DELIVERABLE D.T5.1.3

Improvements in flood loss estimation methods

EMfloodReilience

INTERREG Euregio Maas-Rijn | Project No. EMR228

The EMfloodResilience project is being carried out within the context of Interreg V-A Euregio Meuse-Rhine and is 90% funded by the European Regional Development Fund.

Dissemination level	Public
Type of deliverable	Report
Work package	WP5
Deliverable number	D.T5.1.3
Status - version, date	V1, 11/12/2023 (final)
Deliverable leader	**Delft University of Technology** Ir. Nils van der Vliet Prof. Dr. Ir. Matthijs Kok
Deliverable contributors	**University of Liège** Ir. Daniela Rodriguez Castro Prof Dr. Benjamin Dewals **RWTH Aachen University** Eva Vonden, M.Sc. Dr.-Ing. Elena-Maria Klopries
Contractual date of delivery	31/12/2023
Keywords	Flood damage modeling, flood loss, survey, damage function, flood impact data

Legal Disclaimer

Table of contents

List of Figures

List of Tables

List of abbreviations and acronyms

Abbreviation	Meaning
AHN	Actueel hoogtebestand Nederland (Current Elevation Model Netherlands)
BAG	Basisregistratie Adressen en Gebouwen (base registration adresses and buildings)
BE	Belgium
BEAM	Basic European Asset Map
BGT	Basisregistratie Grootschalige Topografie (Large-scale Topography Base Registry)
CLC	Corine Land Cover
DE	Germany
GIS	Geographical Information System
MBE	Mean Bias Error
NL	The Netherlands
NRW	North Rhine-Westphalia
RMSE	root mean squared error
RRMSE	relative root mean squared error
SQM of WL	Semi-quantitative method of WL
SSM	Schade en Slachtoffer Module (Damage and Victim module)
WL	Waterschap Limburg (The Water Authority of Limburg)
WSS	WaterSchadeSchatter (WaterDamageEstimator)

Executive Summary

The EU Floods Directive mandates all member states to conduct periodic flood hazard and risk assessments. However, the approaches to economic damage assessments differ across the Euregio Meuse-Rhine. The three countries—Germany, the Netherlands, and Belgium—utilize distinct damage models, resulting in significant variations in calculated economic damages. Flood damage models are crucial for determining flood risk and gaining insights into the cost-benefit efficiency of measures. We have seen in the three countries that relative simple, semi-quantitative, approaches are employed to estimate potential flood damage at regional levels.

To analyze the diverse methods used in the Euregio Meuse-Rhine, survey data from the July 2021 event is collected and used to compare model results. Various perspectives are compared to identify areas where model improvements can be made. In this research, a recently adapted model for the Walloon region is analyzed. Unfortunately, it is very rare that extensive and consistent flood damage data are collected transnationally, mainly because private insurance companies are not able to share the data on individual objects. Hence, it is difficult to use and analyze various damage models with a large dataset. However, this research demonstrates the value and effectiveness of comparing damage models for different locations and in combination with different models, potentially leading to model improvements by leveraging the strengths of others.

The overall trend in current damage models raises the question of whether a more detailed model leads to a better model performance. Since damage depends on many factors that are challenging to collect, one can argue that assessing the damage of a region as accurately as possible involves using models that estimate average damage effectively. This implies that local details should only be used if corresponding data are available and reliable; otherwise, there is a risk that details may not add value.

The focus of this research is directed toward damages to buildings, including the aspects of household content damages. This means that the results of this research are specific to this part of the damage models; conclusions can differ in other categories of the models. By concentrating on building damage, a clear understanding of the strengths and weaknesses of this type of damage is obtained.

Samenvatting

De EU Overstromingsrichtlijn verplicht alle lidstaten om periodieke overstromingsgevaar- en risicobeoordelingen uit te voeren. In de Euregio Maas-Rijn verschillen echter de benaderingen voor economische schadebeoordelingen. De drie landen - Duitsland, Nederland en België - maken gebruik van verschillende overstromingsschademodellen, wat resulteert in aanzienlijke variaties in berekende economische schade. Schademodellen zijn cruciaal om overstromingsrisico's te bepalen en inzicht te krijgen in de kosteneffectiviteit van maatregelen. Tijdens dit onderzoek is gebleken dat in de drie landen relatief eenvoudige, semi-kwantitatieve, benaderingen worden toegepast om potentiële overstromingsschade op regionaal niveau te schatten.

Om de diverse methoden die in de Euregio Maas-Rijn worden gebruikt te analyseren, zijn enquêtes uitgevoerd met betrekking tot de overstroming in juli 2021. Deze enquêtes zijn gebruikt om de resultaten van schademodellen te vergelijken. Diverse perspectieven zijn vergeleken om aspecten te identificeren waar verbeteringen aan schademodellen kunnen worden aangebracht. In dit onderzoek is onder andere een recent aangepast model voor de Waalse regio van België geanalyseerd. Uitgebreide en consistente gegevens over overstromingsschade worden zeer zelden verzameld, voornamelijk omdat particuliere verzekeringsmaatschappijen de gegevens over individuele objecten niet kunnen delen. Het is daarom ingewikkeld gebleken om uitgebreide datasets te vinden waarmee de verschillende schademodellen gebruikt en geanalyseerd kunnen worden. Desondanks toont dit onderzoek de waarde en effectiviteit aan van het vergelijken van schademodellen op verschillende locaties en onderling met elkaar. Wat vervolgens kan leiden tot verbeterpunten van de modellen door gebruik te maken van de sterke punten van andere modellen.

De algehele trend in de huidige schademodellen roept de vraag op of een gedetailleerder model leidt tot een beter schademodel op kleine schaal. Echter, schade is afhankelijk van diverse moeilijk te verzamelen factoren wat voor de benodigde aannames kan zorgen. Daarom kan men betogen dat een goede inschatting van de schade vereist dat schademodellen gemiddeld gezien het schadebedrag van een gebied goed kunnen bepalen. Dit impliceert dat lokale details alleen gebruikt moeten worden wanneer deze beschikbaar en betrouwbaar zijn. Anders voegt de mate van detail wellicht geen waarde toe, wat mogelijk zelfs ruis kan veroorzaken.

De focus van dit onderzoek en daarmee de resultaten ligt op schade aan gebouwen, inclusief inboedelschade. De conclusies kunnen verschillen voor andere categorieën zoals voor infrastructuur en landbouw in de schademodellen. Door ons te concentreren op schade aan gebouwen krijgen we een duidelijk begrip van de sterke en zwakke punten van dit type schadeberekeningen.

Résumé

La directive Inondations de l'Union européenne impose à tous les états membres d'évaluer périodiquement l'aléa et le risque d'inondation. Cependant, les approches pour l'évaluations des dommages économiques diffèrent au sein de l'Euregio Meuse-Rhin. Les régions considérées ici, dans les trois pays (Allemagne, Pays-Bas et Belgique), utilisent des modèles de dommages distincts, ce qui peut conduire à d'importantes variations dans les estimations des dommages économiques. Ces modèles de dommages induits par les inondations sont cruciaux pour déterminer le niveau de risque et évaluer l'efficacité coût-bénéfice de mesures de réduction de ce risque. Des approches relativement simples et semi-quantitatives sont majoritairement utilisées pour estimer les dommages potentiels dus aux inondations au niveau régional.

Afin d'évaluer les différentes méthodes utilisées dans l'Euregio Meuse-Rhin, des données récoltées dans le cadre d'enquête de terrain, réalisées à la suite des inondations de 2021, ont été comparées aux prédictions des modèles. Diverses perspectives sont envisagées afin d'identifier les aspects sur lesquels des améliorations peuvent être apportées aux modèles. Dans cette recherche, un modèle récemment adapté pour la Région wallonne est analysé (INSYDE-BE). Il est rare que des données détaillées à propos des dommages induits par des inondations soient collectées de manière cohérente à travers plusieurs pays et mises à profit pour évaluer des modèles de dommages. La recherche présentée ici illustre la plus-value de comparaisons systématiques de modèles de dommages, développés dans différents contextes, pour identifier des voies d'amélioration de ces modèles en exploitant les points forts des autres.

Par conséquent, il est difficile d'utiliser et d'analyser divers modèles de dommages avec un ensemble de données important. Cependant, cette recherche démontre la valeur et l'efficacité de la comparaison des modèles de dommages pour différentes localités et en combinaison avec différents modèles, potentiellement conduisant à des améliorations en exploitant les points forts des autres.

Une question importante est le niveau de détails le plus adéquat pour un modèle de dommages. Étant donné que les dommages dépendent de nombreux facteurs difficiles à collecter, on pourrait être tenté de privilégier une méthode de calcul qui estime correctement la moyenne des dommages à l'échelle d'une région. De manière générale, une approche détaillée se justifie si les données correspondantes sont disponibles et fiables; sinon, il existe un risque qu'augmenter le niveau de détails n'ajoute pas de valeur.

Cette recherche est principalement focalisée sur les dommages aux bâtiments résidentiels, y compris au contenu. Pour ce type de dommages, la recherche a mis en évidence des points forts et des faiblesses des modèles de dommage régionaux disponibles. En revanche, les conclusions ne sont vraisemblablement pas transposables telles quelles à d'autres types d'enjeux.

Zusammenfassung

Die EU-Hochwasserrisikomanagementrichtlinie schreibt vor, dass alle Mitgliedstaaten Hochwassergefahren- und -risikobewertungen durchführen müssen. Die Ansätze für die ökonomische Schadensbewertung unterscheiden sich jedoch in der Euregio Maas-Rhein. Die drei Länder - Deutschland, die Niederlande und Belgien - verwenden unterschiedliche Schadensmodelle, was zu erheblichen Unterschieden in den berechneten wirtschaftlichen Schäden führt. Hochwasserschadensmodelle sind entscheidend, um das Hochwasserrisiko zu bestimmen und die Kosten-Nutzen-Effizienz von Maßnahmen abzuschätzen. In allen drei Ländern werden relativ einfache, halbquantitative Ansätze verwendet um potenzielle Hochwasserschäden auf regionaler Ebene abzu schätzen.

Um die verschiedenen Methoden, die in der Euregio Maas-Rhein angewendet werden zu analysieren, wurden in einer Umfrage Daten zum Hochwasserereignis im Juli 2021 gesammelt und zum Vergleich der Modellergebnisse verwendet. Verschiedene Perspektiven werden verglichen, um ezu identifizieren, an welchen StellenVerbesserungen der Schadensmodelle vorgenommen werden können. In der vorliegenden Studie wird ein kürzlich angepasstes Modell für die belgische Region Wallonien analysiert. Diese Analyse zeigt, dass der Vergleich von Schadensmodellen für unterschiedlichee Standorte und in Kombination mit verschiedenen Modellen möglicherweise zu einer Verbesserung der Modelle führt, in dem die Stärken anderer Modelle genutzt werden. Da die bei Versicherungsunternehmen vorliegenden Daten meist nicht öffentlich zugänglich sind, ist es jedoch meist schwierig, verschiedene Schadensmodelle anhand eines großen Datensatzes zu analysieren.

Insgesamt wird deutlichwird die Frage aufgeworfen, ob ein detaillierteres Schadensmodell grundsätzlich zu einem besseren Modellergebnis führt. Da die Schäden von vielen schwer zu erfassenden Faktoren abhängen, kann es sinnvoller sein, die Bewertung der Schäden einer Region mittels Modellen durchzuführen, die auf einer effektiven durchschnittlichen Schätzung basieren. Dies impliziert, dass lokale Details möglicherweise keinen grundsätzlichen Mehrwert bieten, sondern stattdessen zu Ungenauigkeiten durch fehlende Detailinformationen führen können.

Der Fokus der vorliegenden Untersuchung liegt auf Schäden an Gebäuden einschließlich der Schäden an Hausratsgegenständen. Das bedeutet, dass die Ergebnisse dieser Studie spezifisch für diesen Teil der Schadensmodelle sind; für andere Modellkategorien können Schlussfolgerungen daher anders ausfallen. Durch die Konzentration auf Gebäudeschäden wird ein klares Verständnis der Stärken und Schwächen dieser Art von Schäden erlangt.

1 Introduction

1.1 Background

In July 2021, an atmospheric disturbance named 'Bernd' remained stationary over Europe for several days, causing persistent and intense rainfall across a broad area (CEDIM et al., 2021; Junghänel et al., 2021; Mohr et al., 2023). This prolonged rainfall led to significant flooding in the Meuse and Rhine River basins, affecting among others Belgium, Germany, and the Netherlands (ENW, 2021). The impact was particularly severe in the narrow valleys in western Germany and the southeast part of Belgium, as well as the adjacent transition zones to the lowlands (WVER, 2021). Water levels in the affected villages and cities along the flooded rivers rose to 2 meters or above (Junghänel et al., 2021).

As a result, the region suffered extensive damages, with a documented total of 200 fatalities in Germany and Belgium (ENW, 2021), and hundreds of people sustaining injuries (CEDIM et al., 2021). Numerous houses and villages experienced damage and partial destruction. The infrastructure was heavily affected, adding complexity to the challenges faced by both the affected individuals and the aid workers. This event stands out as one of the most severe catastrophes in Europe in the past half-century (Mohr et al., 2023).

To prevent or lessen such widespread damage in future flood events, governments and water management professionals must adapt and enhance all facets of flood management. Recognizing that floods transcend national borders, the three countries of the Euregio Meuse-Rhine, interconnected by their river systems, must engage in transboundary and river basin-wide cooperation as a crucial step towards effective flood prevention and management (ENW, 2021).

1.2 Objectives/motivation

To enhance preparedness for future extreme flood events, the EMfloodResilience project focuses on understanding the response of rivers and streams to heavy precipitation, identifying control parameters, and assessing the implications for specific geographical regions. This project aims to develop and enhance products urgently needed by authorities and water managers in the Euregio Meuse Rhine, as demonstrated by the event in 2021, in order to mitigate the potential future impacts.

The activities required to achieve this objective are divided into six main work packages, each consisting of various deliverables. Work Package 5 will address both enhancements in flood damage models and the study of extreme precipitation events. To fulfil the objective, the improvements of flood estimation methods (Deliverable 5.1.3) play a crucial role within Work Package 5. The primary goal of this deliverable is to gain insight into the performance and possible improvements of damage models in the affected areas of the Euregio Meuse Rhine. To achieve this, the characteristics of various damage models are analyzed and compared with the surveyed data obtained in Deliverable 5.1.2. Outcomes of the analysis and comparisons are used to provide possible improvements to the damage models included in this research. The compared damage models are various models that are used by water authorities that resulted from Deliverable 5.1.1.

1.3 Content

To create improvements in flood estimation methods, an intensive analysis of the compared damage models is made in relation to the survey data retrieved in the affected areas of the July 2021 flood.
Chapter 2 provides an overview of the data and methods used for damage modelling in Belgium, Germany and the Netherlands. This chapter starts with a discussion of the damage models in the three respective countries and their data needs. Followed by a section about general data and specific data of the July 2021 event needed for damage modelling. After explaining the damage models and the available data, the methods for comparing the damage functions of the damage models are explained. Finally, the assessment for the Belgium INSYDE-BE model is explained. Chapter 3 provides the results and discussion of the analysis methods for the damage model functions and the results of the assessment of the Belgium INSYDE-BE model.
Chapter 4 focuses on the conclusions and prospects followed from this research.

1.4 Elements of this deliverable

This report has the following elements, as stated in chapter 5.1.3 of the project plan:

- Executive summaries of this report in German, Dutch, French and English are available at the beginning of this report.
- A description of the available data in the three EMR countries that can be used as input for damage models is given in Sections 2.2 and 2.3, starting on page 24.
- A description of the methods used to compare damage models is given in Section 2.4, starting on page 34.
- A discussion on the analysis results for damage modeling can be found together with the results in Chapter 3, starting on page 41.
- The conclusion and recommendations on possible improvements can be found in Chapter 4 on page 73.
- The invitation, the minutes, list of attendees and pictures of the webinar/workshop can be found in Chapter 5, starting on page 76.

2 Data and methods

2.1 Damage modeling methods/approaches

An overview of the different damage modeling methods per country is given in Table 1.

*Table 1 Overview of the damage models encountered during Deliverable 5.1.1. *models also used in practice.*

Role:	Belgium	Germany	The Netherlands
Existing academic calibrated models	INSYDE-BE (partial calibration, to be validated)	BEAM*	SSM2017* WSS*
Practical used models	Semi-quantitative (score-based) approaches only, no estimation of monetary losses	Semi-quantitative approaches only, number of affected people and category of land use	simplified-quantitative method (fixed price/ footprint (300eur/m2) of a house for water depths >0.15m)

2.1.1 Belgium

Belgium, as a federal state, is composed of three regions: Flanders, Wallonia, and Brussels. For the scope of this research, our focus was solely on the Walloon region (Wallonia). In Wallonia, there is currently no established monetary flood damage model in place for the management of flood risk. Thus far, the prevalent approach consists in employing semi-quantitative methods or relying on subcontracting consulting firms to estimate flood damages.
In the previous year, an established flood damage model (INSYDE), which had been originally developed and verified for Italy, was transferred to the Walloon region as described by (Scorzini et al., 2022). However, the model has yet to undergo validation due to the absence of flood damage data specific to the Walloon region at the time when the model was developed. Following the extreme flood event in July 2021, the University of Liege conducted a field campaign, marking the first instance of flood damage data collection in the Walloon region. This newly acquired data is now being used to validate the model, and the ongoing analysis is currently in progress. Consequently, this study will use the Italian model, as originally adapted for the Walloon region, and referred to as INSYDE-BE (Scorzini et al., 2022).

INSYDE-BE is a synthetic flood damage model (i.e., a damage model built based on what-if-questions from experts), a multi-variable model, which uses various input variables that describe the hazard and the vulnerability of the exposed items. Operating at a micro-scale (i.e., at building level), INSYDE-BE assesses the flood damages in residential buildings estimating the total damage per building summing the cost of repairing (or removing and replacing) all the affected components in the building. It's important to note that INSYDE-BE does not account for damage to the contents of the building. The affected components are categorized into seven groups: clean-up, removal, non-structural elements, structural elements, finishing materials, doors and windows and the building's systems.

The damage (C_{ij}) of each building component (indexed with symbol i) and subcomponent (indexed with symbol j) is expressed as a function of the damage extension (ext_{ij}), the unitary price of the specific activity regarding the damage building component (up_{ij}) and an additional factor (r_{ds}) depending on whether the damage mechanism is considered deterministic or probabilistic.

$$C_{ij} = ext_{ij} \cdot up_{ij} \cdot r_{ds}$$

The model calculates the total damage per building (D) as the sum of the damage to each building component C_{ij} (Scorzini et al., 2022).

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

where n is the number of components of the building damage and mi is the number of considered subcomponents for damage component number I.

For estimating the damage per building, the model uses 24 input variables, 6 for characterizing the hazard (Table 2) and 18 for representing the building's interior and exterior conditions before the flood event (Table 3). It is well known that gathering all the input variables for the model is challenging, therefore, the model considers default values based on regional statistics from different sources (i.e., virtual and field surveys, synthetic analysis, grey literature, and statistical data) in the case when input variables are missing.

Table 2. Hazard parameters included in INSYDE-BE.

Var	Description	Range of values	Default values
he	Water depth outside the building [m]	≥ 0	N/A
h	Water depth inside the building [m]	[0, IH]	h = he - GL
v	Maximum velocity of the water perpendicular to the building [ms-1]	≥ 0	0.5
d	Flood duration: persistence of water inside the building [hours]	> 0	34
s	Sediment load [% of water volume]	[0,1]	0.05
q	Water quality: presence of pollutants [-]	0 is no; 1 is yes	1

Table 3. Building parameters included in INSYDE-BE.

Var	Description	Range of values	Default values
FA	Footprint area [m^2]	> 0	110 (BT = 1) 75 (BT = 2) 75 (BT = 3) 95 (BT = 4)
IA	Internal area [m^2]	> 0	0.9·FA
BA	Basement area [m^2]	≥ 0	0.5·FA
BP	Basement perimeter [m]	≥ 0	$4 \cdot (BA)^{1/2}$
EP	External perimeter [m]	> 0	$4 \cdot (FA)^{1/2}$ (BT = 1; BT=4) $(2 \cdot FA)^{1/2}$ (BT = 3; PB=2) $2 \cdot (2 \cdot FA)^{1/2}$ (BT = 3; PB=1) $3 \cdot (FA)^{1/2}$ (BT = 2)
IP	Internal perimeter [m]	> 0	0.64·FA+17.02 (BT = 1; BT = 4) 0.42·FA+27.29 (BT = 3) 0.56·FA+12.9 (BT = 1)
NF	Number of floors [-]	≥ 1	2
IH	Interfloor height [m]	> 0	3.5
BH	Basement height [m]	> 0	2.5
GL	Ground floor level [m]	≥ 0	0.2 (BT = 1; BT = 2; BT=3) 0.1 (BT=4)
BL	Basement level [m]	≤ 0	-GL-BH-0.3
BT	Building type	1 - detached 2 - semi-detached 3 - attached 4 - apartment	3
BS	Building structure	1 - reinf. concrete 2 - masonry	2
FL	Finishing level	0.8 - low 1 - medium 1.2 high	1
LM	Level of maintenance	0.9 - low 1 - medium 1.1 - high	1
YY	Year of construction	≥ 0	1940
PD	Heating system distribution	1 - centralized 2 - distributed	1 (if YY<=1990) 2 (otherwise)
PB	Building position	1 - corner 2 - center 3 - else	2
EFM	Exterior finishing material	1 - plaster 2 - stone 3 - masonry 4 - stone & bricks	3

As previously mentioned, the model estimates the absolute damage to the building and it uses unitary prices of the required activities to remove, replace or repair the different building components damaged during the flood event. These unitary prices can be easily replaced by taking into account the annual reference prices for construction activities in the Walloon region or any other region/country where the model will be implemented.

2.1.2 Germany

North Rhine-Westphalia (NRW), which was highly affected by the flood of July 2021 is a federal state in Germany with it’s own ministries including the ministry of the Environment. It is divided into five district governments (Bezirksregierungen). The district governments are the authorities in charge of the realization of the steps demanded in the EU Floods Directive: conduct preliminary flood risk assessment, set up flood hazard maps and flood risk maps and develop flood risk management plans. They report their results to the federal ministry of NRW, who has to report the result to the EU. Superior to the federal state ministries but without authority to make legal decisions is the LAWA, the German working group on water issues of the federal states and the national government (Bund/Länder-Arbeitsgemeinschaft Wasser), which coordinates trans-federal working groups and develops recommendations.

The district governments of NRW generally do not perform any damage modelling but follow the working cycle of the EU Flood Directive. Flood hazard and exposure modelling are expressed by creating the flood hazard maps. Hydraulic calculations are mostly done by consultancy offices in 2D. During the first two cycles, the preliminary flood risk assessment, including identifying the areas at risk, was done without any standardized calculation of potential monetary damage. So far in NRW, no damage modelling approaches including standardized monetary flood damage models are used in the general large-scale process of flood risk determination. Some semi-quantitative approaches to estimate flood damages which rely on expert knowledge were used.

In January 2018, the working group “Flood protection and hydrology” of the LAWA decided to standardize the estimation of monetary flood damage Germany-wide uniformly for the third cycle of the EU Floods Directive.

The idea is to use the BEAM (Basic European Assets Maps) dataset 2021, which is a standardized set of area-related data on land use and land cover as well as assets in Germany (LAWA, 2022). BEAM was developed as part of the SAFER (Services and Applications For Emergency Response) project as part of a multi-level or multi-scale system of spatial asset data for Europe-wide use in the assessment of risks caused by various natural hazards and is designed for use at the mesoscale, i.e. for regions and districts (Assmann, 2022).

The BEAM dataset contains 90 different land use categories and 16 asset categories that are assigned to the land use categories (LAWA, 2022). Each asset category is allocated a damage function depending on the water depths. The asset categories and their related damage functions can be seen in Table 4.

