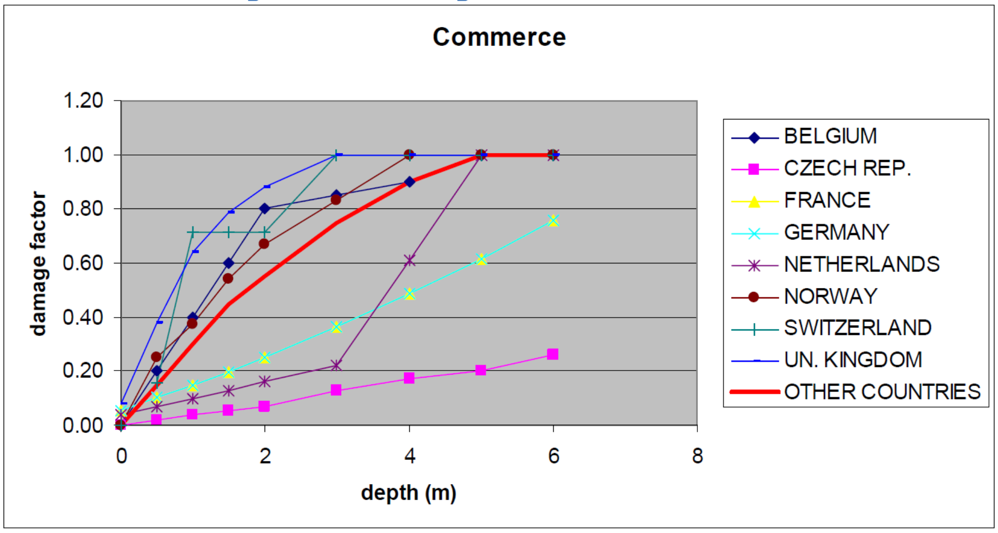
The commerce maximum damage values all have inventory included.

Figure F-4: Damage per square meter for commerce.



Switzerland has by far the largest damage value; Norway and UK are in the intermediate region and have quite similar functions, while on the other hand Germany, France, the Czech Republic and The Netherlands have quite low values. The average maximum damage value for the category commerce at 6 m. depth is 621 €/m^2.

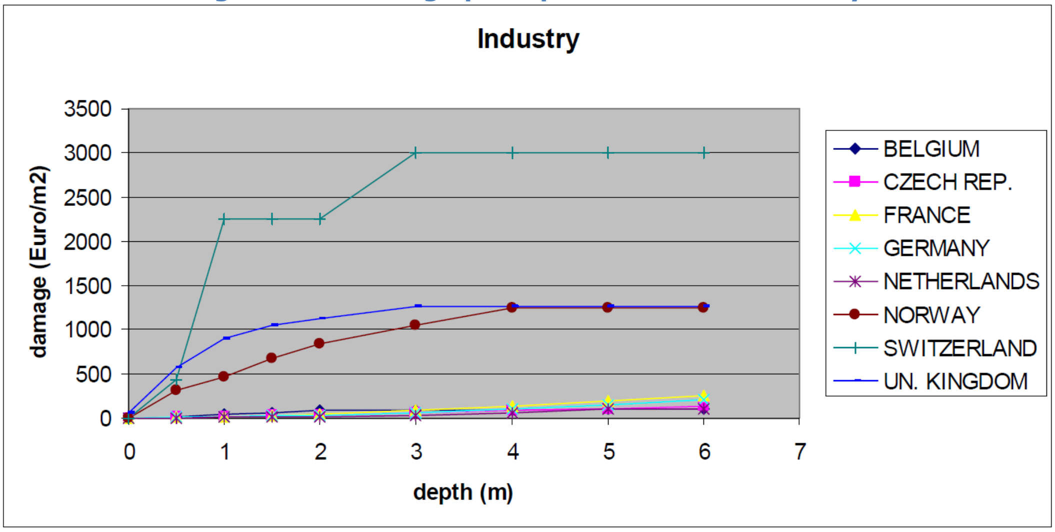
Figure F-5: Damage factor for commerce.



