ICFM

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Damage Prognosis of Dynamic Flood Events Using a System of Harmonized Damage Grades and Considering Uncertainties

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Institute for Catastrophic Loss Reduction

INNOVARU

Project: Assessment of the vulnerability of standardized existing buildings under the influence of extreme natural hazards

Project: 3D location information for areas affected by heavy rain and flooding

Western Engineering

1. Motivation

EDAC Damage Surveys after severe Flood Events

Flood 2002 in Saxony

Flood 2013 in Saxony

Flash Flood in Braunsbach 2016

Photos: EDAC 2002, 2013, 2016

EDAC Damage Surveys after severe Flood Events

Flood 2002 in Saxony

Flood 2013 in Saxony

Flash Flood in Braunsbach 2016

→ **Heavy structural damage is possible due to flood impact**

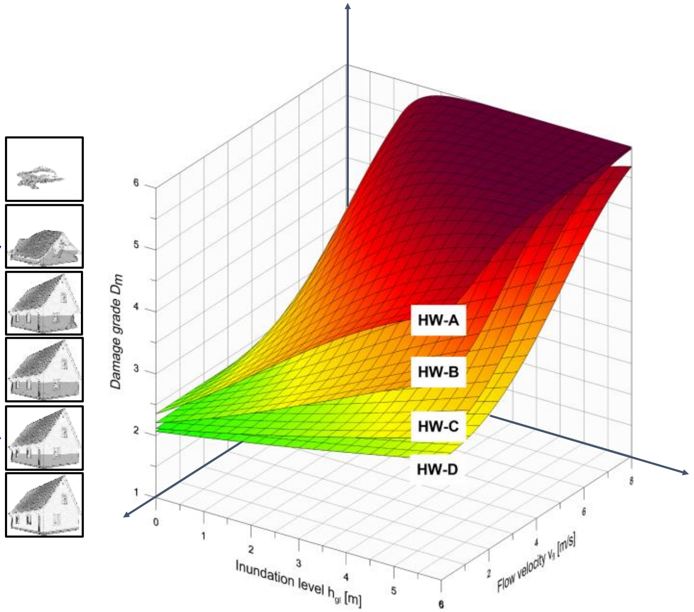
Photos: EDAC 2002, 2013, 2016

EDAC Flood Damage Model: Damage and Loss Prognosis

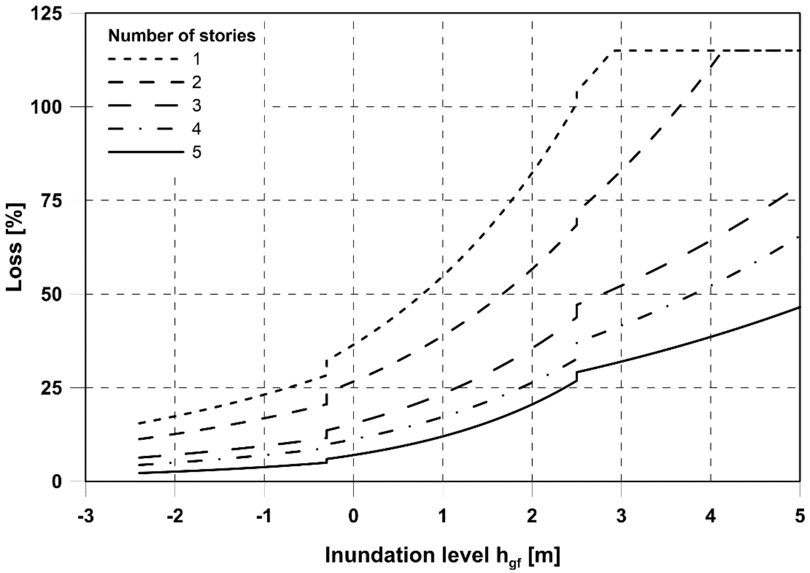
Analysis and assessment of actual damage events: Saxony 2002, 2010, 2013; Ahr Valley 2021