Table 4: BEAM damage functions (Assmann, 2022; LAWA, 2022)

#	Asset category/ Layer	damage function (x = water level [m], y = degree of damage)		Content
		x	y	
1	building	< 8 m > 8 m	y = 0.125 x y = 1	Specific asset value of private buildings [€/m²]
2	household	< 1 m 1 m – 7 m > 7 m	y = 0.4 x y = 0.3 + 0.1 x y = 1	Specific asset value of household contents [€/m²]
3	vehicles	< 0.25 m 0.25 m – 1.5 m > 1.5 m	y = 0 y = 0.24 x - 0.06 y = 0.3	Specific asset value of vehicles [€/m²]
4	nav_agriculture	< 10 m > 10 m	y = 0.1 x y = 1	Specific asset value of net fixed assets in the agricultural sector [€/m²]
5	nav_industry	< 8 m > 8 m	y = 0.125 x y = 1	Specific asset value of net fixed assets in the industrial sector [€/m²]
6	nav_service	< 8 m > 8 m	y = 0.125 x y = 1	Specific asset value of net fixed assets in the service sector [€/m²]
7	sit_agriculture	< 1 m > 1 m	y = x y = 1	Specific asset value Inventories in the agricultural sector [€/m²]
8	sit_industry	< 2 m 2 m – 4 m > 14 m	y = 0.2 x y = 0.3 + 0.05 x y = 1	Specific asset value Inventories in the industrial sector [€/m²]
9	sit_service	< 2 m 2 m – 6 m > 6 m	y = 0.4 x y = 0.7 + 0.05 x y = 1	Specific asset value Inventories in the service sector [€/m²]
10	livestock	< 1 m > 1 m	y = x y = 1	Specific asset value of the livestock [€/m²]
11	agriculture	< 0.1 m > 0.1 m	y = 0.5 x y = 0.05	Specific asset value of the land use categories (one unit value per land use category [€/m²]
12	grassland	< 0.1 m > 0.1 m	y = 0.5 x y = 0.05	
13	forest	< 1 m > 1 m	y = 0.5 x y = 0.05	
14	roads	< 1 m > 1 m	y = 0.1 x y = 0.1	
15	rail	< 1 m > 1 m	y = 0.1 x y = 0.1	
16	sports	< 0.25 m > 0.25 m	y = 0.4 x y = 0.1	

To determine the damage potential with BEAM, the water depths occurring during a selected flood event are intersected with a vector or grid-related asset categories and then added up for the area under consideration (LAWA, 2022). The basis for the land use and land cover data is provided by the latest versions of the Corine Land Cover (CLC) data products collected by the EU, which are available for all areas and based on uniform criteria and mapping standards, and the Urban Atlas (UA), which is available at a higher resolution but only in metropolitan areas (LAWA, 2022). The result of this is the German BEAM dataset (status 2021) in the form of a comprehensive polygon data set, which also contains linear elements as polygons with an extension which is available on the WasserBLIcK-Homepage (LAWA, 2022). Each polygon is associated with exactly one of the 90 land use categories (LAWA, 2022). The required socio-economic data comes from various sources. Basically, data from the EUROSTAT database is processed and analyzed. In addition, values from national statistical offices and other sources are used (Assmann, 2022). All input data used is available free of charge on a permanent basis and is regularly created or continuously updated by EU mechanisms (Assmann, 2022).

The general concept of BEAM assets and their use in risk assessment is shown in *Figure 1*.

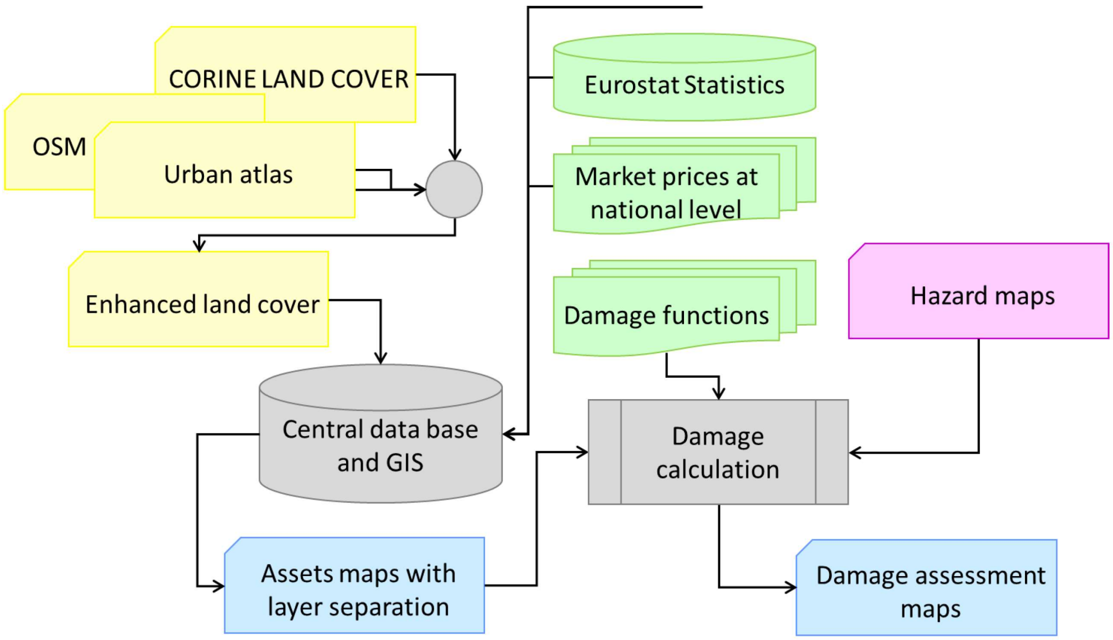


Figure 1: General concept of BEAM assets and their use in risk assessment (Assmann, 2022).

2.1.3 The Netherlands

The Netherlands is a country that exists for almost a fifth of its surface area out of water, meaning that good water management and flood protection are needed to avoid casualties and damages as well as possible. To understand water management in the Netherlands, it is necessary to make a distinction between the primary water system (the sea, the big lakes and the main rivers where primary flood defenses protect the area) and the regional water system (with canal levees and the small rivers, like the Geul). The primary flood defenses prevent catastrophic disasters, for example the Delta works that were built in response to the big flood event in the Southwest of the Netherlands in 1953. As the large amount of water in the country also shaped the Netherlands, dikes and levees were built to protect the land from rivers and sea. Flood risk standards of the primary flood defense system are included in the law via the Dutch ‘Water Act’, to protect the flood-prone areas covering 50% to 60% of the country. To implement measures to reduce flood risk, the effectiveness is compared to the reduction in flood and damage. This latter is performed by running damage modeling before and after the implementation of measures through hydrodynamic models. In the Netherlands, there are different approaches when it comes to damage modeling. For now, the focus lies on the commonly used methods in the Netherlands concerning the area of Limburg.

There is a differentiation in responsibility between the water systems in the Netherlands. There are different water authorities in charge of flood risk standards for primary flood defenses, dunes and flood barriers but also for regional dikes and regional areas. The Ministry is responsible for the primary flood defenses and the provinces for the regional water system and its levees. In both cases, water authorities act as executors of the standards by doing the management and maintenance of the system.

Rijkswaterstaat commonly uses SSM2017 as a damage and loss-of-life modeling method for floods because of breaches in the primary flood defenses (Rijkswaterstaat, 2023). Every six years an update of the SSM model is performed. An alternative damage model, the WaterSchadeSchatter (WSS), is more commonly used by Water Authorities in regional areas as this model is more focused on relatively low inundation depths. The WSS model is updated every year when the Dutch datasets on land use and houses are updated. The WSS is made for Water Authorities, initiated by the STOWA, who organizes tools and new development for the water authorities. There is no official common approach among the Water Authorities for damage modeling, and it is not uncommon for Water Authorities to use more simple calculations for damage modeling, to quickly assess risks and measure impact, as Waterschap Limburg does with a simplified quantitative method for residential buildings within their Water in Balance project to solve regional bottlenecks (Waterschap Limburg, 2023).

Inputs and Data Features for the Damage Models

The damage model SSM2017 contains damage functions for different types of categories, like infrastructure, housing (divided into multiple classes), and industry but also contains loss of life functions. The damage factor functions can vary based on water depth up to depths of 5 meters and give a factor either per object or per square meter of living area. In the SSM2017 model, the functions cannot be altered by the user to obtain consistency among the calculated damage for official hazard assessments. A version of SSM called Delft-FIAT is made to be altered and tuned to the user’s needs when wanted. The damage functions are based on earlier events and expert knowledge. Which functions are used in the SSM model and their corresponding maximum damage number differ between the three main modules that can be run, which are:

- The not protected area (NL: Buitendijks) approach is meant for the consequences of floods caused by a breach of a primary levee.
- The protected area (NL: Binnendijks) approach is meant for the consequences of floods in unprotected areas that are subject to frequent floodings, like the areas along the primary water system and regional water system.
- The regional area approach is meant for the consequences of floods caused by the breach of a regional levee.

The SSM2017 model uses a water depth map as input to calculate the corresponding hazard. Optionally an incremental file (to calculate the rate for rise and arrival times), rate of rise and arrival files (instead of the incremental file) and a velocity map can be added. Not using the rate of rise option could result in a potential underestimation of the loss of life but does not influence the damage calculated (Deltares, 2020). The object files that are used in SSM2017 to determine the damages per category are based on different sources like the BAG (houses and businesses), CBS (population and other land use) and NWB -roads and railways (infrastructure). The object files are aggregated into 4 resolution options that can be used to calculate the model, which are 5 m, 25 m, 50 m, and 100 m.

The simplified quantitative method of Waterschap Limburg uses a water depth map combined with the houses and business registration of the BAG to obtain buildings at risk. A building is labeled as a building at risk when there is more than 0.15 meters of water depth against the property. This method calculates a fixed price per floor area (footprint of the building) as building damage for buildings at risk. A subsequent difference is made between the area of the water body against the building to label a building as a local or a regional issue, this label does not influence the damage.

The WaterSchadeSchatter (WSS) is a damage model focused on water depths of 1 to 30 cm. One of the key differences between the SSM2017 and the WSS model is their scope. SSM is mainly built for floods and breaches, whereas WSS is specifically intended for static floods caused by for example extreme precipitation. Furthermore, the WSS model uses a much higher resolution, which makes it more suitable for damage calculations of floods caused by for example precipitation events. Since the inundations in these situations are most of the time limited and in densely built areas. The WSS model contains a high detail of damage function for different categories, especially for agricultural areas. The functions consist of three types of variables that can influence the damage, which are the water depth, duration and season. The latter two are in the standard settings of WSS not causing any damage to buildings. A user could change all functions when sees fit. This makes the WSS model flexible but also less comparable if everyone uses different functions. How the damage numbers and functions are constructed are well documented in the user manual with a practical approach. The input is always water level, which can be added in multiple forms resulting in different types of outcome. Examples are a water level raster, a series of water level rasters or a series of water levels per shape area. Note that the WSS model calculates the water depth in the background with the use of the Elevation map of AHN, which is a high-resolution elevation model. The land use map used within the WaterSchadeSchatter is a combination of the BAG (buildings), BGT (land use), Top10NL (land use) and the BRP (crop plots).

The damage factor functions of the SSM2017 and WSS damage models for residential buildings are visualized in Figure 2. For commercial settings, there are also multiple damage functions based on different categories.

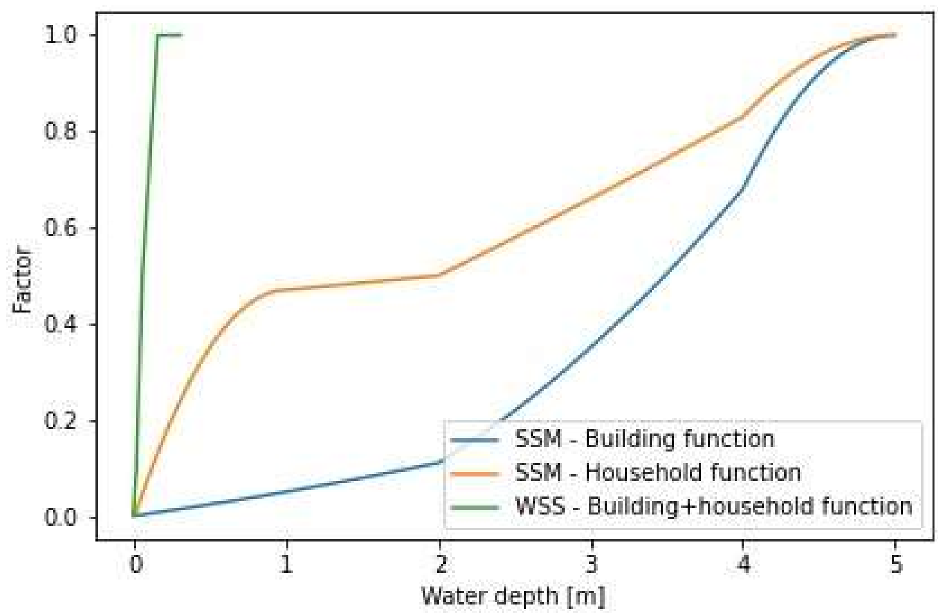


Figure 2 Damage functions, damage factor vs. water depth, for the Dutch SSM2017 and WSS models. Note: The maximum damage corresponding to a damage factor of 1 Is not equal for the models.

2.2 Data collection for flood damage modeling

2.2.1 Belgium

As reported in Deliverable 5.1.1, the Walloon region in Belgium does not have a single standardized procedure for flood damage estimation. Currently, the methods for assessing flood damages in specific flood scenarios primarily involve semi-quantitative techniques or the outsourcing of tasks to consulting firms. Nevertheless, the region possesses all the necessary data inputs for such estimations, in compliance with the requirements of the European Flood Directive.

For preparing flood hazard maps, currently, the return periods of 25, 50 and 100 years are systematically used. Along some rivers, an additional scenario is considered, in which the 100-year flow rate was magnified by a factor of 1.30. This may be regarded either as a more extreme scenario or as an estimate of the 100-year flood under a wet climate change scenario. The flood hazard maps result from the combination of (i) the recurrence (return period or occurrence) of a flood or rainfall event causing runoff, and (ii) the magnitude of a flood or rainfall-runoff event (flood depth), resulting in four hazard levels: high, intermediate, low and very low. In Figure 3, a fluvial flood hazard map in the municipality of Theux is shown. The hazard maps may be retrieved from https://geoapps.wallonie.be

In addition to the flood hazard maps, in the Walloon region in Belgium, there is a building registration file that contains the shapes of buildings and their functions. This database, as the previous one can be viewed and retrieved from this website: https://geoportail.wallonie.be/.

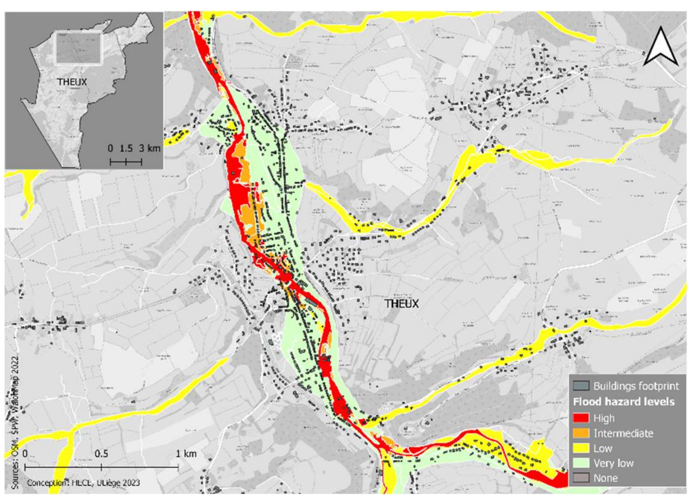


Figure 3: Example of flood hazard map in Belgium – Municipality of Theux

2.2.2 Germany

In NRW, the return periods for the flood hazard maps are 5-20 years for the high probability scenario, 100 years for the medium probability scenario and extreme flood event which means a return period of 200-1000 years for the low probability scenarios. The flood hazard and flood risk maps for all watercourses in NRW currently can be downloaded as PDF-files on the website https://flussgebiete.nrw.de. However, this is only possible until the end of 2023, as the maps lately are provided at the new map service https://giscloud.nrw.de as interactive GIS-based online maps. Additionally the latest flood hazard and flood risk maps are provided on the website https://elwasweb.nrw.de, which is a professional information system for water management in NRW and on the interactive website of the environmental ministry of NRW https://uvo.nrw.de. An example of the flood hazard and flood risk maps is shown in Figure 4 for the village of Vicht, which was heavily impacted by the flood in July 2021.

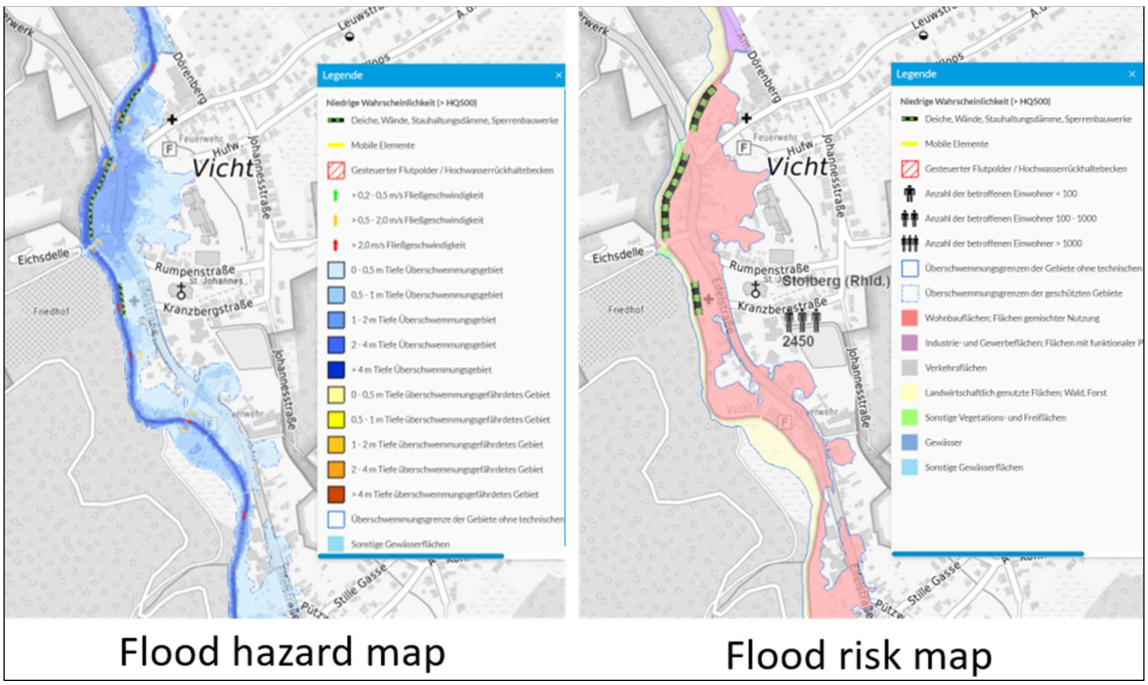


Figure 4: Example of a flood hazard map (left) and a flood risk map (right) in Germany, NRW

For NRW, various data is available in the online portals https://opengeodata.nrw.de/produkte, https://geoportal.nrw and https://open.nrw. Shapes of the buildings are available as well as 3D building models, but no further building information is included.

2.2.3 The Netherlands

In terms of flood risk and flood hazard approach, the Netherlands has included the Floods directive into the Dutch 'Water Act' law. The EU members decide what purposes and what deducted measures they focus on in the flood risk management plans. The Netherlands chose an approach that focuses on the current knowledge and policy (Helpdesk Water, 2023). No new policy is developed to include the ROR in the Dutch 'Water Act' law, but as much connection with current programs is sought. This is all possible since extended research has already been performed in terms of flood safety. The flood risk and flood hazard maps of previous programs are improved and supplemented with information on regional waters. The flood risk and hazard maps are available on www.risicokaart.nl. Actual insights on flood risk are deducted from four flood scenarios with different return periods:

1) High risk of flooding with a chance of once every ten years (± 1/10y)
2) Middle high risk of flooding with a chance of once every hundred years (± 1/100y)
3) Small risk of flooding with a chance of once every thousand years (± 1/1000y)
4) Extraordinary event of flooding with a chance of once every ten-thousand years (± 1/10.000y)

Flood risk from surface run-off of precipitation is not included in this approach, there are also no inundation protection standards only design criteria for sewers and spatial designs. Although there are protection standards set for different land uses caused by inundation from water bodies, mostly nuance floodings, resulting from rainfall, this is set by the so-called Provincial standards (previously NBW standards) for regional areas (I&W, n.d.).

For regional waterways and regional areas, the Water Authority of Limburg (WL) models different scenarios to test if the systems still meet the safety standards. For regional waters, T10, T25 and T100 are scenarios that are included in the modeling. The Water Authority of Limburg will in the near future also include T500 and or T1000 scenarios to include the effects of these extremer events (Waterschap Limburg, 2023). The assessment of the regional water system is performed every six years but is not always shared with the public like the maps for the Floods directive.

Furthermore, in the Netherlands, there is a general building database available that is used for damage modeling. This database includes addresses, construction years, living areas and general building functions connected to spatial polygons in a shapefile. This database is freely accessible to download and can be viewed in the BAG viewer: https://bagviewer.kadaster.nl/lvbag/bag-viewer

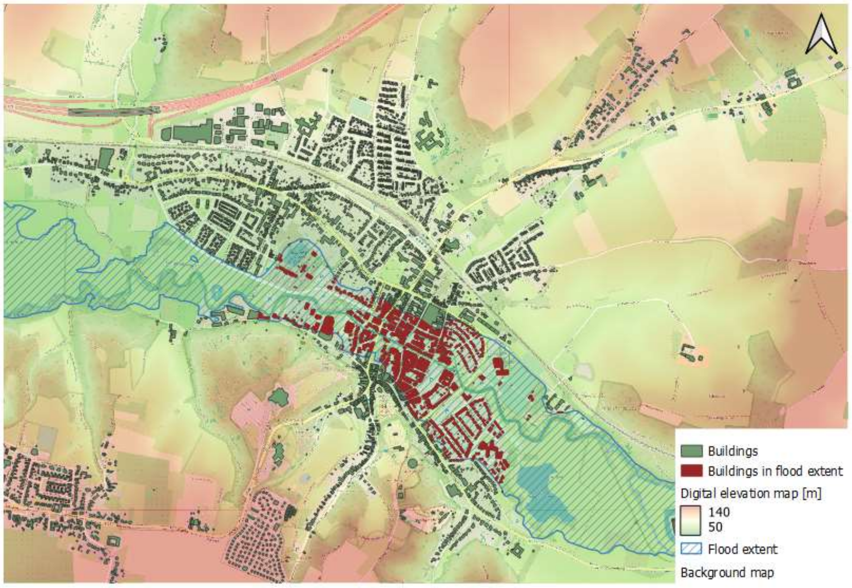


Figure 5: Example of the BAG data set in Valkenburg

2.3 Data collection of the July 2021 event

The damage model analysis of this research is primarily performed in the area of the conducted in-field surveys of Deliverable 5.1.2, where an overview of these areas can be seen in Table 5. For more in-depth information about the survey data, the report of Deliverable 5.1.2 could be accessed. Besides the survey data, additional water depth and damage information needed to be collected to further assess the damage functions. For Belgium, Germany and the Netherlands different data was available, which is further elaborated in the paragraphs below.

Table 5 Overview of the case study areas

Role:	Belgium	Germany	The Netherlands
Locations	Theux, Vaux (Chaudfontaine)	Zweifall, Vicht, Stolberg, Eschweiler, Weisweiler	Valkenburg and Gulpen-Wittem
Sectors	Housing	Housing	Housing and businesses
Population in the area	13.875 inh.	116,169 inh. ((Stadt Eschweiler, n.d.) and (Kupferstadt Stolberg, n.d.))	Respectively 16.456 (CBS, 2023c) and 14.204 inh. (CBS, 2023a)

2.3.1 Belgium

Shortly after the July 2021 flood event, Belgian authorities and involved stakeholders initiated extensive data collection efforts in all the affected areas.

