POLITECNICO DI MILANO

School of Civil, Environmental and Land Management Engineering

Master of Science in Environmental and Land Planning Engineering

THE FLOOD DAMAGE MODELS REPOSITORY

AN OPPORTUNITY TO BRIDGE KNOWLEDGE GAPS ON FLOOD DAMAGE ASSESSMENT TOOLS

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Abstract

Flood damage assessment is a key component of flood risk management, allowing for the definition and the evaluation of the effective risk mitigation strategies. The evaluation of flood damage is performed through flood damage models, which describe the relationship between risk parameters (hazard, exposure and vulnerability related) and the damage itself. Such models are characterized by different level of reliability, complexity and robustness and, nowadays, no model can be considered as a standard.

Given this framework, the main purpose of this thesis is the development of a Flood Damage Models Repository (FDM), aimed at supporting flood damage modelers and non-expert users in the choice of the best available models for a specific context and a specific problem at stake. In doing so, the FDM represents also an opportunity to bridge the existing knowledge gaps on flood damage assessment tools.

Each flood damage model contained in the FDM has been described by means of a conceptual structure, according to which the model is characterized by different attributes, supporting the users in the choice and implementation of the model. The conceptual structure of the models has been translated into a database that, for each model, returns a specification sheet neatly reproducing all the attributes of the conceptual model. The construction of the conceptual database came along with its informatic implementation in a specific software and later in a website, that is the effective tool the user will handle.

The version of the FDM presented in this thesis is in its alpha state. Future developments include the presentation of the Repository to the scientific community, which can contribute by enlarging and improving the already existing database.

Sintesi

La valutazione del danno alluvionale è un elemento chiave della gestione del rischio alluvionale, permettendo di definire e valutare efficaci strategie di mitigazione del rischio.
La valutazione del danno alluvionale viene eseguita attraverso modelli di danno, i quali descrivono la relazione tra i parametri del rischio (riferiti a pericolosità, esposizione e vulnerabilità) e il danno stesso. Questi modelli sono caratterizzati da diversi livelli di affidabilità, complessità e robustezza e, attualmente, nessun modello può essere considerato uno standard.
In questo contesto, l'obiettivo principale di questa tesi è lo sviluppo di un Flood Damage Models Repository (FDM), il quale mira a supportare i modellatori del danno alluvionale e gli utenti non esperti nella scelta del miglior modello disponibile per un contesto e un problema specifico. In tal modo, l'FDM rappresenta anche un'opportunità per colmare l'attuale carenza di conoscenza sugli strumenti di valutazione del danno alluvionale.
Ciascun modello di danno contenuto nell'FDM è stato descritto attraverso una struttura concettuale, secondo la quale il modello è caratterizzato da diversi attributi, a supporto dell'utente nella scelta e nell'implementazione del modello. La struttura concettuale dei modelli è stata tradotta in un database, il quale, per ciascun modello, restituisce una scheda di specifica che riproduce ordinatamente tutti gli attributi del modello concettuale.
La costruzione del database concettuale viene accostata alla sua implementazione informatica in un software specifico e, successivamente, in un sito web, che rappresenta lo strumento effettivo utilizzato dall'utente.
La versione dell'FDM presentata in questa tesi è la versione preliminare. I suoi sviluppi futuri prevedono la sua presentazione alla comunità scientifica, la quale potrò contribuire nell'ingrandire e migliorare la struttura del database già esistente.

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1. Introduction

1.1 Flood damage assessment

Flood damage assessment is gaining greater importance, since flood risk management has become a focal point for policies and companies. In particular, in the recent years, a *shift in thinking* occurred from hazard control to flood risk management. In fact, while in the past flood polices were usually concentrated on the reduction of the probability of occurrence and intensity of the inundations, more recently they focus the attention on the mitigation of risk, looking at its different components (hazard, exposure and vulnerability). To assess the risk and to know how to handle it, the evaluation of the damage is fundamental, since risk is defined as the expected damage that may occur in a certain period of time due to an inundation phenomenon.

Flood damages can be classified into direct and indirect. The first are those which occurs because of the physical contact of the flood water with people, objects or private properties, the second are those which does not depend physically on the flood, but on the direct damages themselves (e.g. production losses to companies that are suppliers of companies that suffer direct damages) (Merz et al., 2010).

A further distinction among flood damages can be made, highlighting the differences between tangible and intangible damages. Tangible damages can be expressed in monetary values (i.e. damage to private buildings), whereas intangible damages cannot be expressed in monetary values (Merz et al., 2010). The evaluation of which are the intangible damages depends on each country regulations. In Italy an example of intangible damage are the losses of human lives.

In the development of this report, the attention is focused purely on direct tangible damages.

The operative tools used for flood damage assessment are flood damage models. They describe the relationship between hazard intensity parameters, exposure parameters, vulnerability parameters and the damage itself.

In literature, there are several flood damage models and all of them are characterized by different levels of complexity, robustness and reliability. Currently, no model can be considered as a standard. They are, in general, context specific and it is difficult to distinguish when it is more suitable a model rather than another one.

The choice of the more suitable model to be implemented can be challenging especially for non-expert users (i.e. technicians, insurance companies, etc.) that don't have a critical knowledge of models limits and usability. In fact, damage models are developed to be applied at a specific scale, for a specific type of flood and focusing on a specific exposed item. However, not always the development and evaluation of flood damage models go together with detailed information about when and where a certain model should be applied, or even the model does not have an explicit calibration and validation, that would document and demonstrate how the model performs and how accurately.

This lack of exhaustive information and knowledge about the model usability may lead to the application of models to regions or flood events that are very different from the ones for which the model has been calibrated.

In such a context, the implementation of a model in a framework different from the calibration one (i.e. different scale of application, different type of floods and even different exposed items) may imply significant errors in the damage estimation.

1.2 Flood Damage Models Repository

Starting from the overview made on the current state of art of flood damage assessment tools, the main objective of the thesis is the development of a Flood Damage Models Repository (FDM), aimed at supporting flood damage modelers in the choice of the best available model for a specific context and a specific problem. In doing so, the FDM represents also an opportunity to increase knowledge gaps on flood damage assessment tools by providing for each available model fundamental key information in order not to lead to an improper use of the model and then significant errors in the flood damage assessment.

The version of the FDM proposed here is a preliminary version, containing 42 different models. Indeed, the main objective was not to create a complete database, but rather to design it and to verify the suitability of the FDM to include all the possible typologies of models, in terms of scale of analysis, type of flood, exposed items, level of uncertainty, etc. In a second step, the FDM will be further tested and completed by asking flood damage modelers and researchers to input other models. This procedure could lead to

additional adjustments or changes of the Flood Damage Models Repository itself, towards a more definitive version of it.
It must be stressed that once completed, the FDM will be more than a database of existing models in literature, but rather an operative tool in the support of flood damage modelers for more reliable damage analysis. In fact, each FDM field has been designed in order to support and help users in the implementation of the model they choose. The FDM is a database which highlights critical issues and strengths of each model, in order to be applied in a specific context. The construction of the database comes along with the implementation of it in a website, that is the effective tool the user will operate. It is provided by a pull-down menu, in which the user can select different filters for browsing the FDM. Starting from the context of application and the type of model that the user needs, the choice of the filters returns in output the model or models that better fit the requirements.

1.3 Methodological approach

At first, the Flood Damage Models Repository has been conceived to have a certain preliminary conceptual structure. In order to evaluate if this conceptual structure was appropriate to understand all the specifications of the models and so if it leads to their correct application, the first step was to try to apply some models and evaluate the associated damage. The evaluation of the damage was carried out using flood data of the city of Lodi, which was affected by a severe event in 2002. The effective implementation of the models has allowed to understand if the conceptual structure of each model could stand and, where appropriate, to modify it. The application of the models was also useful to understand the information of each model, therefore helping in the filling of the fields of the conceptual structure of the FDM and clarifying any doubts. It was helpful to figure out the completeness of the data characterizing the model. In fact, the FDM is aimed to point out the possible difficulties that the user may experience in the application of the model (e.g. the economic damage value is referred to the entire building or only to a single floor?) and to try to elucidate them better.
During this first work step, the preliminary conceptual structure of the FDM turned out to be not sufficiently appropriate for the purpose of the FDM itself. There was the need to review some fields of the structure of the FDM, in order to clarify the difficulties that

the user may experience and to add further fields (i.e. the fields of model output and transferability).

The reliability and the strength of the FDM were further tested not only with the application of the models, but also with models developed for different type of sectors or exposed items, for the purpose of understanding if the structure of the Repository was suitable even with models that differs a lot among each other.

Once established that the version of the FDM was appropriate, the conceptual structure of it was translated into a digital database, that the user can handle with its operative tool: The Flood Damage Models Repository website.

2. Structure of the Flood Damage Models Repository

2.1 Conceptual model

In order to describe the main features of each flood damage model, a conceptual model of them has been developed. See Figure 2.1.

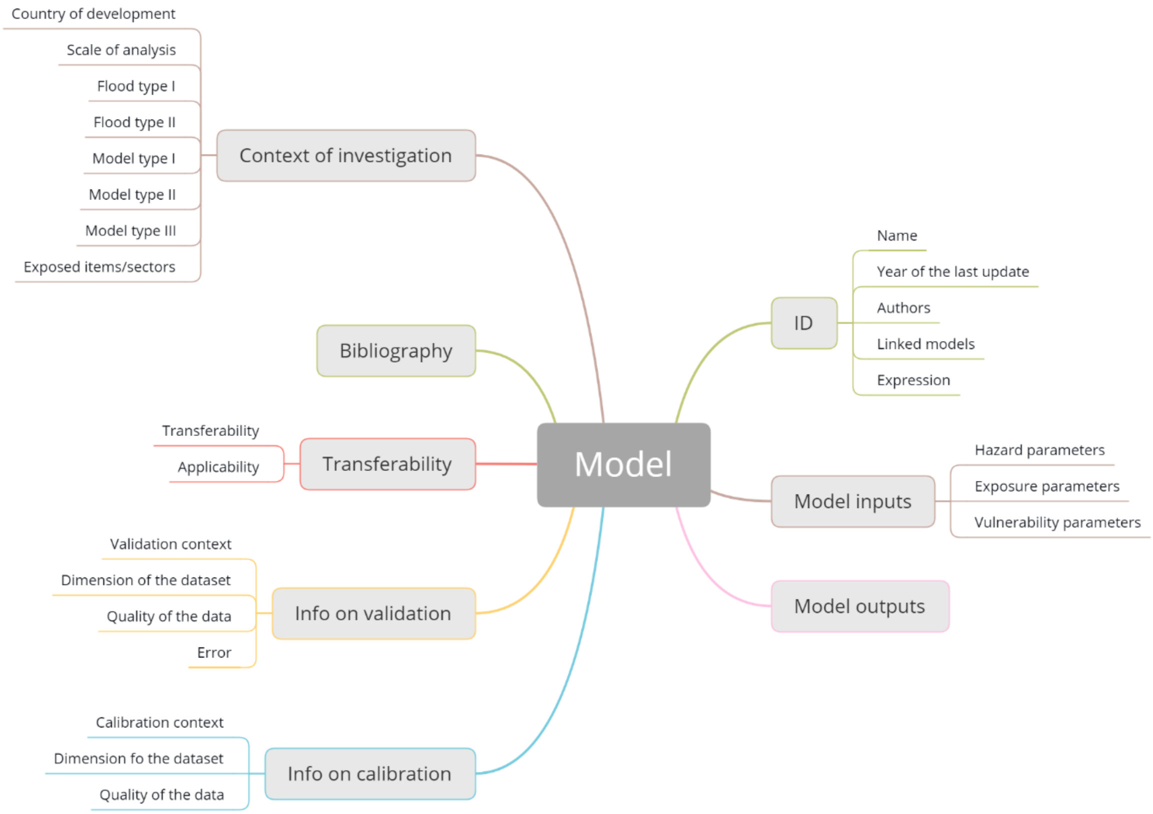

Figure 2.1 - Conceptual model of the structure of each flood damage models. It represents all the features that characterized each flood damage model.

According to the conceptual model, each flood damage model is characterized by the following attributes.

2.1.1 Context of investigation

Country of development

Geographical region in which the model has been derived and calibrated.

Scale of analysis

- *Microscale*

  Local, object-based scale. The damage assessment is based on the single item at risk.
- *Mesoscale*

  The damage assessment is based on spatial aggregations (i.e. land use areas, administrative units, etc), typically with a size of 1 km^2 to 1 ha.
- *Macroscale*

  The damage assessment is based on large-scale spatial units (i.e. countries).

Flood type I

- *Riverine flood*

  Caused by overtopping of riverbanks.
- *Pluvial flood*

  Caused by rainfall.
- *Coastal flood*

  Caused by the incursion of marine waters.

Flood type II

- *Low velocity*

  Typical of big river basins and plain floods with low velocities and high static loads.
- *High velocity*

  Flash floods, typical of dam breaking or small river basins with high velocities, high sediment transport and high dynamic loads.

Model type I

- *Relative*

  Model which expresses the expected loss as a ratio of the total asset value of the element(s) at risk.

- *Absolute*

  Model which estimates the loss directly in monetary or quantitative units.

Model type II

- *Empirical*

  Model calibrated with observed flood damage data collected after real flood events.

- *Synthetic*

  Model based on the investigation of damage mechanisms and hypothetical damage estimates by experts through what-if-analysis (e.g. what is the potential loss if a specific building type is flooded with a flood depth of 1 meter?). This approach is often used when empirical data are not available or of uncertain quality (Gerl et al., 2016).

- *Mixed*

  Model derived from the combination of the empirical and synthetic approach.

Model type III

- *Deterministic*

  Model which supplies damage estimates in a deterministic way.

- *Probabilistic*

  Model which provides the probability distribution of flood loss estimates due to the inclusion of stochastic elements.

Exposed items/sectors

Describes the sector for which the flood damage function is developed.

2.1.2 ID

The ID section represents the distinctiveness unit of each model implemented in the FDM. A model is characterized by its name (often an acronym), its authors and its year of publication. Each model can have linked models, which represent the upgrading version of the model itself or even the application of the same model to different exposed items or sector or at different spatial scales.

The fundamental field that distinguishes the model is its expression, i.e. graph, formula, software, that represents the relationship between the explicative variables (hazard, vulnerability, exposure) and the flood damage.

2.1.3 Model inputs

These specific fields contain the information and the parameters used by the model to describe the explanatory variables. Together with the data information, these fields must be filled also with metadata, namely the data description.

- *Hazard parameters*

  They describe the intensity of the flood event (i.e. flood depths, flood velocities, flood durations, etc.).

- *Exposure parameters*

  They describe the physical quantity of what can be damaged due to an inundation event (i.e. number of buildings, area of the buildings, volume of the buildings, etc.). Very often an exposure parameter can be purely an economic quantification of the exposed asset(s), i.e. the maximum damage.

- *Vulnerability parameters*

  They describe the predisposition (or susceptibility) of the items exposed to risk to be damaged during a flood event. For what concerns for example buildings, the vulnerability parameters can be the materials of which buildings are made, their year of construction or the presence or not of the basement. Instead, on agricultural crops, the vulnerability parameters can be represented for instance by the type of crop.

2.1.4 Model outputs

This field explains what the model output is, e.g. damage to the structure, or damage to the structure plus contents, inventory, etc. In this section, where possible, the elements that contribute to the evaluation of the damage are also clarified (e.g. if the model output refers to the entire volume of the building or to the footprint area).

2.1.5 Info on calibration

These fields contain information about the calibration of the model.

- *Calibration context*
  The context in which the model at issue has been calibrated. In this section it is important to point out the characteristics of the flood event (i.e. flood type, flood depths values, flood velocities values, presence or not of solid transport or pollutants, etc.), together with information about the geographical area (i.e. morphological information, structural typology of buildings, types of crops, etc). This section helps the user to understand in which context the model is more reliable.

- *Dimension of the dataset*
  The amount of data used to calibrate the model.

- *Quality of the data*
  Description of the data used for the model calibration, i.e. if the characteristics of the flood event and the damage data are observed or modelled, to appreciate the reliability of the calibration process.

2.1.6 Info on validation

These fields contain information about the validation of the model.

- *Validation context*
  The context in which the model at issue has been validated. Highlight if the validation is carried out with a specific technique. In this section it is important to point out the characteristics of the flood event (i.e. flood type, flood depths values, flood velocities values, presence or not of solid transport or pollutants, etc.), together with information about the geographical area (i.e. morphological information, structural typology of buildings, types of crops, etc).

- *Dimension of the dataset*
  The amount of data used to validate the model.

- *Quality of the data*
  Description of the data used for the model calibration, i.e. if the characteristics of the flood event and the damage data are observed or modelled.

- *Error*
  The outcoming error derived from the validation of the model (i.e. mean absolute error, root mean square error, bias, etc.) that verifies if the model itself is consistent or not.

2.1.7 Transferability

- *Transferability*
  This field contains information on how easy is for a researcher to transfer the model in another context, e.g. by considering the expression of the model, available information on its derivation/calibration, etc.

- *Applicability*
  This field discuss which are the main issues raised in the application of the model, especially from the point of view of a non-expert user.

2.1.8 Bibliography

Scientific paper or book in which the model development is described.

2.2 Model specification sheet

The conceptual model has been translated into a database. The consultation of each model in this database gives in output a sort of specification sheet, reproducing all the attributes of the conceptual model.

CONTEXT OF INVESTIGATION

- Country of development: ……………………………………………………………..
- Scale of analysis: …………………………………………………………………..
- Flood Type I: ……………………………………………………………………....
- Flood Type II: ……………………………………………………………………..
- Model Type I: ……………………………………………………………………..
- Model Type II: ……………………………………………………………………
- Model Type III: …………………………………………………………………....
- Exposed items/sectors: ……………………………………………………………….

ID

- Name: ……………………………………………………………………………….
- Year of the last update: ……………………………………………………………....
- Authors: ……………………………………………………………………………
- Linked models: ……………………………………………………………………......
- Expression: ……………………………………………………………………………..

Model inputs

- Hazard parameters: ……………………………………………………………………
- Exposure parameters: …………………………………………………………………
- Vulnerability parameters: ……………………………………………………………

Model outputs

……………………………………………………………………………………………

Info on calibration

- Calibration context: …………………………………………………………………
- Dimension of the dataset: ……………………………………………………………....
- Quality of the data: …………………………………………………………………..

Info on validation:

- Validation context: ……………………………………………………………………
- Dimension of the dataset: ……………………………………………………………...
- Quality of the data: …………………………………………………………………
- Error: ………………………………………………………………………………...

Transferability

- Transferability: ………………………………………………………………………
- Applicability: ………………………………………………………………………

Bibliography

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Figure 2.2 - Model specification sheet. It represents the actual implementation of the conceptual model in the database structure.

3. Digital implementation of the Flood Damage Models Repository

3.1 Construction of the database

The conceptual framework of the FDM has been first translated in a database. A database indicates a set of structured or homogeneous information for content and format, stored in an electronic computer and queryable by terminal using expected access keys. It is in fact the digital format, therefore more efficient, equivalent to a data store or file, with the advantage of multiple features and performance implemented automatically on PC basing on the user input.

The program used for the database implementation is *DB Browser for SQLite*[1], developed originally by Mauricio Piacentini from Tabuleiro Producoes. It is a high quality, visual, open source tool to create, design, and edit database files compatible with SQLite, a specific software library written in C language.

This specific software has been chosen since it uses a familiar spreadsheet-like interface and does not required the knowledge of complicated SQL commands.

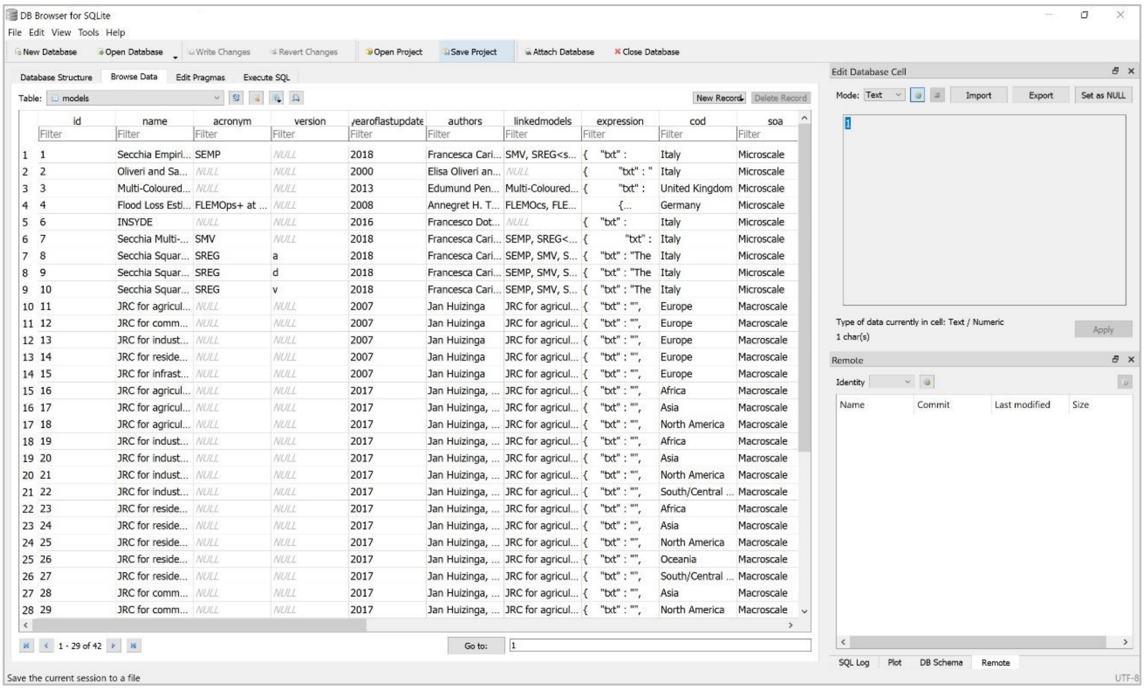

Figure 3.1 - Example of the informatic database structure for the Flood Damage Models Repository.

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[1] Credits to *www.sqlitebrowser.org*

The database structure has been designed following the Entity-Relationship (ER) model. In this specific case the flood damage model is the only Entity, characterized by its own attributes, which correspond to the model features analysed in the previous paragraph. The models contained in the FDM have no relationship with each other (at least not in this version of the Repository) since the sole purpose of the database is to store flood damage models with its attributes.
Every model is identified with a unique primary key (automatically generated and given by the database whenever a new model is stored), following the ER model requirements: the ID attribute.
Every model is disassembled in the structure designed for the FDM. Each row shown by the program corresponds to a single model, while each column represents an attribute of the model which represent the model features explained in the specification sheet (i.e. model inputs, model outputs, info on calibration and validation, etc.).
As previously anticipated, the database can be queryable by inputting specific key words. In the database implementation, the attributes included in the "context of investigation" section of the conceptual models correspond to the filters that the user will make use of in order to browse the FDM. In fact, each field of this section turns into a specific filter that the user can select depending on his/her needs. Each filter is needed to structure the SQL query that the database needs to receive in order to return every object (the model) that has its attributes matching with the selected filters.
The database will most likely return multiple models, especially when few filters are selected and there are a lot of models with similar context of investigation, so that the user can refer to the specification sheet of each model returned to better understand which one suits best for his/her case study.