Vulnerability and damage functions

Structural damages

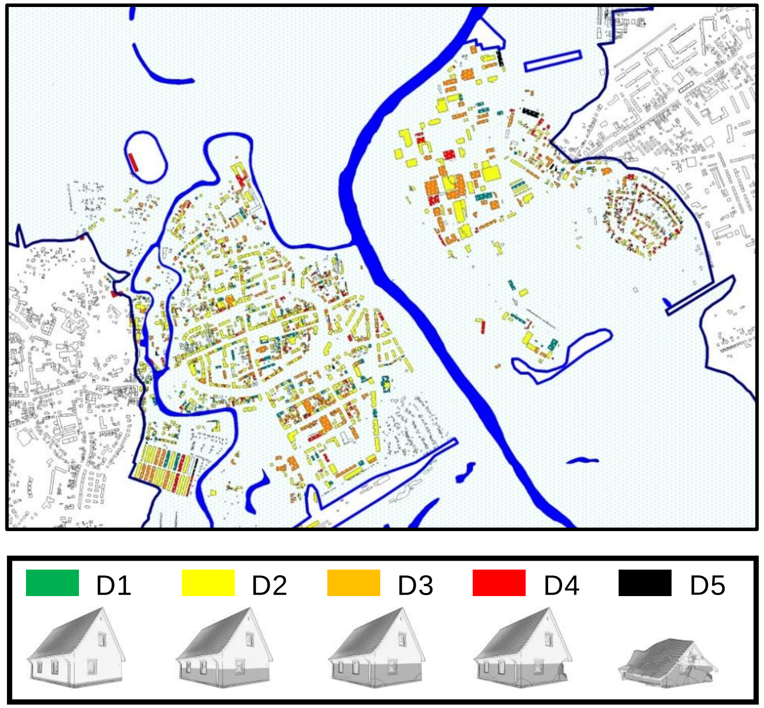


Financial losses (D4, with cellar)

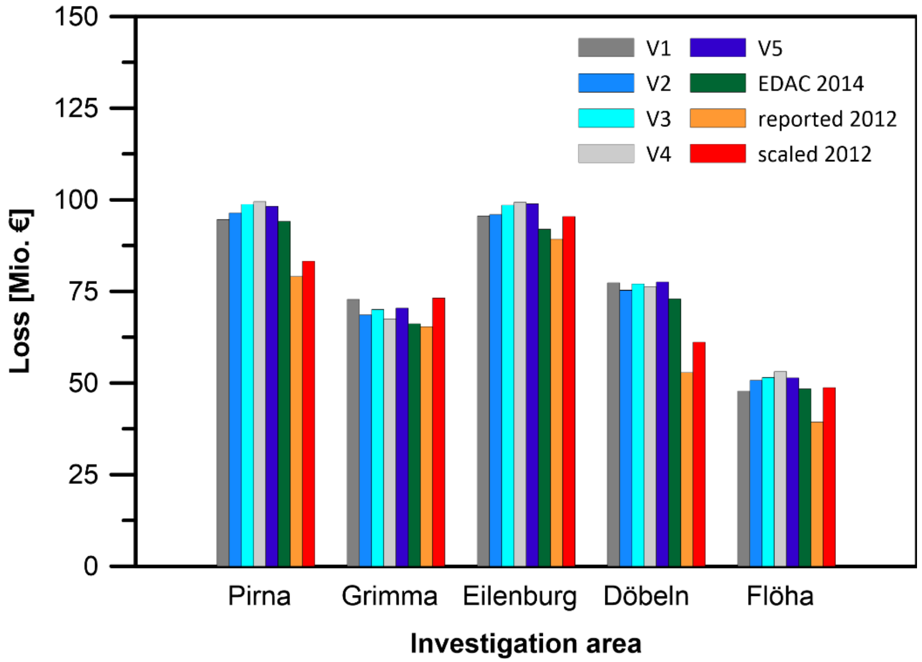


EDAC Flood Damage Model: Application to Flood 2002

Prognosis of structural damages



Loss prognosis (residential buildings)