Aerial and helicopter flights, together with georeferenced points with water levels obtained through field surveys, satellite images from Sentinel 2 and Rapid Mapping Copernicus have been used and combined to create an estimate of the flooded area in July 2021. In the following figure, the estimated flood extent in the municipality of Theux is illustrated. The flood extent file of the July 2021 event can also be viewed and downloaded from the geoportal of the Walloon region (https://geoportail.wallonie.be).

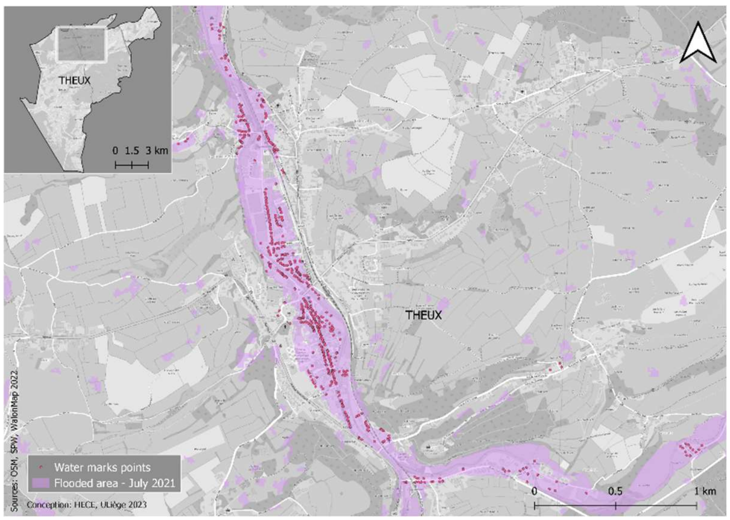


Figure 6. Example of July 2021 flood extend in Belgium – Municipality of Theux

In addition to the flood extent, and additional map containing the water levels can be also found in the geoportal of the water authorities in the Walloon region. An example of such map is shown in Figure 7.

Figure 7. Example of July 2021 flood water depths in Belgium – Municipality of Theux

Besides, inundation maps were computed for the 2021 event in the Vesdre Valley utilizing the WOLF 2D hydrodynamic model developed by the group Hydraulics in Environmental & Civil Engineering (HECE) at the University of Liège (Bruwier et al., 2015; Ernst et al., 2010). The model solves the depth-averaged Reynolds-Averaged Navier-Stokes equations on multi-block Cartesian grides using a finite volume technique. A flux vector splitting developed in-house ensures the stability, accuracy, and efficiency of the computations, even under highly transient flow. The computational core is coded in object-oriented Fortran 2008. The model is equipped with a graphical user interface enabling GIS-type operations for processing of input and output data. WOLF was selected by the regional authorities in Belgium to perform most detailed 2D flow simulations to support official inundation mapping, including in the framework of the European Floods Directive.

For hindcasting the 2021 flood event, the model was run in unsteady mode, with a cell size of 5 m × 5 m. Estimates of the flood waves were obtained from a hydrological assessment (Archambeau et al., 2022). This was necessary since no measurement station captured the peak discharge, as most stations were damaged by the flood. The hydrological modeling was conducted based on a grid of 100 m by 100 m, with a time step of 10 minutes. The model was forced by RADCLIM data (Goudenhoofdt et al., 2023). The computed peak discharges were found about three to four times higher than the previously estimated 100-year flood. This matches the concept of black swan, a highly improbable event which does nonetheless occur (Kreibich et al., 2022). The highest peaks occurred during the night or early in the morning, which has certainly contributed to enhancing the surprise effect for the affected population. An example of a result of the 2D hydrodynamic computation with WOLF is displayed in Figure 8.

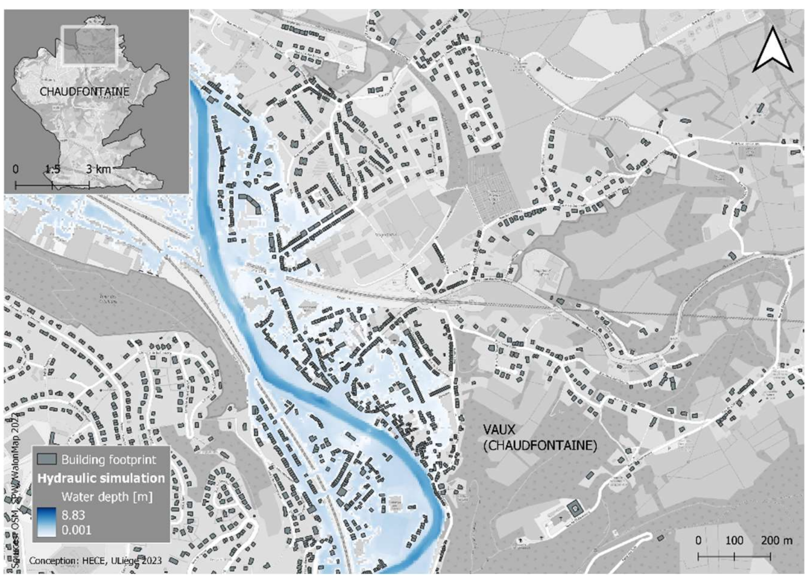


Figure 8. Example of computed flood water depth map in Belgium (Vaux in the municipality of Chaudfontaine) for the July 2021 event

2.3.2 Germany

The Institute of Hydraulic Engineering und Water Resources Management (IWW) of RWTH Aachen University started collecting data about the flood in July 2021 during the event itself by collecting suspended particle samples and taking photos and videos at several locations in the survey area. Shortly after the event flood marks were recorded by the IWW in the survey area which were transferred into first estimations of the flooded areas. Additionally flood marks were provided by the WVER (Wasserverband Eifel-Rur, engl.: Eifel-Rur water board).

The inundation areas and water levels of the 2021 flood event were reconstructed for the Vicht river sub-catchment using the hydrodynamic-numerical software HydroAs for the 2D simulation of natural rivers. The software was developed in 1999 by Dr. Marinko Nujić at the University of the Bundeswehr in Munich and has been continuously developed by the engineering office Hydrotec in Aachen since 2014 ((Nujic, 1999); (Hydrotec, 2023)).

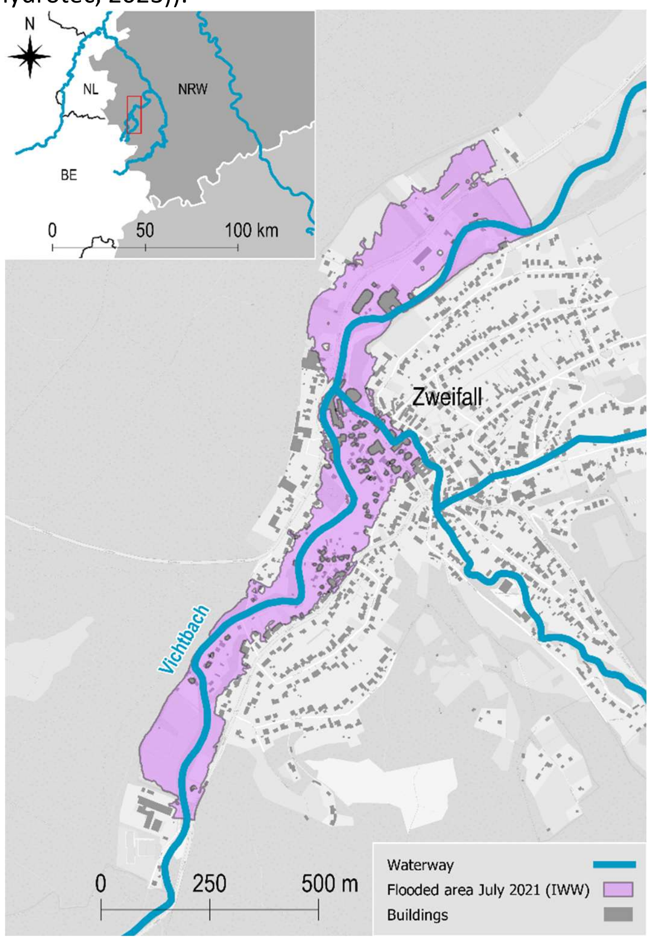


Figure 9: Inundation area in the village Zweifall for the flood event in July 2021, calculated by IWW in HydroAs.

The HydroAs calculations are based on the numerical solution of the shallow water equations and the finite volume method. Thus, the software has a high level of numerical stability. To operate the program, HydroAs is linked to the Surface-water Modeling System (SMS) user interface from Aquaveo. Pre- and post-processing is therefore carried out via the user interface (Hydrotec, 2020).
HydroAs is used across the water management sector in Germany. For example, official flood hazard maps are created with HydroAs. Hence, it was decided to use the software for the reconstruction of inundation areas in the Vicht river sub-catchment.

The 2D model of the Vicht river for the reconstruction of the flooded areas and water levels of the July 2021 flood was built using a DEM with a resolution of 1 m x 1 m, data from the Authoritative Real Estate Cadastre Information System (ALKIS) and cross-sectional data from terrestrial surveys. All input data originates from the year 2022. The model was created in accordance with the procedures and standards for 2D hydraulic modeling of flood hazard maps and calibrated at the Mulartshütte gauge. HydroAs version 6.0.0 was used for hindcasting the July 2021 flood.
The hydrological input data for the reconstruction of the inundation areas was provided by the Wasserverband Eifel-Rur (WVER). These were calculated with the rainfall-runoff model NASIM, which is also distributed by Hydrotec, for the precipitation event in July 2021 for 47 inflow points.
Finally, the flooded areas and water levels were validated with flood marks, which were measured shortly after the event by both the Institute of Hydraulic Engineering and Water Management (IWW) and the WVER mentioned above.

Besides this, data of the flood event in July 2021 was collected by an conducted field survey in Deliverable 5.1.2 of this project including flood characteristics, building characteristics, damage parameters and other. In the German research area 70 affected households participated in the study.

Another survey regarding the flood event in July 2021 is the survey in the study of (Thieken et al., 2023), including 1.315 participants who were affected by the floods in NRW an RP (Rhineland-Palatinate) and also contains participants in the study area of the EMfloodResilience project also asked people about water levels and other flood risk parameters like the warning situation. Another survey was conducted in the course of the KAHR-project (Meyer & Fitz, 2023) which was focused on flood protection measures but also included the damages resulted from the flood in July 2021. 773 people participated, of which 64% were affected by the flood in July 2021.

2.3.3 The Netherlands

In the Netherlands, there has been an effort to collect damage data from the high water event in July 2021. This includes the questionnaire conducted during this research project in Deliverable 5.1.2, where door-to-door questionnaires are conducted. This questionnaire resulted in 212 data points for the damage database of this research, which are located in the case-study areas of the three participating countries, of which 72 data points are from Valkenburg and Gulpen-Wittem. From the performed surveys in the Netherlands, 58 are from residential buildings and 14 are from commercial buildings. There have been multiple efforts to deduct a total view of the occurred damage in the Limburg region.

After the high water event, there have been multiple fact-finding studies performed to research the facts around the event as well as the impact. A large collaboration between many institutes and research companies resulted in an elaborated document with facts and interpretation of the event (ENW, 2021) . For the Geul an effort is made to deduct the flood extent from various sources in an earlier research (Kok et al., 2023), this flood extent is also used as guidance during the questionnaire in the Valkenburg area to deduct and approach the possible flooded houses.

According to research into the occurred damage in the region of Limburg, the total damage amounts to 455 million euro (Kok et al., 2023). This lies within the bandwidth of the previously estimated damage in the study of the ENW factfinding (ENW, 2021) of 350-600 million euro. The claimed damage according to the association of insurers to residential buildings per municipality in 2021 and the total flooded buildings can be seen in Figure 10 (Kok et al., 2023).

The Water Authority of Limburg (WL) ran a hydrodynamic model to simulate the July 2021 event. This model is not calibrated and can only be used as an indication of the water depths and cannot be seen as true.

Furthermore, the BAG, general administrations of buildings, is available for the case-study area and can be viewed in the BAG viewer: https://bagviewer.kadaster.nl/lvbag/bag-viewer.

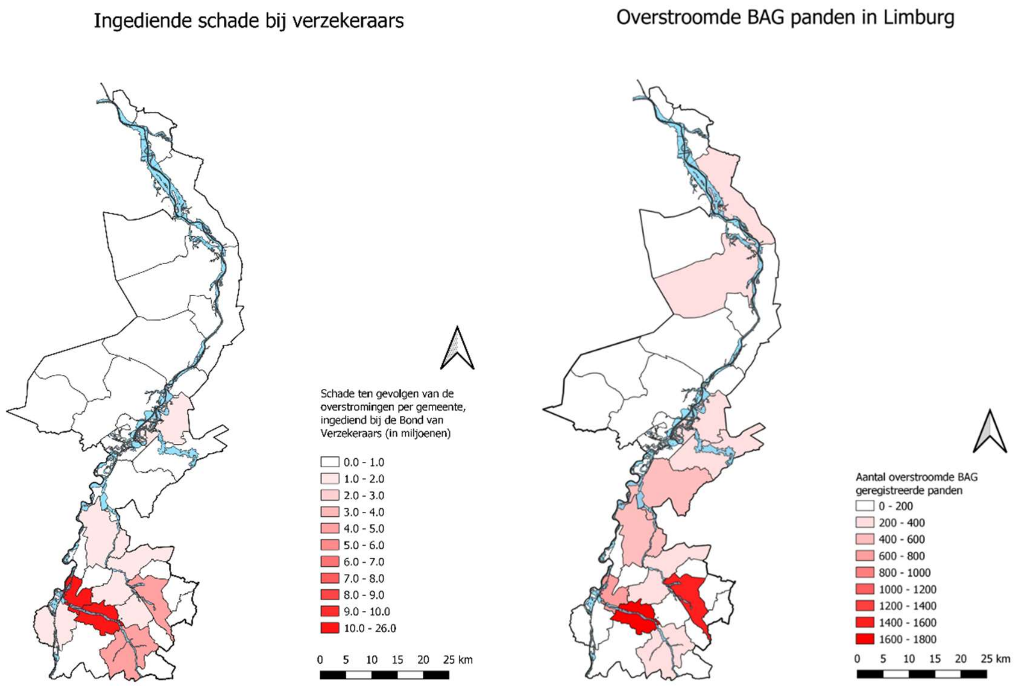


Figure 10 Consumer precipitation damage in 2021, claimed damage (left, source: https://bi.verzekeraars.nl/db/klimaatmonitor.html) and amount of flooded buildings (right) https://bi.verzekeraars.nl/db/klimaatmonitor.html, (Kok et al., 2023)

2.4 Damage Functions Analysis

In-depth damage comparison during this study is performed based on the damage functions of the different methods used by Belgium, Germany and the Netherlands. In the following paragraph, general information on the damage functions applied to houses and commercial buildings for academically used damage models can be found. In section 2.4.2, the analysis of the damage functions is explained in comparison to the different information sources found during this research.

2.4.1 Damage function characteristics

The comparisons between the different damage methods are result-driven. Besides comparison with surveyed and modeled data, the characteristics of the functions are important features to be able to deduct where differences come from and where improvements can be made. The damage functions are all built differently in terms of how damage numbers are calculated. Some functions calculate a factor based on the water depth that needs to be multiplied by the maximum damage number. Other functions have the same approach but are given as damage per area (living area or footprint). There are also much simpler functions where there is a fixed damage starting from a certain threshold of water depth. Therefore in

Table *6*, an overview of the corresponding characteristics of each damage function is shown.

To get an idea of why the models differ from each other, a comparison is made between the models in terms of the used functions in these models. This can result in more background information on where the difference in performance can originate from.

Table 6: Damage function characteristics

Method	INSYDE-BE	BEAM	SSM2017	WSS	Simplified-quantitative method (WL)
Entrance height threshold [m]	N/A	Building: 0m Household: 0m	Building: 0.95m (T10 area) 0.25m (T100 area) 0m (other areas) Household: 1.5m (T10 area) 0.25m (T100 area) 0m (other areas)	Building+household: 0 m	Building+household: 0.15 m
Max damage [euro]	N/A	Building: Not found Household: 700/m^2 (floor area)	Building: 1295/m^2 (living area) Household: 81985	Building+household: 380/m2 (floor area)	Building+household: 300/m2 (floor area)
Year of price level	2020	Unknown	2022	2015	Unknown
Max damage height [m]	N/A	Building: 8 m Household: 7 m	Building: 5 m Household: 5 m	Building+household:: 0.15 m	Building+household: 0.15 m
Type of area usually applied to	Regional areas		Polders, the protected and not protected areas, regional	Regional areas	Regional areas
Type of event made for	Fluvial events		Fluvial and breach events	Pluvial events	Pluvial events
Building damage related to area (groundfloor area or living area) [yes/no]	Building: yes (groundfloor area) Household: No (it does not estimate this damage)	Building: yes (living area) Household: yes (living area)	Building: yes (living area) Household: no	Building+household: yes (floor area)	Building+household: Yes (floor area)

2.4.2 Model comparison

In the previous section, an overview of some of the existing damage models is shown. This overview mainly consists of models and methods used in the Euregio Meuse-Rhine. The conducted fieldwork in the affected areas of the July 2021 event made it possible to compare damage models with actual damage data from this event. The functions of the different damage models are compared with various types of data. The main source of data is the output of the conducted In-depth field interviews of Deliverable 5.1.2. The focus of the interviews has been on damage that occurred to residential buildings and commercial buildings. Therefore, in this research, the damage functions of the building and commercial categories are compared. Due to the relatively low dataset obtained for commercial buildings, the main focus will lie on residential buildings.

The different residential building and household damage functions are applied to the In-depth field interviews in the following ways:

- By comparing the observed damages versus damages calculated using the damage functions, taking into account observed water depth and floor area or living area as input when necessary.
- An analysis is made of the performance of the different damage functions applied within its corresponding country compared to applying them to the neighboring countries. This gives insight into how well-comparable the countries are and how universal the damage functions are. The water depth and damage data are used from the in-depth field surveys for this comparison.
- A comparison between the entrance height thresholds in the damage functions and the surveyed entrance heights is be conducted. This assessment reveals whether the assumed thresholds in the model align with the actual conditions in the surveyed area.

The compared damage functions of the different damage models analyzed differ from each other in output units. SSM2017 for example uses a function to calculate a factor for building damage depending on the water depth. The factor combined with the maximum damage number results in damage/m^2 of living area, where the household function of this model results in damage unrelated to the area. The WSS has a damage function for building and household damage combined which also depends on water depth and area, in this case, the footprint of the building. This shows why the comparisons of the models with the survey data differ slightly from each other in the results.

For the commercial building damages, there has been made an effort to compare the damage functions of the models and to compare the survey data with the different damage models when possible.

2.4.3 Sensitivity analysis (on results)

For the survey case-study areas, a comparison between the modeled water depth maps of the events and the water depth data of the survey is made. To combine the water depths from the hydrodynamic model with the survey data, a few GIS actions are performed:

- The survey data is connected to the building shapes, via the x and y coordinates stored in the personal section of the survey. Note that the personal section of the survey contains sensitive information and is therefore not shared openly.
- A buffer of 2 meters is drawn around the buildings for the cases where the flood extent is not touching the building due to resolution artifacts.
- The maximum water depth is then calculated against all buffered buildings and added to the survey data.

The water depth comparison gives insight into differences between field surveys and hydrodynamic models, which in turn is used to show how this difference can give a variation in calculated damage. Differences in the results of the damage functions with surveyed water depth and modeled water depth of the event are compared. This comparison shows the sensitivity of differences in water depth by the survey and post-event modeled water depths in terms of calculated damage.

2.5 Assessment of Belgium INSYDE-BE model

The absolute damage model adapted for the Walloon region (INSYDE-BE) was tested to estimate the damage to buildings in the aftermath of the July 2021 flood event in the various affected countries considered here. These results were then compared against damage estimates provided by residents during on-site surveys, whose values are mostly based on expert estimations, as detailed in Deliverable 5.1.2.

2.5.1 Imputation of missing input data

The model INSYDE-BE requires various input data, many of which were not gathered during the field surveys. In situations where data is lacking, default values for building characteristics (i.e., vulnerability indicators) were applied, as outlined in Table 3. A different approach was adopted for the missing hazard variables (e.g., flow velocity, flood duration, sediment concentration …). Indeed, the model was originally developed in the context of low to moderate floods, which guided the selection of the recommended default values, including for the hazard variables (as listed in Table 2). In this research, we aim to evaluate damage due to an extreme event (July 2021). This is the reason why the default values for the missing hazard variables were not used here. Instead, higher values were attributed to the missing hazard variables. The selection of these values was guided by a close examination of the fragility curves embedded in the model INSYDE-BE. For each individual missing hazard variable, the value of the variable was set so that the outcome of the fragility functions leads to the highest possible damage. This is motivated by the fact that the flood event of interest here is of a far more extreme nature than any of the previous flood events considered during model development (Scorzini et al., 2022). The resulting values for the missing hazard variables are the following: flow velocity of 4 m/s, flood duration of 48 hours and sediment concentration above 0.2 %. The variable describing water quality was kept at its original default value (i.e., q = 1), which means the presence of contaminants in floodwater. In contrast with the other hazard variables, values of water depth were never assumed. Only buildings for which a value of water depth was reported by respondents during the field surveys were accounted for in the analysis.

The model INSYDE-BE utilizes unit prices for various activities necessary for the replacement or reparation of damaged building items. Since the default values in the model were based on construction prices from the year 2020, a correction factor was applied to adjust the unit prices (incl. for the effect of inflation). The value used for this adjustment was derived from a construction price index obtained from Statbel (https://statbel.fgov.be/en/themes/indicators/prices/construction-output-price-index#figures).

Sensitivity analysis

To further investigate the reasons for underestimation, a sensitivity analysis of the input data to the damages by the model INSYDE-BE is performed by additional model runs. This aims at better understanding the sensitivity of the model predictions to the main input data describing hazard and vulnerability.

The input variable water depth is the most influential input data (Scorzini et al., 2022). It is also affected by a considerable degree of uncertainty. The values used here are based on the memory of the field survey respondents. Considering that the field surveys were conducted more than a year after the food event, it is likely that the water depth values reported by the inhabitants contain errors. Moreover, the water depth outside a building is not uniquely defined. The ground topography around a building can be varied so that water depth is not uniform around a building. This adds to the complexity of interpreting the water depth values recorded by the field surveys. Therefore, to test the sensitivity of the model outcomes to this uncertain input variable, an additional model run has been conducted in which water depth values were increased by 30 %. Though arbitrary, this value is most probably not overestimating the error affecting the surveyed water depth values. Even in the case of water depth values obtained from a hydrodynamic model, it is very likely that an uncertainty of 30 % or above would affect the computed water depths, given the broad range of uncertainties influencing the computations (hydrological inflows, timing of the waves, unknown roughness parameters in urbanized floodplains, morphodynamic effects, clogging of flow paths by debris). The results of this additional model run are displayed in green in Figure 36.

For the sake of testing the model sensitivity to changes in vulnerability variables, a third model run was undertaken, in which the variables “finishing level” (FL in Table 3) and “level of maintenance” (LM in Table 3) were modified. These variables account respectively for how luxurious the finishing materials are and for the quality of preservation of the building's interior and exterior. Both a higher finishing level and a better level of maintenance can lead to higher repair costs, as demonstrated in the model sensitivity analysis conducted by (Scorzini et al., 2022). These two variables were not collected during the field survey, so that the first two model runs consider default values for these input data in line with Table 3: FL = 1 and LM = 1. To test the model sensitivity, it was rerun assuming maximum values for both the finishing level and the level of maintenance: FL = 1.2 and LM = 1.1. The model outcomes, combining a 30 % increase in water depth and the higher values of finishing level and level of maintenance are shown in red in Figure 36.

Table 7. Tests of the flood damage model INSYDE-BE.

Name	**Description**
INSYDE-BE + default values	• Input variables collected in the field survey. • Default values for not collected information.
INSYDE-BE + 1.3h	• Increase in 30% of the water depth.
INSYDE-BE + max values	• Assuming maximum values of the variables finishing level (FL) and level of maintenance (LM).

3 Results and Discussion

In this chapter, the results of the analysis described in paragraphs 2.4 and 2.5 can be found.