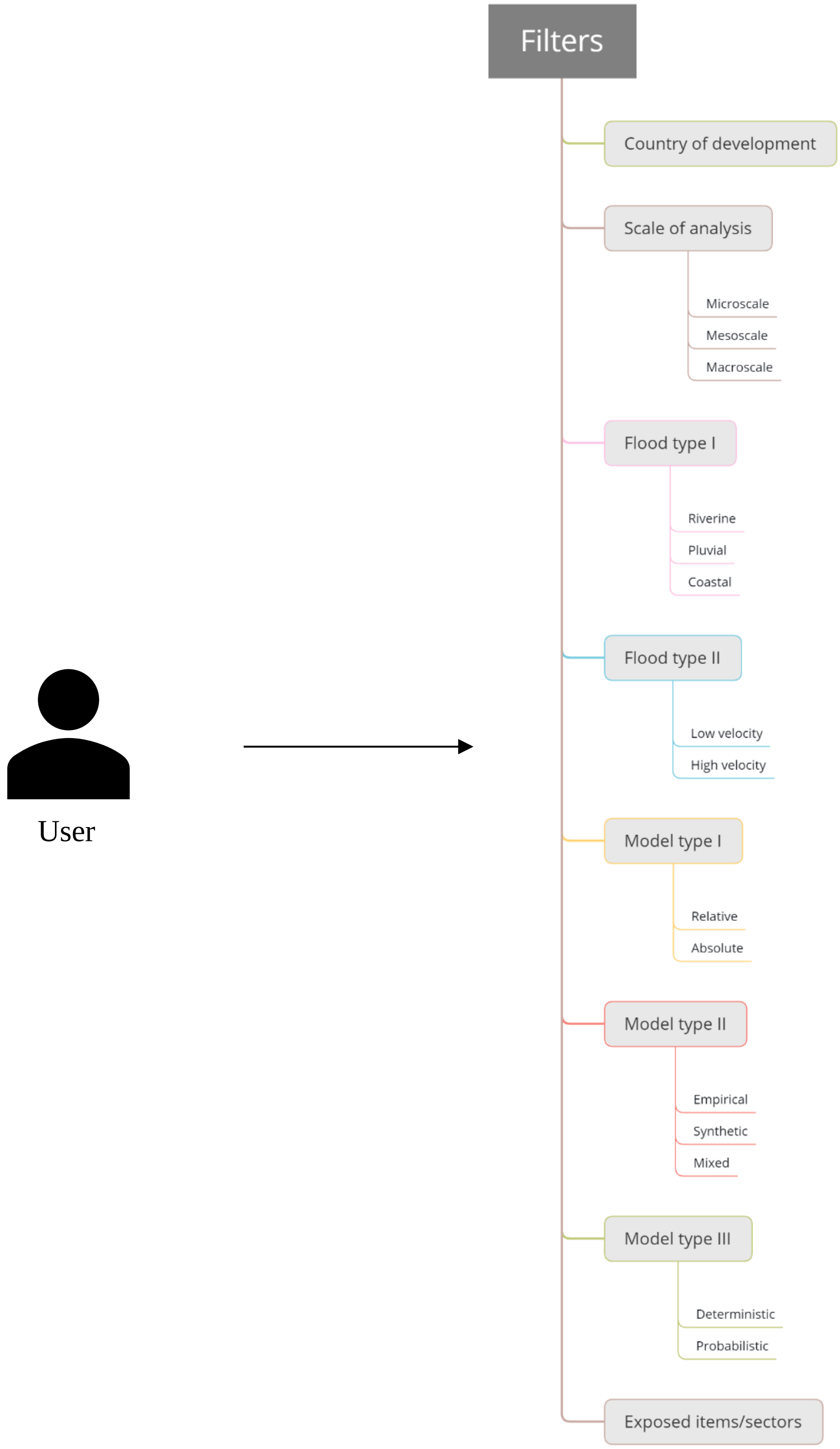

Figure 3.2 - Conceptual structure of the filters for browsing the FDM

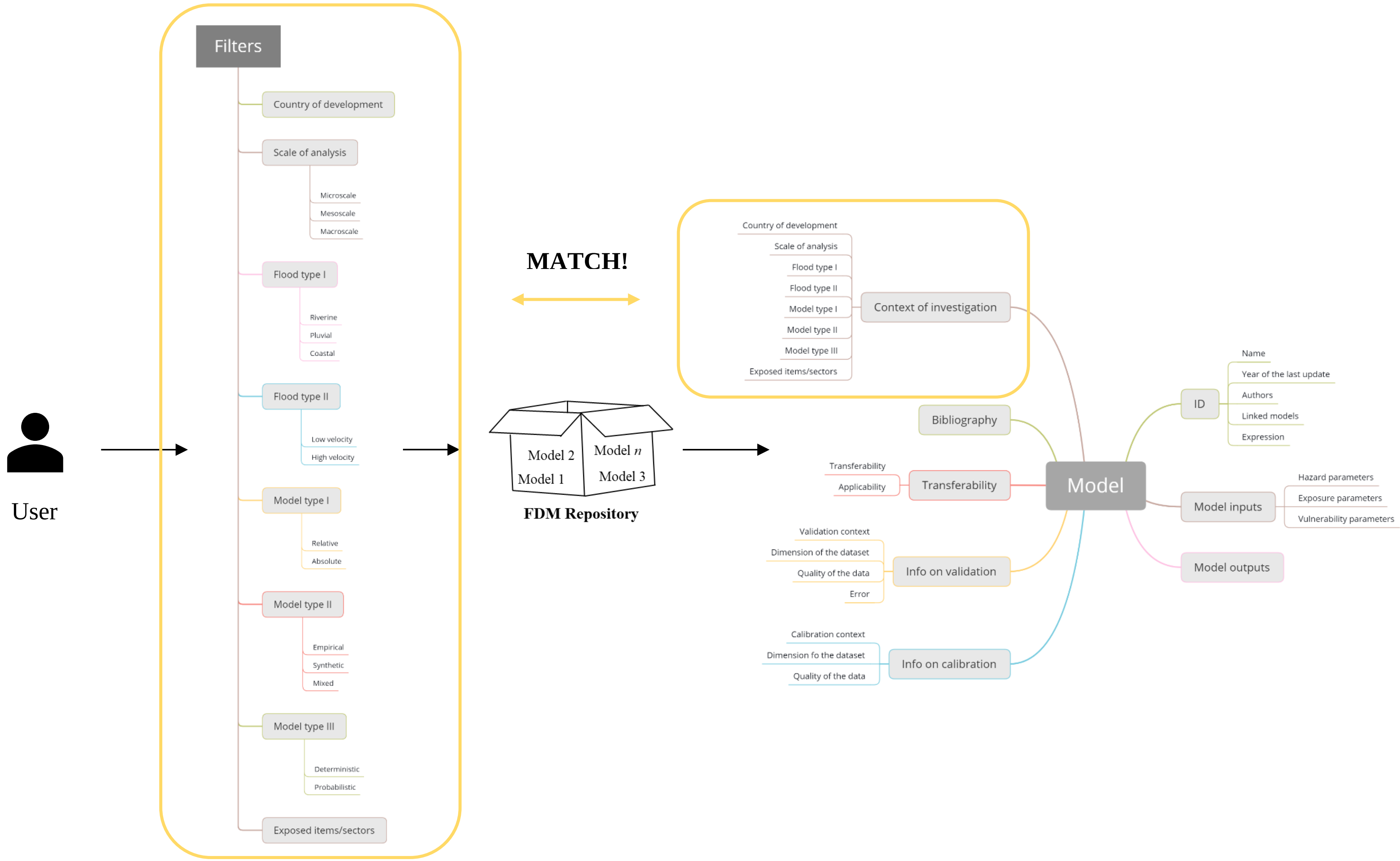

Figure 3.3 - Performance of the FDM. The user can select different filters for browsing the FDM. Starting from the context of application and the type of the model that the user needs, the choice of the filters will return the model or models that best fit the demand.

3.2 Implementation of the website

The digital construction of the FDM database is associated with the implementation of it in a website, that is the effective operative tool the user will handle.
The FDM website is written with the software *Visual Studio Code*. This is an open source and free software which serves as a source code editor working with several computer languages: HTML (HyperText Markup Language), CSS (Cascading Style Sheets) and JavaScript. The website is composed by various code files, neatly located in a specific folder. In the following paragraphs, each website page is described.

3.2.1 Landing page

The landing page is the web page that visitors reach after clicking the FDM specific URL (Uniform Resource Locator). The web page is structured in order to focus the attention of the visitor on the key features of the FDM and immediately understand what the FDM can do and how it operates. The first section of the landing page is composed by three flood inundation photo that slide, on which are imprinted some keyword phrases that promptly give the idea of the Flood Damage Models Repository purpose.

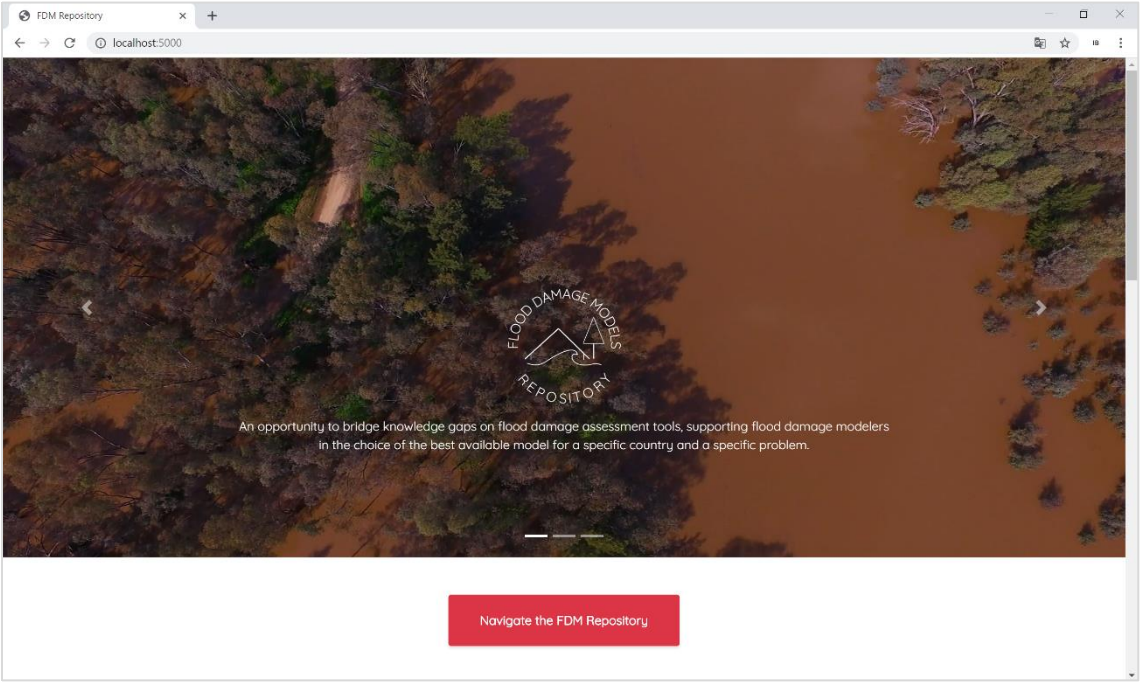

Figure 3.4 - First section of the landing page: example of a sliding photo

The second section of the landing page is composed by an animated bubble chart. The double rounded edge bubbles represent the countries for which the available flood damage models are developed. Each of these bubbles is linked to smaller bubbles representing all the available models for that specific country.

This bubble chart is useful to immediately understand how many flood damage models per country are available.

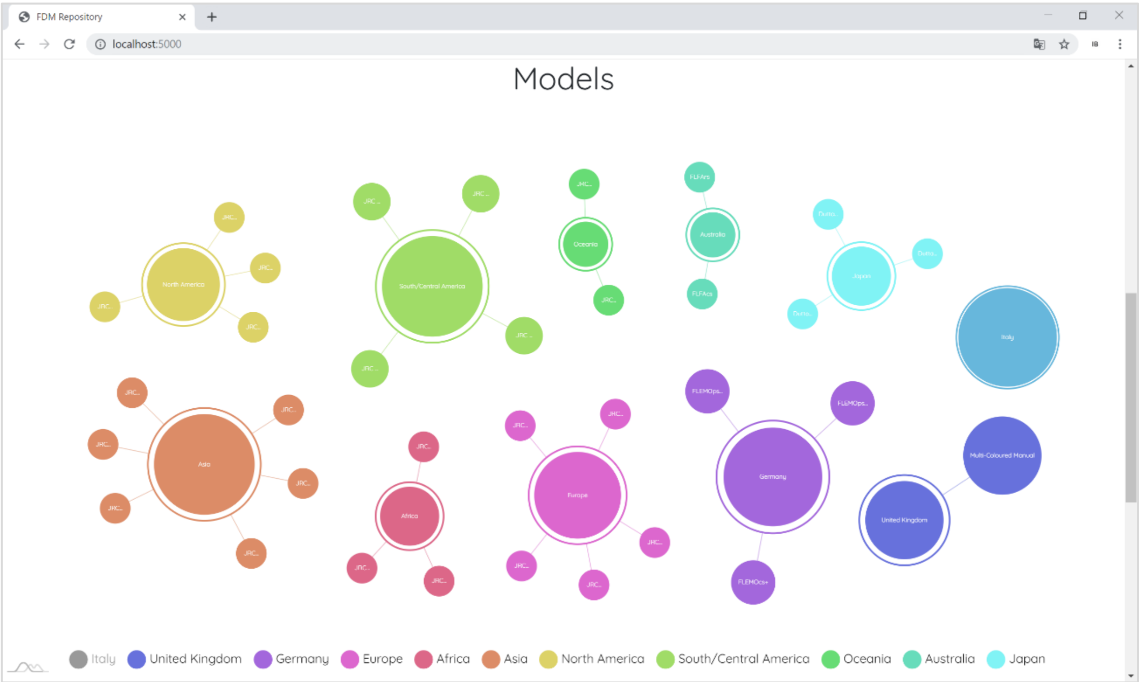

Figure 3.5 – Second section of the landing page: the bubble chart

The third section of the landing page is the *Get Involved* section, in which two separate boxes are presented. The first box allows the user to contact the FDM leaders, for any doubt or clarification, and also to contribute to the development of the FDM by submitting its own model. The second box on the right includes an operative counter, capable of counting in real time which are the uploaded models in the FDM, and which are the not uploaded models yet. The counter updates its values every time a model is entered or removed. The *Not uploaded* button opens a web page in which are listed known flood damage models, not contained in the database yet.

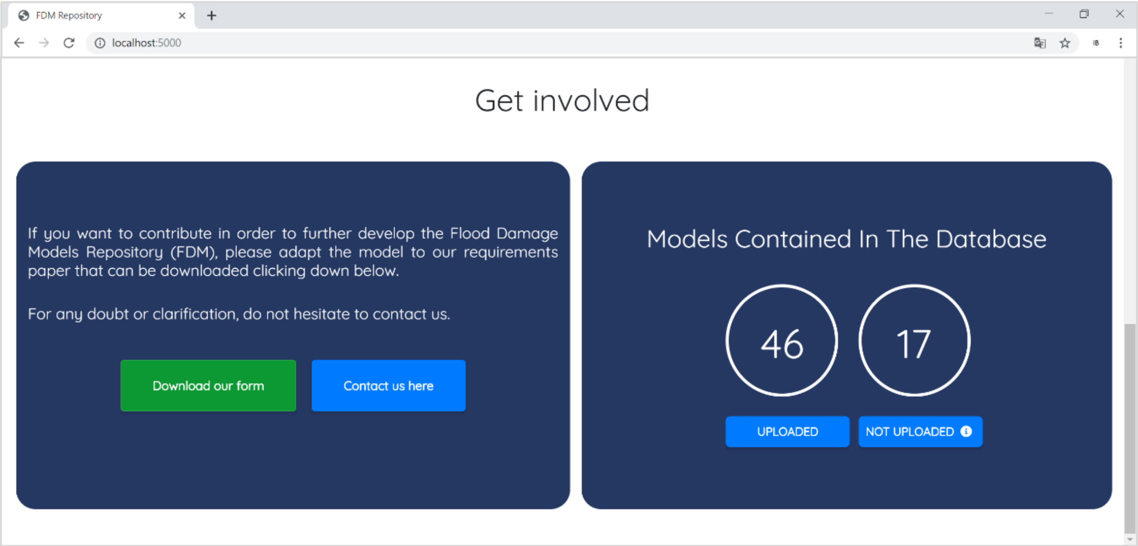

Figure 3.6 - Third section of the landing page: the Get Involved section.

3.2.2 Main page

The main page of the FDM website is reached clicking on the *Navigate the FDM Repository* button on the landing page and it shows up as follows:

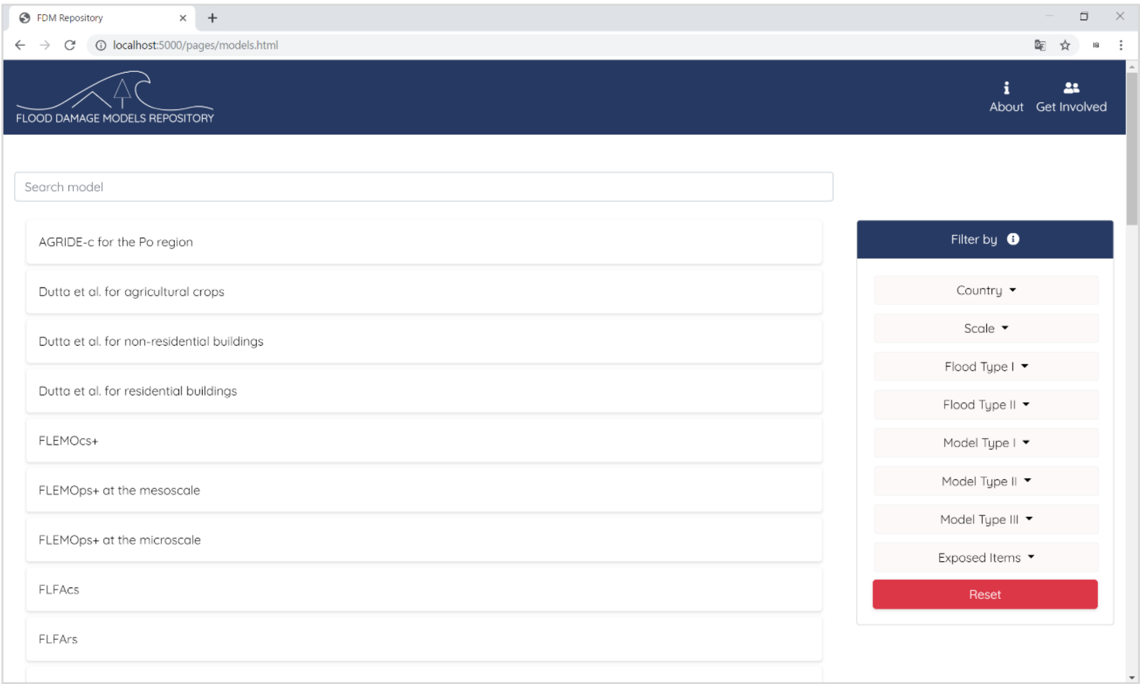

Figure 3.7 - First sight of the main page of the FDM

The web page is composed by a header, which is the initial section of the page (the opposite of the footer) and placed over the central body. It is the region of a page/website, that first will be viewed by the user, and generally contains the distinctive elements of the site, such as the logo and the navigation menu.

Figure 3.8 - Initial section of the page: the header

The navigation menu is composed by two different elements. The first one is the *About* section, in which the main objectives of the FDM are explained, in a more complete way. The second one is the *Get involved* section. It plays the same role of the *Get involved* section in the landing page.

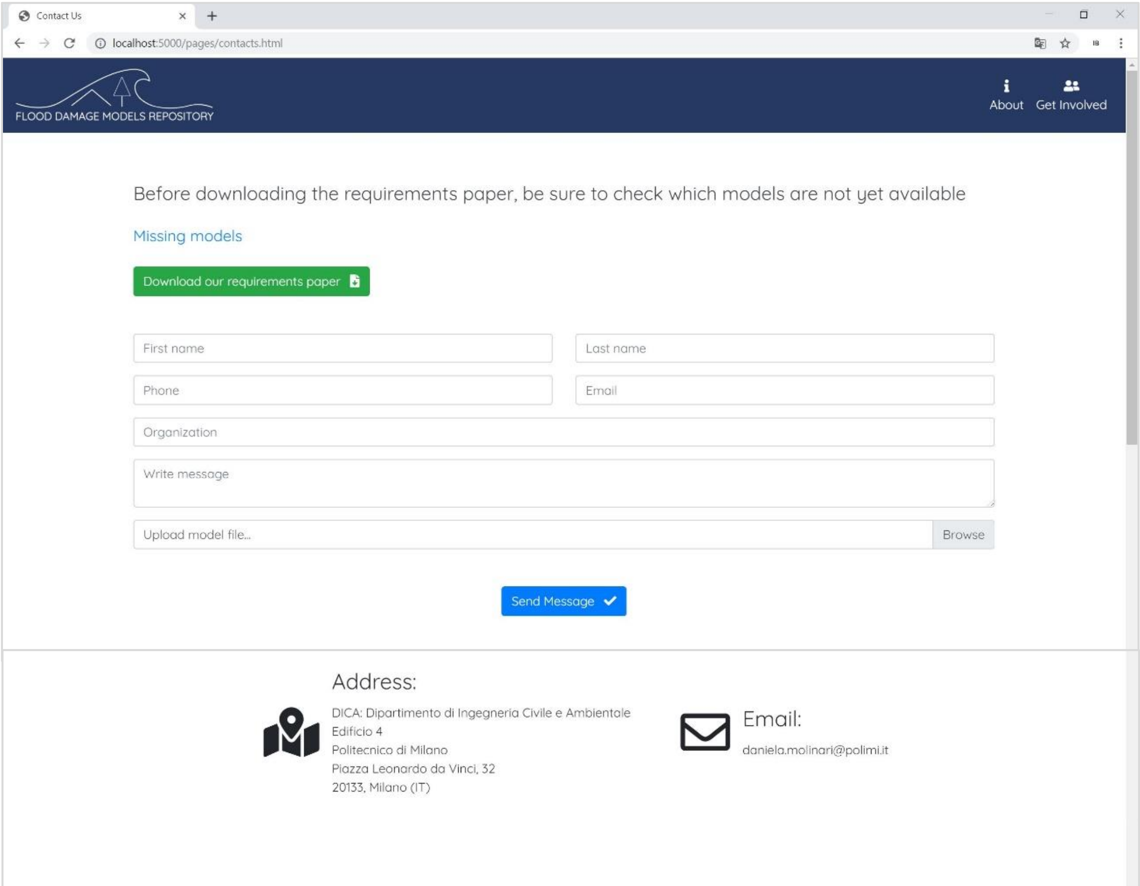

Figure 3.9 - Get Involved section in details

In this section, the user can download and re-upload the requirements paper, and, at the same time, give some personal information (i.e. for which organization he or she works for). The requirements paper shows up as a zip file, in which the user finds a fillable form, equal to the model specification sheet reported in Figure 2.2, together with the instructions for its compilation.

The web page section placed under the central body is the footer. Typically, the footer summarizes the most important information, such as the organization which offers the FDM service (e.g. Politecnico di Milano), together with the links for the *FAQ* (Frequently Asked Questions), and the *Terms of Service and Copyright* and *Privacy Policy*, which are documents that inform the users of the web site about the processing of their personal data. It is important to point out that these latter links are not operating yet. Usually, the footer is equal and common in all the pages that compose the site.

Figure 3.10 - Final section of each FDM website page: the footer

The central body of the main page is composed by the list of all the available flood damage models. Each model is collected in a card, which is clickable and links to the model specification page (i.e. the digital version of the model specification sheet). The user can search a specific model with the help of a search bar placed on the top of the models list, by entering its name.