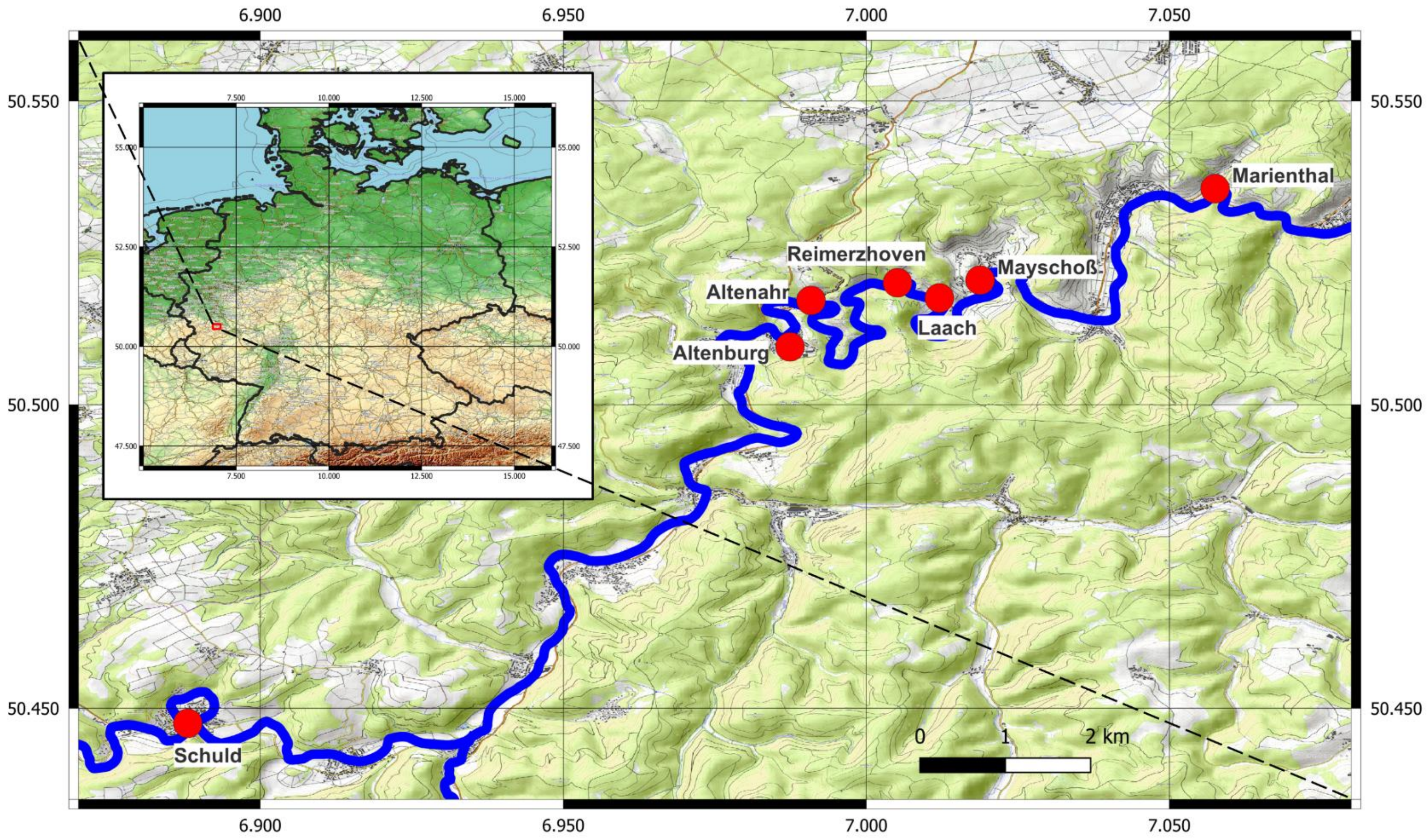
2. Data

Flood 2021 in North Rhine-Westphalia and Rhineland-Palatinate

- **Heavy rain July 14 - 15, 2021,**
- 150 mm rainfall / 24 h,
- Extreme flow rates,
- 184 victims,
- Total losses (federal government): > 30 billion €,
- Extreme destruction of buildings and infrastructure,

→ **Damage survey** by the Earthquake Damage Analysis Center
Period **July 19 - August 05, 2021**

Damage Survey of the 2021 Flood: Investigation Areas in the Ahr Valley



Investigated damage cases:

Ahr Valley:

Residential buildings:	623
Other usage:	555
Total building stock:	1178

Damage Survey of the 2021 Flood: Particularities of Damage

Extreme water level in Altenburg
(> 5 m, Damage grade D2)

Heavy structural damages in Insul
(Damage grade D4)

Photos: EDAC 2021

Damage Survey of the 2021 Flood: Particularities of Damage

Washed away building in Insul (Damage grade D6)

Structural damage due to impact of debris in Schuld (Damage grade D4)

Photos: EDAC 2021

EDAC Flood Damage Data Base

- Comprehensive damage data base (approx. 5000 damage cases) collected after 2002 flood in Saxony,
- Approx. 1200 damage data with flow velocities from Saxonian investigation areas,
- Max. flow velocities: $v_{max} \approx 2.50$ m/s,
- Max. water level above ground level: $h_{gl,max} \approx 4.60$ m

➡ **Extension of the data base is required**

Tsunami Damage Data

- Damage data of of the tsunami after Tohoku earthquake 2011 in Japan,
- > 238.000 damage cases classified into building types,
- Assignment of six damage classes (D1 - D6) and inundation level h,