3.1 Residential damage function comparison

The results of the damage function comparisons are shown and discussed in this section. The comparisons are split into three sections. The damage models are compared on characteristics and their functions in the first section. In the second section the survey data is compared to the damage function outcomes and in the third section the sensitivity of the damage output in combination of uncertainty in the input data is analyzed.

3.1.1 Model Characteristics Comparisons

The different models are compared in this section in terms of the functions to calculate the damage factor as well as the monetary damage when possible. For clarity, a short overview is presented in Table *8* where the differences between the damage models can be seen. This can clarify why slightly different data is presented per model and function.

Table 8 Overview of functions per model for residential buildings

Method	BEAM	SSM2017	INSYDE-BE	WSS	Simplified-quantitative method (WL)
Function for building damage	Input: water depth Output: Euro/m2 living area	Input: water depth Output: Euro/m2 living area	Input: hazard and building parameters (see Table 2 and Table 3) Output: Absolute damage [Euro]	No	No
Function for household damage	Input: water depth Output: Euro/m2 living area	Input: water depth Output: Euro	No	No	No
Function for building and household damage combined	No	No	No	Input: water depth Output: Euro/m2 footprint area	Input: water depth Output: Euro/m2 footprint area
Water depth to reach the maximum factor	Building: 8m Household: 7m	Building: 5m Household: 5m	Building: • Damage to doors: 0.8 m • Damage to windows 1.75 m • Damage to boiler: 1.70 m	Building and household combined: 0.15m	Building and household combined: 0.15m

In Figure 11 it can be noted that the damage functions of the WSS and the Simplified-quantitative method of WL are very much alike. Both are mainly used for pluvial flood events where lower inundations are expected compared to fluvial events. Furthermore, the damage functions of the BEAM and the SSM model are for household damages similar. A key difference is that in the function of SSM, there is a clear change of function noticeable at 1 meter, 2 meters and 4 meters of water depth. The 2-meter and 4-meter jumps are likely effects of a new building level being inundated. The BEAM damage function has a change in gradient at 1 meter of water depth and doesn't change anymore after that. The water depths to reach the maximum damage factor differ as well, with 5 meters for SSM and 7 meters for BEAM. For the building damage factor the SSM and the BEAM function look slightly similar. Two differences are noticeable, which are the linear aspect of the BEAM building function, where again with the SSM model an effect of building levels are present and the maximum water depth to which the maximum damage factor is reached differs, where SSM reaches this point at 5 meters and BEAM reaches this point at 8 meters.

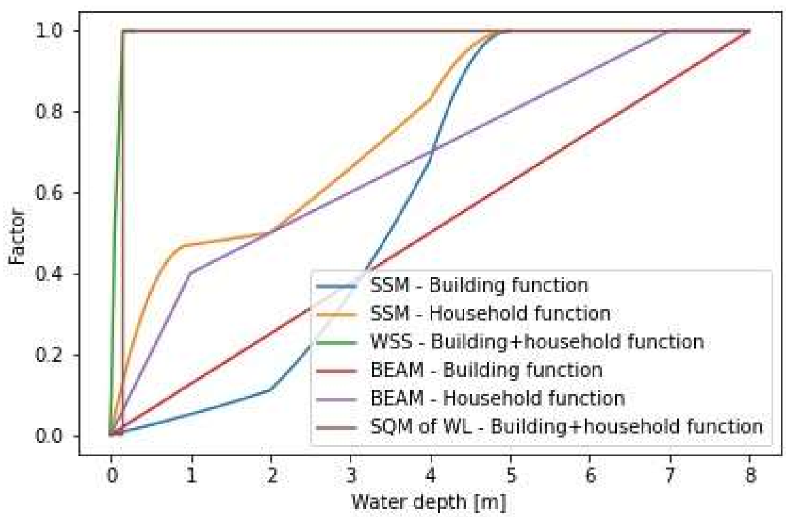


Figure 11 Damage factors of the different damage functions (SQM = Simplified-quantitative method)

The damage factor in itself doesn't indicate something about the monetary damage. Therefore, the functions in combination with the maximum damage numbers are needed to compare monetary damages. The building and household content damage is calculated with a single function for the WSS model and the Simplified-quantitative method of WL. Both result in damage per m^2 of footprint area. For the BEAM model, the building and the household content function are two separate functions but can be combined since they both result in damage per living area. The total damage of a building per water depth with the WSS and with the Simplified-quantitative method of WL are shown in Figure *12*. In Figure *12*, it can be noted that the Simplified-quantitative method of WL and the damage function of the WSS are much alike, both reaching the maximum damage at 0.15 meters of water depth.

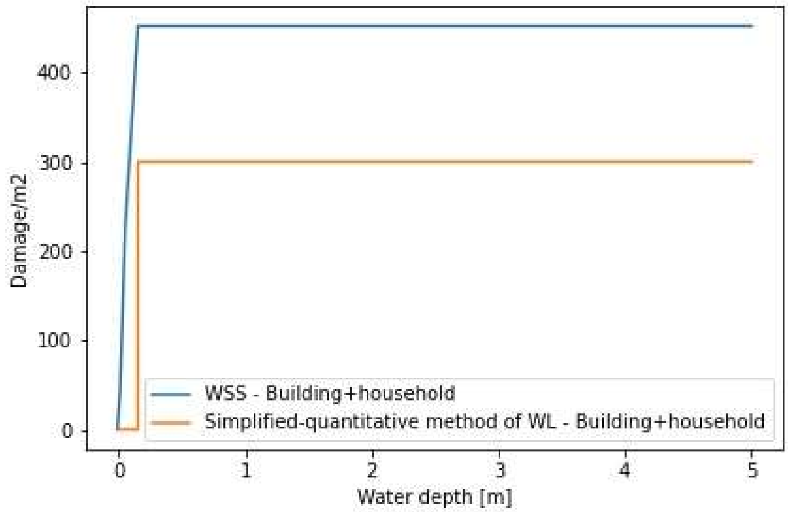


Figure 12 Building+household content damage function comparison, WSS and Simplified-quantitative method of WL. The area is in terms of footprint area.

Additionally, SSM also contains damage functions for Building and Household damage for specific T10 and T100 zones. These functions compared to the standard functions can be seen in Figure *13* and Figure *14*. Within the building functions a so-called threshold value is incorporated from which water depth damage can occur, where the functions have the same form after this threshold. This threshold can be seen as a sill or levee in front of the door. The assumption of areas that are prepared for frequent inundation, translated into higher levees in front of the house entrance, can be seen in these adapted functions. For the T100 zone, this is 0.25 meters and for the T10 zone this is 0.95 meters, after which the functions follow the same line. For the household functions, the same can be seen for the T100 zone with a threshold of 0.25 meters. For the T10 household function, however, it can be seen that the whole function is shifted along the x-axis. Indicating that home-owners take measures when it comes to household content in areas that are frequently flooded by for example elevating all content by 1.5 meters as that now indicates in the function from where damage starts to occur.

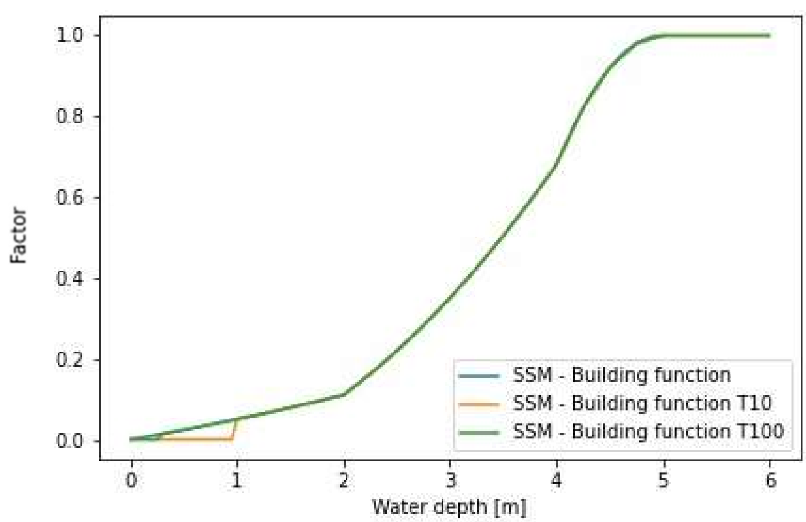


Figure 13 SSM building damage functions

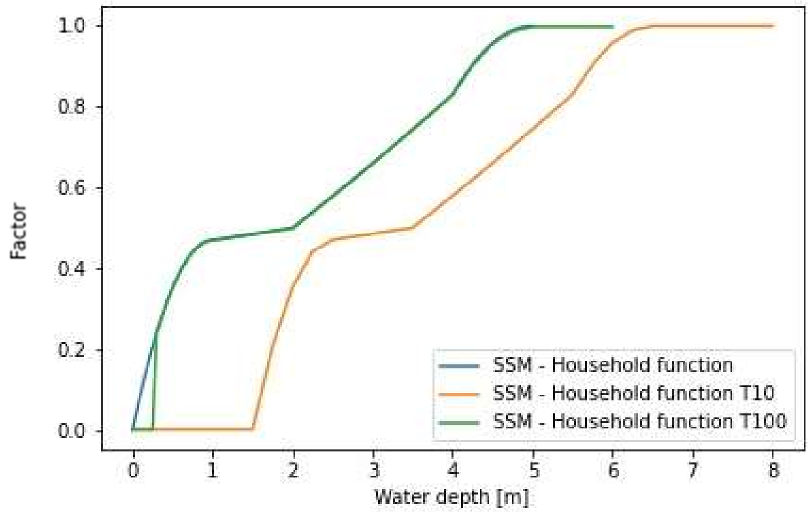


Figure 14 SSM household damage functions

Unlike other models, INSYDE-BE doesn't rely on a distinct function based on water depth levels. Instead, it calculates the damage for each building by taking into account the physical extent of damage and the cost to replace or repair individual components. In cases where the expected damage to components is uncertain, a probability-based factor is incorporated, which is determined by one or more fragility functions dependent on specific hazard variables, such as water depth [m], flow velocity [m/s] and flood duration [h]. For example, when estimating damage to doors, the function calls for a full door replacement if water levels exceed 0.8 m, flood duration extends beyond 36 h, or flow velocity surpasses 1.5 m/s.

The household function of the BEAM and SSM damage models can’t be directly compared since the output of SSM for this function is damage per building and the output of the BEAM model is damage per m^2 of living area. The building function of BEAM and SSM however, can be compared since they are in the same unit. For the BEAM model only the maximum damage number used together with the factor of the function is found for the household function and not the building function. Therefore, no comparison graph is shown.

The maximum damage numbers from

Table *6* are used to put the damage functions in perspective for an average house in the Netherlands. In this case, the assumption is made that the house exists of 3 equal floors and a living area of 120 m^2, resulting in 40 m^2 of ground floor area. The comparison can be seen in Table 9, where it shows that the maximum damage numbers of BEAM and SSM for household damage are relatively equal. The total costs between WSS and SQM of WL are also much alike, although they are a fraction of the maximum damage that is calculated with SSM.

Table 9 Example to compare the maximum outcome of the functions for a house of 120m² living area and a ground floor area of 40 m².

Method Max damage [euro]	BEAM	SSM2017	WSS	Simplified-quantitative method (WL)
Building	No damage number available	1295*120= 155.400	-	-
Household	700*120= 84.000	81.985	-	-
Combined		237.385	15.200	12.000

3.1.2 Model and survey comparison

There are four damage models compared against the in-depth field interview results, which are the damage models of BEAM, SSM2017, Simplified quantitative method (SQM) of WL and WSS. These models are compared in this section since they have separate functions that can be compared to the acquired data. From the damage models of SSM and WSS, it is known from which year the price level originates. Therefore, the maximum damage numbers of these models are corrected for inflation to correspond with the year 2021, the year of the flood event in the Euregio Meuse-Rhine. The inflation numbers are taken from the CBS website for building costs (CBS, 2023b).

The damage model SSM takes into account both the water depth and the total living area of the building when determining the extent of building damage. The survey did not inquire about the living area of the building, which is a feature documented in the Dutch building registration known as the "BAG". Therefore, a comparison of ground floor surface combined with the amount of floor levels from the survey is compared with the living area of the BAG for the Netherlands. In the survey also, the attic and the basement were included in the amount of floor levels. Therefore, a comparison between the ground floor multiplied by all floors, all floors minus 0.5 floor, all floors minus 1 floor and all floors minus 1.5 floor are compared in the scatterplot of Figure *15*, to find the best approximation for this missing feature in the German and Belgian dataset. This way the Belgium and German survey results could be compared with the SSM building damage function. In this research, based on Figure *15*, it is chosen to use the following formula to obtain the total living area for Germany and Belgium, as this showed the best r-squared of the different options:

$$A_{living} = A_{groundfloor} * (floorlevels - 1)$$

From the comparison it needs to be noted that this approach shows not a perfect fit and that this approached living area is only used to compare the damage of the survey with the building damage function of SSM.

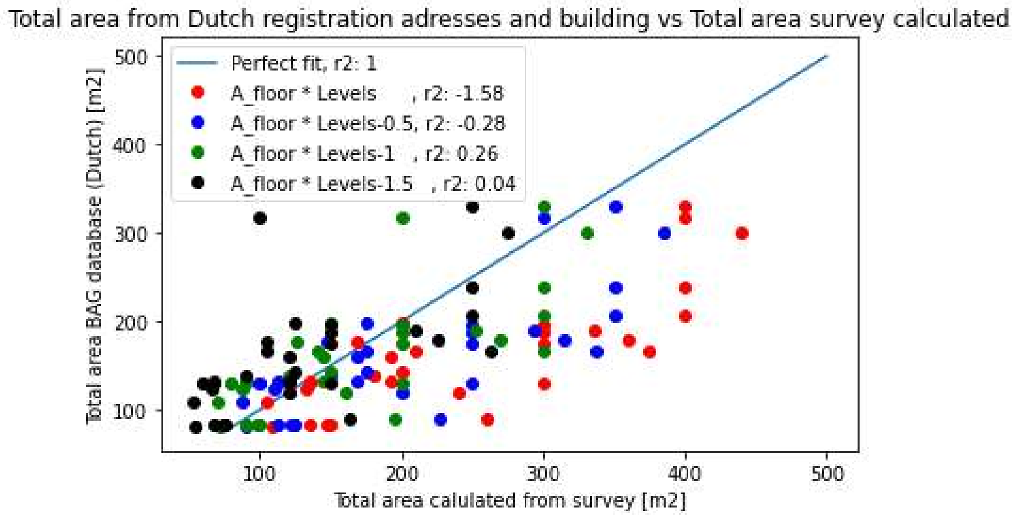


Figure 15 Calculated living area vs living area from the BAG (NL data)

3.1.2.1 Quality assessment of interviews in the Netherlands

The Association of Insurers in the Netherlands monitor data for different types of weather events and shares this data in their Climate-damage-monitor. For the year 2021, this data for precipitation and flooding can be found per municipality. The flooding damage component in Valkenburg and Gulpen-Wittem consists mainly of damage that occurred in July, the month in which the event of this research happened. This shows that the flood and precipitation data of this year can be used to compare the survey data of the July 2021 event, which can be found in Table 10, Table 11 and Table 12.

The government also compensated people for the damages of the July 2021 event by the so-called WTS. The WTS is supposed to compensate for non-insurable damage. In the case of Valkenburg the WTS compensated a lot of the damage compared to the insurance data, which is remarkable. Different categories are present in the data of the WTS, of which ‘Fixed assets’, ‘Building’ and ‘Household content’ is used to obtain a number for the compensation from the WTS in Valkenburg. This number is included in Table 10. The numbers for Gulpen-Wittem were not investigated in (enw, 2023). The damages in Gulpen-Wittem were in general lower than in Valkenburg where the ratio between damage and compensation was relatively close to each other, as can be seen in Table 12.

Table 10: Insurance damage data, source: Climate-damage-monitor. WTS damage data, source: (enw, 2023)

Damage [euro*10^3]	Valkenburg	Gulpen-Wittem
Association of Insurers	36233	5697
WTS	27500	

The flood extent of Figure 10 obtained from (Kok et al., 2023) is used to obtain an estimation of the total amount of houses that were affected by the flood event. During the survey, it was found that this flood extent was relatively accurate except that many houses at the edges were in this flood area but did not have sufficient water against the building to cause damage. This means that the amount of buildings estimated to be affected by the July 2021 event is expected overestimated in Table 11.

Table 11: Buildings in estimated flood area, (Kok et al., 2023)

	Valkenburg	Gulpen-Wittem
Buildings	1649	356

In Table 12 a comparison is made between the survey damage data from Deliverable 5.1.2 and registered data of compensations by the insurances and the government.

For the survey data both for the municipality Valkenburg and Gulpen-Wittem a mean and a median of the total survey damage is calculated in row 2 of Table 12. This is the damage that the survey participants mentioned to have suffered multiplied by the estimation of the affected buildings from Table 11. The third row shows the deviation of damage by dividing the survey data with the compensated registered damage. The same process is also done for the damage data the survey participants mentioned to have received from the insurance, government and donations in rows 4 and 5 of Table 12.

Table 12 Survey comparison to compensated data according to Association of Insurers and government. Insurance damage data source: [Climate-damage-monitor.](#) WTS damage data source: (enw, 2023)*. *this is the mean and median damage multiplied by the amount of estimated buildings affected. ** Compensated data is for the municipality, no mean or average data is available.*

		Mean		Median	
row		Valkenburg	Gulpen-Wittem	Valkenburg	Gulpen-Wittem
1	Compensation registered by Insurance and WTS [euro*10^3]	63733**	5697**	63733**	5697**
2	Survey damage* [euro*10^3]	138072	9510	94818	6230
3	Difference [row2/row1]	**2.17**	**1.67**	**1.49**	**1.09**
4	Survey payout damage* [euro*10^3]	99939	6675	67609	6497
5	Difference [row4/row1]	**1.57**	**1.17**	**1.06**	**1.14**
6	Survey Damage / Survey payout [%]	138	142	140	96

The overview of Table 12 shows that for Gulpen-Wittem the survey damage is closer to the data of the registered compensation data than is the case for Valkenburg. Both municipalities are within a small range of deviation between what is registered and what is seen from the survey, especially if looked at the median value columns of the payout from row 5 of the table. It is expected that the mean values differ more when outliers are present, which causes the mean to shift up. This seams to happen in Valkenburg where a large difference between the mean and median is seen. The comparison of Table 12 gives confidence in the survey data, especially when keeping in mind that the number of affected buildings used to calculate the total damage of row 2 and 4 is expected to be overestimated. This means that the total damage of the survey for the two municipalities are expected to be lower when having a correct view of the amount of affected buildings.

Further what points out is that the surveyed payout is roughly 40% lower than the damage suffered according to the survey participants, as can be seen in Row 6 of the table. For Gulpen-Wittem it seems that most occurred damage is also paid out, based on the median of the dataset.

3.1.2.2 Water depth and damage comparison

The surveyed water depths and damages from the July 2021 event are compared with the different damage model functions investigated within this research. Damages are highly varying among different houses, therefore damage models aim to calculate the average of an area as best as possible within their damage estimation. To get an insight into how well the models perform compared to the July 2021 event, the comparison is split into:

- Building damage
- Household content damage
- Combined building and household content damage

When possible, damage functions of the damage models of BEAM, SSM2017, Simplified quantitative method (SQM) of WL and WSS are shown together. When this is not possible due to different output types of the functions, the functions are shown separately.

To eliminate individual outliers and extremes, the average of damage per bin of 0.25 meters of water depth is also shown in the following three sections, with their corresponding minimum and maximum values as limits. The surveyed damage of the three countries is shown combined in these comparisons with the damage models. Section 3.1.2.3 goes into more detail about the differences among the three countries of the Euregio Meuse-Rhine.

The figures of appendix 7.1, show the water depth compared to the damage of the survey for the building, household content and total damage for each country. The first look into this shows that the damage doesn't increase very clearly with increasing water depth as in contrast of what can be seen in below sections where the damage is shown per unit of area to compare with most damage functions.

Water depth and Building damage

Of the four damage models only SSM and BEAM have a damage function for building and household damage separately. For the building damage function of BEAM, it wasn't possible to obtain the maximum damage number within this research. Therefore, in this section only SSM is compared to the building damage obtained from the survey in Figure *16*. Looking at the single datapoints of Figure *16* it can be seen that SSM is underestimating the building damage occurred during the July 2021 flood event.

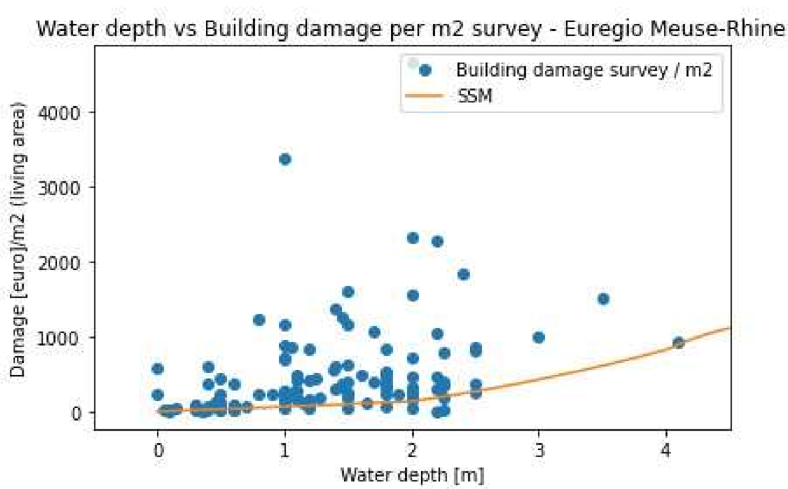


Figure 16 Building damage/m2 living area in the Euregio Meuse-Rhine compared to the SSM household damage function

In Figure *17*, the average building damage in bins of 0.25 meter water depth are shown with the min and max levels of these bins. This shows that on average SSM is underestimating the building damage. What can be noticed is that the minimum values of the 0.25 meter bins are more in line with the SSM building function.

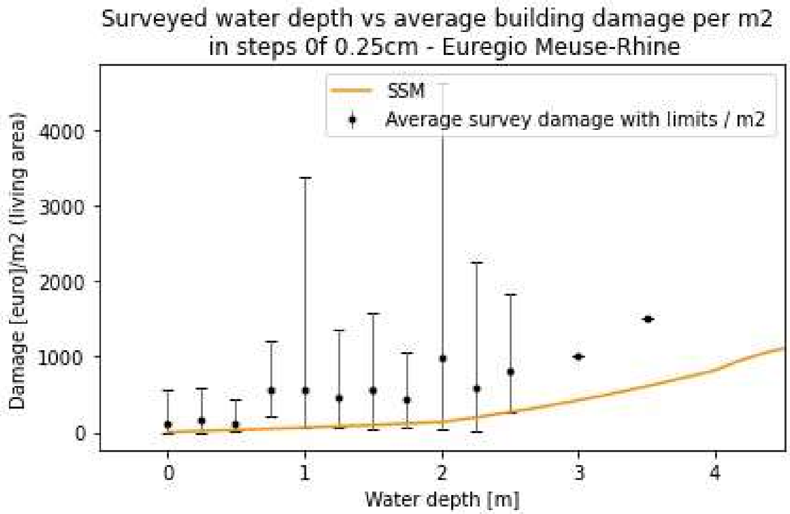


Figure 17 Average building damage/m2 living area in the Euregio Meuse-Rhine compared to the SSM household damage function. The limits show the min and max value of the bin.

Water depth and Household content damage

For the household content damage function of BEAM, it was possible to obtain the maximum damage number within this research. Therefore, in this section BEAM and SSM are compared to the building damage obtained from the survey in Figure *18* and Figure *19*. The output of the BEAM and SSM household content functions are in different units, see y-axis of the graphs. Therefore, the comparisons are shown separately with the corresponding damage. Looking at the single datapoints of Figure *18* it can be seen that the BEAM model is overestimating the building damage occurred during the July 2021 flood event. The same seems to be the case for the SSM model.