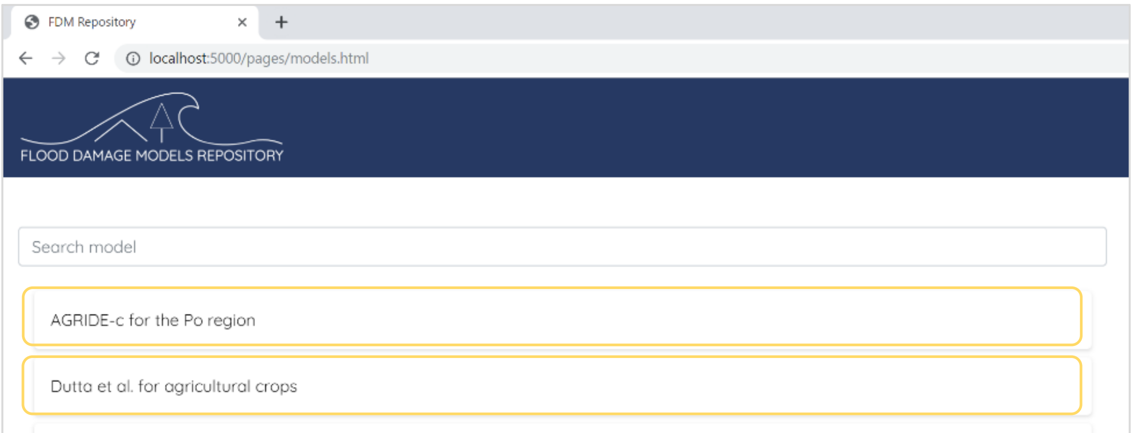

Figure 3.11 - In yellow: example of the card in which each model is collected.

Next to the list of the models, there is a sidebar which is the effective tool the user will operate. It contains the filters for browsing the FDM. The user selects the features of the model he needs, and the web site filters the model(s) which better fits the requirements. The sidebar is accompanied by a legend, in which the meaning of each filter is explained, in order, for the user, to better understand the meaning of each filtering attribute.

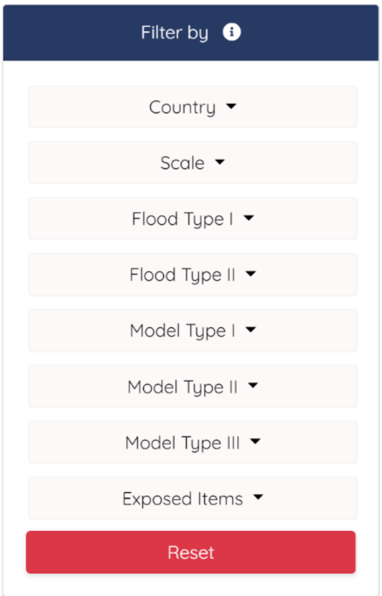

Figure 3.12 - Filters for browsing the FDM.

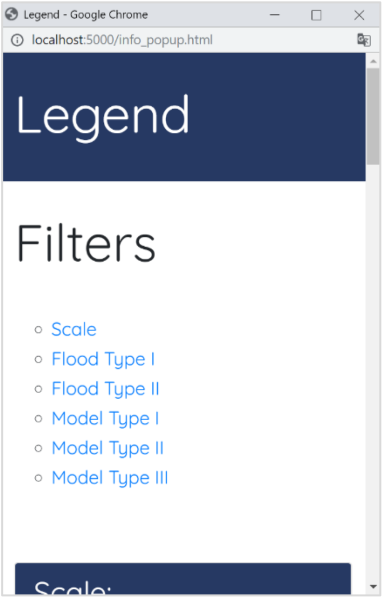

Figure 3.13 - Legend of the filters for browsing the FDM

3.2.3 Model specification page

The model specification page is in fact the digital implementation of the model specification sheet explained in the previous paragraphs.

It is composed by different cards in which each model attributes its collected.

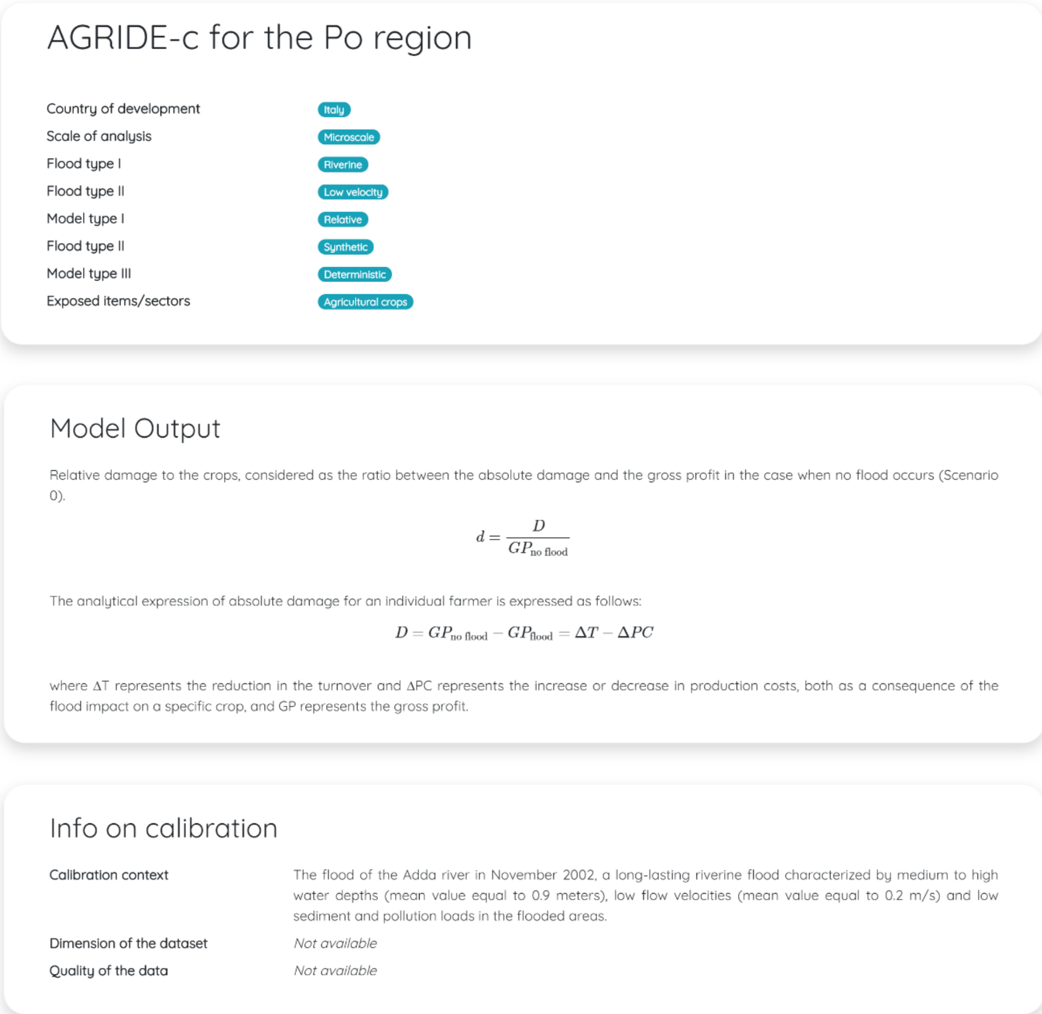

Figure 3.14 - Example of cards with which the model specification page of AGRIDE-c is composed. They are the digital implementation of the characteristics of the conceptual model explained in Chapter 2.

In addition to the model specification sheet, the model specification page presents a section of comparison in which the model in exam is compared with the other available models in the Repository, for the same sector, the same scale of analysis and the same model type (i.e. relative or absolute). Since the main goal of the development of the Flood Damage Models Repository is to create an operative tool that might help flood damage modelers and researchers, it seemed suitable to create a specific section inside the FDM website in which every model performance is compared to the others.
With the help of these simple graphs, the user can evaluate how a certain model evaluates the damage, in comparison with several other models that can be considered similar to it. The more similar models are available, the more effective the comparison turns out to be. In this first edition of the FDM, the more ample category is the one representing absolute or relative flood damage models at the microscale level, developed for the residential context. For this reason, the comparison has been carried out, where possible, evaluating the damage considering both a detached house and a multifamily house of 100 m^2. This distinction has the goal to make the comparison even more exhaustive.
Since the models developed for the other exposed items or sectors (agricultural crops, commercial sector, etc.) are not so many, it is impossible to produce a significant graph of comparison. The only useful parameter to be considered in the evaluation of the damage is the value of the area, set as 100 m^2 for each sector (agricultural crops, commercial sector, industrial sector, transport and infrastructures). As similar models will be inserted in the database, it will be easier to make such a comparison.

For sake of completeness, an example of the model comparison graphs is reported down below:

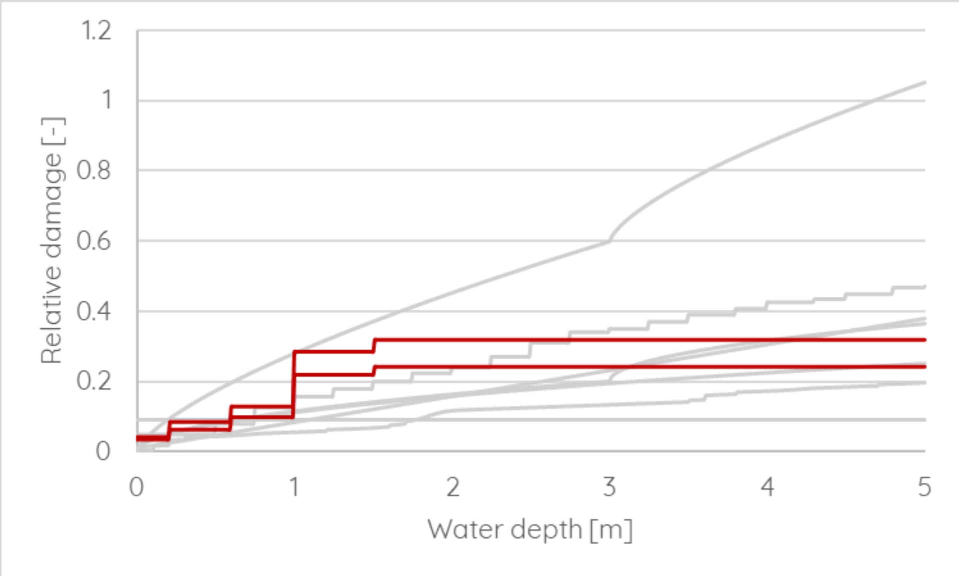

Figure 3.15 - **FLEMOps+** performance considering a RC **detached house** of 100 m^2

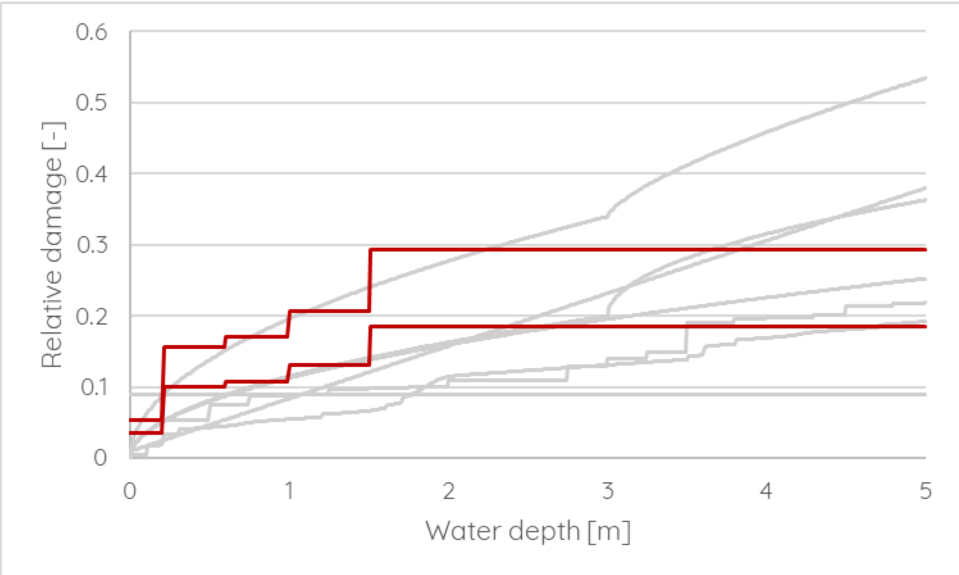

Figure 3.16 - **FLEMOps+** performance considering a RC **multifamily house** of 100 m^2

3.3 Licenses

The FDM Repository will be the result of the work of many modelers and researchers, permanently online and available for all the users. Because of that, it requires a license, representing the contract by which the owner of the rights of the creation defines the legal regime of movement and limits in the use and disposal of the opera. When the opera is a creation work, as in the case of the FDM, the distribution of the copyrighted work is ruled by the Creative Common (CC) license.

A CC license allows the author to give users the right to share, use or even build on the work he/she has created.

There are several typed of Creative Common license, that all grant the so-called *baseline rights:*

Icon	Right	Description
	Attribution (BY)	Licensees may copy, distribute, display and perform the work and make derivative works and remixes based on it only if they give the author or licensor the credits (attribution) in the manner specified by these.
	Share-alike (SA)	Licensees may distribute derivative works only under a license identical ("not more restrictive") to the license that governs the original work. Without share-alike, derivative works might be sublicensed with compatible but more restrictive license clauses, e.g. CC BY to CC BY-NC.
	Non-commercial (NC)	Licensees may copy, distribute, display, and perform the work and make derivative works and remixes based on it only for non-commercial purposes.
	No Derivative Works (ND)	Licensees may copy, distribute, display and perform only verbatim copies of the work, not derivative works and remixes based on it.

Table 3.1 - Details of the baseline rights for CC licenses.

From https://en.wikipedia.org/wiki/Creative_Commons_license#Types_of_licenses

Mixing these conditions leads to several possible combination of licenses.

Since the FDM wants to be an operative tool, the idea is to give it a CC BY license, allowing the user to:

- Share: the user can copy, distribute, communicate, expose, represent and execute the material, by any means and format.
- Modify: the user can remix or transform the material for any purpose, even commercial.

Figure 3.17 - Icon representative of the CC by license.

With this type of license, the disclosure of the FDM will reach as many people as possible, achieving in this way the goal of the FDM, i.e. filling those existing knowledge gaps on flood damage modelling.

3.3.1 Citation of the sources

The FDM contains and will contain several models which are protected by the terms and condition of the scientific journal in which they were published. A further development of the FDM, will be to verify the terms and conditions of each scientific journal in which the damage models are published, to see if it is possible to access to the material, to publish it in the FDM and even possibly to modify it. Where the terms and conditions are not sufficiently clear, it is necessary to contact the editorial staff of the scientific journal itself and ask if and how it is possible to access the needed material.

4. Filling of the Flood Damage Models Repository

The development of this master thesis has a focus on the implementation in the database of 46 different models, which cover different exposed items or sectors, in order to assess the suitability of the database structure to several contexts.

The exposed items/sectors investigated are the following:

1. Residential buildings;
2. Non-residential buildings;
3. Agricultural crops;
4. Commercial sector;
5. Industrial sector;
6. Infrastructures (roads);
7. Transports.

Some of the analysed models can be applied in more than one sector.

For each of the 46 models, a specification sheet has been settled and uploaded in the database. The specification sheet of each model is reported in the paragraph below.

4.1 Residential buildings

4.1.1 DUTTA et al. for residential buildings

Filters for browsing the Repository

- Country of development: Japan
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Dutta et al. for residential buildings
- Year of the last update: 2003
- Authors: Dushmanta Dutta, Srikantha Herath and Katumi Musiake
- Linked models: Dutta et al. for non-residential buildings, Dutta et al. for agricultural crops.
- Expression:

  Stage-damage functions which relate flood damage to flood inundation parameters. Three different functions are modelled, two for the buildings structure and one for the buildings content.

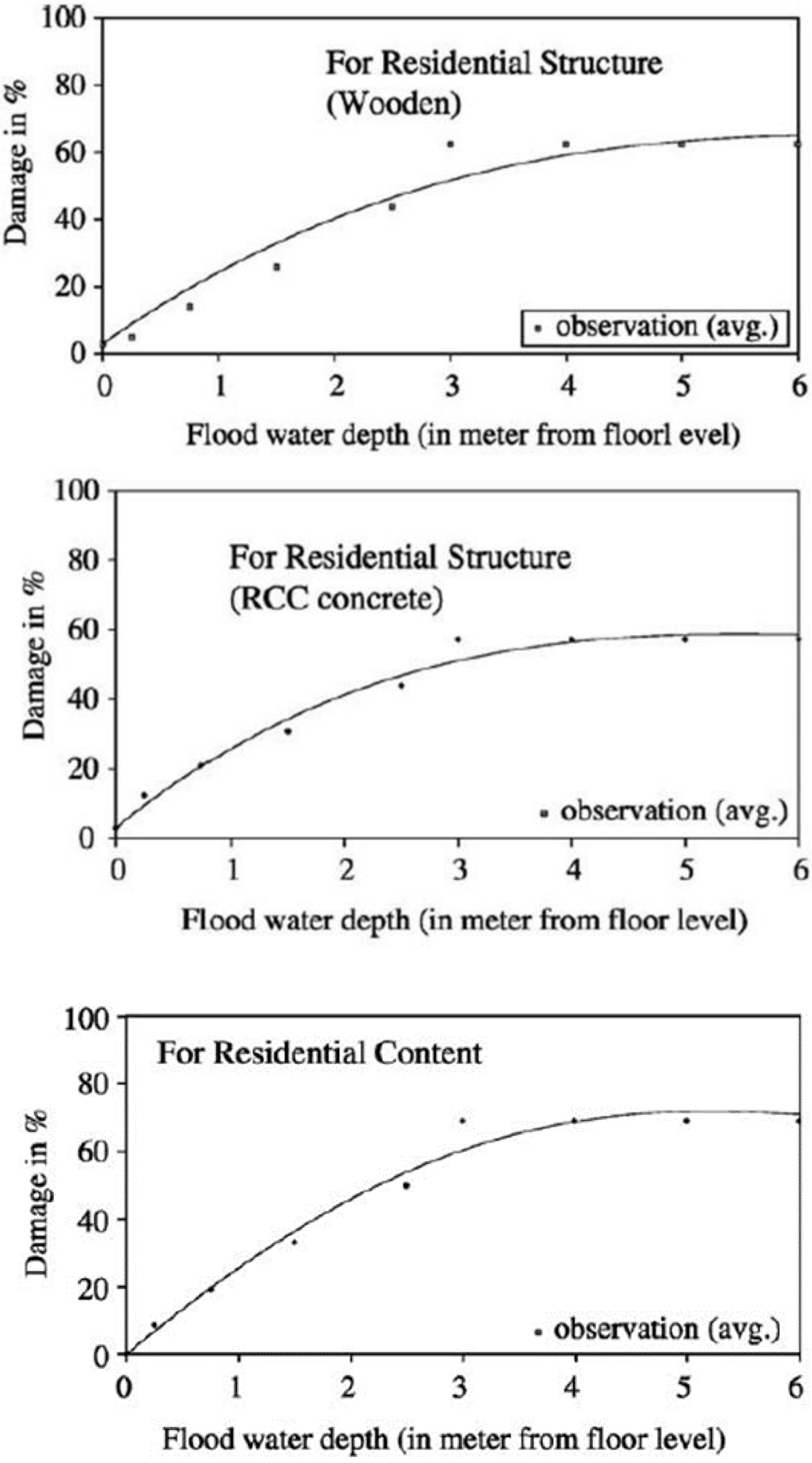

Figure 4.1 - Depth-damage curves formulated for urban damage estimation.
From Dutta et al., Journal of Hydrology, 2003.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Total residential floor area, household distribution, content value per household, unit price for building structures and building content, in the reference unit.
- Vulnerability parameters: Building structure (wood or reinforced concrete).

Model outputs

Relative damage to residential structure and residential content with respect to the price of the corresponding item.

Info on calibration

- Calibration context: The stage-damage functions are derived from the averaged and normalized data published by the Japanese Ministry of Construction which are based on the site survey data accumulated since 1954.
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: The model is not easily transferable since its expression is not explicit.

  Applicability: Since the expression of the model is not explicit, the application of the model can be done, with significant approximation, by measuring on the graphs of the stage-damage functions the values of flood water depth and relative damage corresponding to the binned values. After collecting all the binned values, extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage.

The application of the model remains uncertain due to the absence of information about the calibration and validation context and, moreover, the only distinction in wooden or reinforced concrete structures makes the application of the model good just for similar residential context.

Bibliography

Dutta D., Herath S., Musiake K., *A mathematical model for flood loss estimation*, in “Journal of Hydrology 277(1-2)”, pp. 24-49.

4.1.2 FLEMOps+ at the microscale

Flood Loss Estimation Model for the private sector

Filters for browsing the Repository

- Country of development: Germany
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: FLEMOps+
- Year of the last update: 2008
- Authors: Annegret H. Thieken, Anja Olschewski, Heidi Kreibich, Steve Kobsch and Bruno Merz
- Linked models: FLEMOcs+, FLEMOps+ at the macroscale.
- Expression:

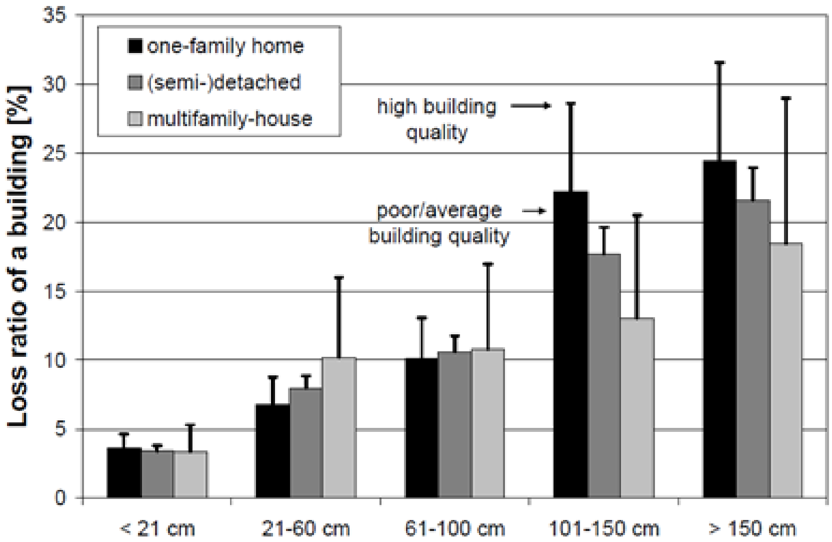

Figure 4.2 - Micro-scale FLEMOps model for the estimation of flood losses to residential buildings considering water level, building type and building quality, derived from data of 1697 households affected by the august 2002 flood.
From Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

If appropriate information is available, the model considers also scaling factors for building losses due to private precautionary measures and the contamination of the floodwater:

	Loss at residential buildings
No contamination, no precaution	0.92
No contamination, good precaution	0.64
No contamination, very good precaution	0.41
Medium contamination, no precaution	1.20
Medium contamination, good precaution	0.86
Medium contamination, very good precaution	0.71
Heavy contamination, no precaution	1.58

Table 4.1 - Scaling factors for building losses in the private and commercial due to private and precautionary measures and the contamination of the floodwater.
Adapted from Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

Model inputs

- Hazard parameters: Water depths above ground surface, contamination of the flood water.
- Exposure parameters: Total asset value of the building, not clear if it is considered as the replacement value of the building, or as the depreciated market value of the building.
- Vulnerability parameters: Building quality (finishing level of the building: high or poor), building type (one-family house, semi-detached house or multifamily house) and mitigation (no precaution, good precaution, very good precaution).

Model outputs

Loss ratios to the structure of the building, considered as the relation between the building loss and the corresponding total asset value of the building. It is not clear if the model output refers to the damage to the entire building or to the damage to the flooded area.

Info on calibration

- Calibration context: In August 2002, a severe flood event occurred in Central Europe (Germany, Austria, the Czech Republic and Slovakia). Heavy precipitation with record-breaking amounts, e.g. of 312 mm within 24 h, had been observed at the gauging station Zinnwald-Georgenfeld, and resulted in high discharges and water levels in the rivers Elbe and Danube and some of their tributaries.
- Dimension of the dataset: 1697 households affected.
- Quality of the data: Eligible flood damage data about the august 2002 flood event that hits the rivers Elbe, Danube and their tributaries. The inhabitants were surveyed by computer-aided telephone interviews. About 180 questions regarding flood impact, contamination of the flood water, flood warning, emergency measures, evacuation, cleaning-up, characteristic of and losses to household contents and buildings, recovery of the affected household, precautionary measures, flood experience, socio-economic variables.