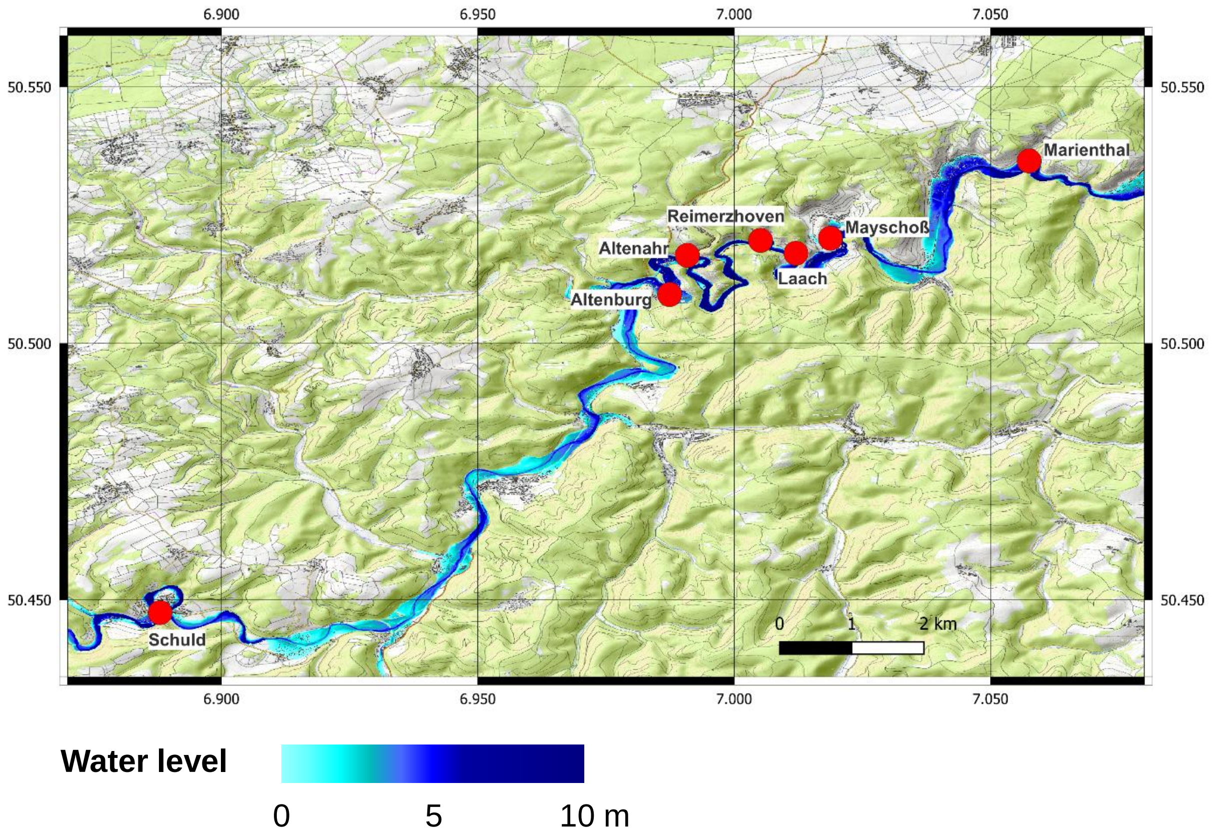
→ Estimation of flow velocities : $v = F_r \cdot \sqrt{g \cdot h}$

→ Determination of average Froude numbers F_r and classification of building types in vulnerability classes (Maiwald & Schwarz, 2017).