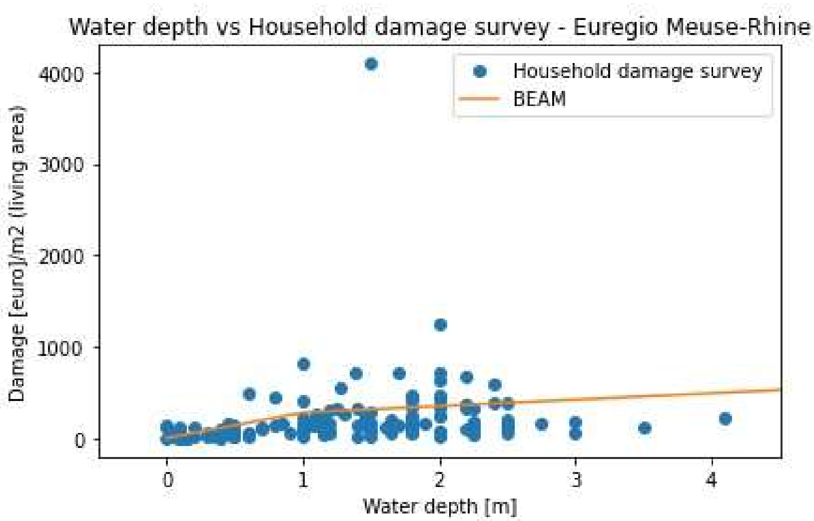


Figure 18 Household content damage/m^2 living area in the Euregio Meuse-Rhine compared to the BEAM household content damage function

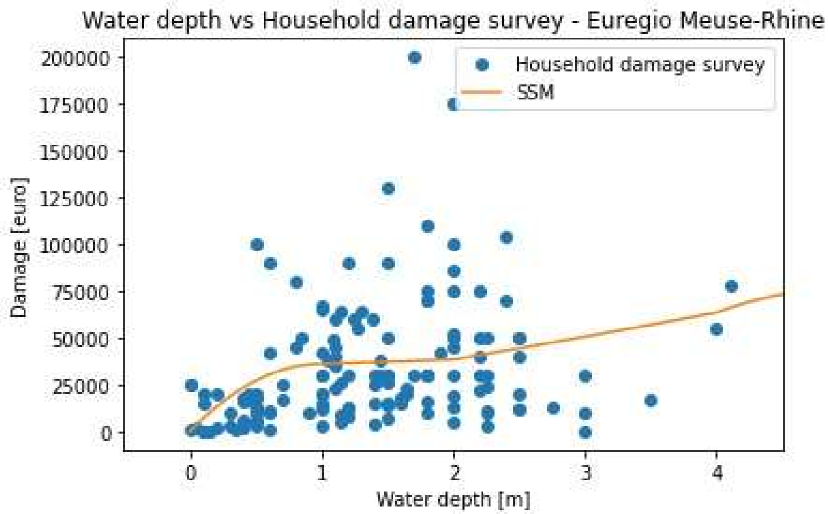


Figure 19 Household content damage/building in the Euregio Meuse-Rhine compared to the SSM household content damage function

In Figure *20* and Figure *21*, the average household content damage in bins of 0.25 meter water depth are shown with the min and max levels of these bins. This shows that on average BEAM shows good results up to 1 meter of water depth. After that it seems to overestimate the damage to the household contents.

For the SSM model however, it seems that overall the calculated damage is in line with the surveyed data. After 2.5 meters of water depth the surveyed household content damage changes abruptly. This is also the domain where little data is available from previous events.

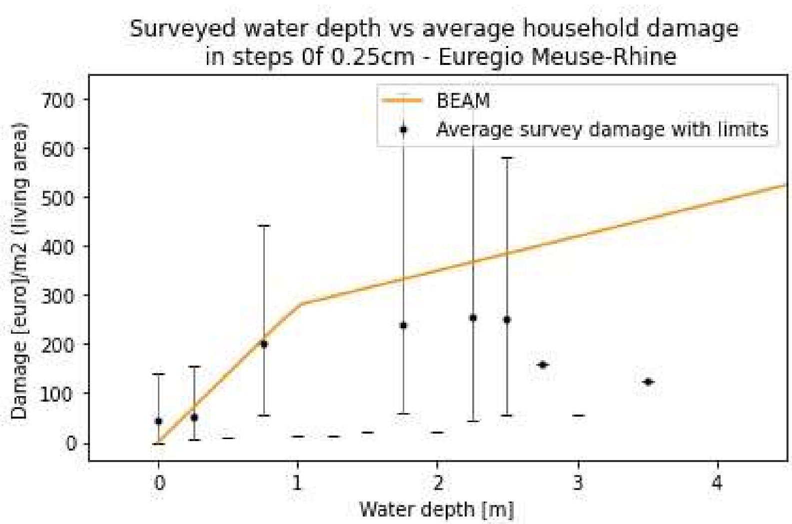


Figure 20 Average household content damage/m^2 living area in the Euregio Meuse-Rhine compared to the BEAM household content damage function. The limits show the min and max value of the bin.

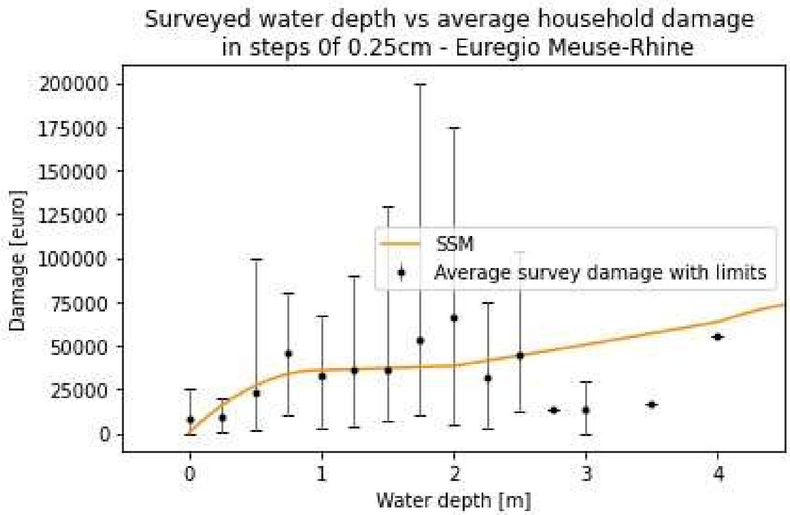


Figure 21 Average household content damage/building in the Euregio Meuse-Rhine compared to the SSM household content damage function. The limits show the min and max value of the bin.

Water depth and total damage

For the total damage of the BEAM model it wasn't possible to show comparisons within this research due to the missing maximum damage number for the building function. Therefore, in this section WSS and the Simplified-quantitative method of WL are shown together in Figure *22*. In this figure, it can be seen that for the first 1 meter of water depth the functions of both WSS as the Simplified-quantitative method of WL seem to overestimate the damage. This is followed by a clear underestimation for higher water depths. Both models are made for inundation events with relatively small water depths, pluvial events.

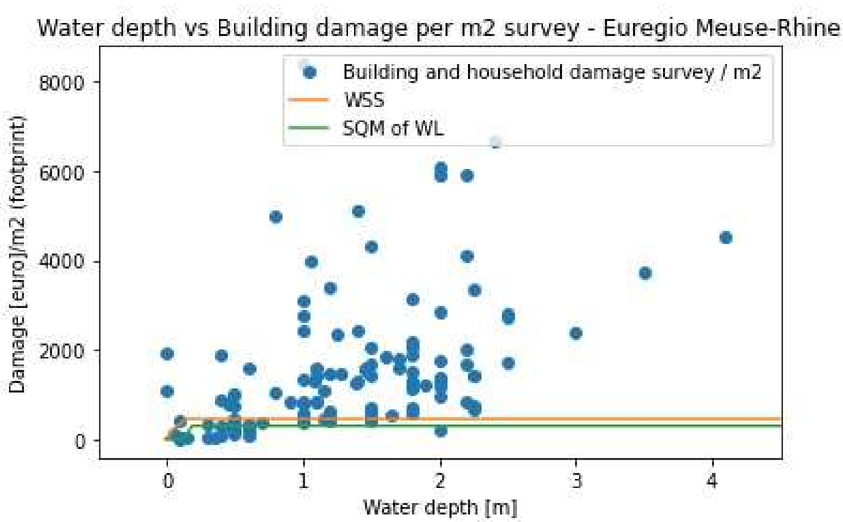


Figure 22 Total damage/m^2 footprint in the Euregio Meuse-Rhine compared to the WSS and the SQM damage function

In Figure *23*, the average total damage in bins of 0.25 meter water depth are shown with the min and max levels of these bins. This shows that on average the WSS shows results for the first 0.5 meters that seem to fit, although this small section is very sensitive for increases in water depth. The Simplified-quantitative method of WL already underestimates from the beginning. The small window of water depths where the damage varies is very sensitive for small water depth errors, resulting in very little or already the maximum damage.

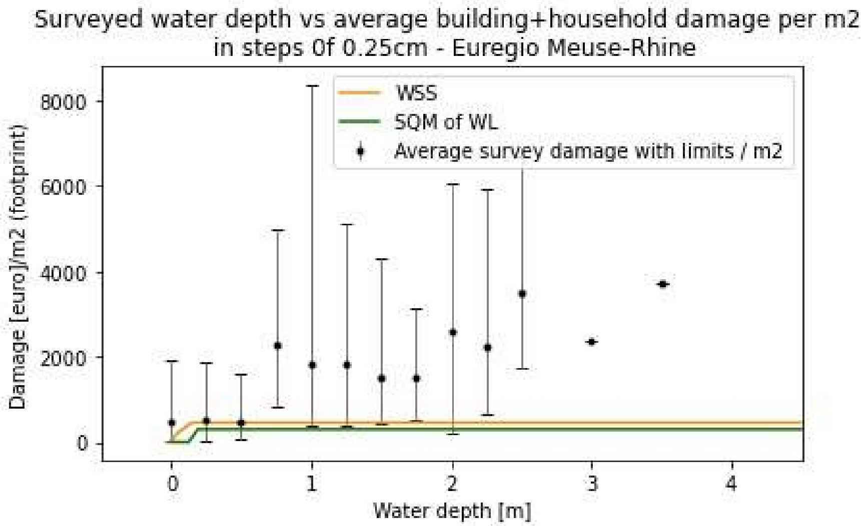


Figure 23 Average total damage/m2 footprint in the Euregio Meuse-Rhine compared to the WSS and the SQM damage function. The limits show the min and max value of the bin.

3.1.2.3 Compatibility of damage models among Euregio Meus Rhine

In this section the damage models are compared to the individual datapoints obtained from the survey for each country separately. This done for building damage, household content damage and the combination of both damage types.

Building damage model comparison between countries

The Dutch model SSM for building damage matches the building damage occurred in Belgium and the Netherlands much better than it matches the German building damage. This shows that the damage occurred in Germany was much higher in general for the same water depths.

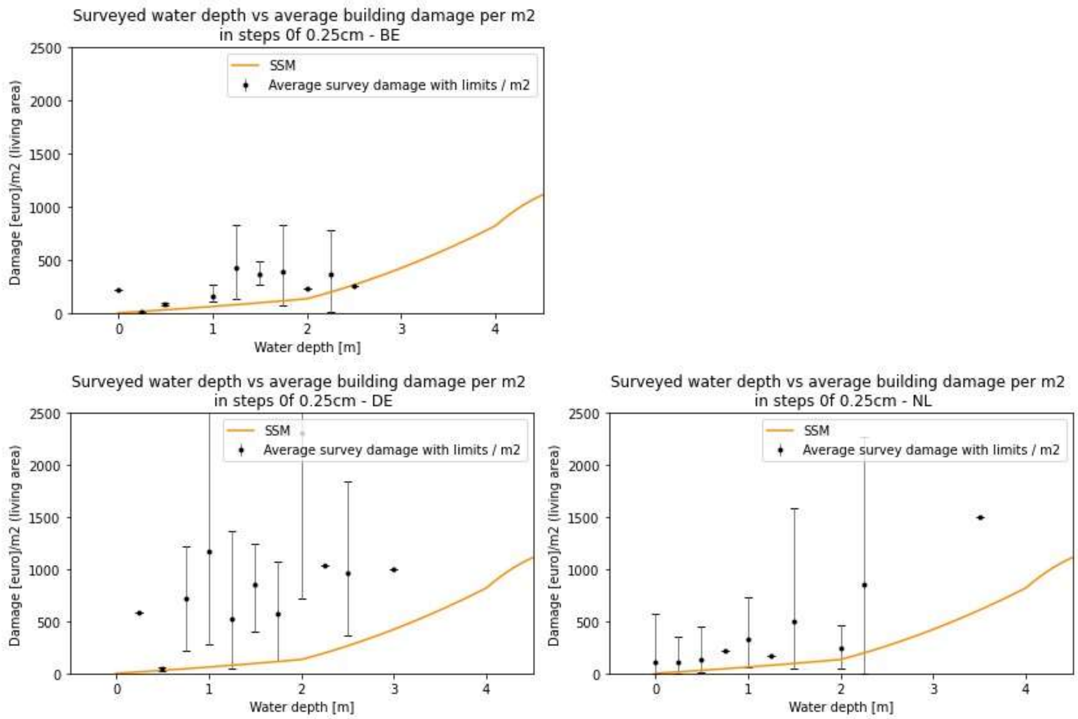


Figure 24 Average building damage by SSM comparison of countries. The limits show the min and max value of the bin.

Household content damage model comparison between countries

The damage model BEAM for the household content damage is roughly in line for all three countries, see Figure 25. It seems that the household damage in Belgium flattens at a smaller water depth, around 1 meter, than it does for Germany and the Netherlands. Though it needs to be kept in mind that for every bin of 0.25 meter water depth, there is a different amount of surveyed points available.

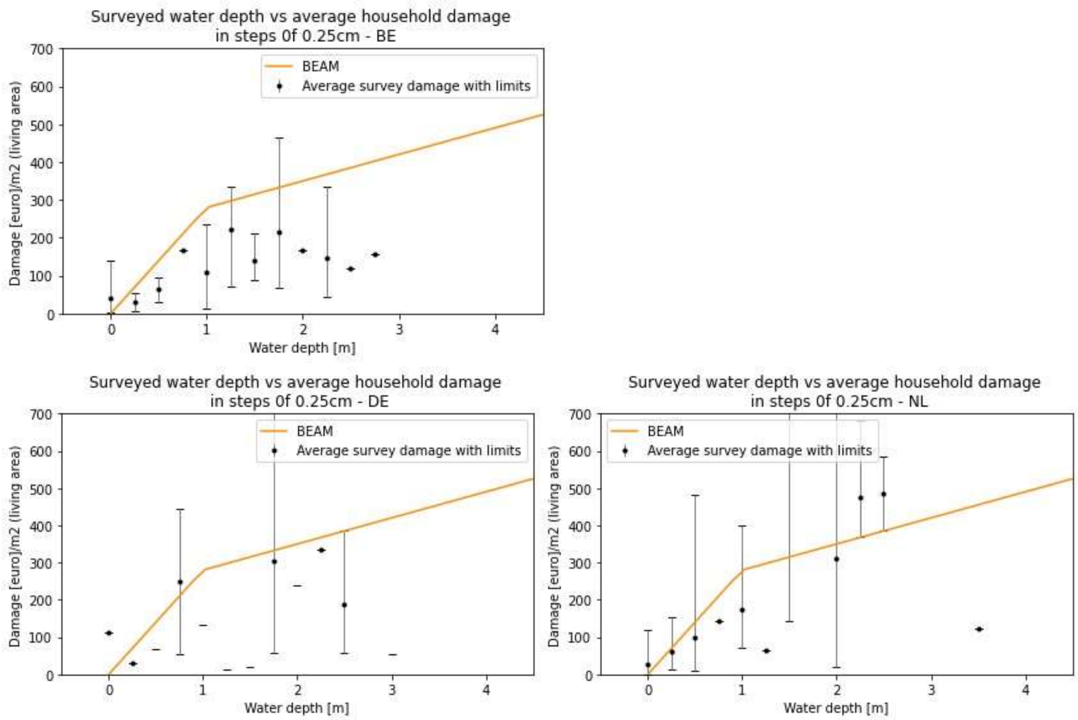


Figure 25 Average household content damage by BEAM comparison of countries. The limits show the min and max value of the bin.

In Figure 26 the household content damage of the three countries can be seen in relation to the household content damage function of SSM (damage/building), which is in a different unit than the BEAM household content damage (damage/floor area of a building). As mentioned earlier during the analysis of the separate functions, it can be seen that there are two slope changes in the damage function that follow the occurred damage for all three countries quite well. The first slope change is around 1 meter that indicates that furniture on the floor are all inundated and damaged. After 2 meter of water depth the damage function increases again indicating it represents inundating a new floor level and hence new damages. The household content damage function of SSM seems to fit slightly better for Germany and the Netherlands in comparison with the damages of Belgium.

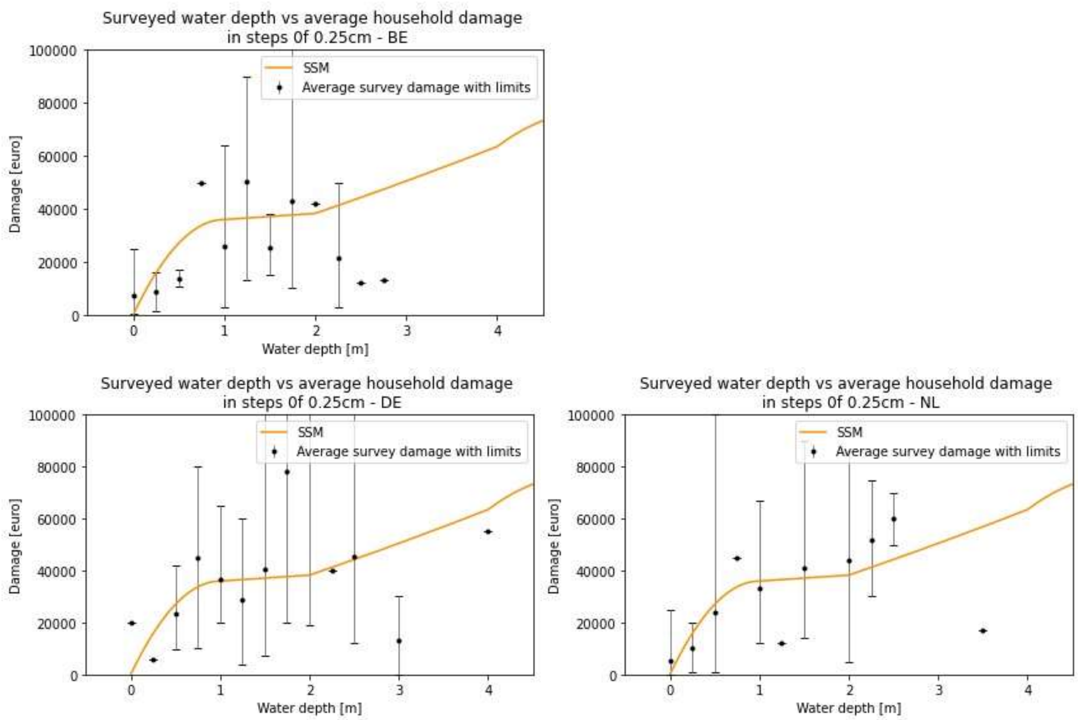


Figure 26 Average household content damage by SSM comparison of countries. The limits show the min and max value of the bin.

Building and household content damage model comparison between countries

For the total damage of a building, including household content and building damage the model of WSS is compared together with the semi-quantitative method (SQM) of WL in Figure 27. Both damage models are made for small inundation events (pluvial events) and are not designed for events with high water depths that are most likely induced by fluvial events. In the Netherlands, the flood event of July 2021 resulted in much lower water depths, where both damage models have a relative good fit until 0.5 meter of water depth, after that it clearly underestimates the damage. Germany shows much higher damages starting from lower inundation levels and for Belgium the damage shows more randomness for small inundations. For the July 2021 it can be concluded that both damage models underestimate the occurred damage.

The other damage model functions were incomplete or resulted in different units for both types of damages and are therefore not shown in the graph.

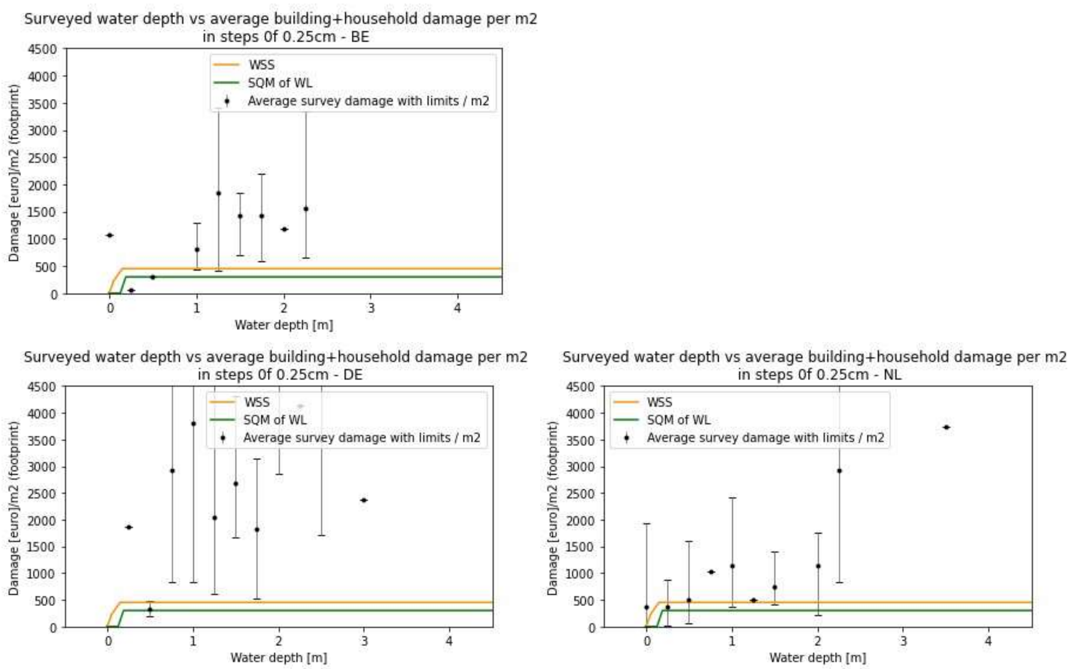


Figure 27 Average building and household damage by WSS and SQM comparison of countries. The limits show the min and max value of the bin.

3.1.2.4 Entrance threshold analysis

In some of the damage functions, there is a predefined threshold at which damage initiates. The water depth thresholds in damage functions are established to encompass a point at which water infiltration into the building occurs. This might involve features such as raised door sills or elevated entrance heights. However, a limitation of this approach lies in the fact that the thresholds for water infiltration need to be adjusted dynamically, largely contingent on the frequency of flooding events. This means that areas prone to more frequent inundation flooding incidents (pluvial and/or fluvial events) will have higher entrance threshold levels compared to regions that seldom encounter inundation of the street.

In Figure 28, the entrance heights for the three countries can be seen, which are obtained from the survey of this research. Here it can be noted that the spread and the overall in entrance height is larger for Germany compared to Belgium and the Netherlands. This could indicate that the surveyed German regions are more subjected to inundation and prepared the entrance height accordingly.