Info on validation

- Validation context: Same context as calibration: the August flood of 2002.
- Dimension of the dataset: Records of eligible repair, representing the building loss, in three affected municipalities in Saxony:
  - 379 loss records from Doblen
  - 550 loss records from Eilenburg
  - 345 loss records from Grimma

  together with information about the building types and water depths at the buildings.
- Quality of the data: Observed eligible repair costs, building types, observed and/or simulated water depths, level of contamination and precaution derived from the telephone interviews used for the calibration.
- Error: The total and mean building loss estimates in the three municipalities are calculated. A resampling method (bootstrap technique) was performed with all loss records per municipality so that a confidence interval of the total and the mean building loss could be constructed. Loss estimates that fall within the 95% interval

of the resampled data were assumed to be acceptable. FLEMOps performs well with observed water levels and not with simulated water levels.

	Total damage [Mill. Euro]	Mean building damage [Euro]	Model evaluation
Municipality of Döbeln (n = 379; CV = 131%)			
SAB – eligible costs	45.71	120610	
95% bootstrap interval of SAB-data	40.24…52.28	106260 …137940	
FLEMOps+ with observed water levels	42.86	113090	+
FLEMOps+ with simulated water levels (1D-Model, see [13])	39.46	104119	-
FLEMOps+, with simulated water levels (LISFLOOD-FP, provided by GFZ Potsdam)	40.99	108143	+
Municipality of Eilenburg (n = 550; CV = 115%)			
SAB – eligible costs	54.46	99023	
95% bootstrap interval of SAB-data	49.97…60.61	90979…109700	
FLEMOps+ with interpolated water level observations	55.40	100728	+
FLEMOps+ with simulated water levels (LISFLOOD-FP provided by GFZ Potsdam)	45.34	82431	-
Municipality of Grimma (n = 345; CV = 82%)			
SAB – eligible costs	44.45	128830	
95% bootstrap interval of SAB-data	40.75…48.43	117850…140360	
FLEMOps+ with observed water levels	48.48	140519	(+)
FLEMOps+, with simulated water levels (2D-Model, provided by the Saxonian Dam Authority)	47.75	138393	+

Figure 4.3 – Building loss estimates on the micro-scale in three municipalities affected by the flooding in august 2002.
From Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

To get the weaknesses of the model, model performance was examined in different classes of water levels and flow velocities.

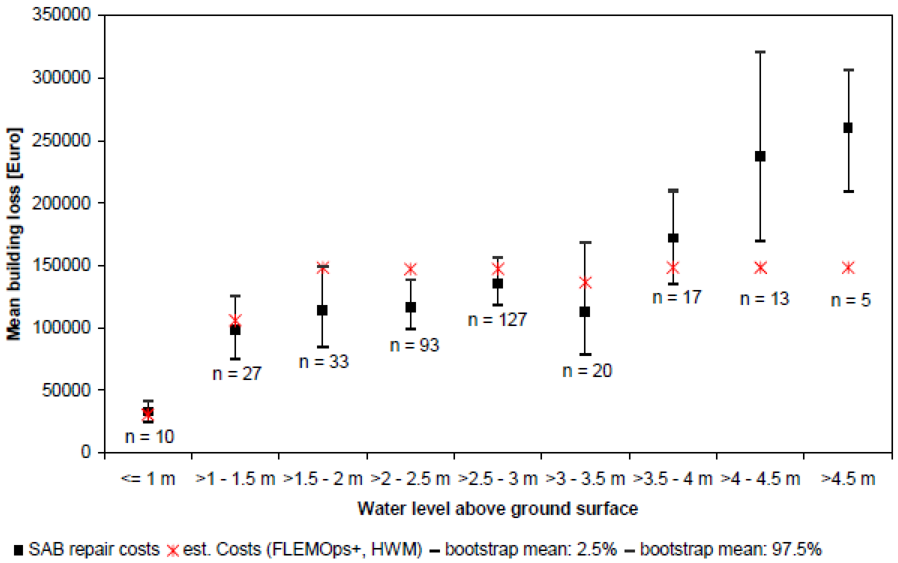

Figure 4.4 – Performance of the model FLEMOps+ in different water level classes using 345 loss records from the municipalities of Grimma.
From Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

Transferability

- Transferability: Since the model is given in graphical terms, the functions governing the model are unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the graph that expresses the model into a step graph, with each step with the same value of relative damage.

  Otherwise, translate the graph that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  Since the model requires a distinction in terms of building quality and building type, its application in another context results to be fine only if enough data about the two parameters are available. For the Italian context in particular, it is difficult to have enough information about the finishing level of each interested building (micro-scale level) without making some approximations, since the only information available are at the meso-scale.

  In addition to that, the model considers the percentage damage as the ratio between the building loss and the corresponding total asset value of the building. In the application of the model, it may be difficult to know this last information.

Bibliography

Thieken A.H., Olschewski A., Kreibich H., Kobsch S., Merz B., *Development and evaluation of FLEMOps – a new Flood Estimation Model for the private sector,* in "WIT Transactions on Ecology and the Environment 118*",* 2008, pp. 315-324.

4.1.3 FLEMOps+ at the mesoscale

Flood Loss Estimation Model for the private sector

Filters for browsing the Repository

- Country of development: Germany
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: FLEMOps+ at the mesoscale
- Year of the last update: 2008
- Authors: Annegret H. Thieken, Anja Olschewski, Heidi Kreibich, Steve Kobsch and Bruno Merz
- Linked models: FLEMOps+ at the microscale, FLEMOcs+
- Expression:

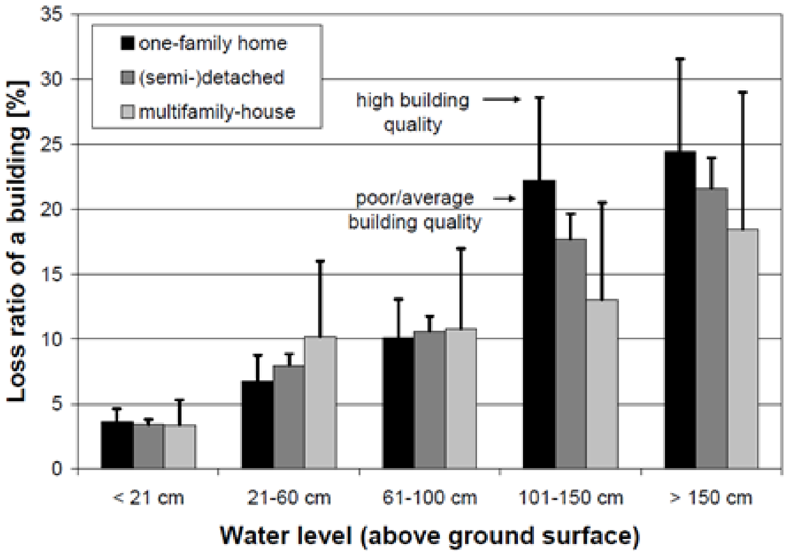

Figure 4.5 - Micro-scale FLEMOps model for the estimation of flood losses to residential buildings considering water level, building type and building quality, derived from data of 1697 households affected by the august 2002 flood. From Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

Starting from the expression of the model, valid for the microscale assessment, the damage values corresponding to the three building types are weighted, for each water depth, by considering the mean percentages of the building types which are typical of different German municipalities. By considering also the building quality, this results in ten different loss model variations.

Cluster	Share EFH [%]	Share RDH [%]	Share MFH [%]	Description
1	12.00	5.13	82.87	Dominated by MFH
2	31.35	24.58	44.07	Mixed (high share of MFH)
3	37.51	46.19	16.30	Mixed (high share of RDH)
4	68.51	21.43	10.05	Mixed (high share of EFH)
5	92.25	4.81	2.94	Dominated by one-family houses
all	73.25	14.30	12.50	Mean composition

Table 4.2 - Typical composition of building types (data are given in percentage of building type per cluster, EFH: one-family home, RDH: (semi-)detached home, MFH: multi-family house.
Adapted from Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

If appropriate information is available, the model considers also scaling factors for building losses due to private precautionary measures and the contamination of the floodwater:

	Loss at residential buildings
No contamination, no precaution	0.92
No contamination, good precaution	0.64
No contamination, very good precaution	0.41
Medium contamination, no precaution	1.20
Medium contamination, good precaution	0.86
Medium contamination, very good precaution	0.71
Heavy contamination, no precaution	1.58

Table 4.3 - Scaling factors for building losses in the private and commercial due to private and precautionary measures and the contamination of the floodwater.
Adapted from Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

Model inputs

- Hazard parameters: Water depth above ground surface, contamination of the flood water.
- Exposure parameters: Total asset value of the building, not clear if it is considered as the replacement value of the building, or as the depreciated market value of the building.
- Vulnerability parameters: Building quality (finishing level of the building: high or poor), building type (one-family house, semi-detached house or multifamily house) and mitigation (no precaution, good precaution, very good precaution), according to the microscale development of the FLEMOps+, together with information about the type of German municipality.

Model outputs

Loss ratios to the structure of the buildings, considered as the relation between the building loss and the corresponding total asset value of the buildings. It is not clear if the model output refers to the damage to the entire building or to the damage to the flooded area.

Info on calibration

- Calibration context: Starting from the microscale model, the FLEMOps+ at the macroscale level overcomes the scale mismatch using census data.
- Dimension of the dataset: Whole Germany.
- Quality of the data: INFAS Geodaten GmbH provides census data containing information about the absolute and relative numbers of different building types and their quality per postal zone or per municipality, for the whole Germany. The building types of the postal zones were classified by means of a cluster analysis.

Info on validation

- Validation context: The model is applied to five Saxonian municipalities affected by the 2002 August flood and to five municipalities in Baden-Wuerttemberg, affected by a flood in the December 1993. In addition to that, the model is compared with three simple stage-damage functions:
    1. $y = \frac{2x^2+2x}{100}$ [*ICPR Model*]

2. $y = 0.02x$ [*MURL Model*]

3. $y = \frac{27\sqrt{x}}{100}$ [*HYDROTEC Model*].

where *y* is the loss ratio and *x* is the water depth in meters.

- Dimension of the dataset: 10 municipalities.
- Quality of the data: Simulated water depths, observed damage data.
- Error: The losses for the 2002 August flood are best estimated by FLEMOps+. The stage-damage functions tend to underestimate or overestimate.

  For FLEMOps+, the mean relative error of the estimates for the 2002 event is 24%, while for the 1993 event is more than 1000%.

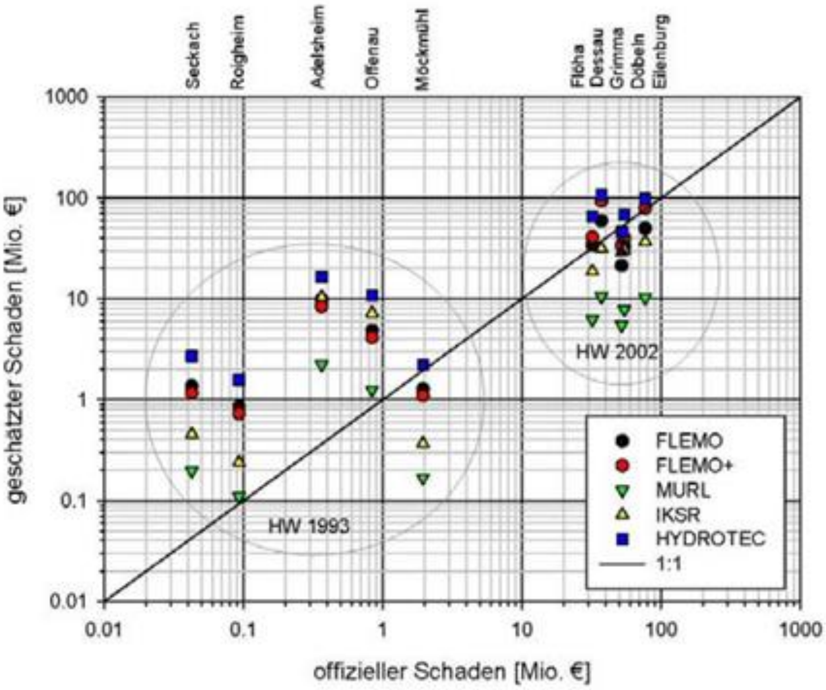

Figure 4.6 - Official repair costs and estimated building losses in ten municipalities that were affected by flooding in 1993 or in 2002.
From Thieken et al., WIT Transaction on Ecology and the Environment, 2008.

Transferability

- Transferability: Since the model is given in graphical terms, the functions governing the model are unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

The first option is to translate the graph that expresses the model into a step graph, with each step with the same value of relative damage. Otherwise, translate the graph that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage.

One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point. Since the model requires a distinction in terms of building quality and building type, its application in another context results to be fine only if enough data about the quality of the building are available.

In addition to that, the model considers the percentage damage as the ratio between the building loss and the corresponding total asset value of the building. In the application of the model, it is difficult to know this last information.

Bibliography

Thieken A.H., Olschewski A., Kreibich H., Kobsch S., Merz B., *Development and evaluation of FLEMOps – a new Flood Estimation Model for the private sector,* in "WIT Transactions on Ecology and the Environment 118*",* 2008, pp. 315-324.

4.1.4 FLFArs

Flood Loss Function for Australian residential structures

Filters for browsing the Repository

- Country of development: Australia
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Probabilistic
- Exposed item/sectors: Residential buildings

ID

- Name: FLFArs
- Year of the last update: 2015
- Authors: Roozbeth Hasanzadeh Nafari, Tuan Ngo and William Lehman
- Linked models: FLFAcs, FLF-IT
- Expression:

  The damage in each storey of a building is expressed with a general function:

  $$d_{h_i} = \left(\frac{h_i}{H_i}\right)^{\frac{1}{r_i}} \cdot D_{max_i}$$

  where:

  - d_{h_i} is the damage percentage for the *i*th floor, corresponding to the depth of water above the *i*th floor;
  - r_i is the rate of alteration in the percentage of damage relative to the growth of h_i over H_i of the building, for the *i*th floor;
  - h_i is the water depth above the *i*th floor;
  - H_i is the maximum height of the building;
  - D_{max_i} is the maximum percentage of damage for the *i*th floor.

The parameters r_i and D_{max_i}, resulting from the calibration in the Australian context, are listed in the table below.

One-storey buildings					
Wall type	Number of samples	Parameters	***Range of parameters***		
			Minimum	***Most-likely***	***Maximum***
Timber	89	**r**	1.3	1.55	2
		D_{max}	64%	70%	74%
Brick	143	**r**	1.2	1.45	1.9
		D_{max}	54%	60%	65%
Two-storey buildings					
Wall type	Number of samples	Parameters	***Range of parameters***		
			Minimum	***Most-likely***	***Maximum***
Timber	49	**r_1**	1.5	2.33	2.4
		r_2	1.3	1.5	1.55
		D_{max1}	38%	42%	43%
		D_{max2}	25%	28%	28%
Brick	38	**r_1**	1.4	2	2.3
		r_2	1.2	1.4	1.5
		D_{max1}	32.5%	34%	36%
		D_{max2}	25.5%	26%	28%

Table 4.4 - Number of samples and range of r and Dmax values, calculated by the bootstrap and chi-square test for one-storey buildings and two-storey buildings.
Adapted from Hasanzadeh Nafari et al., NHESS, 2015.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Total asset value of the building, not clear if it is considered as the replacement value of the building, or as the market value of the building.
- Vulnerability parameters: Number of stories, building walls type (masonry or timber).

Model outputs

Relative damage to the building for each stage of water. The model considers only the damage to the structure and mechanical and electrical facilities.

Info on calibration

- Calibration context: The flood event occurred in Bundaberg (Queensland) from 21 to 29 January 2013 as a result of Tropical Cyclone Oswald. The height of the floodwaters in the city from Burnett river reached 9.53 meters at its peak.
- Dimension of the dataset: 319 building samples.
- Quality of the data: Official data set provided by the Queensland Reconstruction Authority.

Info on validation

- Validation context: The 2012 flood event in the city of Roma, located in the Maranoa region in Queensland.
- Dimension of the dataset: 150 residential buildings (46 one-storey buildings with timber walls, 14 two-storey buildings with timber walls, 78 one-storey buildings with brick walls and 12 two-storey buildings with brick walls).
- Quality of the data: Observed damage data, observed water depths (flood level relative to the first floor), observed building types.
- Error:

Table 4.5 - Error statistics of depth-damage function performance for the flood event of February 2012 (MBE: mean bias error; MAE: mean absolute error, RMSE: root mean squared error).
Adapted from Hasanzadeh Nafari et al., NHESS, 2016.

MBE	**MAE**	**RMSE**
-0.001	0.03	0.04

Transferability

- Transferability: The model is described by a function that depends on the two parameters *r* and D_{max}, which are calibrated for the Australian context, and so the transferability of the model itself is limited to contexts similar to the one for which the model is calibrated.
- Applicability: The model is user friendly and the parameter of its function are easy to be obtained.

Bibliography

Hasanzadeh Nafari R., Ngo T., Lehman W., *Calibration and validation of FLFArs – a new Flood Loss function for Australian residential structures*, in "Natural Hazards and Earth System Sciences 16(1)", 2016a, pp. 15-27.

4.1.5 FLF-IT

Flood Loss Function for Italian residential structures

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical-synthetic
- Model type III: Probabilistic
- Exposed item/sectors: Residential buildings

ID

- Name: FLF-IT
- Year of the last update: 2017
- Authors: Roozbeth Hasanzadeh Nafari, Mattia Amadio, Tuan Ngo and Jaroslav Mysiak
- Linked models: FLFArs, FLFAcs
- Expression:

  The damage percentage can be expressed by the following general function:

$$d_h = \left(\frac{h}{H}\right)^{\frac{1}{r}} \cdot D_{max}$$

  where:

  - d_h is the damage percentage;
  - r is the rate of alteration in the percentage of damage relative to the growth of h over H of the floor;
  - h is the water depth;
  - H is the total height of the floor;
  - D_{max} is the total percentage of damage, corresponding to the total height of the floor.

The parameters r and D_{max}, resulting from the calibration in the Italian context, are listed in the table below:

	Minimum	Most likely	Maximum
r	2.7	2	1.7
D_{max}	0.1	0.2	0.4

Table 4.6 - Number of samples and range of r and D_{max} values, calculated by the bootstrap and chi-square test of goodness of fit.
Adapted from Hasanzadeh Nafari et al., NHESS, 2017

Model inputs

- Hazard parameters: Water depths
- Exposure parameters: Footprint area of the building, mean depreciated value of the residential property.
- Vulnerability parameters: Number of floors

Model outputs

Relative structural damage to the building for each stage of water. The model is created in order to consider the damage in each storey of the building, but because of the low water depths of the calibration context, only the ground floors have been affected by the flood, so, in this specific case, the model output is not referred to the damage to the entire building, but only to the first floor.

Info on calibration

- Calibration context: River flood event in Emilia-Romagna at the beginning of 2014. Water depths are between 0 and 3 meters, water velocity is on the order of 0.05 m/s. The residential structures in the area have mainly the same characteristics: brick or concrete buildings with no underground basement or parking and with at least two or three floors.
- Dimension of the dataset: 613 damage data. A bootstrapping approach has been employed to resample the damage data 1000 times, in order to choose the most appropriate values of r and D_{max}, selected by the chi-square test of goodness of fit. These two previous steps were repeated 1000 times and 1000 sets of parameters were generated.
- Quality of the data: Modelled water depth and observed damage records

Info on validation

- Validation context: The validation context is the same as the calibration, regarding the river flood event in Email-Romagna at the beginning of 2014.
- Dimension of the dataset: The dimension of the dataset used for the validation is the same of the calibration. The set of values was shuffled and divided into three equal parts and then three iterations of model calibration and model testing were completed. For each iteration, one subset was used for the model testing and the other two were used for the model calibration.
- Quality of the data: Modelled water depths and observed damage records
- Error:

	MBE	MAE	RMSE
Iteration 1	0.015	0.092	0.119
Iteration 2	-0.010	0.104	0.157
Iteration 3	-0.009	0.091	0.133
Average	0.00	0.10	0.14

Table 4.7 - Error estimation for the performance of the FLF-IT model (MBE: mean bias error; MAE: mean absolute error; RMSE: root mean squared error).
Adapted from Hasanzadeh Nafari et al., NHESS, 2017.

Transferability

- Transferability: The model is described by a function that depends on the two parameters *r* and D_{max}, which are calibrated for the Italian context, and so the transferability of the model itself is limited to contexts similar to the one for which the model is calibrated.
- Applicability: The model is user friendly and the parameter of its function are easy to be obtained.

Bibliography

Hasanzadeh Nafari R., Amadio M., Ngo T., Mysiak J., *Flood loss modelling with FLF-IT: A new Flood Loss Function for Italian residential structures*, in "Natural Hazards and Earth System Sciences 17(7)", 2017, pp. 1047-1059.

4.1.6 INSYDE

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low velocity, high velocity
- Model type I: Relative, absolute
- Model type II: Synthetic
- Model type III: Deterministic, probabilistic
- Exposed item/sectors: Residential buildings

ID

- Name: INSYDE
- Year of the last update: 2016
- Authors: Francesco Dottori, Rui Figueiredo, Mario L.V. Martina, Daniela Molinari and Anna Rita Scorzini
- Linked models:
- Expression: The total economic damage to each building *D* is obtained by summing each damage components C_i, which includes clean-up and removal costs, structural damages, non-structural damages, damage to finishing elements, damage to windows and doors, and damage to building systems, with a total number of components *n*. Each component C_i is subdivided into m_i different subcomponents C_{ij}, referring to the reparation of the damaged elements or to their removal and replacement. For each subcomponent, a mathematical function describing the damage mechanism and associated cost is formulated.

$$D = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} \sum_{j=1}^{m_i} C_{ij}$$

$$C_{ij} = f(event\ features, building\ characteristics, unit\ prices)$$

The model considers that for some of the building components, given a certain flood hazard intensity measure IM, there are two possible damage state DS, not damaged (ds0) and damaged (ds1), each with a probability of occurrence. Each damage state is associated with a damage ratio R (repair cost of the component/replacement cost). In INSYDE full repair or replacement is necessary, so R=1 when damage occurs.

$C_{ij} = unit\, price_{ij} \cdot extension_{ij} \cdot E[R]$

$E[R] = r_0 p(ds_0) + r_1 p(ds_1) = p(ds_1)$ which is the expected damage ratio, representing the repair cost of the component divided by its replacement cost, given as the sum of the probability of occurrence of the two possible damage states (not damaged: ds_0; damaged: ds_1)

Note: The model is implemented in R code. For downloading the code and for the details about damage functions for each single buildings' component refer to the appendix of the paper cited in the bibliography.

Model inputs

- Hazard parameters: Water depth inside and outside the building; maximum velocity of the water perpendicular to the building; sediment load (% on the water volume); duration of the flood event and water quality (presence or not of pollutant).
- Exposure parameters: Building characteristics:
    - Footprint area;
    - Internal area;
    - Basement area;
    - External perimeter;
    - Internal perimeter;
    - Basement perimeter.
- Vulnerability parameters: Building characteristics:
    - Number of floors;
    - Inter-floor height;
    - Basement height;
    - Ground floor level;
    - Basement level;
    - Building type (detached house, semi-detached house or apartment);

- Building structure (RC or masonry);
- Finishing level (low, medium or high);
- Year of construction;
- Heating system distribution (centralized or distributed);
- Heating system type (radiator or pavement).

Model outputs

Absolute damage [€/m^2 or €/m^3] to individual components of the building.

Relative damage [%/m^2] to individual components of the building, considering the square meters of flooded area, including the basement.

Info on calibration

- Calibration context: Damage functions are designed using the support of existing scientific and technical literature, loss adjustment studies and damage surveys carried out for past flood events in Italy. In particular, using highly detailed damage data about the November 2012 flood in Umbria. The event was the consequence of a widespread, high-intensity rainfall exceeding a return period of 200 years, and leading numerous rivers to exceed the alarm and flooding discharge thresholds. Because of the morphology of the Umbria region, flooding occurred with different features in areas ranging from flat floodplains to narrow mountain valleys. Flood duration ranged from several days to few hours, assuming the features of riverine or flash flood: the persistence of almost steady water in the first case, and high-velocity flows with significant sediment load in the second. Observed discharges in the plain area correspond to a return period of 100 years for the main rivers.
- Dimension of the dataset: Data for about 60 buildings.
- Quality of the data: Observed damage data, hazard parameters and building features.