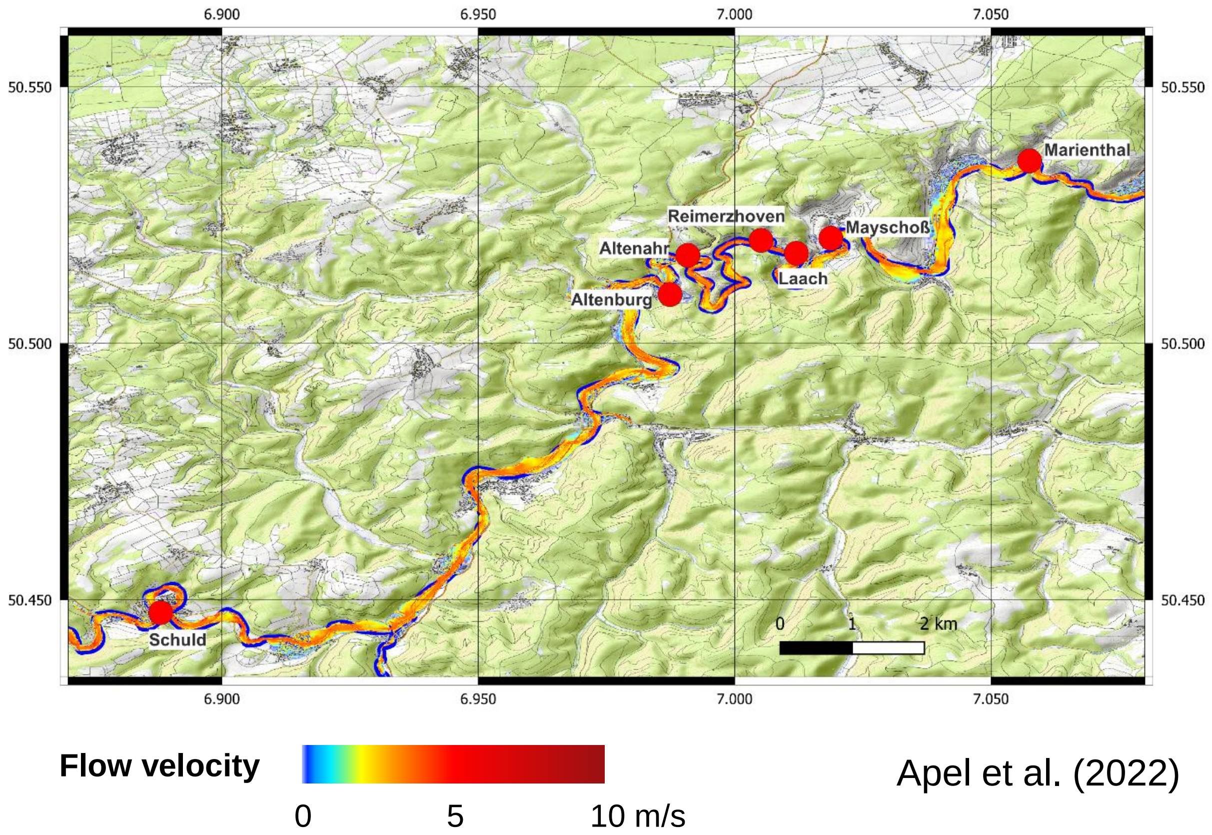
2. Data

Ahr Valley: 2D - Flood Scenario (GFZ Helmholtz Centre for Geoscience Potsdam)

Water level



Flow velocity



Apel et al. (2022)

Damage Scale For Flooding

Damage grade	Damage		Description
	Structural	Non structural	
D1	none	light	only wetting through; dirt
D2	light	moderate	slight cracking to loadbearing walls; doors and windows pushed in; washing out of foundations; *replacement of finshings necessary; contamination*
D3	moderate	heavy	larger cracking in loadbearing walls and slabs; settlement; collapse of non-loadbearing walls; *replacement of non-loadbearing building elements necessary*
D4	heavy	very heavy	collapse of loadbearing walls, slabs; *replacement of loadbearing walls, slabs*
D5	very heavy	(very heavy)	collapse of larger parts of building; *demolition necessary*
D6	complete	(complete)	dislocation: building completely washed away, toppled or displaced from foundation

Reference: Maiwald & Schwarz (2019)

Flood vulnerability classes

Building type	Flood vulnerability class HW-					
	A	B	C	D	E	F
Clay	○					
Prefabricated timber frame	—	○	—			
Timber frame with masonry or clay infills	—	○	···			
Masonry	···	···—	○	···		
Reinforced concrete			···	○		
Flood resistant design				—	○	
Flood evasive design						○

- ○ Most likely vulnerability class
- − Probable range of scatter
- ··· Range of less probable, exceptional cases

Reference: Schwarz et al. (2018)

Elements of the uncertainty chain

- Impact side: water level, flow velocity,
- Resistance side: location, building type / vulnerability class and replacement values,
- Scatter of structural damage and the losses by same impact level,

First step: Description of the uncertainties in the prognosis of structural damage using fragility functions considering water level and flow velocity