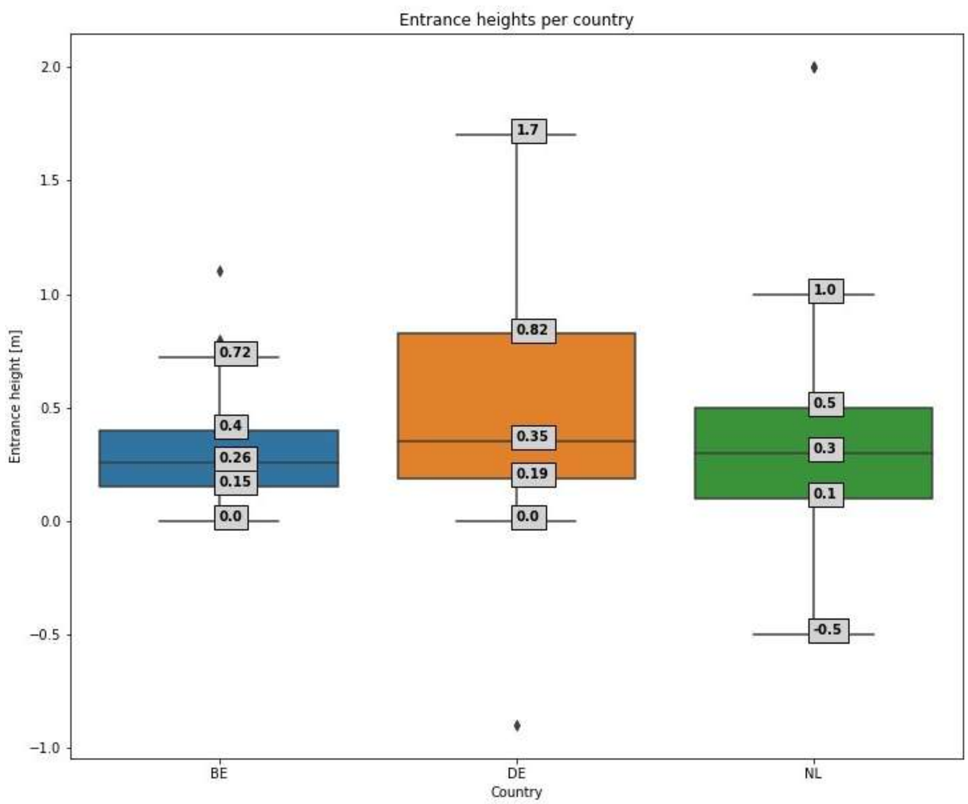


Figure 28 Boxplot of the entrance height levels obtained from the interviews

The entrance thresholds and other characteristics of the different damage models can be found in

Table *6*. From this table, it can be seen that only the simplified quantitative method of WL and the model SSM contain a threshold for the damage functions. For the Netherlands, the T100 damage functions of SSM are in the range of the found entrance heights in the Valkenburg area. The simplified quantitative method of WL shows a threshold which seems on the low side for the Valkenburg area. At the same time, the damage models containing no entrance threshold at all could be improved for the areas of interest in this research by adding this feature. The entrance height is not always the level from where water can enter a building, gaps, ventilation panels and basement windows can cause water to enter before even reaching the entrance height. This also shows that it is difficult to implement and to assign a number to this feature.

3.1.3 Sensitivity analysis results

In the coming section, the damage models are analyzed on the sensitivity of the damage outcome when introducing uncertainty of water depth input. For Belgium and the Netherlands, there are water depth maps available of the July 2021 event. Where Belgium used ground observations to make a synthetic water depth map and the Netherlands used a preliminary hydro-dynamic model to obtain a water depth map. The latter is made with a non-calibrated model and thus cannot be seen as final and reliable. The effort to use this additional water depth data is merely a way to see how sensitive the outcome of the damage models are on uncertain input data. Floodmaps of Germany arrived at the end of this research and couldn't be included anymore, therefore only the maps of the Netherlands and Belgium are compared.

For both Belgium and the Netherlands, the available water depth maps additional to the survey are used to compare how they differ, which can be seen in Figure 2. The deviations of the maximum water depth found within 2 meters of the surveyed buildings compared to the surveyed water depth are large. For both countries, the model data show more often higher water depths than lower water depths compared to the survey data. This could indicate that either the modelled data is overestimated or that the surveyed water depths are estimated too low. There are only a few points located on the orange line indicating a perfect match between survey and model data. This means, it can be expected that the damage models therefore give different outcomes between the two sources of input data. This comparison can be found in the coming sections for each damage model.

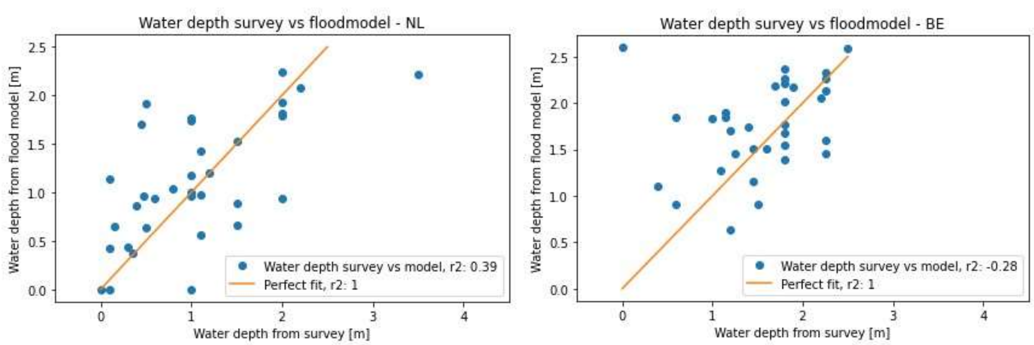


Figure 29 Water depth comparison of survey data with model data

3.1.3.1 BEAM sensitivity analysis

For the BEAM damage model as mentioned earlier, only the maximum damage for the damage function of the household content damage was found. Therefore, only the household content damage is compared for the BEAM damage model. The results for Belgium show a high resemblance in damage between both water depth input data. There are a few points showing a difference in damage, this is mainly for the points where the survey resulted in much lower water depths compared to the modelled data. For the Netherlands there are more data points showing a deviating damage result for the two water depth sources. The r-squared of the water depths sources for the Netherlands is also worse as can be seen in Figure 29.

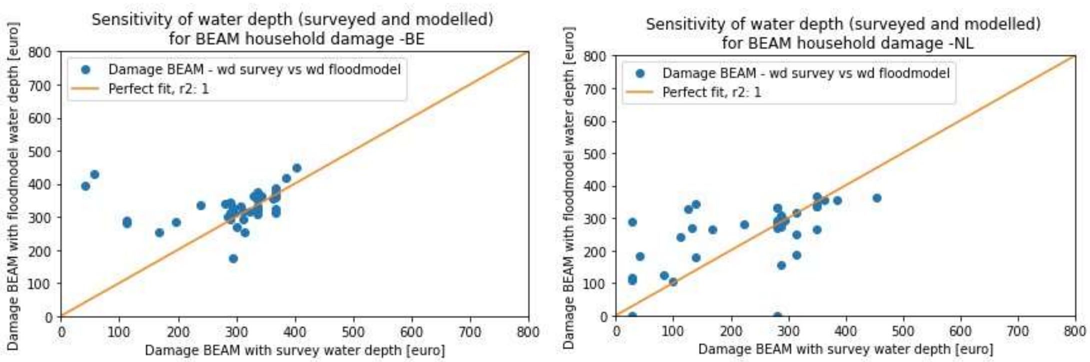


Figure 30 Household damage by BEAM comparison with surveyed and modeled water depth as input

3.1.3.2 SSM sensitivity analysis

For the Dutch damage model, SSM there are two functions that can be compared, household content and building damage. The first thing that points out is that the damage for the Belgium water depths look much higher than for the Netherlands, see Figure 31. This indicates that higher water depths are an important driver for higher building damages in this damage function.

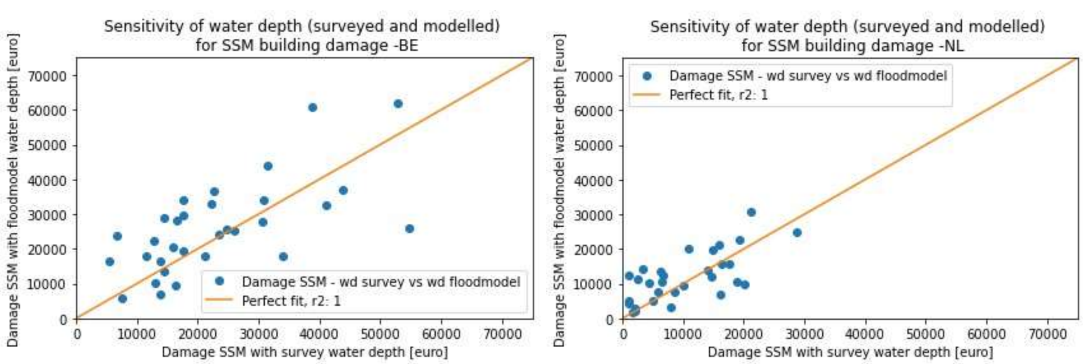


Figure 31 Building damage by SSM comparison with surveyed and modeled water depth as input

For the household content damage, the damages are more in the same range between the Netherlands and Belgium, see Figure 32. This indicates that the water depth difference between the countries is in a lower degree import for the amount of damage calculated by the household content function of SSM. Furthermore, also deviations in water depth have smaller influence on the household content damage output compared to the building damage, where much higher differences can be seen between surveyed and modelled water depth data. The difference seems smaller for SSM than seen for the BEAM model, when comparing the household content damage outcomes.

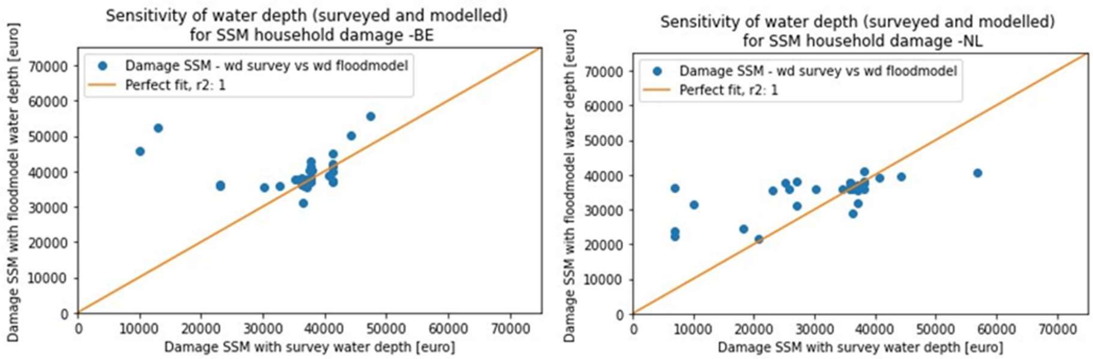


Figure 32 Household content damage by SSM comparison with surveyed and modeled water depth as input

3.1.3.3 WSS sensitivity analysis

For the damage model WSS the deviation of water depth for this event is almost non-existing. This is caused because the maximum damage is reached after 15 cm of water depth. Meaning this model is only sensitive for water depth input data lower than 15 cm of water depth, everything above this threshold is for this damage model, which main focus is on fluvial events, seen as equal damage. This unsensitive behavior to water depth is caused by the flaws of the WSS, which is the small range of water depth to reach maximum damage.

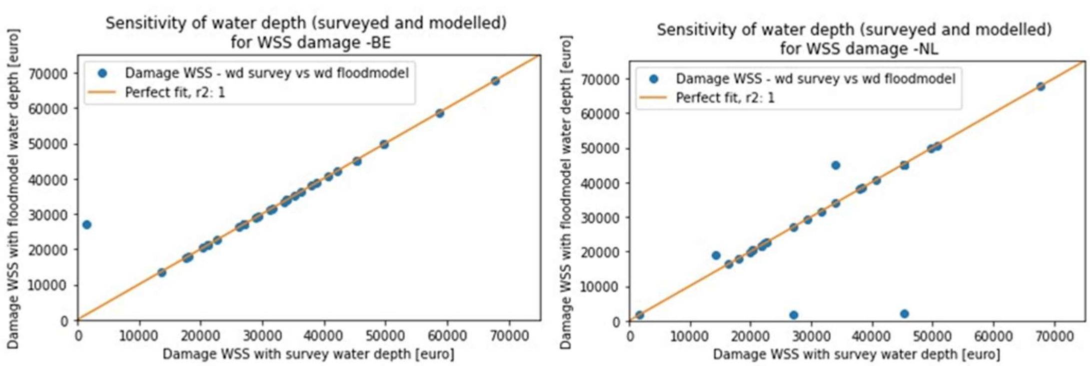


Figure 33 Total damage by WSS comparison with surveyed and modeled water depth as input

3.1.3.4 Simplified quantitative method (SQM) of WL sensitivity analysis

For the simplified quantitative method of WL, it is almost the same case as for the damage model WSS. In this case any water depth above 15 cm causes damage, which is fixed after this point. This means that this damage function is also not sensitive for water depth uncertainty if sufficiently inundated. When looking at shallow water depths this changes around the 15 cm water depth point.

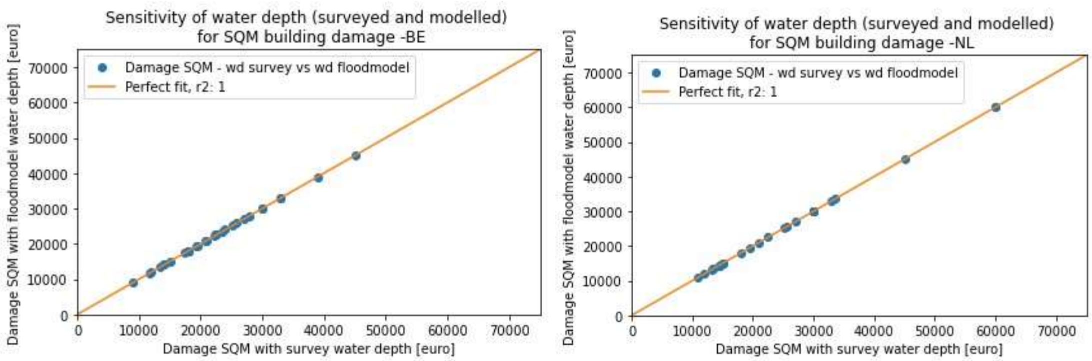


Figure 34 Total damage by SQM of WL comparison with surveyed and modeled water depth as input

3.2 Assessment of INSYDE-BE model

Model application

The flood damage model was applied for the surveyed buildings as reported in Deliverable 5.1.2, in the three involved countries. Figure 35 compares the model outcomes to the surveyed damage estimates. The damage model appears to perform very differently depending on the range of flood damage. For moderate monetary damages (i.e., up to about 50,000 euros), the model estimations are overall in fair agreement with the values reported by the survey respondents, with a maximum relative root mean squared error (RRMSE) of 20% as shown in Figure 40 (b). Conversely, the extent of damage appears underestimated in all three countries, for the case of higher reported damages (see Figure 40 (a)).

This pattern in the results is not surprising. Indeed, as pointed out by various authors (Molinari et al., 2020; Scorzini et al., 2022; Wagenaar et al., 2018) flood damage models are inherently tailored to a specific context. Therefore, when a model originally designed for one context is applied to estimate damage in a different context than the one for which it was originally created, the model performance tends to decrease. This variation in model performance occurs because the model relies on the hazard characteristics and the vulnerabilities of the exposed items, which differ between regions and types of floods (moderate vs. extreme). This contributes to explain the underperformance of the model for the highest flood damages, which differ from the context for which INSYDE-BE was developed, as detailed by (Scorzini et al., 2022). It also explains why model performance is lower in other countries than Belgium, particularly in Germany, as INSYDE-BE utilizes default values for hazard and building characteristics rooted in the Belgian context. This is exemplified by the substantial differences between model outcomes and observed damages in Germany Figure 35(b) and Figure 37 to Figure 40 (a).

Moreover, even for Belgium, INSYDE-BE was not validated due to a lack of damage data at building level at the time of model development (Scorzini et al., 2022). However, Deliverable 5.1.2 in this project, together with additional interviews conducted by the University of Liège in the aftermath of the July 2021 flood, have led to the creation of a new object-level damage database, which creates an opportunity for recalibrating and validating the model so that it can be reliably used in the Walloon region for the assessment of flood damage in residential buildings. This future recalibration of the model will consider the hazard conditions and extent of reported damages in the extreme event of 2021, allowing the model performance to be substantially improved for the case of extreme floods.

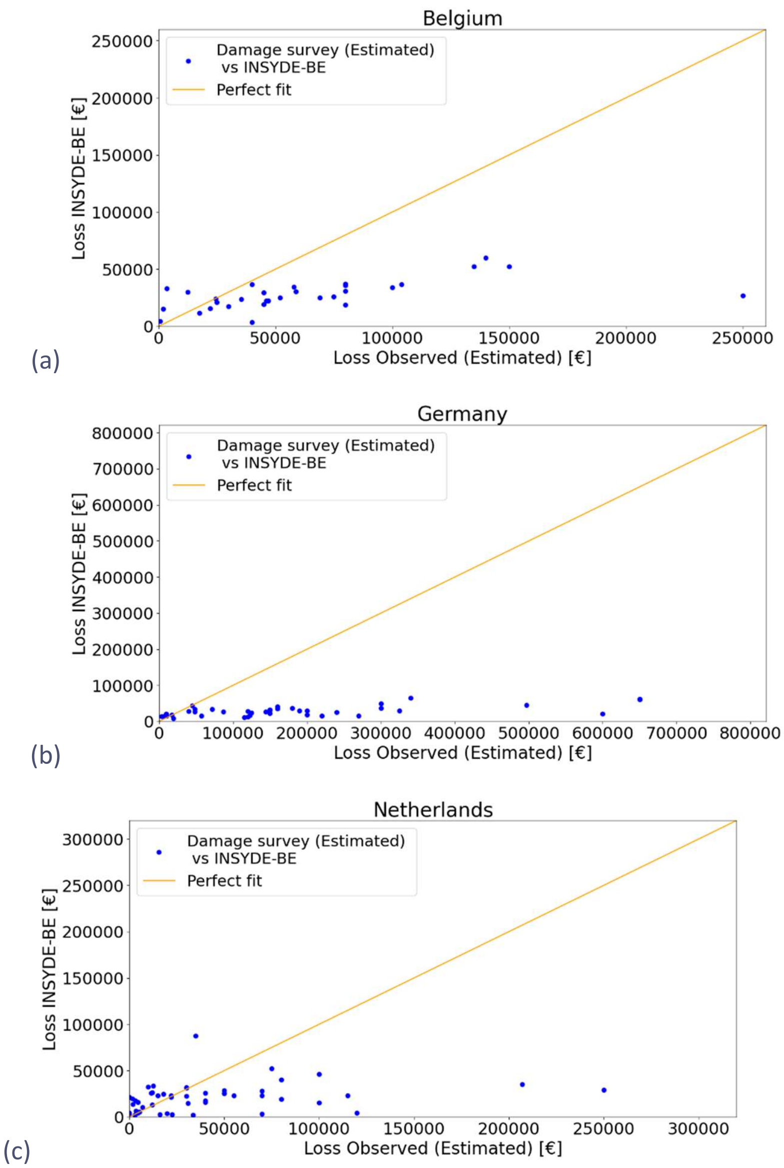


Figure 35. Performance of the flood damage model INSYDE-BE vs reported losses for the surveyed buildings in Belgium, Germany and the Netherlands.

As explained in 2.5.2, three different configurations of the model have been undertaken. For the last one, considering a 30% of increase in the water depth value, and the maximum values that the variables finishing level and level of maintenance, the results are shown in red in Figure 36. For Germany the changes do not lead to a significant variation as the estimations in the higher damage range remains very low compared to the observations (Figure 36b). In the context of Belgium and the Netherlands, the third model run leads to a general upward adjustment in all estimations rather than merely elevating specific values (Figure 36a and c). This is attributed to the uniform value assigned to the altered variables for all buildings. This suggests that assessing variables like finishing level and level of maintenance in future field surveys and within vulnerability databases is of paramount importance for achieving more accurate damage estimations.

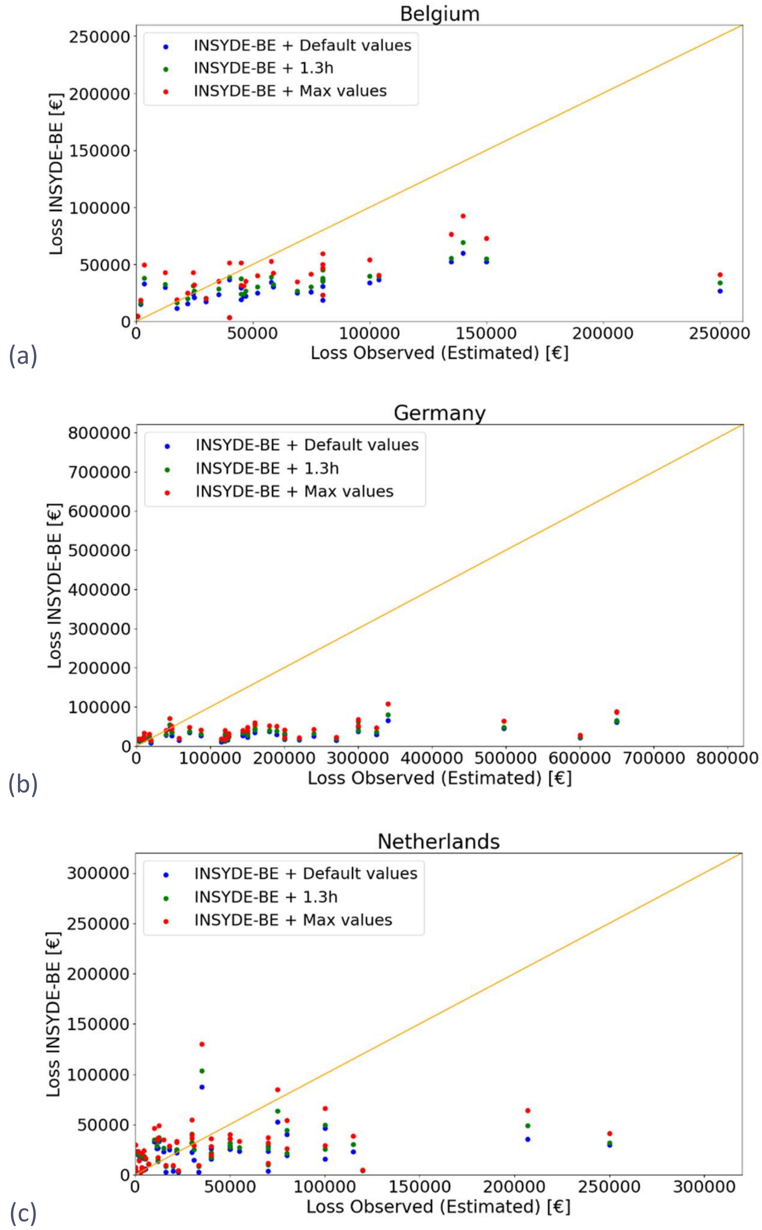


Figure 36. Performance of the flood damage model INSYDE-BE vs reported losses for the surveyed buildings in Belgium, Germany and the Netherlands. (Blue) Estimation with input values from the field survey and default values defined in the model, (Green) considering an increase of 30% in the water depth, and in (Red) the increase in water depth, and additionally the maximum values for the variables Finishing level and Level of maintenance.

To assess the performance of the model, various error metrics have been computed. Mean Bias Error (MBE) was employed to estimates the model's tendency to either overestimate or underestimate damage in comparison to values reported by residents. A positive bias indicates model overestimation, while a negative sign signifies underestimation of damage. As illustrated in Figure 37(a), the model consistently tends to underestimate damage across the three countries. Nonetheless, the model's performance exhibits improvement when the analysis is focused on damage values below 50,000 Euros, as depicted in Figure 37 (b). This improvement can be attributed to the model's development, which has been tailored for low-to-moderate flood events.

Notably, in general, the estimation for Germany is less accurate, which can be referred to the more extreme hazard characteristics observed in comparison with the other two countries. In contrast, the Netherlands exhibits a performance similar to Belgium. This similarity can be connected to more analogous conditions in terms of hazard and vulnerability, factors used to develop the tested model.

In addition to bias, the calculation of root mean squared error (RMSE) is undertaken to assess the precision of the predictive model. Relative values are also examined to provide a measure of the error relative to the range of the target value. All error metrics are applied to the three countries across three sets of variable conditions. When considering all losses, the model demonstrates a lower error under the maximum values configuration, approximately 20% for Belgium and the Netherlands, and approximately 70% for Germany (Figure 40 (a)).

Analysing just the losses under 50.000 Euros, the relative error is lower than 20% for the three countries. Interestingly, under this threshold, the most accurate estimation occurs not when all the values are maximum, but specifically when the error in the reported water depth is taken into account. This underscores once more the significance of collecting vulnerability characteristics of exposed buildings for accurate estimation of flood-induced damages.