Industry

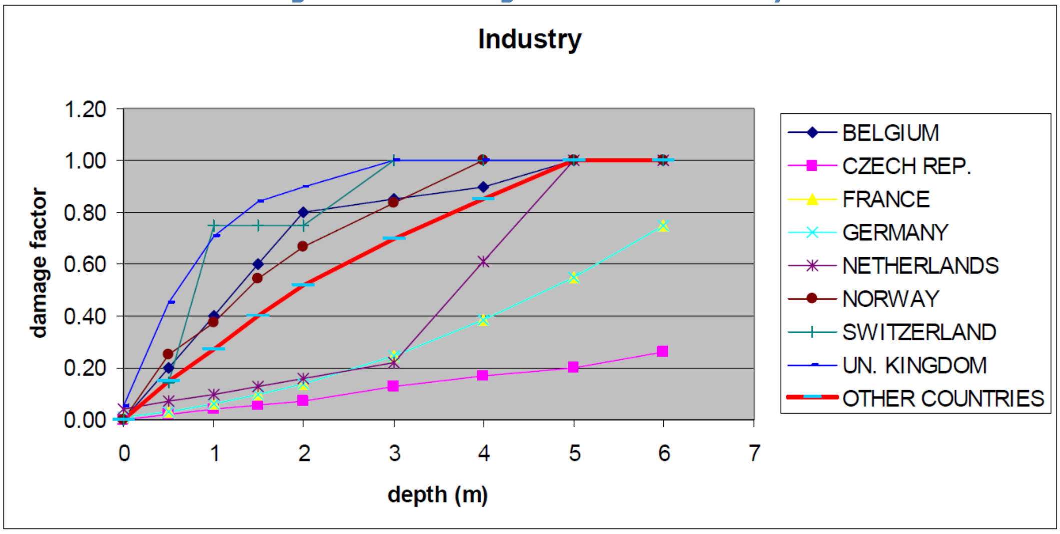
The industry maximum damage values all have inventories included.

Figure F-6: Damage per square meter for industry.



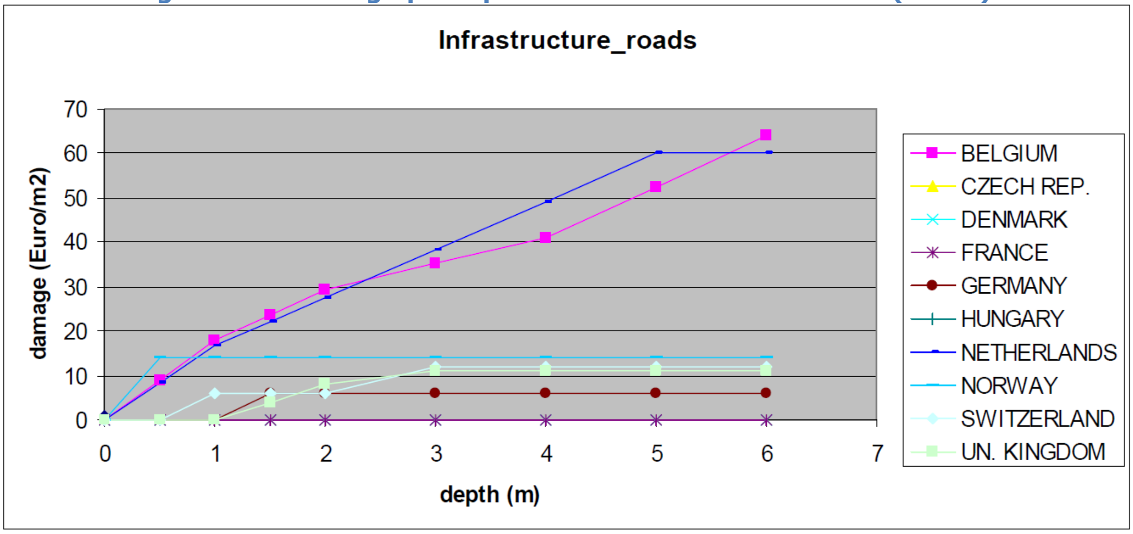
Switzerland has by far the largest damage value; Norway and UK are in the intermediate region and have quite similar functions, while on the other hand Germany, France, the Czech Republic and The Netherlands have quite low values. The average maximum damage value for the category industry at 6 m depth is 534 €/m^2.

Figure F-7: Damage factor for industry.



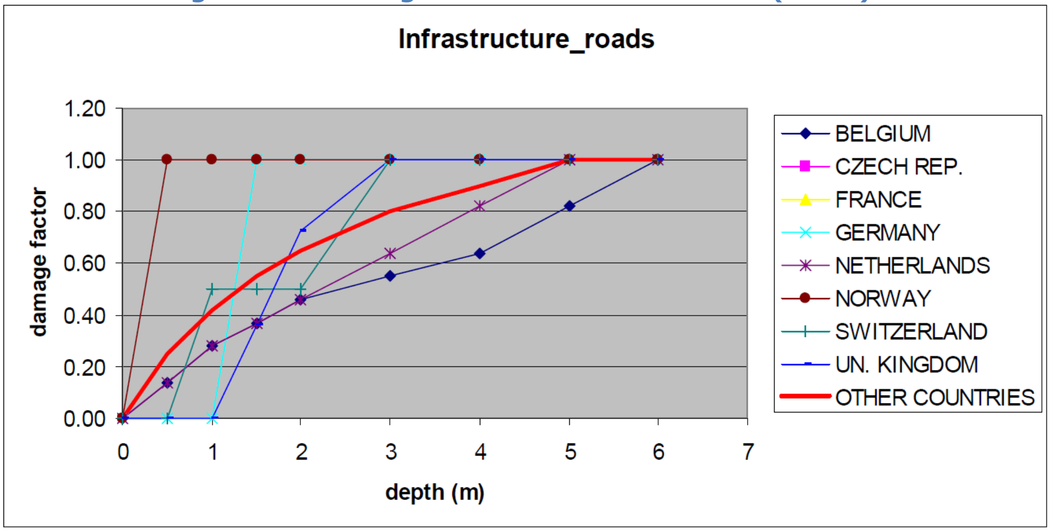
Roads

Figure F-8: Damage per square meter for infrastructure (roads).