Info on validation

- Validation context: The model was validated using loss data of the 2010 flood collected by the municipality of Caldogno (Veneto, Italy). In the 2010 flood, an estimated area of 3.3 km^2 was inundated, consisting of approximately 0.7 km^2 of urban area and 2.6 km^2 of agriculture and natural land cover. Large share of low water depths, with an average value of about 0.8m, fine-grained sediment (*s = 0.05*), RC and masonry building type, detached, semi-detached and apartments house building typology.

- Dimension of the dataset: Loss data related to 300 affected buildings.
- Quality of the data: Modelled external water depth; modelled flow velocity; observed sediment load; observed floor area and number of floors of damaged buildings; observed structural type of damage buildings; observed typology of damaged buildings with a further distinction between elements with or without basement; observed quality of the building (finishing level) and observed year of construction.
- Error: Applying INSYDE deterministically, light out that the calculated total loss was equal to EUR 7.42 million, with a relative error of -1.7%. The model tended to overestimate low damages and to underestimate high ones, with a root mean square error equal to EUR 28996. The results presented above were compared with those obtained by applying other deterministic micro-scale damage functions from literature.

	Debo (1982)	Dutta et al. (2003)	FLEMOps	Oliveri and Santoro (2000)	Luino et al. (2009)	Arrighi et al. (2013)	INSYDE
Calculated loss [EUR million]	5.79	13.10	6.58	5.93	10.95	6.34	7.42
Relative error [%]	-23.3	+73.6	-12.8	-21.4	+45.2	-16.0	-1.7
RMSE [EUR]	28302	34990	28116	27972	30230	29622	28996

Table 4.8 - Comparison of loss estimates produced by INSYDE and other models in literature. Adapted from Dottori et al., NHESS, 2016.

Transferability

- Transferability: Since the model is explicit, it is possible to both change its functions and calibrate the parameters on the context in exam.
- Applicability: The model is no user friendly. There are no explicit damage curves. There are many micro-scale parameters that are not always available, but it has the advantage of being able to set up default values, in case of lack of information. Despite the fact that the model is no user friendly, it has the advantage of a very flexible structure that allows easy modification of the model structure and the model parameters for the application in another countries, for other types of assets and even other type of scale of analysis (e.g. the macroscale level).

Bibliography

Dottori F., Figueiredo R., Martina M.L.V., Molinari D., Scorzini A.R., *INSYDE: a synthetic, probabilistic flood damage model based on explicit cost analysis,* in "Natural Hazards and Earth System Sciences 16(12)", 2016, pp. 2577-2591.

Molinari D., Scorzini A.R., *On the influence of input data quality to Flood damage Estimation: The performance of the INSYDE model,* in "Water (Switzerland) 9(9)", 2017, p. 688.

4.1.7 JRC for residential buildings (Africa)

Filters for browsing the Repository

- Country of development: Africa
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: JRC for residential buildings (Africa)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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

Table 4.9 - Average continental damage function for Africa - residential buildings.
Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Residential buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to residential land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in Africa is 495 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.1.8 JRC for residential buildings (Asia)

Filters for browsing the Repository

- Country of development: Asia
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: JRC for residential buildings (Asia)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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

Table 4.10 - Average continental damage function for Asia - residential buildings.
Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Residential buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to residential land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in Asia is 111 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.1.9 JRC for residential buildings (Europe)

Filters for browsing the Repository

- Country of development: Europe
- Scale of analysis: Macroscale
- Flood type I:
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: JRC for residential buildings (Europe)
- Year of the last update: 2007
- Authors: Jan Huizinga
- Linked models: JRC for agricultural crops (Europe), JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania) and JRC for residential buildings (South/Central America).

- Expression:

Water depth [m]	Damage factor
0	0
0.5	0.25
1	0.4
1.5	0.5
2	0.6
3	0.75
4	0.85
5	0.95
6	1.00

Table 4.11 - Average continental damage function for Europe - residential buildings.
Adapted from Huizinga J., EU, 2007.

Model inputs

- Hazard parameters: Water depth.
- Exposure parameters: Buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to residential land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor for the buildings structure and content, considered as the ratio between the absolute damage [€/m^2] and the national maximum damage value [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value for residential buildings is 750 €/m^2, considering the 2007 price level.

Info on calibration

- Calibration context: Data collection from three different sources: the Internet, the available literature at HVK consultants and damage assessment experts from different countries. The authors of literature found on the Internet (Neo BV, Gent University, Czech Technical University Prague and Stockholm University) were subjected to a non-standardized questionnaire by e-mail, in order to get clarification in relation to the inventories of the documents and know issues of the country, and to know if they had any knowledge of damage assessment methods in adjacent countries. The depth-damage function that expresses the model is derived from the average of several depth-damage functions coming from these different sources.

- Dimension of the dataset: On the Internet, quantitative information about eleven different countries (Belgium, Czech Republic, Denmark, France, Germany, Hungary, Norway, Sweden, Switzerland, The Netherlands and United Kingdom) were found.
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2007, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

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

4.1.10 JRC for residential buildings (North America)

Filters for browsing the Repository

- Country of development: North America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: JRC for residential buildings (North America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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

Table 4.12 - Average continental damage function for North America - residential buildings.
Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Residential buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to residential land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in North America is 788 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.1.11 JRC for residential buildings (Oceania)

Filters for browsing the Repository

- Country of development: Oceania
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: JRC for residential buildings (Oceania)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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

Table 4.13 - Average continental damage function for Oceania - residential buildings.
Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Residential buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to residential land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in Oceania is 541 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.1.12 JRC for residential buildings (South/Central America)

Filters for browsing the Repository

- Country of development: South America, Central America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: JRC for residential buildings (South/Central America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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

Table 4.14 - Average continental damage function for South/Central America - residential buildings.
Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Residential buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to residential land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in South/Central America is 215 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.1.13 Multi – Coloured Manual

Filters for browsing the Repository

- Country of development: United Kingdom
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Absolute
- Model type II: Synthetic
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Flood and Coastal Erosion Risk Management (Multi-Coloured Manual)
- Year of the last update: 2013
- Authors: Edumund Penning-Rowsell, C. Johnson, Sylvia Tunstall, S. Tapsell, Joe Morris, John Chatterton and C. Green
- Linked models: Multi-Coloured Manual for other sectors
- Expression:

  Standard depth/damage data available in tabular form. The most detailed standard data provided is for five house types, seven building periods and four different social classes of the dwellings' occupants. This gives to 140 basic data sets in total.

  To access all the 140 standard depth-damage data, make reference to the Appendix of Chapter 4 set in the manual cited in the bibliography section.

Model inputs

- Hazard parameters: Water depths above and below ground floor level, duration of the flood event (long: more than 12 hours; short: less than 12 hours),
- Exposure parameters: Area of the buildings.
- Vulnerability parameters:
    - Building type and structure (detached, semi-detached, terrace (a row of houses built in one block in a uniform style), bungalow (a low house having only one storey, lightly built), flat);
    - Building age (pre 1919, 1919-1944, 1945-1964, 1965-1974, 1975-1985, post 1985);
    - Social class (AB: upper middle and middle class, C1: lower middle class, C2: skilled working class, DE: working class and those at the lowest level of subsistence).

Model outputs

Absolute damage/square meters [£].

The model separates the damage in building fabric damage (paths and paved areas, gardens/fences/sheds, external main building, plasterwork, floors, joinery, internal decorations, plumbing and electrical) and household inventory damage (domestic appliances, heating equipment, audio/video, furniture, personal effects, floor coverings/curtains, garden/DIY/leisure, domestic clean-up). This division helps to understand which components of damage contribute the most to the final total absolute damage.

Info on calibration

- Calibration context: Residential context of the United Kingdom in the 70's – 80's.
- Dimension of the dataset: 28 typical dwellings types.
- Quality of the data: Hypothesized hazard parameters, observed exposure and vulnerability parameters.

Info on validation:

- Error: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Validation context: *Not available*

Transferability

- Transferability: The model does not have a clear expression, so it is difficult to transfer it in another context without making evident approximations.
- Applicability: The model is easily applicable because it gives several possible combination of standard depth/damage data, depending on how many vulnerability parameters are accessible to the users. Nevertheless, the output of the model consists in absolute damage calculated in pounds [£]. The application of the model in another country requires the conversion of pounds in the local currency, considering also that the value of the pounds is stated for the United Kingdom annual context in which the model has been calibrated. Even if the application of the model is easy, it can lead to significant approximations, since it can be done in different ways. The first option is to translate the graph that expresses the model into a step graph, with each step with the same value of relative damage. Otherwise, translate the graph that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage. One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

Bibliography

Penning-Rowsell E., Johnson C., Tunstall S., Tapsell S., Morris J., Chatterton J., Green C., *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal (Multi-Coloured Manual)*, Routledge, 2013.

4.1.14 Oliveri and Santoro

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low velocity
- Model type I: Relative
- Model type II: Synthetic
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Oliveri et al.
- Year of the last update: 2000
- Authors: Elisa Oliveri and Mario Santoro
- Linked models: *Not available*
- Expression:

h [m]	BT1 %	BT2 %	h [m]	BT1 %	BT2 %	h [m]	BT1 %	BT2 %	h [m]	BT1 %	BT2 %
0.25	4.8	5.3	2	24	11	3.8	40.7	19.6	5.5	49	22.5
0.5	7.8	7.5	2.25	27	11	4	42.6	19.8	5.8	50	23
0.75	12.5	8.8	2.5	31	11	4.3	43.5	20.1	6	50	23.7
1	15.6	9	2.75	34	13	4.5	44.9	21.5	6.3	50	24
1.25	17.8	9.7	3	35	14	4.8	46.8	21.7	6.5	50	24.3
1.5	19.9	9.9	3.25	37	15	5	47.1	22	6.8	50	24.5
1.75	22.3	10	3.5	39	19	5.3	48.2	22.2	7	50	24.8

Table 4.15 - Percentage of the total value of the damaged property.
Adapted from Oliveri and Santoro, Urban Water, 2000.

The two columns *BT1* and *BT2* represent the damage percentage, calculated as the ratio between the replacement cost and the estimated total value of the building.

In particular, *BT1* concerns a building type with one or two storeys, without basement; while *BT2* concerns a building type with more than two storeys, still without basement.

Model inputs

- Hazard parameters: External water depths.
- Exposure parameters: Volume of the building, estimated total value of the building considered as the replacement value of the building.
- Vulnerability parameters: Number of floors of the buildings

Model outputs

Relative damage to structure and content (furniture and appliances), considered as the ratio between the total replacement cost and the estimated total value of the building.

Info on calibration

- Calibration context: Urban area of Palermo
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Error: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Validation context: *Not available*

Transferability

- Transferability: The model is not easy transferable since its functions are not explicit

  Applicability: Dividing the buildings in the two categories (*BT1* and *BT2*), the application of the model in another context results to be good only in residential frameworks similar to the calibration one.

  In addition to that, the model considers the water depths as increments of steps equal to 0.25 meters. To handle this limitation, the application of the model to another case study (in which there are different values of water depths) can be done in two different ways, still with significant approximations.

The first option is to translate the table that expresses the model into a step graph, with each step with the same value of relative damage.

Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines for each series. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage.

One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

In addition to that, the model considers the percentage damage as the ratio between the total replacement cost and the estimated total value of the building (structure plus contents). In the application of the model, it may be difficult to know this last information.

Bibliography

Oliveri E., Santoro M., *Estimation of urban flood damages – The case study of Palermo,* in "Urban Water 2(3)*"*, 2000, pp. 223-234.

4.1.15 SEMP – Secchia Empirical Damage Model

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Secchia Empirical Damage Model (SEMP)
- Year of the last update: 2018
- Authors: Francesca Carisi, Kai Schröter, Alessio Domeneghetti, Heidi Kreibich and Attilio Castellarin
- Linked models: $SREG_d$, $SREG_v$, $SREG_a$, SMV.
- Expression: Empirical curve obtained from the linear interpolation procedure between the following values of water depth and relative damage to buildings.

h [m]	**Relative damage [-]**
0	0
0.125	0.058
0.375	0.058
0.625	0.059
0.875	0.06
1.125	0.06
1.375	0.072
1.625	0.094
1.875	0.161
2.1	0.226

Table 4.16 - SEMP model: empirical curve obtained from the binning procedure in terms of water depth [h] and relative damage to buildings.
Adapted from Carisi et al., NHESS, 2018.

Model inputs

- Hazard parameters: Maximum water depths.
- Exposure parameters: Market value of the buildings [EUR/m^2].
- Vulnerability parameters: *Not available*

Model outputs

Relative damage to the structure of the building, considered as the percentage of damage per m^2 to be multiplied by the market value of the building. It is important to point out that the model takes into account the damage relative to the footprint area of each building, since only the first floor was considered in the analysis, due to persistent low values (always below 2.1 meters) of water depths.

Info on calibration

- Calibration context: The inundation event that occurred in Italy in 2014 and was caused by a beach in the right embankment of the Secchia river during an intense flood event. The collapse of the levee caused the inundation of the municipalities of Modena, Bastiglia and Bomporto in less than 30 hours. The over-flowing volume was estimated around 37 x 10^6 m^3, flooding an area of about 52 km^2.
  The studied area is mainly flat. The structural typology of buildings affected was mainly masonry, reinforce concrete or a combination of the two. Maximum water depths on the order of 0.12-2.10 meters, maximum water velocities on the order of 0-1.95 m/s.
- Dimension of the dataset: 1330 affected private properties.
- Quality of the data: Simulated maximum water depths. Market buildings value coming from Italian Revenue Agency reports. Observed damage data coming from a collection campaign. Citizens were asked to complete forms about public property damages, private properties, furniture and registered good damages, dividing all into different asset typologies: building damages (structural parts, non-structural parts and installations), content damages (furniture and household appliances) and structural damages to common parts and registered goods.

Info on validation:

- Validation context: Same context as the calibration.
- Dimension of the dataset: Starting from the calibration dataset, the validation uses a split-sample validation procedure. Two-thirds of the records are randomly selected from the dataset for calibrating the model, which is then applied to the remaining one-third of the data.
- Quality of the data: Same quality of the data as the calibration.
- Error:

Bias [-]	MAE [-]	RMSE [-]
-0.042	0.080	0.130

Table 4.17 - Performance of the uni-variable model developed based on local data in estimating relative damages and overall monetary loss to buildings.
Adapted from Carisi et al., NHESS, 2018.

Transferability

- Transferability: The model is easily transferable since the damage curve is given by the linear regression of binned values and so the expression is clearly stated.
- Applicability: The model is user friendly, since it depends only on one parameter, the water depth and the clear expression of the model does not lead to possible approximations of the model.

Bibliography

Carisi F., Schröter K., Domeneghetti A., Kreibich H., Castellarin A., *Development and assessment of uni- and multivariable flood loss models for Emilia-Romagna (Italy),* in "Natural Hazards and Earth System Sciences 18(7)", 2018, pp. 2057-2079.

4.1.16 SMV – Secchia Multi-Variable damage model

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Secchia Multi-Variable damage model (SMV)
- Year of the last update: 2018
- Authors: Francesca Carisi, Kai Schröter, Alessio Domeneghetti, Heidi Kreibich and Attilio Castellarin
- Linked models: SEMP, $SREG_d$, $SREG_v$, $SREG_a$.
- Expression: Starting from the Secchia 2014 dataset, the model consists in carrying out 500 bootstrap reruns of each record of the dataset. For each of these 500 reruns, a regression tree is created. At the end there will be 500 different regression trees, depending on the analysed dataset. The estimated damage for each record is the average of the estimates of the 500 regression trees.

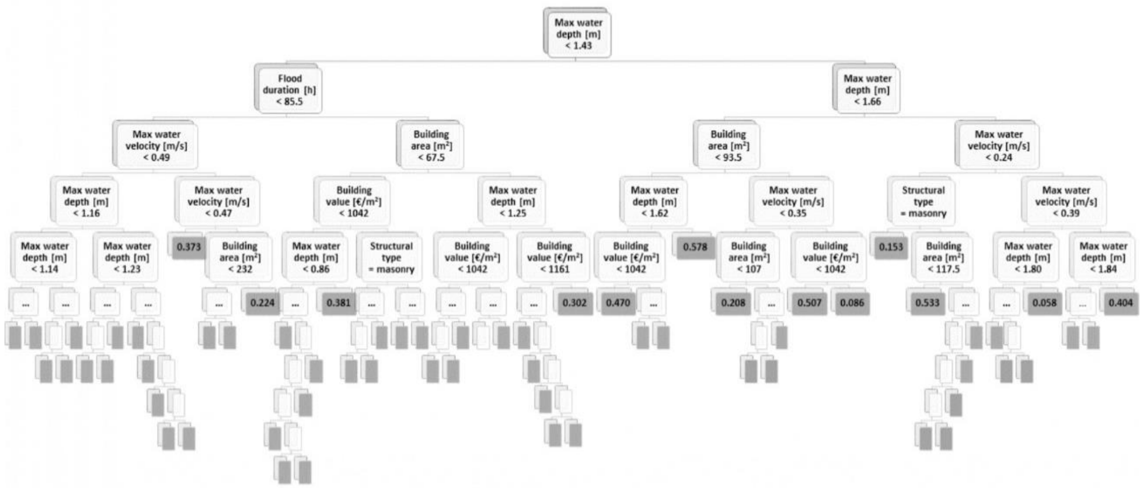

Figure 4.7 - Example of a tree built with the RF algorithm on the basis of the Secchia dataset. White boxes represent splitting nodes, together with the indication of the splitting variable and its splitting value; grey boxes represent final nodes and the estimation of the relative building damages of that branch. The tree is cut off at an arbitrary level for the sake of clarity.
From Carisi et al., NHESS, 2018.

The model is studied using the random forest (RF) algorithm implemented in the *R* package *randomForest*.

Model inputs

- Hazard parameters: Maximum water depths, flood durations, maximum water velocities.
- Exposure parameters: Market value of the building [EUR/m^2].
- Vulnerability parameters: Structural typology (masonry, reinforced concrete and a combination of the two).

Model outputs

Relative damage to the structure of the building, considered as the percentage of damage per m^2 to be multiplied by the market value of the building. It is important to point out that the model takes into account the damage relative to the footprint area of each building (without basement), since only the first floor was considered in the analysis, due to persistent low values (always below 2.1 meters) of water depths.

Info on calibration

- Calibration context: The inundation event that occurred in Italy in 2014 and was caused by a beach in the right embankment of the Secchia river during an intense flood event. The collapse of the levee caused the inundation of the municipalities of Modena, Bastiglia and Bomporto in less than 30 hours. The area remained flooded for more than 48 hours. The over-flowing volume was estimated around 37 x 10^6 m^3, flooding an area of about 52 km^2.

  The studied area is mainly flat. The structural typology of buildings affected was mainly masonry, reinforce concrete or a combination of the two. Maximum water depths on the order of 0.12-2.10 meters, maximum water velocities on the order of 0-1.95 m/s.
- Dimension of the dataset: 1330 affected private properties.
- Quality of the data: Simulated maximum water depths, maximum water velocities and flood durations. Observed structural typologies. Market buildings value coming from Italian Revenue Agency reports. Observed damage data coming from a collection campaign. Citizens were asked to complete forms about public property damages, private properties, furniture and registered good damages, dividing all into different asset typologies: building damages (structural parts, non-structural parts and installations), content damages (furniture and household appliances) and structural damages to common parts and registered goods.

Info on validation:

- Validation context: Same context as the calibration.
- Dimension of the dataset: Starting from the calibration dataset, the validation uses a split-sample validation procedure. Two-thirds of the records are randomly selected from the dataset for calibrating the model, which is then applied to the remaining one-third of the data.
- Quality of the data: Same quality of the data as the calibration.
- Error:

Bias [-]	MAE [-]	RMSE [-]
-0.021	0.078	0.120

Table 4.18 - Performance of the multivariable model developed based on local data in estimating relative damages and overall monetary loss to buildings.
Adapted from Carisi et al., NHESS, 2018.

Transferability

- Transferability: Since the model is implemented in a specific software and so its parameters are related to the specific calibration framework, its application is suitable only in a context as similar as possible to the one of the calibration. Otherwise, in a very different context, the user must re-calibrate with the randomForest package the entire model. In this case the result of the modelling will be no more the SMV, but a different model.
- Applicability: The model is no user friendly, since its application requires the use of a specific software.

Bibliography

Carisi F., Schröter K., Domeneghetti A., Kreibich H., Castellarin A., *Development and assessment of uni- and multivariable flood loss models for Emilia-Romagna (Italy),* in "Natural Hazards and Earth System Sciences 18(7)", 2018, pp. 2057-2079.

4.1.17 $SREG_a$ – Secchia square root Regression damage model

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Secchia Square Root Regression damage model ($SREG_a$)
- Year of the last update: 2018
- Authors: Francesca Carisi, Kai Schröter, Alessio Domeneghetti, Heidi Kreibich and Attilio Castellarin
- Linked models: SEMP, $SREG_d$, $SREG_v$, SMV.
- Expression: The model quantifies the relative monetary damage to buildings by regression relationship. It calculates the damage by regressing observed relative loss against building footprint area.

$$D_{SREG_a} = 0.009 \cdot \sqrt{a}$$

Model inputs

- Hazard parameters: *Not available*
- Exposure parameters: Market value of the buildings [EUR/m^2], buildings area
- Vulnerability parameters: *Not available*

Model outputs

Relative damage to the structure of the building, considered as the percentage of damage per m^2 to be multiplied by the market value of the building. It is important to point out that the model takes into account the damage relative to the footprint area of each building, since only the first floor was considered in the analysis, due to persistent low values (always below 2.1 meters) of water depths.

Info on calibration

- Calibration context: The inundation event that occurred in Italy in 2014 and was caused by a beach in the right embankment of the Secchia river during an intense flood event. The collapse of the levee caused the inundation of the municipalities of Modena, Bastiglia and Bomporto in less than 30 hours. The over-flowing volume was estimated around 37 x 10^6 m^3, flooding an area of about 52 km^2.
  The studied area is mainly flat. The structural typology of buildings affected was mainly masonry, reinforce concrete or a combination of the two. Maximum water depths on the order of 0.12-2.10 meters, maximum water velocities on the order of 0-1.95 m/s.
- Dimension of the dataset: 1330 affected private properties.
- Quality of the data: Observed building footprint area values. Market buildings value coming from Italian Revenue Agency reports. Observed damage data coming from a collection campaign. Citizens were asked to complete forms about public property damages, private properties, furniture and registered good damages, dividing all into different asset typologies: building damages (structural parts, non-structural parts and installations), content damages (furniture and household appliances) and structural damages to common parts and registered goods.

Info on validation:

- Validation context: Same context as the calibration.
- Dimension of the dataset: Starting from the calibration dataset, the validation uses a split-sample validation procedure. Two-thirds of the records are randomly selected from the dataset for calibrating the model, which is then applied to the remaining one-third of the data.

- Quality of the data: Same quality of the data as the calibration.
- Error:

Bias [-]	MAE [-]	RMSE [-]
-0.010	0.090	0.129

Table 4.19 - Performance of the uni-variable model developed based on local data in estimating relative damages and overall monetary loss to buildings.
Adapted from Carisi et al., NHESS, 2018.

Transferability

- Transferability: The model is easily transferable since the expression of the economic damage is clearly stated.
- Applicability: The model is user friendly, since it depends on easily available parameters.

Bibliography

Carisi F., Schröter K., Domeneghetti A., Kreibich H., Castellarin A., *Development and assessment of uni- and multivariable flood loss models for Emilia-Romagna (Italy),* in “Natural Hazards and Earth System Sciences 18(7)”, 2018, pp. 2057-2079.