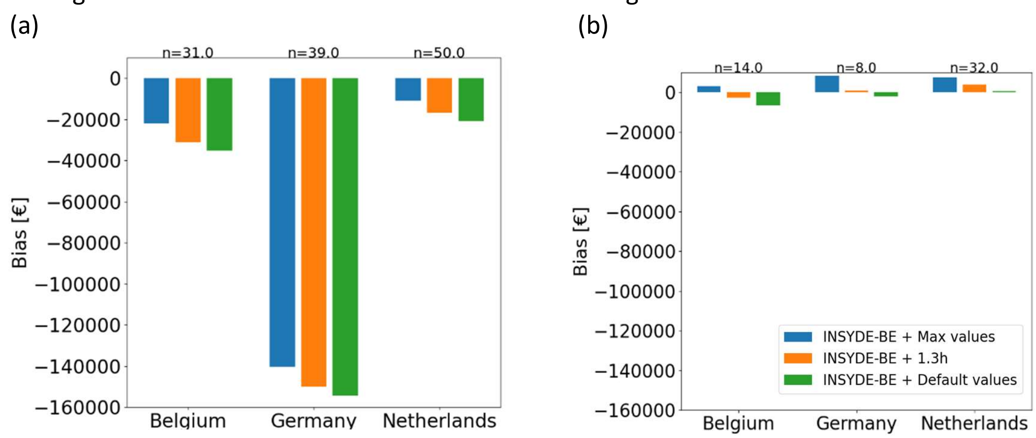


Figure 37. Mean Bias Error (MBE) of INSYDE-BE for the different countries and different input data (a) Considering all the losses. (b) Considering just the losses under a threshold of 50.000€

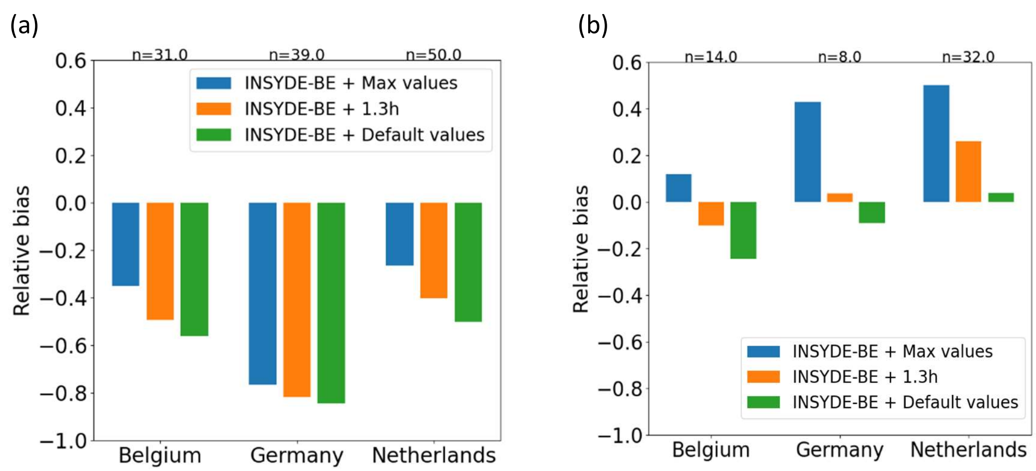


Figure 38. Relative Mean Bias Error (RMBE) of INSYDE-BE for the different countries and different input data (a) Considering all the losses. (b) Considering just the losses under a threshold of 50.000€

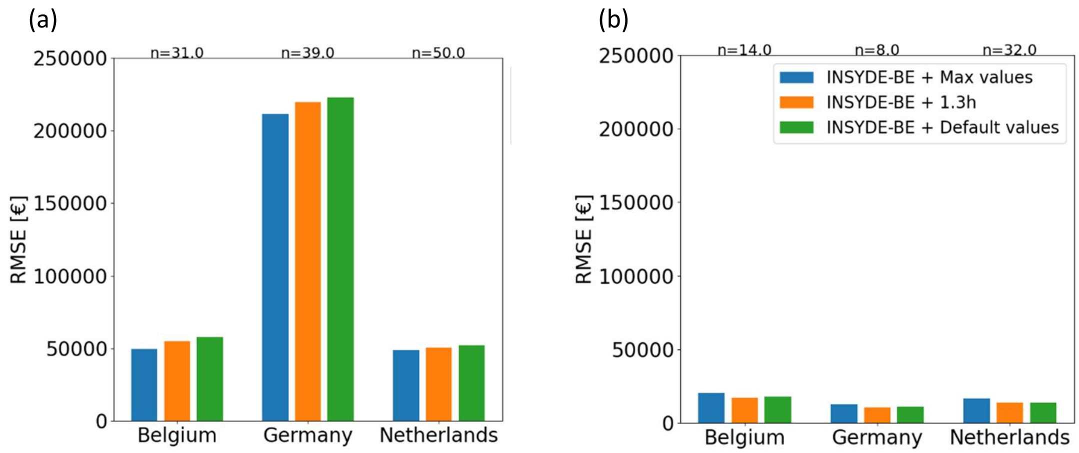


Figure 39. Root mean squared error (RMSE) of INSYDE-BE for the different countries and different input data (a) Considering all the losses. (b) Considering just the losses under a threshold of 50.000€

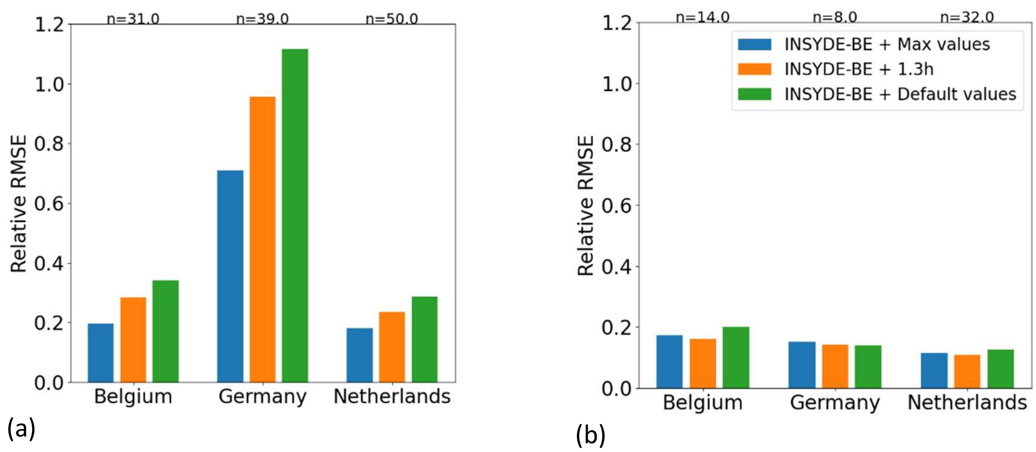


Figure 40. Relative root mean squared error (RRMSE) of INSYDE-BE for the different countries and different input data (a) Considering all the losses. (b) Considering just the losses under a threshold of 50.000€

3.3 Commercial damage function comparison

For the commercial buildings surveyed, several possible damage functions can be used to compare. Most of the surveyed commercial buildings were either restaurants, cafes or hotels. One of the buildings was a gift shop. For SSM, there are several commercial damage categories, which can be found in Table 13. For these seven categories, there are three damage functions and all categories have different maximum damage numbers, which can be seen in Table 13. The damage functions for commercial damage outputs a total building for SSM. The three different commercial SSM functions are shown in Figure 41.

*Table 13 SSM commercial categories, *damage numbers from 2022*

Category	Max. damage [euro/m2 living area]*	Function
Commercial: Gathering	194	A
Commercial: Shops	1796	A
Commercial: Healthcare	2689	B
Commercial: Office	1607	B
Commercial: Education	1228	B
Commercial: Sports	113	C
Commercial: Industry	1420	C

The BEAM model contains two commercial categories, which are Industry and Service. Both categories have a damage function for assets and one for inventory. The damage functions for asset damage are the same for the two commercial categories. Therefore, only three functions are shown in Figure 41. For the commercial damage functions no maximum damage numbers were found.

The WSS model contains several categories for the commercial sector: Industry, Office, Shop, Gathering, accommodation, sport, education, and healthcare. For all commercial categories the function and maximum damage are the same. Therefore, in Figure 41, one function for the WSS model is shown. The function and maximum damage of the commercial categories are the same for the residential building function.

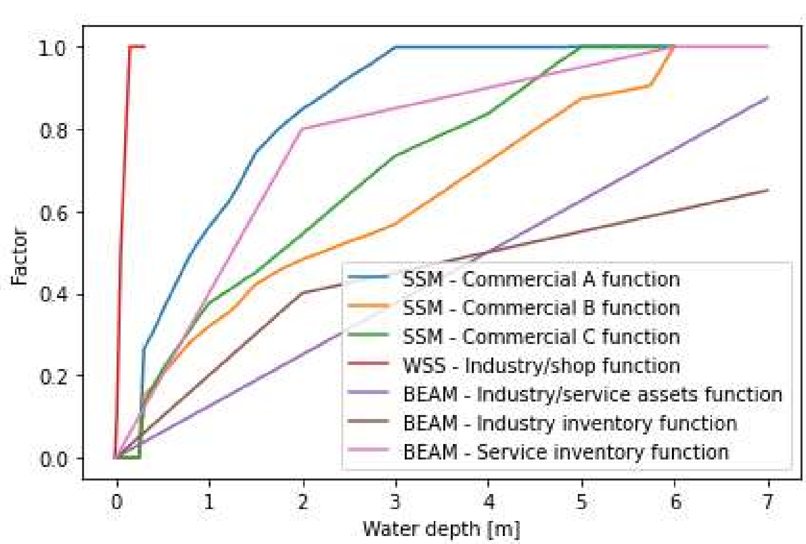


Figure 41 Damage function commercial sector

It can be noted from Figure 41, that most functions, contain a change of slope in the function at a certain water depth. The reasons for these changes of slope can be when a new floor is inundated, after a certain water depth all equipment is damaged, the walls need to be redone after moisture infiltrated etc.

There is no category in SSM for cafes and restaurants, this is seen as gathering spaces according to the object data of the damage model. The gathering function shows a strong underestimation, therefore the shop function is also shown for comparison in Figure *42*. The maximum damage for gatherings and shops differs by a factor 9, see Table 13, leaving the impression that Gatherings is not the adequate category for this type of commercial building. Hence one gift shop is included and two hotels, whereas the other data points are cafes or restaurants.
WSS shows also for commercial building damage an underestimation, as seen for residential buildings. Note that the output of SSM and WSS is in a different unit, respectively in living area and ground floor area, resulting in separate figures. There is little data available for commercial buildings to compare but the below comparisons of Figure *42* and Figure *43* show a first impression.

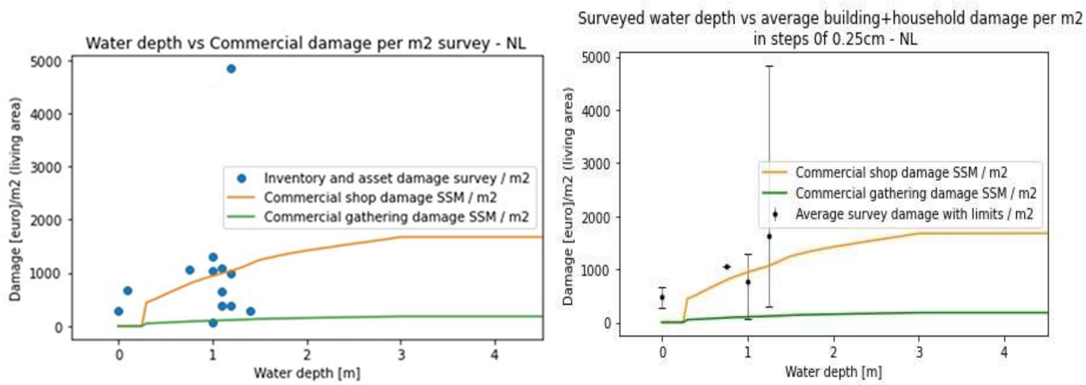


Figure 42 Commercial damage by SSM comparison with surveyed water depth as input, all data (left), aggregated data(right). The limits are showing the min and max value of the figure on the right.

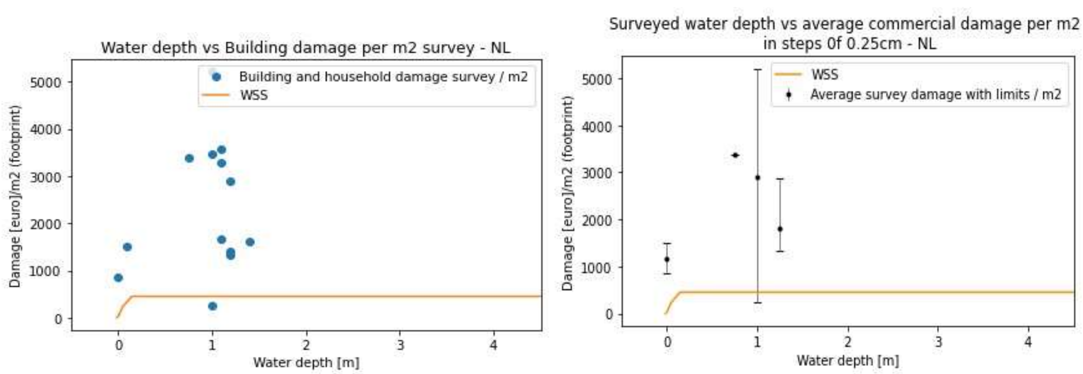


Figure 43 Commercial damage by WSS comparison with surveyed water depth as input, all data (left), aggregated data(right). The limits are showing the min and max value of the figure on the right.

Additionally in Appendix (7.2) figures of the commercial damage are presented against the water depth without taking the areas into account, see Figure 52 and Figure 53. In these two figures, the commercial damage does not seem to increase with increasing water depth. This indicates that the area of the building shows to be an important feature for the surveyed commercial buildings. Based on Figure *42* and Figure *43* it seems that taking into account the living area instead of the ground floor area increasing damage is seen when looking at the averaged water depth approach (figures on the right of Figure *42* and Figure *43*). There is a small data set for commercial buildings available, which means that this conclusion can change when this data set increases.

4 Conclusion and recommendations

4.1 Conclusion

The July 2021 events caused a devastating damage to the flooded areas in parts of Belgium, Germany and the Netherlands. The Interreg EMfloodResilience project aims to improve the flood management across borders for future events on various aspects, for example on precipitation fore/now-casting, early warning, debris modelling and damage modelling among others.

In the context of this project, Deliverable 5.1.3 conducted a comparison and analysis of different damage models previously identified in Deliverable 5.1.1. The survey data collected in Deliverable 5.1.2 has served as a crucial dataset for assessing and comparing these damage models against each other in relation to the event. Additional data, next to the survey data, has been collected for further insights and analysis possibilities.

There are four damage models compared based on their damage functions, which were:

- SSM (Schade en Slachtoffer Module)
  - Building and Household damage separately
- WSS (WaterSchadeSchatter)
  - Building and Household damage combined
- Semi quantitative method of WL
  - Building and Household damage combined
- BEAM
  - Building and Household damage separately

Furthermore, the INSYDE-BE model has been applied to the July 2021 event as this is a synthetic, multivariable flood damage model with more complex relationships in the background. Therefore, the outcome targeted on building damage is compared to the survey data to get insights into its performance.

In this study, the main findings indicate that, concerning household content damage, both the BEAM and SSM models yield results consistent with the survey dataset. The building damage however seems strongly underestimated by all models. Collecting specific data of buildings is found difficult. Regarding the INSYDE-BE model, it has been determined that the outcome is influenced by specific variables required for the model. This underscores the importance of having high-quality data for optimal performance of this model.

Although it is not known how representable the limited damage dataset (sample) is in respect to the rest of the affected areas. During this research it has been concluded that a dataset as collected for Deliverable 5.1.2 is of great value to compare and analyze damage models for specific events and areas. The surveyed areas of Belgium, Germany and the Netherlands differ in damage, inundation levels and the combination of the two. Regional differences such as slope, entrance heights, building type all influences the amount of damage for a certain water depth. This shows that it remains a challenge to identify one damage model that fits all situations. Nevertheless, many insights have been gathered when analyzing the results, which have led to the recommendation outlined below.

4.2 Recommendations

Different damage models in the three countries Belgium, Germany and the Netherlands are collected in this research. They are applied with their respective damage functions directly on the water depth observed by the surveyed participants of the research. This means that model artefacts like resolution are not present but instead, human factors were added by this approach. For future research, the effects of model resolution should be investigated, as for the Dutch model SSM the highest resolution is 5 meters and for the WSS (WaterSchadeSchatter) this is 0.5 meters. Whether this higher resolution results in better results is interesting to know and can be analyzed for different types of areas and events.

In SSM, there is no subcategory or function for commercial damage of hotels/restaurants/cafes. This group is often linked to the so-called "gathering" function in the SSM model. The comparison between the model and the data showed in this research that the "gathering" category highly underestimates the commercial damage of the event of July 2021. This indicates that a different category, like for example "shops", or a new function is needed for this type of commercial damage. Many damage categories are already present for most of the damage models, as well as for SSM. Hereby it is the question if the amount of categories is adding value or noise.

For commercial buildings, the area of a building is, based on the limited data, an important explaining variable for damage of commercial buildings, where the total area shows the best response with increasing water depth. For future research, it is interesting to further analyze what the best relationship is between damage and the area of a (residential) building by using ground floor area or living area for other events. Most of the models use area of a building as a variable, but which type of area needs to be considered isn't clear for all models. More details, as mentioned by adding more categories, can introduce overfitting by capturing and fitting on noise and random fluctuations. In other words, the model can become overly tailored to the training set and does not capture the underlying patterns that are present in a possible broader dataset. The obtained survey data show there is a relationship with area and should therefore be looked into with more detail.

A strong point of SSM is the possibility to use categories corresponding to a chosen set of return periods (characterizing the frequency of flooding at the location of the considered asset). Effectively, the return period of the functions results in slightly altered damage functions to introduce regional differences of how often an area is flooded. The idea behind this is that areas that flood often are assumed to be better prepared and protected against floodings (e.g. wet- or dry-proofing of buildings) compared to areas that rarely or never flood. This seems like a valuable aspect, which is not directly tested in this research. Therefore, further research into this aspect in comparison with the obtained data of this research is needed. It is suggested for regional areas to look at a category for T=25 years as this is the main protection level for build-up areas in the south of Limburg, while for the rest of the Netherlands this is mostly T=100 years. Therefore, if this model is used more often in regional areas it makes sense to include T=25 years for building damage functions.

The insurance industry has valuable flood damage data on houses and other buildings. This data is not available for research projects, which is needed to further improve and analyze the current damage models for different circumstances. It is recommended that anonymous insurance damage data be made available for flood events, with as much as possible detail. This could also show how representable the obtained dataset of the July 2021 in the field is compared to the rest of the affected regions.

For models like BEAM and WSS/SQM of WL, it is advised to investigate the aspect of threshold levels before damage occurs, as most buildings in the affected areas have door entrances higher than the ground level. Hereby it could be good for all models to insert a certain standard threshold that fits in most areas, as this is now absent and doesn't incentivize users to investigate into this and specify this for their area of interest.

During this research, the damage functions of buildings were analyzed, excluding other categories typically present in most functions, such as infrastructure and agriculture. This is a different aspect that is also interesting to compare and analyze, ideally with actual data from flood events obtained in the field or from insurers.

The Walloon region does not have an official monetary damage model. Therefore, the INSYDE model was adapted to the Walloon region, which resulted in the INSYDE-BE model. The results of this model indicate its sensitivity to certain aspects, including errors in water depth and variations in variables related to the finishing level and the maintenance level of buildings. Due to the complexity and uncertainty of all the necessary variables, it is crucial to collect accurate data for the area of interest when using the model in its current form, or run the model with default values which were tailored to the Walloon region. Additional research can be conducted to determine the necessity of all variables and to identify the sensitivity in damage determination. There is also room for improvement for higher damage ranges, as losses are relatively accurately calculated up to values of about 50,000 euros.

With the obtained dataset in this research, many additional comparisons can be made, which can show new insights or possible improvements. Some additional comparisons can be:

- Analyze the current maximum damage of the damage models for building and household content, with the main focus on the building damage. Is the maximum value still representative since the building damage models show such an underestimation of the damage?
- An analysis of the specific areas of the surveyed dataset, to investigate whether the differences in damage can be linked to geographical characteristics like slope, or degree of urbanization.
- How the damages of the high water depths of the research correspond to the maximum damage numbers of the models, as this is the range where little data is available in general.
- Is the damage data from the surveys representative for the damage in all the surveyed areas, or is there a bias in the survey.

5 Workshop/webinar dissemination of the results

In the afternoon of December, the 4th the final conference of the Interreg EMfloodResilience project has taken place. During the morning of this day a workshop/webinar was given to share the results of work package 5.1.1, 5.1.2 and 5.1.3 to stakeholders and water managers. The speakers of this workshop/webinar were:

- Delft University of Technology
  - Ir. Nils van der Vliet
- University of Liège
  - Daniela Castro Rodriguez Castro
  - Prof Dr. Benjamin Dewals
- RWTH Aachen University
  - Eva Vonden

The workshop has been a success with an enthusiastic public. In, the separate appendix, section 7.3.1 shows some impression photos of the workshop can be found. The minutes of the workshop can be found in 7.3.3.

The list of attendees can be found in, the separate appendix, section 7.3.2, where can be seen that a large group of interested participants from 21 different institutions and companies were present.
The invitation to the workshop/webinar can be found in appendix 7.3.4, where the invite was send to the internal project group, the mailing list of the Meuse-Rhine symposium (took place at September 12th in Liege) and to the water authorities who participated in the cross border surveys of Deliverable 5.1.1. A "Save the date" invite was sent, which was followed, closer to the event, by an additional email containing the registration possibility and the online link to the webinar.

6 References

Archambeau, P., Erpicum, S., Dewals, B., & Pirotton, M. (2022). *Reconstruction des valeurs hydrologiques associées aux évènements de juillet 2021 dans la vallée de la Vesdre*.

Assmann, A. (2022). *Where are Europe's Assets? An introduction to the Basic European Assets Map (BEAM)*. https://www.geomer.de/fileadmin/geomer/Resources/Public/Images/Slider/2022-Basic-European-Asset-Map-Manual.pdf

Bruwier, M., Erpicum, S., Pirotton, M., Archambeau, P., & Dewals, B. J. (2015). Assessing the operation rules of a reservoir system based on a detailed modelling chain. *Natural Hazards and Earth System Sciences*, *15*(3), 365–379. https://doi.org/10.5194/nhess-15-365-2015

CBS. (2023a). *GULPEN-WITTEM*. https://www.citypopulation.de/en/netherlands/admin/limburg/1729__gulpen_wittem/

CBS. (2023b). *Nieuwbouwwoningen; inputprijsindex bouwkosten 2000=100, vanaf 1990 Gewijzigd op: 30 oktober 2023*. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80444ned/table?fromstatweb

CBS. (2023c, February 5). *VALKENBURG AAN DE GEUL*. https://citypopulation.de/en/netherlands/admin/limburg/0994__valkenburg_aan_de_geul/

CEDIM, Schäfer, A., Mühr, B., Daniell, J., Ehret, U., Ehmele, F., Küpfer, K., Brand, J., Wisotzky, C., Skapski, J., Rentz, L., Mohr, S., & Kunz, M. (2021). *Hochwasser Mitteleuropa, Juli 2021 (Deutschland) : 21. Juli 2021 – Bericht Nr. 1 „Nordrhein-Westfalen & Rheinland-Pfalz"*. Center for Disaster Management and Risk Reduction Technology (CEDIM), Karlsruher Institut für Technologie (KIT). https://doi.org/10.5445/IR/1000135730

Deltares. (2020). *Gebruikershandleiding Schade Slachtoffer Module* .