Mathematical formulation of fragility functions

$$F_{D_i}(x) = \Phi\left(\frac{\ln(x) - \mu}{\sigma}\right)$$

$$x = h_{gl} + h_{gl} \cdot v_{fl}^2$$

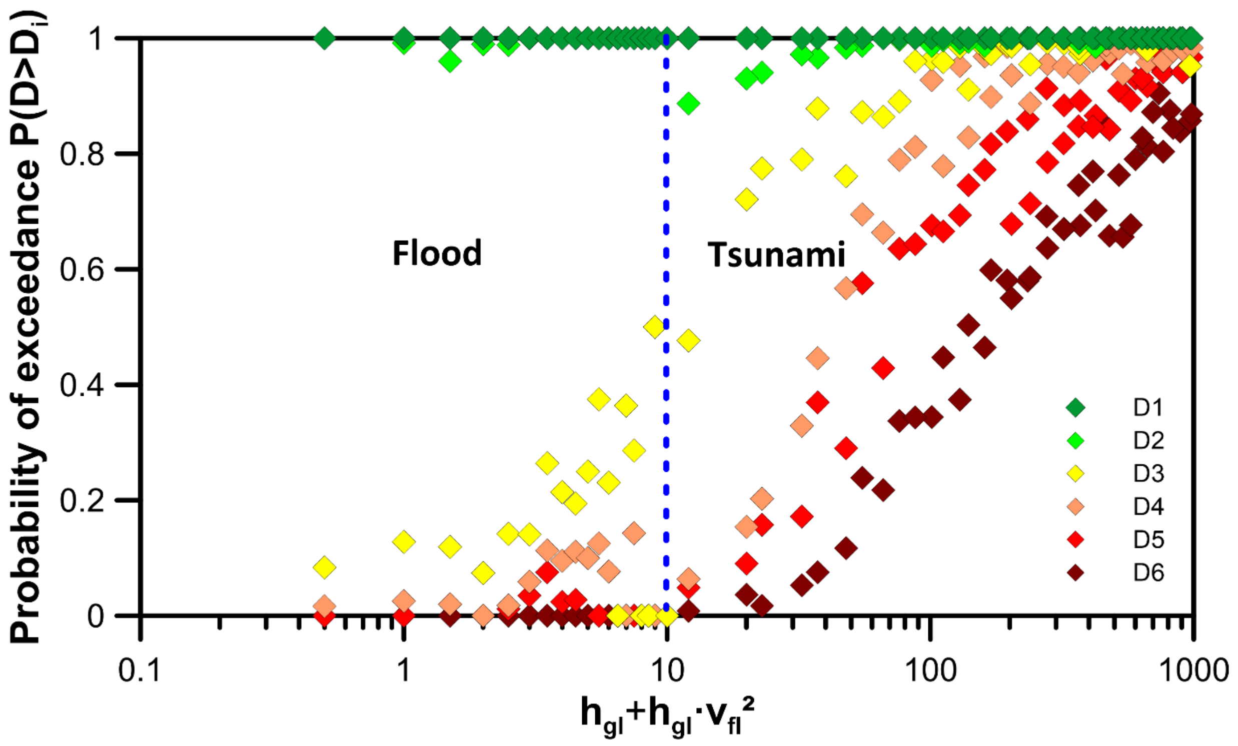
- x - impact parameter
- Φ - standard normal distribution
- μ - logarithmic mean
- σ - logarithmic standard deviation
- h_{gl} - water level above ground level
- v_{fl} - flow velocity

$F_{Di}(x)$: conditional probability that the structure will reach or exceed the damage grade D_i

$$P\left[D_i \mid x\right] = F_{D_i}(x) - F_{D_i+1}(x)$$

Probability that a building will be damaged up to the damage grade D_i

Probabilities of exceedance of the damage grades D_i for vulnerability class HW-C (combined data set)

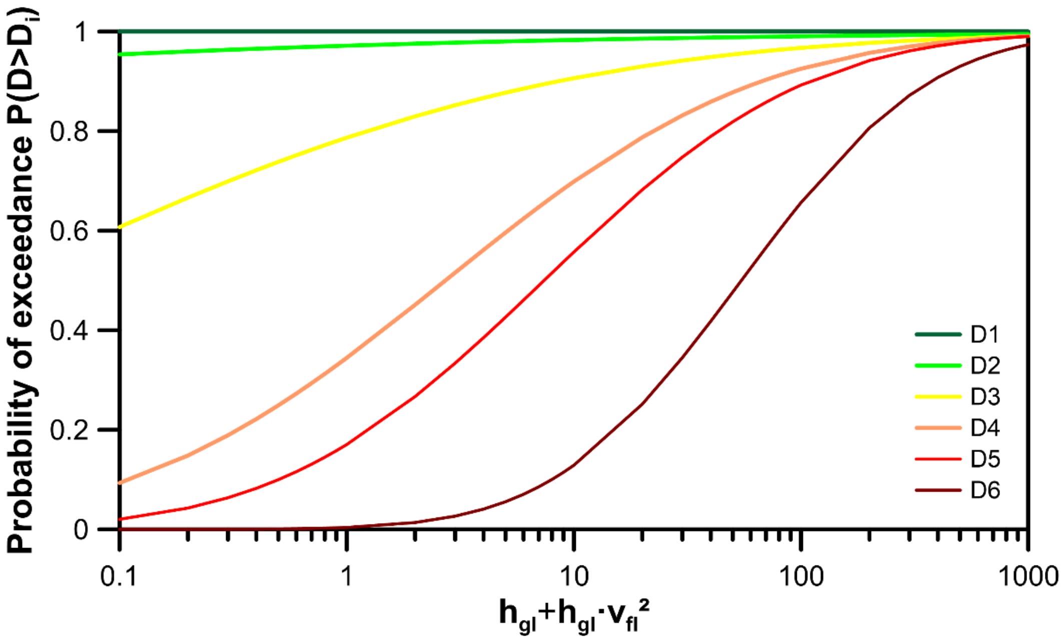


Maiwald and Schwarz (2022)