4.1.18 $SREG_d$ – Secchia square root Regression damage model

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Secchia Square Root Regression damage model ($SREG_d$)
- Year of the last update: 2018
- Authors: Francesca Carisi, Kai Schröter, Alessio Domeneghetti, Heidi Kreibich and Attilio Castellarin
- Linked models: SEMP, $SREG_v$, $SREG_a$, SMV.
- Expression: The model quantifies the relative monetary damage to buildings by regression relationship. It calculates the damage by regressing observed relative loss against maximum water depth.

$$D_{SREG_d} = 0.113 \cdot \sqrt{h}$$

Model inputs

- Hazard parameters: Water depth and water velocity.
- Exposure parameters: Market value of the building [EUR/m^2].
- Vulnerability parameters: *Not available*

Model outputs

Relative damage to the structure of the building, considered as the percentage of damage per m^2 to be multiplied by the market value of the building. It is important to point out that the model takes into account the damage relative to the footprint area of each building, since only the first floor was considered in the analysis, due to persistent low values (always below 2.1 meters) of water depths.

Info on calibration

- Calibration context: The inundation event that occurred in Italy in 2014 and was caused by a beach in the right embankment of the Secchia river during an intense flood event. The collapse of the levee caused the inundation of the municipalities of Modena, Bastiglia and Bomporto in less than 30 hours. The over-flowing volume was estimated around 37 x 10^6 m^3, flooding an area of about 52 km^2.
  The studied area is mainly flat. The structural typology of buildings affected was mainly masonry, reinforce concrete or a combination of the two. Maximum water depths on the order of 0.12-2.10 meters, maximum water velocities on the order of 0-1.95 m/s.
- Dimension of the dataset: 1330 affected private properties.
- Quality of the data: Simulated maximum water depths. Market buildings value coming from Italian Revenue Agency reports. Observed damage data coming from a collection campaign. Citizens were asked to complete forms about public property damages, private properties, furniture and registered good damages, dividing all into different asset typologies: building damages (structural parts, non-structural parts and installations), content damages (furniture and household appliances) and structural damages to common parts and registered goods.

Info on validation:

- Validation context: Same context as the calibration.
- Dimension of the dataset: Starting from the calibration dataset, the validation uses a split-sample validation procedure. Two-thirds of the records are randomly selected from the dataset for calibrating the model, which is then applied to the remaining one-third of the data.
- Quality of the data: Same quality of the data as the calibration.

- Error:

Bias [-]	MAE [-]	RMSE [-]
-0.003	0.089	0.125

Table 4.20 - Performance of the uni-variable model developed based on local data in estimating relative damages and overall monetary loss to buildings.
Adapted from Carisi et al., NHESS, 2018.

Transferability

- Transferability: The model is easily transferable since the expression of the economic damage is clearly stated.
- Applicability: The model is user friendly, since it depends on easily available parameters.

Bibliography

Carisi F., Schröter K., Domeneghetti A., Kreibich H., Castellarin A., *Development and assessment of uni- and multivariable flood loss models for Emilia-Romagna (Italy),* in "Natural Hazards and Earth System Sciences 18(7)", 2018, pp. 2057-2079.

4.1.19 $SREG_v$ – Secchia square root Regression damage model

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings

ID

- Name: Secchia Square Root Regression damage model ($SREG_v$)
- Year of the last update: 2018
- Authors: Francesca Carisi, Kai Schröter, Alessio Domeneghetti, Heidi Kreibich and Attilio Castellarin
- Linked models: SEMP, $SREG_d$, $SREG_a$, SMV.
- Expression: The model quantifies the relative monetary damage to buildings by regression relationship. It calculates the damage by regressing observed relative loss against maximum water velocity.

$$D_{SREG_v} = 0.007 \cdot \sqrt{v} + 0.104$$

Model inputs

- Hazard parameters: Water velocity
- Exposure parameters: Market value of the buildings [EUR/m^2]
- Vulnerability parameters: *Not available*

Model outputs

Relative damage to the structure and contents of the building, considered as the percentage of damage per m^2 to be multiplied by the market value of the building. It is important to point out that the model takes into account the damage relative to the footprint area of each building, since only the first floor was considered in the analysis, due to persistent low values (always below 2.1 meters) of water depths.

Info on calibration

- Calibration context: The inundation event that occurred in Italy in 2014 and was caused by a beach in the right embankment of the Secchia river during an intense flood event. The collapse of the levee caused the inundation of the municipalities of Modena, Bastiglia and Bomporto in less than 30 hours. The over-flowing volume was estimated around 37 x 10^6 m^3, flooding an area of about 52 km^2.
  The studied area is mainly flat. The structural typology of buildings affected was mainly masonry, reinforce concrete or a combination of the two. Maximum water depths on the order of 0.12-2.10 meters, maximum water velocities on the order of 0-1.95 m/s.
- Dimension of the dataset: 1330 affected private properties
- Quality of the data: Simulated maximum water velocities. Market buildings value coming from Italian Revenue Agency reports. Observed damage data coming from a collection campaign. Citizens were asked to complete forms about public property damages, private properties, furniture and registered good damages, dividing all into different asset typologies: building damages (structural parts, non-structural parts and installations), content damages (furniture and household appliances) and structural damages to common parts and registered goods.

Info on validation:

- Validation context: Same context as the calibration.
- Dimension of the dataset: Starting from the calibration dataset, the validation uses a split-sample validation procedure. Two-thirds of the records are randomly selected from the dataset for calibrating the model, which is then applied to the remaining one-third of the data.
- Quality of the data: Same quality of the data as the calibration.

- Error:

Bias [-]	MAE [-]	RMSE [-]
0.000	0.090	0.125

Table 4.21 - Performance of the uni-variable model developed based on local data in estimating relative damages and overall monetary loss to buildings.
Adapted from Carisi et al., NHESS, 2018.

Transferability

- Transferability: The model is easily transferable since the expression of the economic damage is clearly stated.
- Applicability: The model is user friendly, since it depends on easily available parameters.

Bibliography

Carisi F., Schröter K., Domeneghetti A., Kreibich H., Castellarin A., *Development and assessment of uni- and multivariable flood loss models for Emilia-Romagna (Italy),* in "Natural Hazards and Earth System Sciences 18(7)", 2018, pp. 2057-207.

4.2 Non-residential buildings

4.2.1 Dutta et al. for non-residential buildings

Filters for browsing the Repository

- Country of development: Japan
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Non-residential buildings

ID

- Name: Dutta et al.
- Year of the last update: 2003
- Authors: Dushmanta Dutta, Srikantha Herath and Katumi Musiake
- Linked models: Dutta et al. for residential buildings, Dutta et al. for agricultural crops.
- Expression:

  Stage-damage functions which relate flood damage to flood inundation parameters. Two different functions are modelled, one for the non-residential property and one for the non-residential stocks.

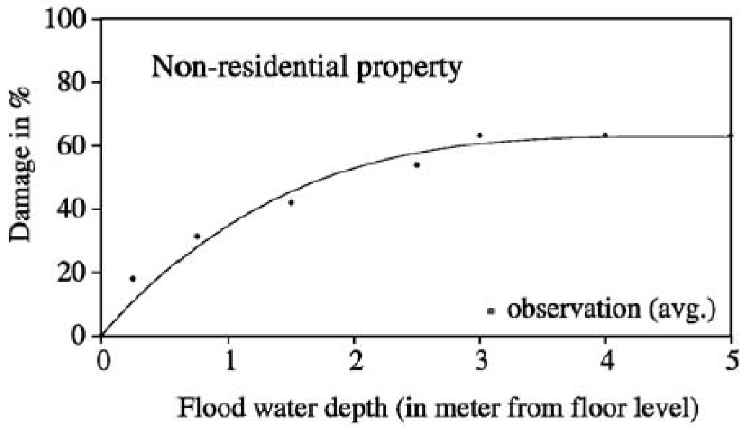

Figure 4.8 - Depth-damage curve formulated for non-residential property damage estimation.
From Dutta et al., Journal of Hydrology, 2003.

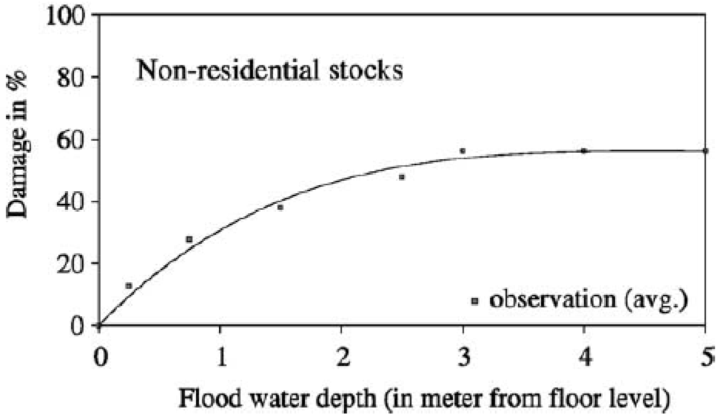

Figure 4.9 - Depth-damage curve formulated for non-residential stocks damage estimation.
From Dutta et al., Journal of Hydrology, 2003.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Total floor area, number of non-residential building per type, unit price of property and stock per type, in the reference unit.
- Vulnerability parameters: Type of non-residential buildings (mining, construction, production, electricity/gas/water supply, transportation, wholesale and retailed sale, finance and insurance, real estate, service and government). These vulnerability parameter does not influence the damage curve, but only the unit price per category.

Model outputs

Relative damage to non-residential property and non-residential stocks with respect to the price of the corresponding item.

Info on calibration

- Calibration context: The stage-damage functions are derived from the averaged and normalized data published by the Japanese Ministry of Construction which are based on the site survey data accumulated since 1954.
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: The model is not easily transferable since its expression is not explicit.
- Applicability: Since the expression of the model is not explicit, the application of the model can be done, with significant approximation, by measuring on the graphs of the stage-damage functions the values of flood water depth and relative damage corresponding to the binned values. After collecting all the binned values, extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage.

Bibliography

Dutta D., Herath S., Musiake K., *A mathematical model for flood loss estimation,* in "Journal of Hydrology 277(1-2)", pp. 24-49.

4.3 Agricultural crops

4.3.1 AGRIDE-c for the Po region

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low velocity
- Model type I: Relative
- Model type II: Synthetic
- Model type III: Deterministic
- Exposed item/sectors: Agricultural crops

ID

- Name: AGRIDE-c for the Po region
- Year of the last update: 2019
- Authors: Daniela Molinari, Anna Rita Scorzini, Alice Gallazzi and Francesco Ballio.
- Linked models: *Not available*
- Expression: The expression is stated for the application of the model in the Po region. It illustrates the damage for four different type of crops (maize, wheat, barley crop and grassland), referring to the case of minimum or conventional tillage. An example of the expression of the model, stated for the maize crops, is reported below. For further information, refer to the scientific paper cited in the bibliography section.

Phase	Water depth < 130 cm	Strategy	Flood duration [days] <5	5	6	7	8	9	10	11	>11
Bare field	Jan	c	36%								
		r	-								
		a	-								
	Feb	c	36%								
		r	-								
		a	-								
	Mar	c	36%								
		r	-								
		a	-								
Initial phase	Apr	c	-								
		r	80%								
		a	158%								
	May	c	-								
		r	80%								
		a	158%								
Growing	Jun	c	36%	63%	90%	117%	144%	171%	198%	225%	-
		r	80%								
		a	-	187%							
Flowering	Jul	c	36%	90%	144%	198%	-				
		r	-								
		a	-	191%							
	Aug	c	36%	90%	144%	198%	-				
		r	-								
		a	-	191%							
Maturation	Sep	c	36%								
		r	-								
		a	-								
	Oct	c	36%								
		r	-								
		a	-								
Bare field	Nov	c	36%								
		r	-								
		a	-								
	Dec	c	36%								
		r	-								
		a	-								

Phase	Water depth ≥ 130 cm	Strategy	Flood duration [days] <5	5	6	7	8	9	10	11	>11
Bare field	Jan	c	36%								
		r	-								
		a	-								
	Feb	c	36%								
		r	-								
		a	-								
	Mar	c	36%								
		r	-								
		a	-								
Initial phase	Apr	c	-								
		r	80%								
		a	158%								
	May	c	-								
		r	80%								
		a	158%								
Growing	Jun	c	36%	63%	90%	117%	144%	171%	198%	225%	-
		r	80%								
		a	-	187%							
Flowering	Jul	c	-								
		r	-								
		a	191%								
	Aug	c	-								
		r	-								
		a	191%								
Maturation	Sep	c	36%					90%	144%	198%	-
		r	-								
		a	-					195%			
	Oct	c	36%					90%	144%	198%	-
		r	-								
		a	-					195%			
Bare field	Nov	c	36%								
		r	-								
		a	-								
	Dec	c	36%								
		r	-								
		a	-								

Figure 4.10 - Relative damage to maize crops (in case of minimum tillage) for the different combination times of occurrence of the flood, flood intensities and damage alleviation strategies ("c"=continuation, "r"=reseeding, "a"=abandoning).
From Molinari et al., NHESS, 2019.

Model inputs

- Hazard parameters: Time of the flood, water depths and flood durations.
- Exposure parameters: Area of the crops.
- Vulnerability parameters: Damage alleviation strategy (continuation, reseeding and abandoning), type of crop.

Model outputs

Relative damage to the crops, considered as the ratio between the absolute damage and the gross profit in the case when no flood occurs (Scenario 0).

$$d = \frac{D}{GP_{no\ flood}}$$

The analytical expression of absolute damage for an individual farmer is expressed as follows:

$$D = GP_{no\ flood} - GP_{flood} = \Delta T - \Delta PC$$

where ΔT represents the reduction in the turnover and ΔPC represents the increase or decrease in production costs, both as a consequence of the flood impact on a specific crop, and GP represents the gross profit.

Info on calibration

- Calibration context: The model has been developed using an expert-based approach. Information has been derived by an investigation of literature and a consultation with experts (i.e. agronomists and representatives of the authorities). These information have been supplemented with the analysis of a real case, the flood of the Adda river in November 2002, a long-lasting riverine flood characterized by medium to high water depths (mean value equal to 0.9 meters), low flow velocities (mean value equal to 0.2 m/s) and low sediment and pollution loads in the flooded areas.
- Dimension of the dataset: *Not available*
- Quality of the data: Observed water depths and damage data.

Info on validation:

- Error: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Validation context: *Not available*

Transferability

- Transferability: The model allows an easy transferability, since it clearly states each step that composes the model (Scenario 0, physical model, alleviation strategies, etc.). The transferability in another context can be done by simply modifying the parameters that describe each model step.
- Applicability: The model is easy applicable, also thanks to an attached *Excel* file, whose link is reported in the model paper. Changing the model parameters, the *Excel* file calculates automatically the damage percentage. The parameters to be submitted to the model are easy to be obtained.

Bibliography

Molinari, D., Scorzini, A. R., Gallazzi, A., and Ballio, F., *AGRIDE-c, a conceptual model for the estimation of flood damage to crops: development and implementation,* in "Natural Hazards and Earth System Sciences", in review, 2019.

4.3.2 Dutta et al. for agricultural crops

Filters for browsing the Repository

- Country of development: Japan
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Agricultural crops

ID

- Name: Dutta et al. for agricultural crops
- Year of the last update: 2003
- Authors: Dushmanta Dutta, Srikantha Herath and Katumi Musiake
- Linked models: Dutta et al. for residential buildings, Dutta et al. for non-residential buildings
- Expression:

  Stage-damage functions which relate flood damage to flood inundation parameters for different classes of crops. Based on the nature of damage due to floods, crops are categorized into eight classes.

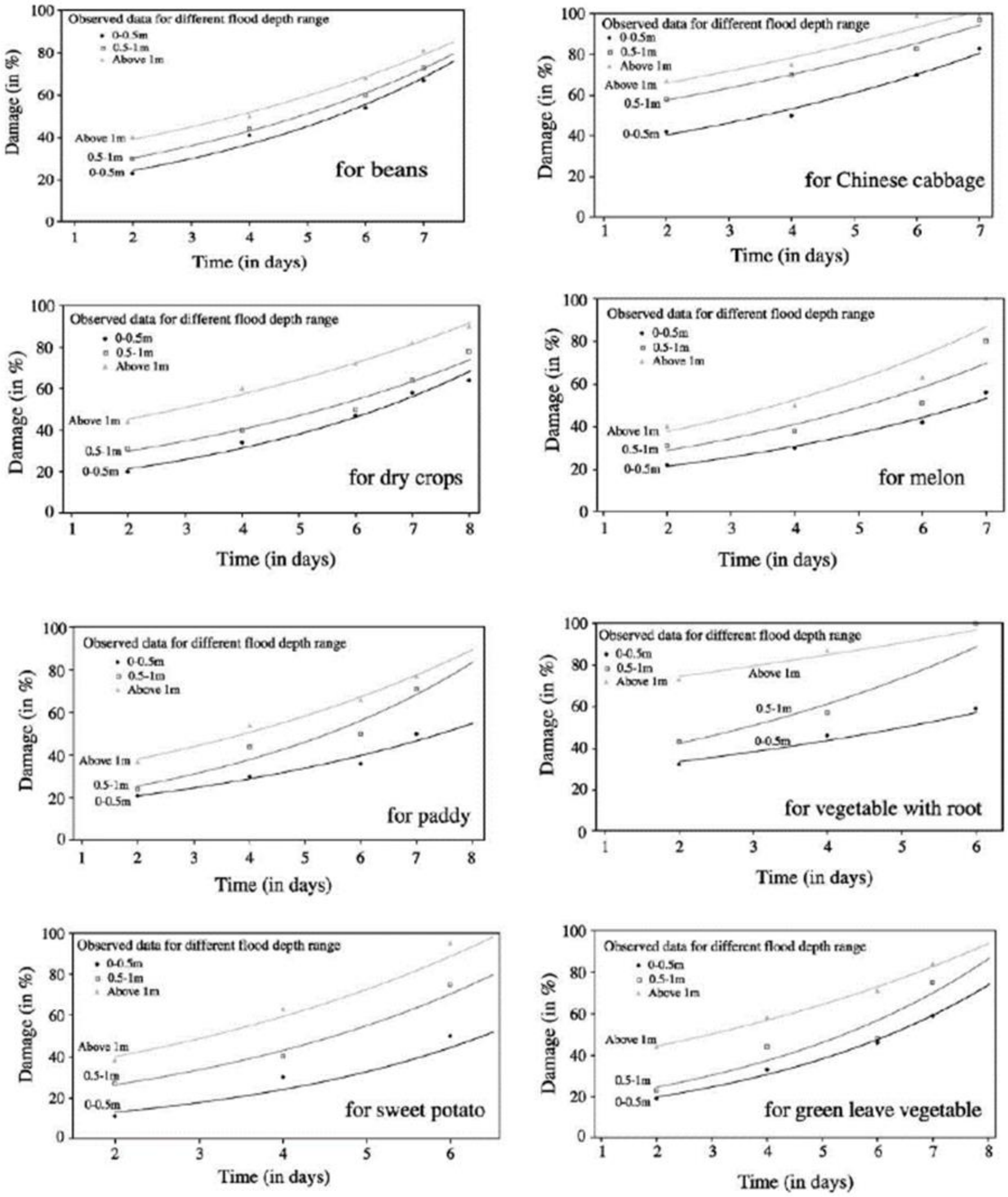

Figure 4.11 - Stage-damage functions formulated for agricultural product damage estimation.
From Dutta et al., Journal of Hydrology, 2003.

Model inputs

- Hazard parameters: Water depths, flood durations.
- Exposure parameters: Area of the crops, yield per crop per unit area and market value of each type of crop per unit weight.
- Vulnerability parameters: Type of crop (beans, Chinese cabbages, dry crops, melon, paddy, vegetables with roots, sweet potatoes and green leave vegetables).

Model outputs

Relative damage to different types of agricultural crops, per unit area, with respect to the yield in the no-flood scenario.

Info on calibration

- Calibration context: The stage-damage functions are derived from the averaged and normalized data published by the Japanese Ministry of Construction which are based on the site survey data accumulated since 1954.
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Error: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Validation context: *Not available*

Transferability

- Transferability: The model is no easily transferable since its expression is not explicit.
- Applicability: The application of the model results to be good just for agricultural context equal to the eight crops modelled. Since the expression of the model is not explicit, the application of the model can be done, with significant approximation, by measuring on the graphs of the stage-damage functions the values of flood water depth and relative damage corresponding to the binned values. After collecting all the binned values, extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage.

Bibliography

Dutta D., Herath S., Musiake K., *A mathematical model for flood loss estimation,* in "Journal of Hydrology 277(1-2)", pp. 24-49.

4.3.3 JRC for agricultural crops (Africa)

Filters for browsing the Repository

- Country of development: Africa
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Agricultural crops

ID

- Name: JRC for agricultural crops (Africa)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.22 - Average continental damage function for Africa – agricultural crops.
Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Agricultural land [km^2]. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective crops area, or to the area related to agricultural land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in Africa is 0.12 €/m^2, considering the 2010 price level.

Info on calibration

- Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- <u>Validation context:</u> *Not available*
- <u>Dimension of the dataset:</u> *Not available*
- <u>Quality of the data:</u> *Not available*
- <u>Error:</u> *Not available*

Transferability

- <u>Transferability:</u> Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- <u>Applicability:</u> The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.3.4 JRC for agricultural crops (Asia)

Filters for browsing the Repository

- Country of development: Asia
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Agricultural crops

ID

- Name: JRC for agricultural crops (Asia)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.23 - Average continental damage function for Asia – agricultural crops.
Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Agricultural land [km^2]. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective crops area, or to the area related to agricultural land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in Asia is 0.03 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.3.5 JRC for agricultural crops (Europe)

Filters for browsing the Repository

- Country of development: Europe
- Scale of analysis: Macroscale
- Flood type I: Riverine
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Agricultural crops

ID

- Name: JRC for agricultural crops (Europe)
- Year of the last update: 2007
- Authors: Jan Huizinga
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

Water depth [m]	Damage factor
0	0
0.5	0.3
1	0.55
1.5	0.65
2	0.75
3	0.85
4	0.95
5	1.00
6	1.00

Table 4.24 - Average continental damage function for Europe – agricultural crops.
Adapted from Huizinga, EU, 2007.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Agricultural land [km^2]. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective crops, or to the area related to agricultural land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor for the buildings structure and content, considered as the ratio between the absolute damage [€/m^2] and the national maximum damage value [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value for agriculture is 0.77 €/m^2, considering the 2007 price level.

Info on calibration

- Calibration context: Data collection from three different sources: the Internet, the available literature at HVK consultants and damage assessment experts from different countries. The authors of literature found on the Internet (Neo BV, Gent University, Czech Technical University Prague and Stockholm University) were subjected to a non-standardized questionnaire by e-mail, in order to get clarification in relation to the inventories of the documents and know issues of the

country, and to know if they had any knowledge of damage assessment methods in adjacent countries. The depth-damage function that expresses the model is derived from the average of several depth-damage functions coming from these different sources.

- Dimension of the dataset: On the Internet, quantitative information about eleven different countries (Belgium, Czech Republic, Denmark, France, Germany, Hungary, Norway, Sweden, Switzerland, The Netherlands and United Kingdom) were found.
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2007, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

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

4.3.6 JRC for agricultural crops (North America)

Filters for browsing the Repository

- Country of development: North America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Agricultural crops

ID

- Name: JRC for agricultural crops (North America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.25 - Average continental damage function for Nord America – agricultural crops. Adapted from Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Agricultural land [km^2]. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective crops area, or to the area related to agricultural land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in North America is 662 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.4 Commercial sector

4.4.1 FLFAcs

Flood Loss Function for Australian commercial structures

Filters for browsing the Repository

- Country of development: Australia
- Scale of analysis: Microscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Probabilistic
- Exposed item/sectors: Commercial sector

ID

- Name: FLFAcs
- Year of the last update: 2015
- Authors: Roozbeth Hasanzadeh Nafari, Tuan Ngo and William Lehman
- Linked models: FLFArs, FLF-IT
- Expression:

  The damage in each storey of a building is expressed with a general function:

$$d_{h_i} = \left(\frac{h_i}{H_i}\right)^{\frac{1}{r_i}} \cdot D_{max\,i}$$

  where:

  - d_{h_i} is the damage percentage for the *i*th floor, corresponding to the depth of water above the *i*th floor;
  - r_i is the rate of alteration in the percentage of damage relative to the growth of h_i over H_i of the building, for the *i*th floor;
  - h_i is the water depth above the *i*th floor;
  - H_i is the maximum height of the building;
  - $D_{max\,i}$ is the maximum percentage of damage for the *i*th floor.