ENW. (2021). *Hoogwater 2021 Feiten en Duiding*.

enw. (2023). *Verzekeren van overstromingen vanuit het primaire systeem aantrekkelijk?*

Ernst, J., Dewals, B. J., Detrembleur, S., Archambeau, P., Erpicum, S., & Pirotton, M. (2010). Micro-scale flood risk analysis based on detailed 2D hydraulic modelling and high resolution geographic data. *Natural Hazards*, *55*(2), 181–209. https://doi.org/10.1007/s11069-010-9520-y

Goudenhoofdt, E., Journée, M., & Delobbe, L. (2023). *Observational rainfall data of the 2021 mid-July flood event in Belgium – Part 2. Radar product RADFLOOD21*. Zenodo. https://doi.org/10.5281/zenodo.7739993

Helpdesk Water. (2023). *EU richtlijn overstromingsrisico*. https://www.helpdeskwater.nl/onderwerpen/wetgeving-beleid/europese-richtlijn-overstromingsrisico/eu-richtlijn-overstromingsrisico/

Hydrotec. (2020). *HYDRO_AS-2D – Benutzerhandbuch. Aachen: Hydrotec Ingenieurgesellschaft für Wasser und Umwelt mbH.* .

Hydrotec. (2023). *Entwicklung von Hydrotec*. https://www.hydrotec.de/unternehmen/geschichte/?cookie-state-change=1701442434498

I&W. (n.d.). *Normen wateroverlast*. Retrieved October 12, 2023, from https://www.infomil.nl/onderwerpen/lucht-water/handboek-water/thema-s/wateroverlast/normen-wateroverlast/

Junghänel, Bisolli, Daßler, Fleckenstein, Imbery, Janssen, Kaspar, Lengfeld, Leppelt, Rauthe, Rauthe-Schöch, Rocek, Walawender, & Weigl. (2021). *Hydro-klimatologische Einordnung der Stark- und Dauerniederschläge in Teilen Deutschlands im Zusammenhang mit dem Tiefdruckgebiet „Bernd" vom 12. bis 19. Juli 2021* (D. Wetterdienst, Ed.). Deutscher Wetterdienst.

Kok, M., Bake de, D., & Bruijns, R. (2023). *Actualisatie inschatting schade Limburg 2021*.

Kreibich, H., Van Loon, A. F., Schröter, K., Ward, P. J., Mazzoleni, M., Sairam, N., Abeshu, G. W., Agafonova, S., AghaKouchak, A., Aksoy, H., Alvarez-Garreton, C., Aznar, B., Balkhi, L., Barendrecht, M. H., Biancamaria, S., Bos-Burgering, L., Bradley, C., Budiyono, Y., Buytaert, W., … Di Baldassarre, G. (2022). The challenge of unprecedented floods and droughts in risk management. *Nature*, *608*(7921), 80–86. https://doi.org/10.1038/s41586-022-04917-5

Kupferstadt Stolberg. (n.d.). *Altersstruktur. Unter Mitarbeit von Iris Jansen. Bürgerservide Stolberg.*

LAWA. (2022). *Empfehlungen für die Überprüfung der vorläufigen Bewertung des Hochwasserrisikos und der Risikogebiete nach EG-HWRM-RL. BUND/LÄNDER-ARBEITSGEMEINSCHAFT WASSER.*

Meyer, H., & Fitz, F. (2023). *Entwicklung und Ergebnisse der Umfrage „Gefahrenbewusstsein und Eigenvorsorgemaßnahmen für Starkregen und Hochwasser" am KAHR-Infomobil. Report of Work Packages 12, 12.3 and 12.4 in the project ‚Wissenschaftliche Begleitung der Wiederaufbauprozesse nach der Flutkatastrophe in Rheinland-Pfalz und Nordrhein-Westfalen: Impulse für Resilienz und Klimaanpassung (KAHR)'*.

Mohr, S., Ehret, U., Kunz, M., Ludwig, P., Caldas-Alvarez, A., Daniell, J. E., Ehmele, F., Feldmann, H., Franca, M. J., Gattke, C., Hundhausen, M., Knippertz, P., Küpfer, K., Mühr, B., Pinto, J. G., Quinting, J., Schäfer, A. M., Scheibel, M., Seidel, F., & Wisotzky, C. (2023). A multi-disciplinary analysis of the exceptional flood event of July 2021 in central Europe – Part 1: Event description and analysis. *Natural Hazards and Earth System Sciences*, *23*(2), 525–551. https://doi.org/10.5194/nhess-23-525-2023

Molinari, D., Scorzini, A. R., Arrighi, C., Carisi, F., Castelli, F., Domeneghetti, A., Gallazzi, A., Galliani, M., Grelot, F., Kellermann, P., Kreibich, H., Mohor, G. S., Mosimann, M., Natho, S., Richert, C., Schroeter, K., Thieken, A. H., Zischg, A. P., & Ballio, F. (2020). Are flood damage models converging to ``reality''? Lessons learnt from a blind test. *Natural Hazards and Earth System Sciences*, *20*(11), 2997–3017. https://doi.org/10.5194/nhess-20-2997-2020

Nujic, M. (1999). Praktischer Einsatz eines hochgenauen Verfahrens für die Berechnung von tiefengemittelten Strömungen. *Mitteilungen Des Instituts Für Wasserwesen Der Universität Der Bundeswehr München*, *64*.

Rijkswaterstaat. (2023). *Cross-border damage model interview. Interview with D. Riedstra by Nils van der Vliet.*

Scorzini, A. R., Dewals, B., Rodriguez Castro, D., Archambeau, P., & Molinari, D. (2022). INSYDE-BE: adaptation of the INSYDE model to the Walloon region (Belgium). *Natural Hazards and Earth System Sciences*, *22*(5), 1743–1761. https://doi.org/10.5194/nhess-22-1743-2022

Stadt Eschweiler. (n.d.). *Staitstischer Jahresbericht der Stadt Eschweiler. 2020. Online verfügbar unter*. Retrieved November 7, 2023, from https://www.eschweiler.de/stadt-rathaus/eschweiler-in-zahlen-fakten/jahresberichte/statistischer-jahresbericht-2020.pdf?cid=8dt, zuletzt geprüft am 25.10.2023

Thieken, A., Bubeck, P., Heidenreich, A., Keyserlingk, J. von, Dillenardt, L., & Otto, A. (2023). Performance of the flood warning system in Germany in July 2021 - insights from affected residents. *Natural Hazards and Earth System Sciences*, *23*(2), 973–990.

Wagenaar, D., Lüdtke, S., Schröter, K., Bouwer, L. M., & Kreibich, H. (2018). Regional and Temporal Transferability of Multivariable Flood Damage Models. *Water Resources Research*, *54*(5), 3688–3703. https://doi.org/https://doi.org/10.1029/2017WR022233

Waterschap Limburg. (2023). *Cross-border damage model interview. Interview with F. Heijens by Nils van der Vliet.*

WVER. (2021). *WVER und IWW erhalten Förderbescheid zur wissenschaftlichen Begleitung des Wiederaufbaus in den Hochwassergebieten in NRW und Rheinland-Pfalz*. Wasserverband Eifel-Ruhr (WVER).

7 Appendices

7.1 Residential damage data

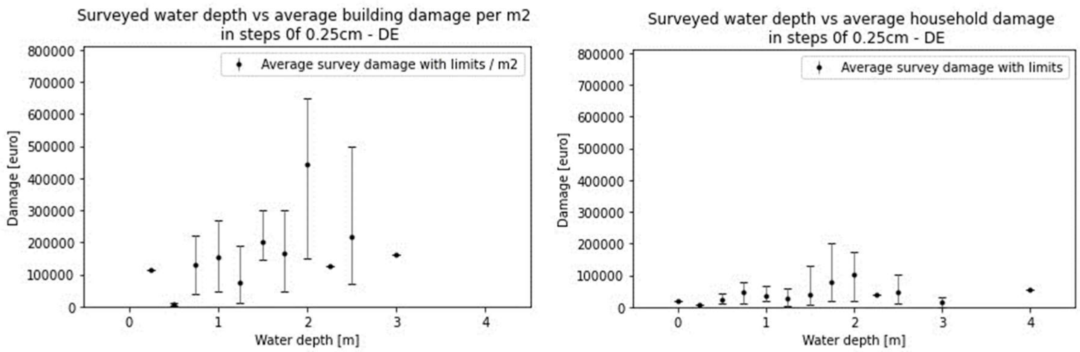


Figure 44 Residential survey damage, average building damage (left), average household content damage (right) for DE.

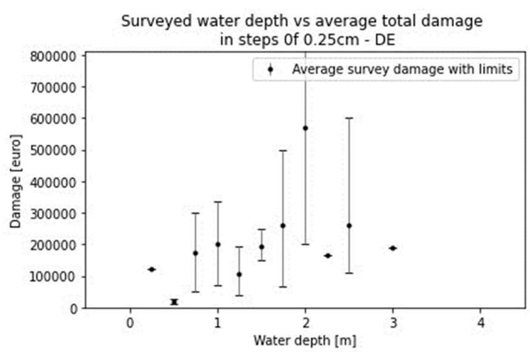


Figure 45 Residential survey damage, average total damage (building+household content) for DE. The limits show the min and max value of the bin.

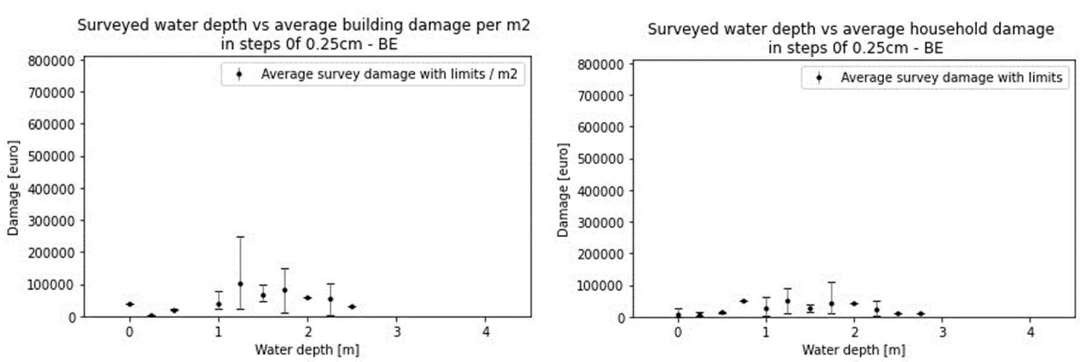


Figure 46 Residential survey damage, average building damage (left), average household content damage (right) for BE. The limits show the min and max value of the bin.

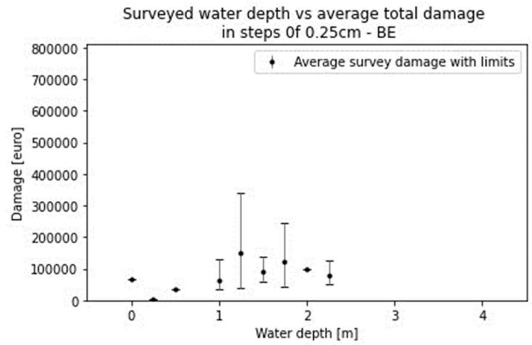
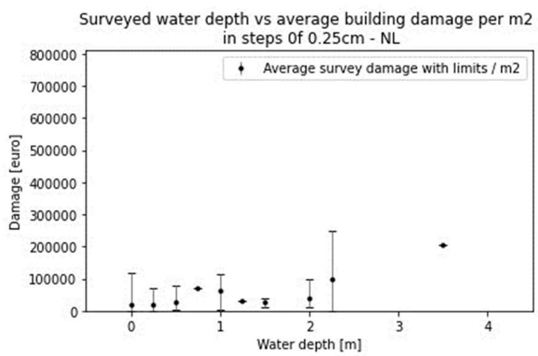


Figure 47 Residential survey damage, average total damage (building+household content) for BE.



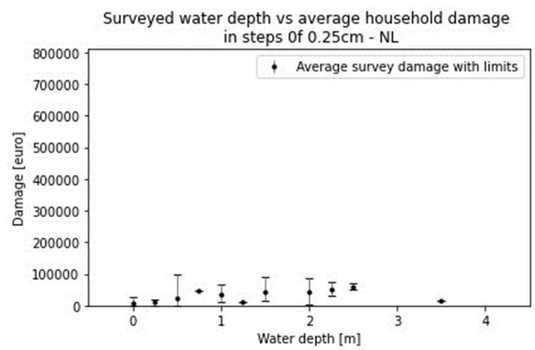


Figure 48 Residential survey damage, average building damage (left), average household content damage (right) for NL.

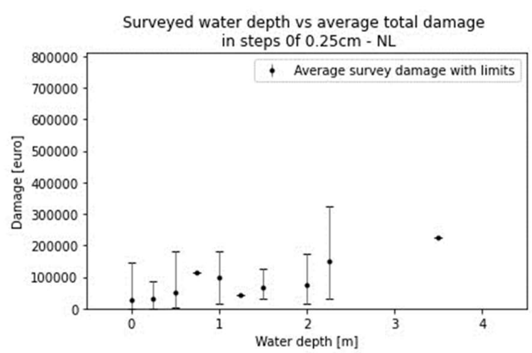
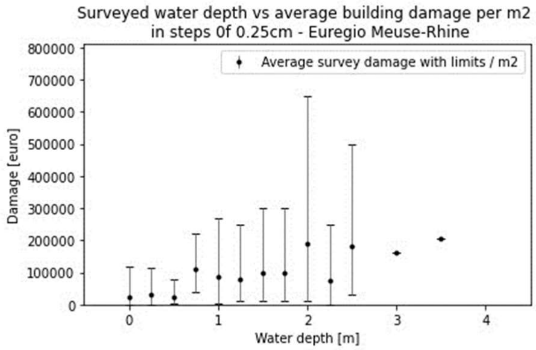


Figure 49 Residential survey damage, average total damage (building+household content) for NL. The limits show the min and max value of the bin.



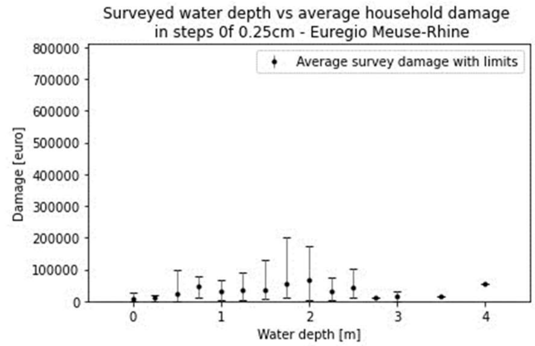


Figure 50 Residential survey damage, average building damage (left), average household content damage (right) for Euregio Meuse-Rhine.

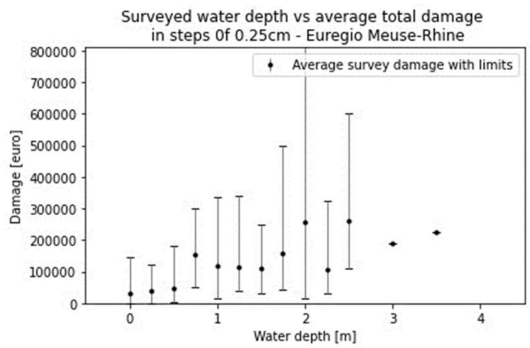
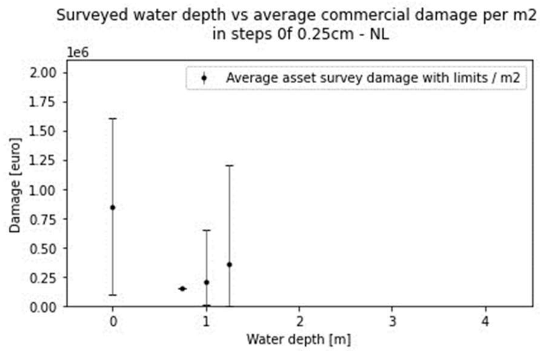


Figure 51 Residential survey damage, average total damage (building+household content) for Euregio Meuse-Rhine. The limits show the min and max value of the bin.

7.2 Commercial damage data



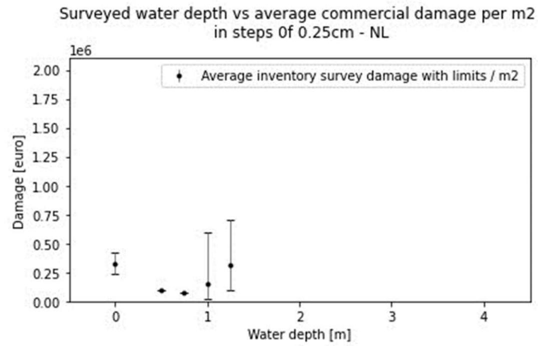


Figure 52 Commercial survey damage, average asset damage (left), average inventory damage (right).

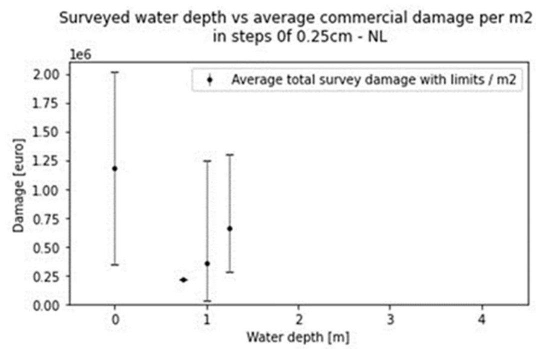


Figure 53 Commercial survey damage, average total damage (asset+inventory). The limits show the min and max value of the bin.

7.3 Workshop/Webinar

7.3.1 Photos

In the separate appendix 7.3 impression photos and a screenshot of the workshop/webinar can be found. This part is not included in the main report due to privacy reasons.

7.3.2 List of attendees

The list of attendees is a combination of participators online and participators in real-life. Of the participants, 23 participants where physically present in Liege coming from 21 different institutions and companies. In the separate appendix 7.3 the list of present institutions and companies and the list of attendees can be found. This document is not included in the main report due to privacy reasons.

7.3.3 Workshop/webinar minutes

Minutes of the questions and discussion during the workshop/webinar of work package 5.1 can be found below.

Start 10 AM: Introduction by Benjamin Dewals

Start 10.10 AM: Presentation Deliverable 5.1.1:

A presentation was given of the result from the cross-border flood damage research. The differences in approach, responsibilities and methods were presented int his part.

Remark: At the Wurm river the BEAM data was used within the EMfloodResilience project and is similar to WSS; Beam is commonly used in Baden-Wuerttemberg.

Remark: 50-60% of flood-prone area in the Netherlands corresponds to the whole country, not just river flood-prone areas but also coastal areas.

Question: People have claimed the duration of the flood waters in their houses as an important factor to the increase in the damages in the buildings, do you consider this variable in the models?

- For instance, the INSYDE-BE model considers it. Having different damage factors depending on the duration of the water in the building. This variable was collected during the field survey of 5.1.2, but the people did not correctly remember the time of arrival and retreat of the water, so the is not enough data for this variable in this case. We did not yet analyze the correlation of this variable.

Question: Did you look at the aftermath of the flood? How long did it take to reopen businesses/build back their houses etc?

- Yes, we did look at this during the research.

Start 10.30: Presentation Deliverable 5.1.2:

The outcomes and analysis of the joint questionnaire on flood impact data was presented. Different interesting aspect of the response were included.

Question: How people want to get information on crisis management plans? Letter? Email?

- Eva: Not just digital information. Elderly people have claimed not always its possible for them to access to this type of information.

Question: Can you explain the problem of expropriation in Belgium?

- Daniela: Concern of the population, of the house being demolished after mayor refurbishment after the July 2021 flood event.

Question: Is information of severe damaged areas included in the study?

- Daniela: No, not for all countries the most damaged areas are surveyed. Belgium, for example, performed a survey to the more extreme affected areas in an earlier research. In this research a bit less affected area was included in the survey.

Start 11.10: Presentation Deliverable 5.1.3:

During this deliverable focussed on improvements of flood impact methods of the workshop, the process of data collection, analysis, the damage models and comparisons were presented. This was followed by the main findings and recommendations of this deliverable.

Question of the presenter to the audience: How would you define the term damage?

- Damage to building and contents
- Period that you are not being able to use house/living in damaged house
- Irreplaceable items
- phycological damage

Question: The WaterSchadeSchatter (WSS) was only applicable for 0.25 m, right?

- Nils: Yes, the WSS is designed for events where the damage varies up to 30 cm of water depth. For building damage the damage varies up to 15 cm of water depth. The WSS model is designed for pluvial event, nevertheless its was interesting to see its performance in comparison to the fluvial flood event of July 2021.

Question: Do you have any recommendations on how the duration of flooding affects damage?

- Nils: At this moment not based on this research. But if buildings are flooded, water will infiltrate the walls. So there is probably not too much difference if the flooding lasts for hours or days. However, it could be looked into further research.

Question: Does the INSIDE-BE model require a lot of input data on buildings?

- Nils: Yes. It can be quite hard to get all data. Often estimations need to be made on building properties.
- Daniela: the model includes many variables. Ideally you would use proper local input data. But the model also has default values, if data is unknown for your specific case.

Remark: Not a surprise that WSS perform poorly for river flooding with h>>0.3m, due it is developed for pluvial flooding.

7.3.4 Invitation

Below the additional email with registration possibilities and the option to join the webinar online can be found. On the next page the "Save the date" invite can be found that was sent to introduce the workshop/webinar and to ensure that invitees reserved this date in their agenda.

"

Dear Invitee,

As an addition to the save the date that was sent earlier, we hereby send you some extra information.

We would like to have an overview of the people attending the workshop/webinar and therefore we would like to ask if you could fill in the registration form below.

The details of the exact location of the event can be found via the registration link.

https://forms.gle/fWH1cmtir3RfBVNm9

For the participants attending the workshop/webinar online, the below Teams link can be used to access the event online.

We are looking forward to welcoming you on December 4th!

Kind regards,

Nils van der Vliet

EMFloodResilience - Flood damage

Organizer: Rodriguez Castro Daniela

Start Date: December 4, 2023 10:00 AM
End Date: December 4, 2023 12:30 PM
Join on your computer or mobile app:

Click here to join the meeting

If you don't want to receive e-mails with respect to this event, please respond to this e-mail and ask for removal from the mailing list.

"

Table 14 Save the date invite, damage modelling

SAVE THE DATE!

Dear invitee,

We are delighted to invite you to our upcoming side-event workshop focused on Damage Modeling within the Interreg EMfloodResilience project (website). During this session, we will be unveiling the outcomes of three pivotal deliverables related to damage modeling, work package 5.1. Our presentation will encompass an in-depth examination of how damage modeling has been structured across the three participating countries, the findings from interviews, and insights into the current performance and possible improvements of the damage models, with a special emphasis on the Euregio Meuse-Rhine. This will be an opportunity to gain field insights into the damage caused by the July 2021 floods. Will the damage correspond to our estimations and will the damage models we use match in the affected hilly areas? Join the event and find out!

The workshop is scheduled for December 4, 2023, running from 10:00 AM to 12:00 PM.
Please ensure to reserve this date on your calendar. The presentations will take place at the University of Liège in room A3 (building B7b). In order to provide access for individuals who are unable to attend in person, we will distribute a digital link to the workshop, effectively converting it into a webinar.

Our research has revolved around the collection, analysis, and discussion of data pertaining to the July 2021 flood event, with a particular focus on the damages incurred during this calamity. Following the presentations on damage modeling, a short presentation will be given about the debris modeling performed within the EMfloodResilience project.

The invitation with a registration link will follow later on. Via this Save the Date we would like to attend you already of this upcoming event.

The speakers during this event will be:
Deliverable 5.1.1, Cross border flood damage estimation:

- Benjamin Dewals (ULiège) / Elena-Maria Klopries (RWTH Aachen)

Deliverable 5.1.2, Joint questionnaire in flood impact data:

- Daniela Rodriguez (ULiège) / Eva Vonden (RWTH Aachen)

Deliverable 5.1.3, Improvements on flood estimation methods:

- Nils van der Vliet (TU Delft) / Matthijs Kok (TU Delft)

Deliverable 4.1.1, Debris modelling

- Sébastien Erpicum (ULiège) / Lisa Burghardt (RWTH Aachen) / Daan Poppema (TU Delft)

Where: University of Liege, room A3 (building B7b)

When: 04-12-2023

Time: 10:00 to 12:00

If you don't want to receive e-mails with respect to this event, please respond to this e-mail and ask for removal from the mailing list.