Maximum damage for roads differs largely between the considered countries. Belgium and Switzerland have by far the largest damage values, the rest of the explore countries have quite low values. The average maximum damage value for the category roads at 6 m. water depth is 24 €/m^2.

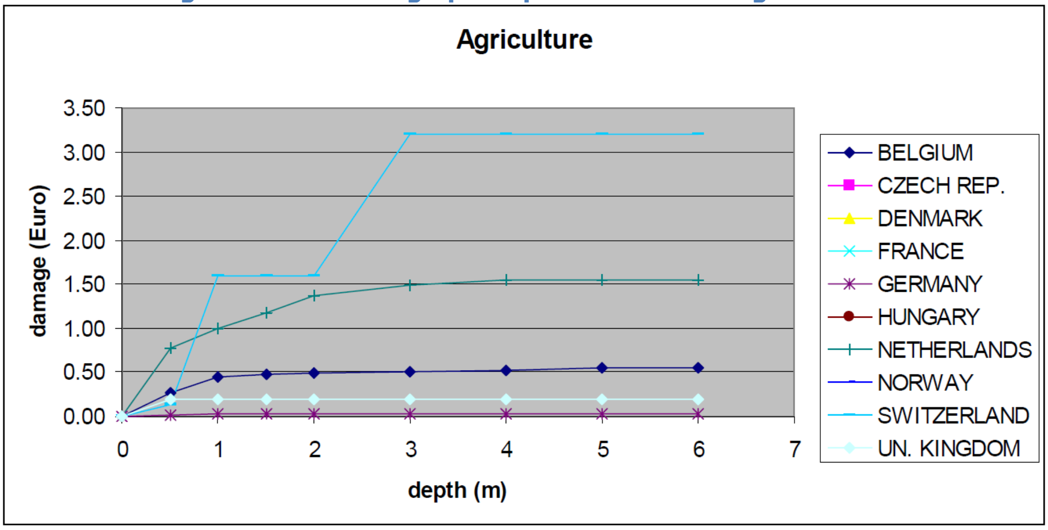
Figure F-9: Damage factor for infrastructure (roads).



Agriculture

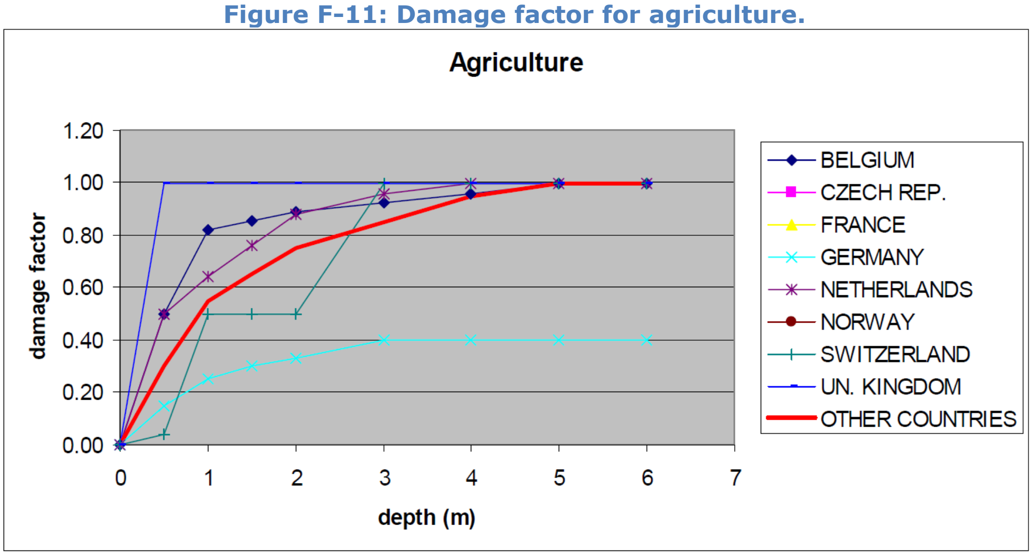
For agriculture large differences exist between the functions. Switzerland has by far the largest damage values, the Netherlands has an intermediate value and the rest lower values.

Figure F-10: Damage per square meter for agriculture.



The average maximum damage value for the category agriculture at 6m depth is 0.77 €/m^2.

Figure F-11: Damage factor for agriculture.



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