The parameters r_i and D_{max_i}, resulting from the calibration in the Australian context, are listed in the table below.

Number of samples	Parameters	*Range of parameters*		
		Minimum	***Most-likely***	***Maximum***
155	**r**	1.1	1.85	2
	D_{max}	48%	50%	60%

Table 4.26 – Number of samples and range of r and D_{max} values, calculated by the bootstrap and chi-square test goodness of fit.
Adapted from Hasanzadeh Nafari et al., International Journal of Disaster Risk Reduction, 2015.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Total asset value of the building, not clear if it is considered as the replacement value of the building, or as the market value of the building.
- Vulnerability parameters: Number of stories.

Model outputs

Relative damage to the building for each stage of water. The model considers only the damage to the structure and mechanical and electrical facilities.

Info on calibration

- Calibration context: The flood event occurred in Bundaberg (Queensland) from 21 to 29 January 2013 as a result of Tropical Cyclone Oswald. The height of the floodwaters in the city from Burnett river reached 9.53 meters at its peak.
- Dimension of the dataset: 155 masonry wall commercial buildings.
- Quality of the data: Official data set provided by the Queensland Reconstruction Authority.

Info on validation

- Validation context: The 2013 flood event in Bundaberg, as in the calibration context.
- Dimension of the dataset: The dimension of the dataset used for the validation is the same as the calibration. The set of values was shuffled and divided into three equal parts and then three iterations of model calibration and model testing were completed. For each iteration, one subset was used for the model testing and the other two were used for the model calibration.
- Quality of the data: Official data set provided by the Queensland Reconstruction Authority.
- Error:

	MBE	MAE	RMSE
Iteration 1	0.00	0.05	0.06
Iteration 2	0.00	0.04	0.05
Iteration 3	0.00	0.05	0.08
Average	0.00	0.05	0.06

Table 4.27 – Error estimation for performance of the applied damage functions (MBE: mean bias error; MAE: mean absolute error; RMSE: root mean squared error).
From Hasanzadeh Nafari et al., International of Disaster Risk Reduction, 2015.

Transferability

- Transferability: The model is described by a function that depends on the two parameters *r* and D_{max}, which are calibrated for the Australian context, and so the transferability of the model itself is limited to contexts similar to the one for which the model is calibrated.
- Applicability: The model is user friendly and the parameter of its function are easy to be obtained.

Bibliography

Hasanzadeh Nafari R., Ngo T., Lehman W., *Development and evaluation of FLFAcs – a new Flood Loss function for Australian commercial structures,* in "International Journal of Disaster Risk Reduction 17", 2016b, pp. 13-23.

4.4.2 JRC for commercial sector (Asia)

Filters for browsing the Repository

- Country of development: Africa
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Commercial sector

ID

- Name: JRC for commercial sector (Asia)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.28 – Average continental damage function for Asia – commercial sector.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to commercial land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in Asia is 138 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.4.3 JRC for commercial sector (Europe)

Filters for browsing the Repository

- Country of development: Europe
- Scale of analysis: Macroscale
- Flood type I:
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Commercial sector

ID

- Name: JRC for commercial sector (Europe)
- Year of the last update: 2007
- Authors: Jan Huizinga
- Linked models: JRC for agricultural crops (Europe), JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

Water depth [m]	Damage factor
0	0
0.5	0.15
1	0.3
1.5	0.45
2	0.55
3	0.75
4	0.90
5	1.00
6	1.00

Table 4.29 - Average continental damage function for Europe – commercial sector.
From Huizinga J., EU, 2007.

Model inputs

- Hazard parameters: Water depth.
- Exposure parameters: Buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to commercial land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor for the buildings structure and content, considered as the ratio between the absolute damage [€/m^2] and the national maximum damage value [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value for commerce is 621 €/m^2, considering the 2007 price level.

Info on calibration

- Calibration context: Data collection from three different sources: the Internet, the available literature at HVK consultants and damage assessment experts from different countries. The authors of literature found on the Internet (Neo BV, Gent University, Czech Technical University Prague and Stockholm University) were subjected to a non-standardized questionnaire by e-mail, in order to get clarification in relation to the inventories of the documents and know issues of the

country, and to know if they had any knowledge of damage assessment methods in adjacent countries. The depth-damage function that expresses the model is derived from the average of several depth-damage functions coming from these different sources.

- Dimension of the dataset: On the Internet, quantitative information about eleven different countries (Belgium, Czech Republic, Denmark, France, Germany, Hungary, Norway, Sweden, Switzerland, The Netherlands and United Kingdom) were found.
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2007, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

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

4.4.4 JRC for commercial sector (North America)

Filters for browsing the Repository

- Country of development: North America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Commercial sector

ID

- Name: JRC for commercial sector (North America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.30 - Average continental damage function for North America – commercial sector.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to commercial land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in North America is 1889 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.4.5 JRC for commercial sector (Oceania)

Filters for browsing the Repository

- Country of development: Oceania
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Commercial sector

ID

- Name: JRC for commercial sector (Oceania)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.31 - Average continental damage function for Oceania – commercial sector.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to commercial land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in Oceania is 506 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.4.6 JRC for commercial sector (South/Central America)

Filters for browsing the Repository

- Country of development: Central America, South America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Commercial sector

ID

- Name: JRC for commercial sector (South/Central America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.32 - Average continental damage function for South/Central America – commercial sector. From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Buildings area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective buildings' footprint area, or to the area related to commercial land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in South/Central America is 213 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.5 Industrial sector

4.5.1 JRC for industrial sector (Africa)

Filters for browsing the Repository

- Country of development: Africa
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Industrial sector

ID

- Name: JRC for industrial sector (Africa)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.33 - Average continental damage function for Africa – industrial sector.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Industrial sector area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective area, or to the area related to industrial sector land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).

The average maximum damage value in Africa is 120 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.5.2 JRC for industrial sector (Asia)

Filters for browsing the Repository

- Country of development: Asia
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Industrial sector

ID

- Name: JRC for industrial sector (Africa)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.34 - Average continental damage function for Asia – industrial sector.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Industrial sector area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective area, or to the area related to industrial sector land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in Asia is 114 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.5.3 JRC for industrial sector (Europe)

Filters for browsing the Repository

- Country of development: Europe
- Scale of analysis: Macroscale
- Flood type I:
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Industrial sector

ID

- Name: JRC for industrial sector (Europe)
- Year of the last update: 2007
- Authors: Jan Huizinga
- Linked models: JRC for agricultural crops (Europe), JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia), JRC for transport (South/Central America) and JRC for transport (Europe).

- Expression:

Water depth [m]	Damage factor
0	0
0.5	0.15
1	0.27
1.5	0.4
2	0.2
3	0.7
4	0.85
5	1.00
6	1.00

Table 4.35 - Average continental damage function for Europe – industrial sector.
From Huizinga, EU, 2007.

Model inputs

- Hazard parameters: Water depth.
- Exposure parameters: Industrial sector area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective area, or to the area related to industrial sector land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor for the buildings structure and content, considered as the ratio between the absolute damage [€/m^2] and the national maximum damage value [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value for industry is 534 €/m^2, considering the 2007 price level.

Info on calibration

- Calibration context: Data collection from three different sources: the Internet, the available literature at HVK consultants and damage assessment experts from different countries. The authors of literature found on the Internet (Neo BV, Gent University, Czech Technical University Prague and Stockholm University) were subjected to a non-standardized questionnaire by e-mail, in order to get clarification in relation to the inventories of the documents and know issues of the

country, and to know if they had any knowledge of damage assessment methods in adjacent countries. The depth-damage function that expresses the model is derived from the average of several depth-damage functions coming from these different sources.

- Dimension of the dataset: On the Internet, quantitative information about eleven different countries (Belgium, Czech Republic, Denmark, France, Germany, Hungary, Norway, Sweden, Switzerland, The Netherlands and United Kingdom) were found.
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2007, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

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

4.5.4 JRC for industrial sector (North America)

Filters for browsing the Repository

- Country of development: North America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Industrial sector

ID

- Name: JRC for industrial sector (North America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.36 - Average continental damage function for North America – industrial sector.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Industrial sector area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective area, or to the area related to industrial sector land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in North America is 1830 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.5.5 JRC for industrial sector (South/Central America)

Filters for browsing the Repository

- Country of development: Central America, South America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Industrial sector

ID

- Name: JRC for industrial sector (South/Central America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.37 - Average continental damage function for South/Central America – industrial sector.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Industrial sector area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective area, or to the area related to industrial sector land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in South/Central America is 137 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.6 Infrastructures (roads)

4.6.1 JRC for infrastructures (Asia)

Filters for browsing the Repository

- Country of development: Asia
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Infrastructures (roads)

ID

- Name: JRC for infrastructures (Asia)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.38 - Average continental damage function for Asia – infrastructures (roads).
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Infrastructures area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective area occupied by the infrastructure, or to the area related to infrastructures land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in Asia is 4 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.6.2 JRC for infrastructures (Europe)

Filters for browsing the Repository

- Country of development: Europe
- Scale of analysis: Macroscale
- Flood type I:
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Infrastructures (roads)

ID

- Name: JRC for infrastructures (Europe)
- Year of the last update: 2007
- Authors: Jan Huizinga
- Linked models: JRC for agricultural crops (Europe), JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America), JRC for transport (Asia) and JRC for transport (South/Central America).

- Expression:

Water depth [m]	Damage factor
0	0
0.5	0.25
1	0.42
1.5	0.55
2	0.65
3	0.8
4	0.9
5	1.00
6	1.00

Table 4.39 - Average continental damage function for Europe – infrastructures (roads).
From Huizinga, EU, 2007.

Model inputs

- Hazard parameters: Water depth.
- Exposure parameters: Infrastructures area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective area occupied by the infrastructure, or to the area related to infrastructure land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor for the buildings structure and content, considered as the ratio between the absolute damage [€/m^2] and the national maximum damage value [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value for infrastructures is 24 €/m^2, considering the 2007 price level.

Info on calibration

- Calibration context: Data collection from three different sources: the Internet, the available literature at HVK consultants and damage assessment experts from different countries. The authors of literature found on the Internet (Neo BV, Gent University, Czech Technical University Prague and Stockholm University) were subjected to a non-standardized questionnaire by e-mail, in order to get clarification in relation to the inventories of the documents and know issues of the

country, and to know if they had any knowledge of damage assessment methods in adjacent countries. The depth-damage function that expresses the model is derived from the average of several depth-damage functions coming from these different sources.

- Dimension of the dataset: On the Internet, quantitative information about eleven different countries (Belgium, Czech Republic, Denmark, France, Germany, Hungary, Norway, Sweden, Switzerland, The Netherlands and United Kingdom) were found.
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2007, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

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

4.7 Transports

4.7.1 JRC for transport (Asia)

Filters for browsing the Repository

- Country of development: Africa
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Transport

ID

- Name: JRC for transport (Asia)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America) and JRC for transport (South/Central America).

- Expression:

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	1.00

Table 4.40 - Average continental damage function for Asia – transport.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Transport area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective occupied area, or to the area related to the transport land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in Asia is 209 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.
  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.
  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.
  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.
  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.
  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.7.2 JRC for transport (South/Central America)

Filters for browsing the Repository

- Country of development: Central America, South America
- Scale of analysis: Macroscale
- Flood type I: Riverine, coastal
- Flood type II: Both
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Transport

ID

- Name: JRC for transport (South/Central America)
- Year of the last update: 2017
- Authors: Jan Huizinga, Hans de Moel and Wojciech Szewczyk
- Linked models: JRC for agricultural crops (Africa), JRC for agricultural crops (Asia), JRC for agricultural crops (North America), JRC for agricultural crops (Europe), JRC for commercial sector (Europe), JRC for commercial sector (Asia), JRC for commercial sector (North America), JRC for commercial sector (South/Central America), JRC for commercial sector (Oceania), JRC for industrial sector (Europe), JRC for industrial sector (Africa), JRC for industrial sector (Asia), JRC for industrial sector (North America), JRC for industrial sector (South/Central America), JRC for infrastructures (Europe), JRC for infrastructures (Asia), JRC for residential buildings (Europe), JRC for residential buildings (Africa), JRC for residential buildings (Asia), JRC for residential buildings (North America), JRC for residential buildings (Oceania), JRC for residential buildings (South/Central America) and JRC for transport (Asia).

- Expression:

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	1.00

Table 4.41 - Average continental damage function for South/Central America – transport.
From Huizinga et al., EU, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Transport area. Since the model is a macroscale model, it is not clear if the exposed value of area is referred to the effective occupied area, or to the area related to the transport land use.
- Vulnerability parameters: *Not available*

Model outputs

Damage factor, considered as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This fraction spans from zero (no damage) to one (maximum damage).
The average maximum damage value in South/Central America is 23 €/m^2, considering the 2010 price level.

Info on calibration

Calibration context: To construct the flood damage functions, quantitative data from literature and from various sources available at HKV consultants and VU University were collected. The depth-damage function that describes the model is derived from the average of several depth-damage functions coming from the literature.

- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in a tabulated form, the function governing the model is unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the table that expresses the model into a step graph, with each step with the same value of damage factor.

  Otherwise, translate the table that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of damage factor.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  It is important to point out that the model is a macroscale model. The application of it in another context, considering different scales of analysis, may lead to an overestimation or underestimation of the damage.

  In addition to that, the model considers the damage factor, as the ratio between the absolute damage [€/m^2] and the average maximum damage value per continent [€/m^2]. This last value is stated for the year 2010, so it must be adapted to the nowadays value in order to make the application of the model possible.

Bibliography

Huizinga J., Moel H. de, Szewczyk W., *Global flood depth-damage functions. Methodology and the database with guidelines*, EUR 28552 EN. doi: 10.2760/16510, 2017.

4.8 Multi – sectoral models

4.8.1 FLEMOcs+

Flood Loss Estimation Model for the commercial sector

Filters for browsing the Repository

- Country of development: Germany
- Scale of analysis: Microscale, mesoscale
- Flood type I: Riverine
- Flood type II: Low
- Model type I: Relative
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Commercial sector, industrial sector

ID

- Name: FLEMOcs+
- Year of the last update: 2010
- Authors: Heidi Kreibich, Isabel Seifert, Bruno Merz and Annegret H. Thieken
- Linked models: FLEMOps+ at the microscale, FLEMOps+ at the mesoscale
- Expression:

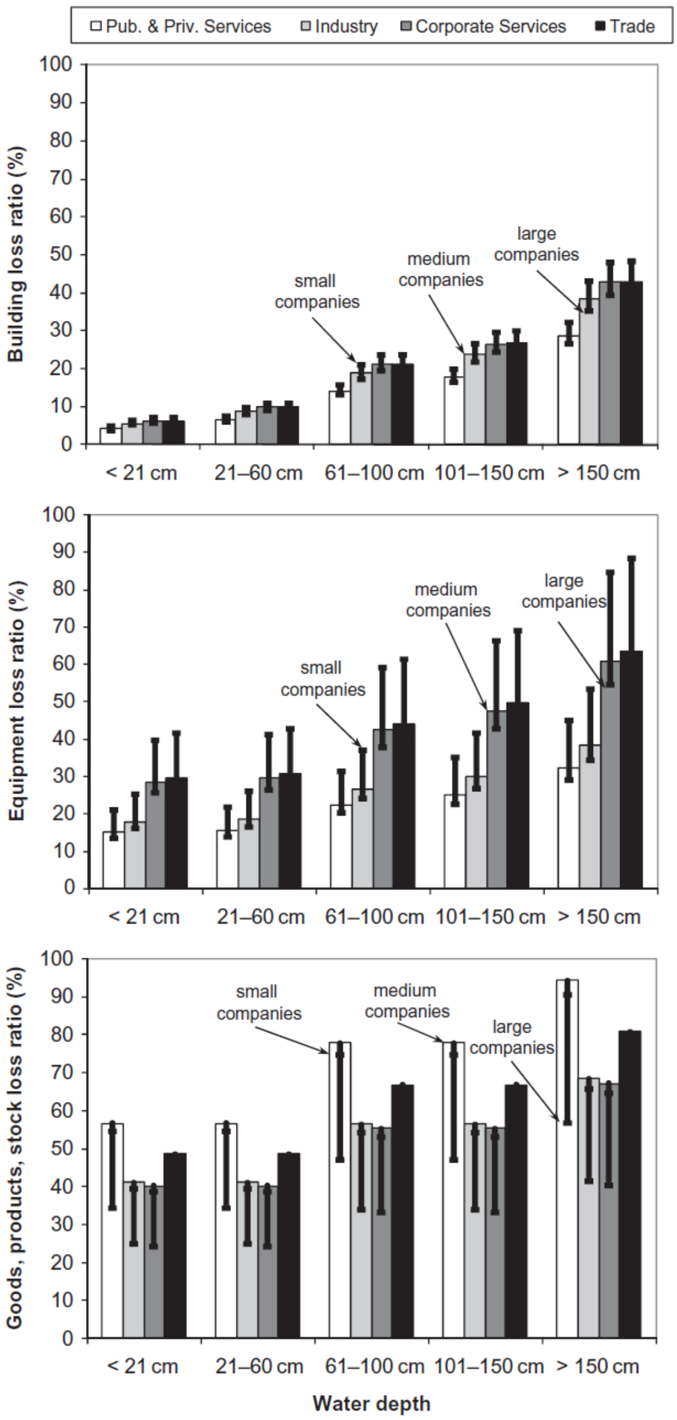

Figure 4.12 - First stage of the FLEMOcs model. Mean loss ratios of flood losses to buildings, equipment and goods, depending on water depth, sector and size of the company.
From Kreibich et al., Hydrological Sciences Journal, 2010.

If appropriate information is available, the model considers also scaling factors for loss ratio due to precautionary measures and contamination of the floodwater:

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

Table 4.42 – Scaling factor for the second stage of the micro-scale FLEMOcs model (FLEMOcs+) for company losses of buildings, equipment, and goods, products and stock, depending on contamination and precaution. From Kreibich et al., Hydrological Science Journal, 2010.

Note: the model can be applied both at the microscale level (i.e. single production sites) and at the mesoscale level (i.e. land-use units).

Model inputs

- Hazard parameters: Water depths, contamination of the flood water.
- Exposure parameters: Total asset value of the building (replacement or depreciated, whether considering goods, products and stocks or the building structure).
- Vulnerability parameters: Size of the company, with respect to the number of employees (small companies: 1-10 employees, medium companies: 11-100 employees, large companies: >100 employees), economic sector (public and private services, producing industry, corporate services, trade).

Model outputs

Mean loss ratio [%] of flood losses to buildings, equipment and goods, products and stock, with respect to the monetary value of the exposed assets (replacement or depreciated). Probably the relative damage to goods, products and stock has been calculated considering the replacement value of the exposed assets, while the relative damage to the buildings has been calculated considering the depreciated value of the exposed assets. It is not clear if the total asset values refer to the damage to the entire building or to the damage to the flooded area.

Info on calibration

- Calibration context: The 2002, 2005 and 2006 floods occurred in Germany. Heavy precipitation with record-breaking amounts, resulted in high discharges and water levels in the rivers Elbe and Danube and some of their tributaries.
- Dimension of the dataset: 642 loss cases. For the 2002 flood, 415 interviews were completed in October 2003 and May 2004. In October 2006, other 227 interviews were completed, with 64 companies affected in the 2002 flood, 102 companies affected in the 2005 flood and 61 companies affected in the 2006 flood.
- Quality of the data: Observed data coming from a standard questionnaire investigation, which addresses the following topics: characteristics of the company, flood characteristics, flood warning, emergency measures, clean-up, characteristics of and damage to the buildings, characteristics of and damage to the contents, interruption and constraints to business, recovery, preparedness, flood experience and awareness.

Info on validation

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Since the model is given in graphical terms, the functions governing the model are unknown, so it is difficult to calibrate and validate them in another context.
- Applicability: The application of the model in another context can be done in different ways, still with significant approximations.

  The first option is to translate the graph that expresses the model into a step graph, with each step with the same value of relative damage.

  Otherwise, translate the graph that expresses the model into a continuous function and extrapolate the tendency lines. Using the equations that expresses these tendency lines, it is possible to calculate, for each water depth, the correspondent interpolated value of relative damage.

  One last option may consist in translate the table that expresses the model into a curve with and assumed linear behaviour between each water-damage point.

  Depending on which approach the user decides to use, the estimation of the damage will be different.

  Since the model requires several important factors influencing the loss ratios, its application in another context results to be fine only if enough data are available (i.e. size of the company, economic sector).

  In addition to that, the model considers the percentage damage as the ratio between the loss and the corresponding total asset value of the exposed item. In the application of the model, it may be difficult to know this last information, in particular for what concerns the total asset value of goods, products and stocks.

Bibliography

Kreibich H., Seifert I., Merz B., Thieken A.H., *Development of FLEMOcs – a new model for the estimation of flood losses in the commercial sector,* in "Hydrological Sciences Journal 55(8)*",* 2010, pp. 1302-1314.

4.8.2 Bignami et al. (water depth)

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low velocity
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings, commercial sector

ID

- Name: Bignami et al. (water depth)
- Year of the last update: 2017
- Authors: Daniele Fabrizio Bignami, Maria Cristina Rulli and Renzo Rosso
- Linked models: Bignami et al. (urban coverage index), Bignami et al. (water velocity), Bignami et al. (bivariate model)
- Expression:

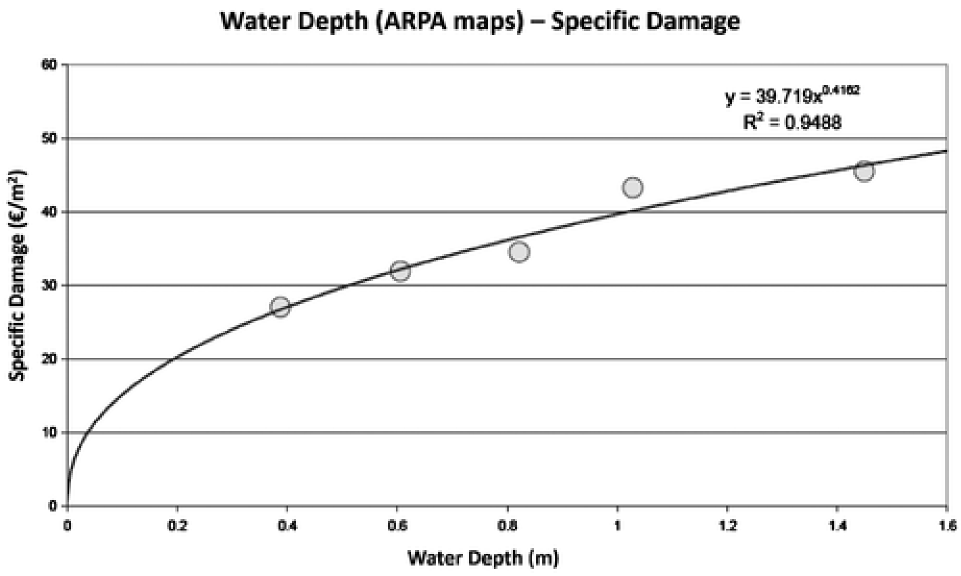

Figure 4.13 - Damage curve 'Water depth versus Specific damage' on the basis of interpolated ARPA maps (water depth data grouped in five classes).
From Bignami et al., Journal of Flood Risk Management, 2017.

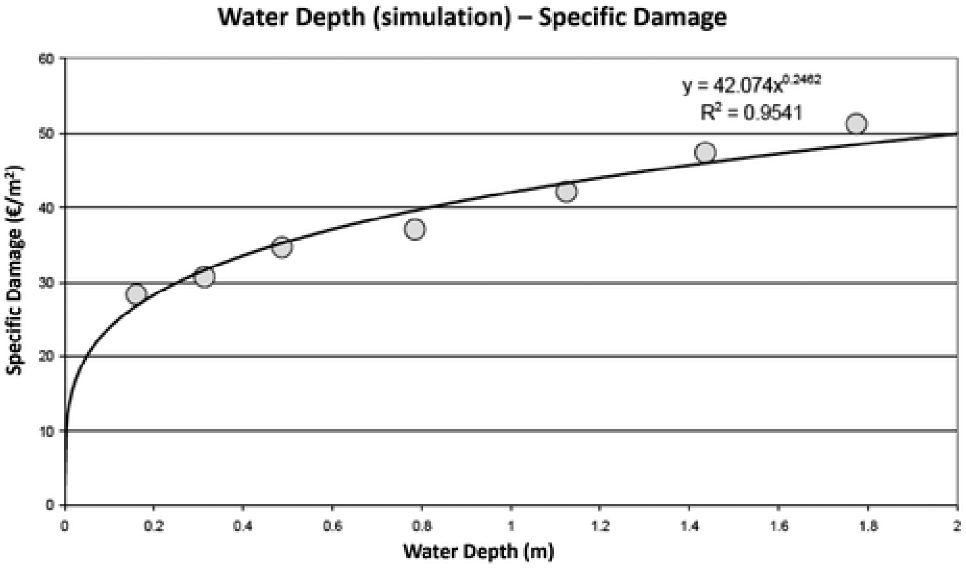

Figure 4.14 - Damage curve 'Water depth versus Specific Damage' on the basis of our simulations (water depth data grouped in seven classes).
From Bignami et al., Journal of Flood Risk Management, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Total area of the reference unit.
- Vulnerability parameters: *Not available*

Model outputs

Absolute damage per square meter of flooded area for structures and contents.

Info on calibration

- Calibration context: The 2000 flood in Piedmont, Italy. From 13 to 16 October 2000, heavy rainfall over the Alps caused a severe flood, combining high precipitation levels, snowmelt and saturated ground conditions. In Piedmont, about 70 km^2 of the land surface was flooded.
  The study areas are two portions of the Po River basin: the sub-basin of the Dora Baltea River and the final part of the Po River basin in Piedmont. The two areas are composed of four and five municipalities respectively: Fiorano Canavese, Banchette, Salerano Canavese, Samone and Pavone Canavese for the Dora Baltea and Trino Vercellese, Morano sul Po, Balzola and Casale Monferrato for the final part of the Po River. The two rivers, in the two areas, flow in flat valleys with spacious flood plains with absence of landslides and debris flow.

- Dimension of the dataset: 7017 requests for aid from private citizens and 351 from enterprises.
- Quality of the data: Modelled mean water depths and observed reimbursed damage data (equal to 70-85% of the real damage, according to the authors). This means that the model data are an underestimation of the declared damage.

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Effective only in contexts similar to the one of the calibration. In addition to that, even if the model has a clear expression, the procedure of aggregation of the points that make the damage curve is not explained.
- Applicability: The model is user friendly and easy to be applied.

Bibliography

Bignami D.F., Rulli M.C., Rosso R., *Testing the use of reimbursement data to obtain damage curves in urbanised areas: the case of the Piedmont flood on October 2000,* in "Journal of Flood Risk Management 11", pp. S575-S593, 2017.

4.8.3 Bignami et al. (urban coverage index)

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low velocity
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings, commercial sector

ID

- Name: Bignami et al. (urban coverage index)
- Year of the last update: 2017
- Authors: Daniele Fabrizio Bignami, Maria Cristina Rulli and Renzo Rosso
- Linked models: Bignami et al. (water depth), Bignami et al. (water velocity), Bignami et al. (bivariate model)
- Expression:

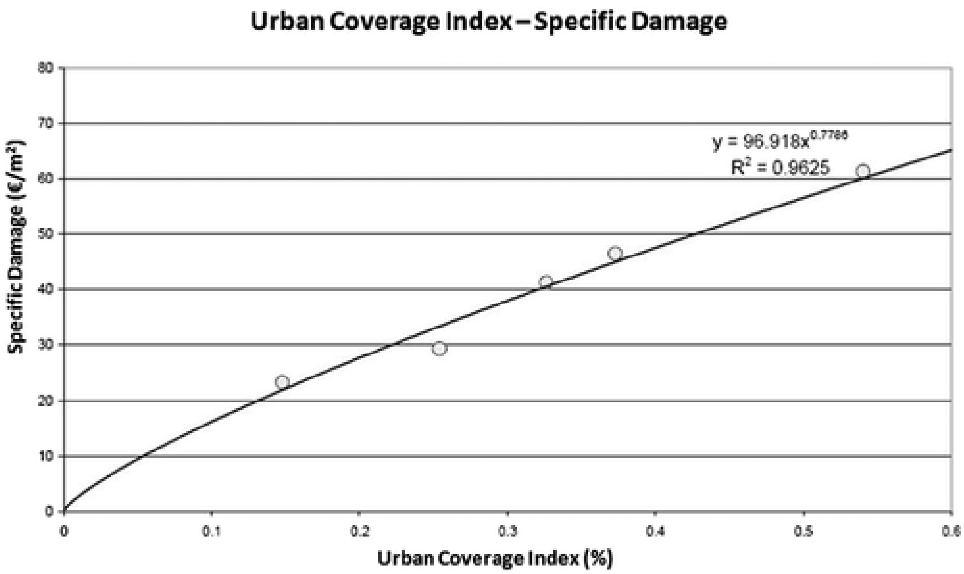

Figure 4.15 - Damage curve 'Specific damage versus Urban coverage index' (water depth data grouped in five classes).
From Bignami et al., Journal of Flood Risk Management, 2017.

Model inputs

- Hazard parameters: *Not available*
- Exposure parameters: Urban coverage index and total area of the reference unit.
- Vulnerability parameters: *Not available*

Model outputs

Absolute damage per square meter of flooded area, for structures and contents.

Info on calibration

- Calibration context: The 2000 flood in Piedmont, Italy. From 13 to 16 October 2000, heavy rainfall over the Alps caused a severe flood, combining high precipitation levels, snowmelt and saturated ground conditions. In Piedmont, about 70 km^2 of the land surface was flooded.

  The study areas are two portions of the Po River basin: the sub-basin of the Dora Baltea River and the final part of the Po River basin in Piedmont. The two areas are composed of four and five municipalities respectively: Fiorano Canavese, Banchette, Salerano Canavese, Samone and Pavone Canavese for the Dora Baltea and Trino Vercellese, Morano sul Po, Balzola and Casale Monferrato for the final part of the Po River. The two rivers, in the two areas, flow in flat valleys with spacious flood plains with absence of landslides and debris flow.
- Dimension of the dataset: 7017 requests for aid from private citizens and 351 from enterprises..
- Quality of the data: Calculated urban cover index, observed reimbursed damage (equal to 70-85% of the real damage, according to the authors). This means that the model data are an underestimation of the declared damage.

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Effective only in contexts similar to the one of the calibration. In addition to that, even if the model has a clear expression, the procedure of aggregation of the points that make the damage curve is not explained.
- Applicability: The model is user friendly and easy to be applied.

Bibliography

Bignami D.F., Rulli M.C., Rosso R., *Testing the use of reimbursement data to obtain damage curves in urbanised areas: the case of the Piedmont flood on October 2000,* in "Journal of Flood Risk Management 11", pp. S575-S593, 2017.

4.8.4 Bignami et al. (water velocity)

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low velocity
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings, commercial sector

ID

- Name: Bignami et al. (water velocity)
- Year of the last update: 2017
- Authors: Daniele Fabrizio Bignami, Maria Cristina Rulli and Renzo Rosso
- Linked models: Bignami et al. (urban coverage index), Bignami et al. (water depth), Bignami et al. (bivariate model)
- Expression:

  Specific damage curve

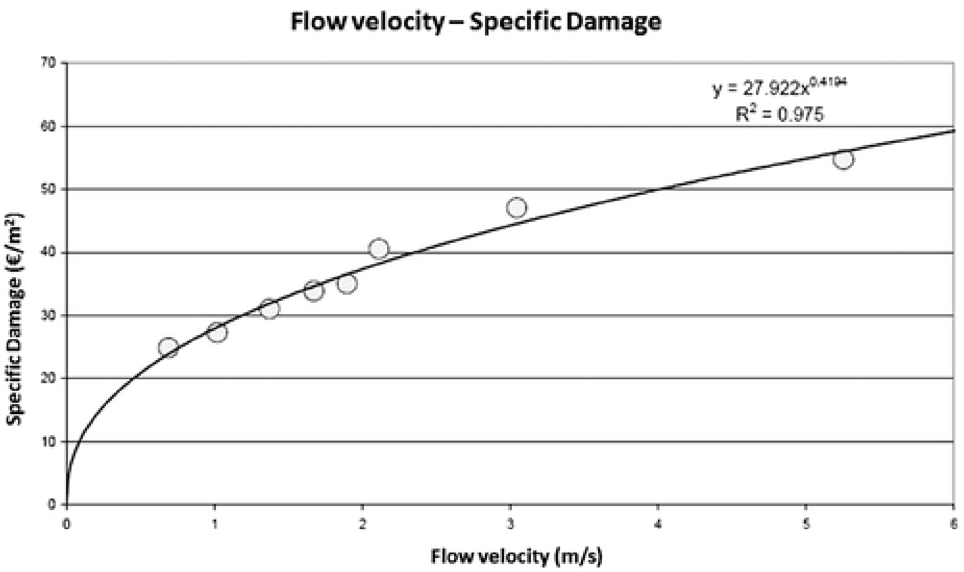

Figure 4.16 - Damage curve 'Flow velocity versus Specific damage' (water depth data grouped in eight classes).
From Bignami et al., Journal of Flood Risk Management, 2017.

Model inputs

- Hazard parameters: Water velocities.
- Exposure parameters: Total area of the reference unit.
- Vulnerability parameters: *Not available*

Model outputs

Absolute damage per square meter of flooded area, for structures and contents.

Info on calibration

- Calibration context: The 2000 flood in Piedmont, Italy. From 13 to 16 October 2000, heavy rainfall over the Alps caused a severe flood, combining high precipitation levels, snowmelt and saturated ground conditions. In Piedmont, about 70 km^2 of the land surface was flooded.
  The study areas are two portions of the Po River basin: the sub-basin of the Dora Baltea River and the final part of the Po River basin in Piedmont. The two areas are composed of four and five municipalities respectively: Fiorano Canavese, Banchette, Salerano Canavese, Samone and Pavone Canavese for the Dora Baltea and Trino Vercellese, Morano sul Po, Balzola and Casale Monferrato for the final part of the Po River. The two rivers, in the two areas, flow in flat valleys with spacious flood plains with absence of landslides and debris flow.
- Dimension of the dataset: 7017 requests for aid from private citizens and 351 from enterprises
- Quality of the data: Modelled mean water velocities and observed reimbursed damage data (equal to 70-85% of the real damage, according to the authors). This means that the model data are an underestimation of the declared damage.

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Effective only in contexts similar to the one of the calibration. In addition to that, even if the model has a clear expression, the procedure of aggregation of the points that make the damage curve is not explained.
- Applicability: The model is user friendly and easy to be applied.

Bibliography

Bignami D.F., Rulli M.C., Rosso R., *Testing the use of reimbursement data to obtain damage curves in urbanised areas: the case of the Piedmont flood on October 2000,* in "Journal of Flood Risk Management 11", pp. S575-S593, 2017.

4.8.5 Bignami et al. (bivariate model)

Filters for browsing the Repository

- Country of development: Italy
- Scale of analysis: Mesoscale
- Flood type I: Riverine
- Flood type II: Low velocity
- Model type I: Absolute
- Model type II: Empirical
- Model type III: Deterministic
- Exposed item/sectors: Residential buildings, commercial sector

ID

- Name: Bignami et al. (bivariate model)
- Year of the last update: 2017
- Authors: Daniele Fabrizio Bignami, Maria Cristina Rulli and Renzo Rosso
- Linked models: Bignami et al. (urban coverage index), Bignami et al. (flow velocity), Bignami et al. (water depth)
- Expression:

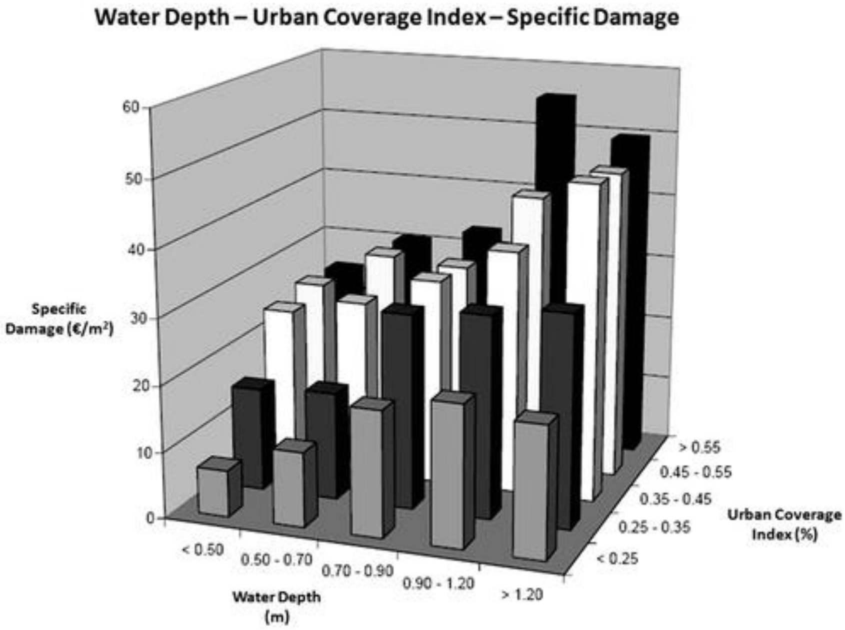

Figure 4.17 - Damage 3D function 'Water depth versus Urban coverage index versus Specific damage' on the basis of interpolated ARPA maps (water depth grouped in eight classes).
From Bignami et al., Journal of Flood Risk Management, 2017.

Model inputs

- Hazard parameters: Water depths.
- Exposure parameters: Total area of the reference unit.
- Vulnerability parameters: Urban coverage index.

Model outputs

Absolute damage per square meter of flooded area, for structures and contents.

Info on calibration

- Calibration context: The 2000 flood in Piedmont, Italy. From 13 to 16 October 2000, heavy rainfall over the Alps caused a severe flood, combining high precipitation levels, snowmelt and saturated ground conditions. In Piedmont, about 70 km^2 of the land surface was flooded.

  The study areas are two portions of the Po River basin: the sub-basin of the Dora Baltea River and the final part of the Po River basin in Piedmont. The two areas are composed of four and five municipalities respectively: Fiorano Canavese, Banchette, Salerano Canavese, Samone and Pavone Canavese for the Dora Baltea and Trino Vercellese, Morano sul Po, Balzola and Casale Monferrato for the final part of the Po River. The two rivers, in the two areas, flow in flat valleys with spacious flood plains with absence of landslides and debris flow.
- Dimension of the dataset: 7017 requests for aid from private citizens and 351 from enterprises
- Quality of the data: Modelled mean water depths, calculated cover index, observed reimbursed damage (equal to 70-85% of the real damage, according to the authors). This means that the model data are an underestimation of the declared damage.

Info on validation:

- Validation context: *Not available*
- Dimension of the dataset: *Not available*
- Quality of the data: *Not available*
- Error: *Not available*

Transferability

- Transferability: Effective only in contexts similar to the one of the calibration. In addition to that, even if the model has a clear expression, the procedure of aggregation of the points that make the damage curve is not explained.
- Applicability: The model is user friendly and easy to be applied.

Bibliography

Bignami D.F., Rulli M.C., Rosso R., *Testing the use of reimbursement data to obtain damage curves in urbanised areas: the case of the Piedmont flood on October 2000,* in "Journal of Flood Risk Management 11", pp. S575-S593, 2017.

4.9 Further development of the Flood Damage Models Repository

The current state of literature includes many more flood damage models, in addition to those already mentioned in the development of this work.

The final goal of the evolution of the FDM is to contain as many flood damage models as possible in order to become even more complete, robust and reliable. The involvement of flood damage modelers and researches plays a major role in pursuing this goal. With their knowledge and experience in flood damage assessment, they can contribute in enlarging the already existing database as well as to verify those already included.

As mentioned before, in the section related to the website implementation, the FDM is furnished with an operative counter, which counts in real time which are the uploaded models and which are the missing models, not uploaded yet. The counter updates its values every time a model(s) is entered or removed.

The missing model section is associated to the list of the not uploaded model, that is updated every time someone becomes aware of the existence of a new model, or every time a new model is being developed.

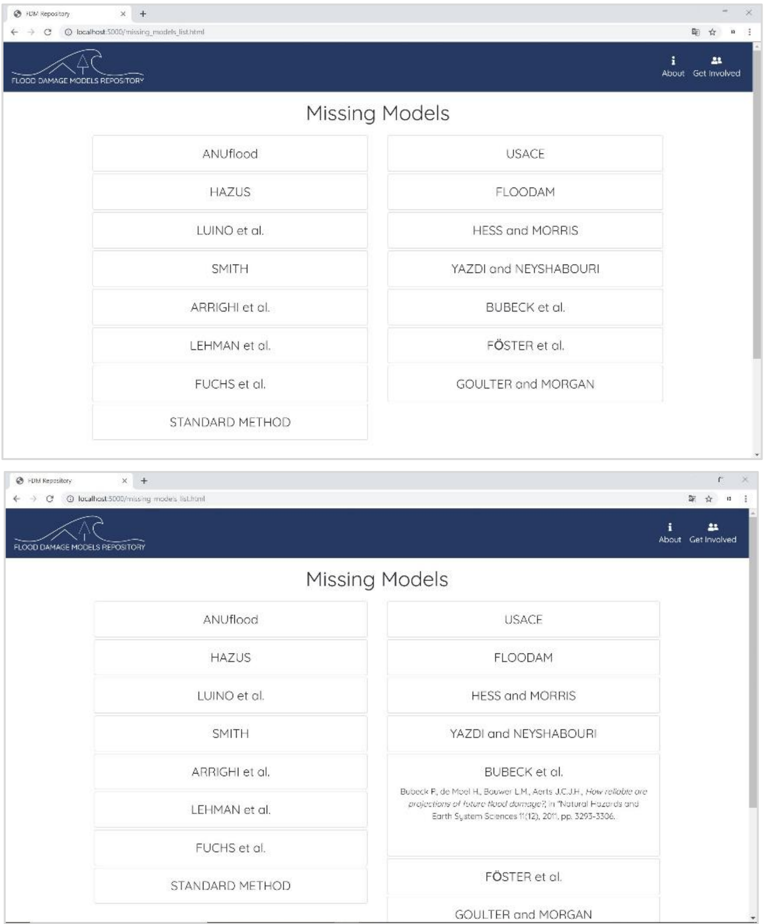

Figure 4.18 - The missing model section as compares in the FDM website. It is composed by the list of all the not available models.

For now, the FDM counts as not uploaded models yet, the following flood damage models, together with their scientific paper.

- **ANUflood**

- **HAZUS-MH**

- **LUINO et al.**

  Luino F., Chiarle M., Nigrelli G., Agangi A., Bidoccu M, Cirio C. G., Giulietto W., *A model for estimating flood damage in Italy: preliminary results*, in "WIT Transactions on Ecology and Environment 98", 2006, pp. 65-74.

- **SMITH D.I.**

  Smith D.I., *Flood damage estimation – a review of urban stage-damage curves and loss functions,* in "Water SA 20", 1994, pp. 231-238.

- **ARRIGHI et al.**

  Arrighi C., Brugioni M., Castelli F., Franceschini S., Mazzanti B., *Urban micro-scale flood risk estimation with parsimonius hydraulic modelling and census data,* in "Natural Hazards and Earth System Sciences 13(5)", 2013, pp. 1375-1391.

- **LEHMAN et al.**

  Lehman W., Hasanzadeh Nafari R., *An Empirical, Functional approach to depth damages*, in "E3S Web of Conferences 7, 05002", 2016.

- **FUCHS et al.**

  Fuchs S., Heiser M., Schlögl M., Zischg A., Papathoma-Köhle M., Keiler M., *Short Communication: A model to predict flood loss in mountain areas,* in "Environmental Modelling and Software 117", 2019, pp.176-180.

- **STANDARD METHOD**

  Kok M., Huizinga H.J., Vrouwenvelder A.C.W.M., Barendregt A., *Standard method 2004. Damage and casualties caused by flooding,* Highway and Hydraulic Engineering Department, 2004.

- **USACE**

  Davis D., Faber B. A., Stedinger J. R., *USACE experience in implementing risk analysis for flood damage reduction* projects, in "Journal of Contemporary Water Research & Education 140(1)", 2008, pp. 3-14.

- **FLOODAM**

  Richert C., Boisgontier H., Grelot F., *Economic assessment of measures aimed at reducing flood damage to buildings using computer modelling and expert judgement*, in "Natural Hazards and Earth System Sciences 161", in review 2019.

- **BN-FLEMOps**

  Schröter K., Kreibich H., Vogel K., Riggelsen C., Scherbaum F., Merz B., *How useful are complex flood damage models?*, in "Water Resources Research 50(4)", 2014, pp. 3378-3395.

- **HESS and MORRIS**

  Hess T.M., Morris J., *Estimating the value of flood alleviation on agricultural grassland*, in "Agricultural Water Management 15(2)", 1988, pp. 141-153.

- **YAZDI and NEYSHABOURI**

  Yazdi J., Neyshabouri S.A.A., *Optimal design of flood-control multi-reservoir system on a watershed scale*, in "Natural Hazards 63(2)", 2012, pp. 629-646.

- **BUBECK et al.**

  Bubeck P., de Moel H., Bouwer L.M., Aerts J.C.J.H., *How reliable are projections of future flood damage?*, in "Natural Hazards and Earth System Sciences 11(12), 2011, pp. 3293-3306.

- **FÖSTER et al.**

  Förster S., Kuhlmann B., Lindenschmidt K.-E., Bronstert A, *Assessing flood risk for a rural detention area*, in "Natural Hazards and Earth System Sciences 8", 2008, pp. 311-322.

- **GOULTER and MORGAN**

  Goulter I. C., Morgan D. R., *Analyzing Alternative Flood Damage reduction Measures on Small Watersheds Using Multiple return Period Floods*, in “Water Resources Research 19(6), 1983, pp. 1376–1382.

This flood damage models list is clearly in update.

5. Conclusions

This thesis presents the conceptualization of a Flood Damage Models Repository and its implementation in a software and in a website. Its principal purpose is to support flood damage modelers in the choice of the best available models for a specific context and a specific problem at stake.

The version of the Flood Damage Models Repository presented in this thesis is a preliminary version. It has been developed primary to represent an opportunity to increase knowledge gaps on flood damage assessment tools by providing for each available model fundamental key information in order not to lead to an improper use of the model and then significant errors in the flood damage assessment. At the end of this first implementation of the FDM, the structure of itself results to be sufficiently good to accomplish the suitability of the FDM to include all the possible typologies of models, in terms of different scale of analysis, type of flood, exposed items, level of uncertainty, etc. Before launching the final version of the FDM, it must be crucial to solve the issues related to the privacy policy.

On this basis, the future development of this work will be its presentation to the scientific community throughout conferences and seminars. In fact, one of the next intentions is the presentation of the FDM at the Flood Risk Management Technical Committee (FRMTC) of the IAHR (International Association for Hydro-Environmental Engineering and Research), throughout which the FDM will be promoted, in order to increase its visibility and to allow its testing to as many people as possible.

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