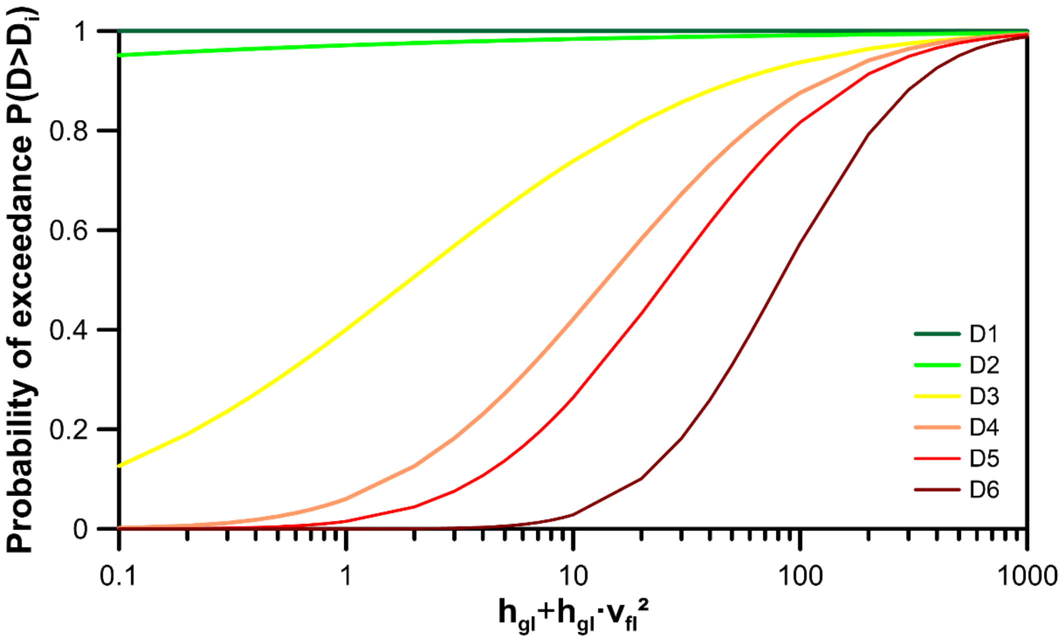
4. Simulative Flood Damage Modelling

Fragility functions

HW-A



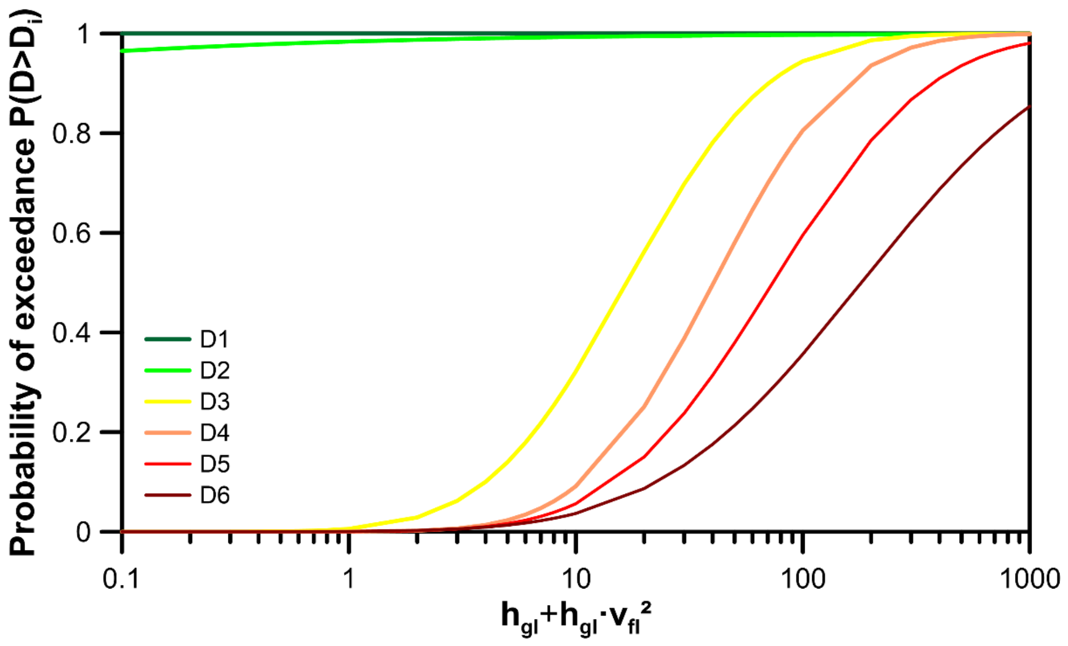
HW-B



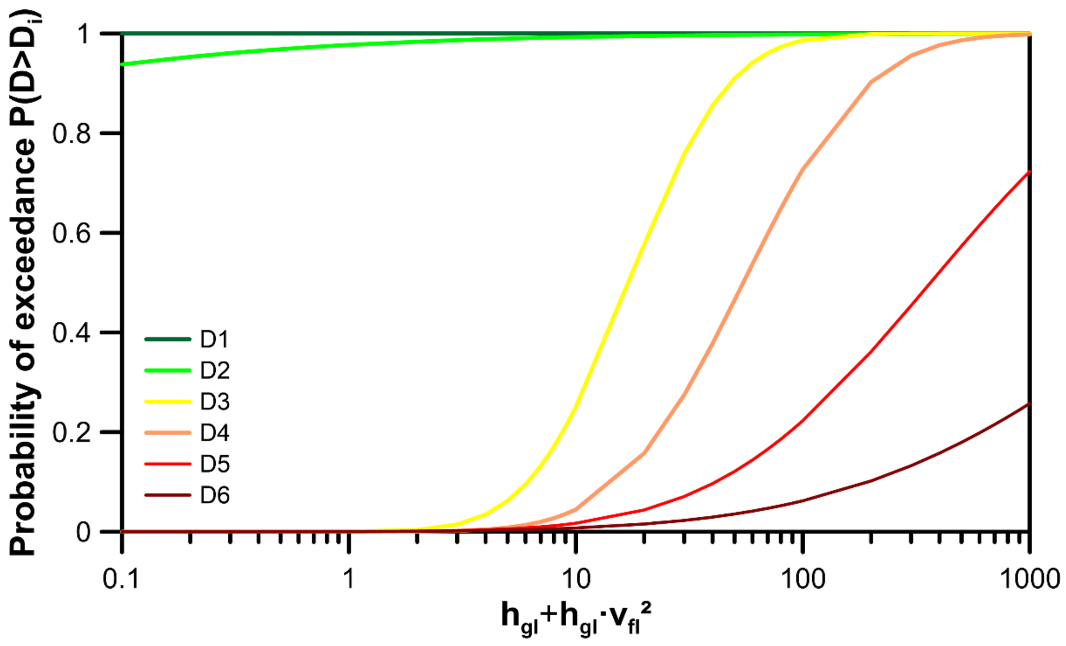
Maiwald and Schwarz (2022)

Fragility functions

HW-C



HW-D



Maiwald and Schwarz (2022)

Application of Monte Carlo Simulation

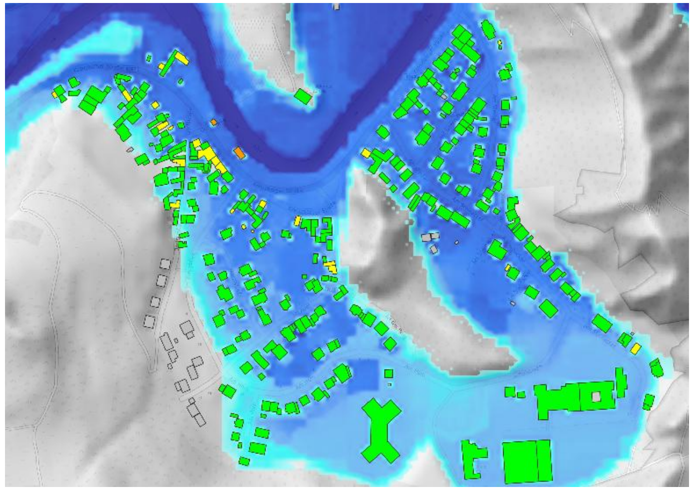
- ‘n times’ realisation of the damage grades according to the corresponding fragility functions for the given impact level,
- Realisation of n = 1000 damage scenarios for each investigation area,
- Calculation of the 50%, 84% fractiles and the mean values of the damage grades,
- Comparison with the real observed damage grades,

→ Error analyses of the simulations.

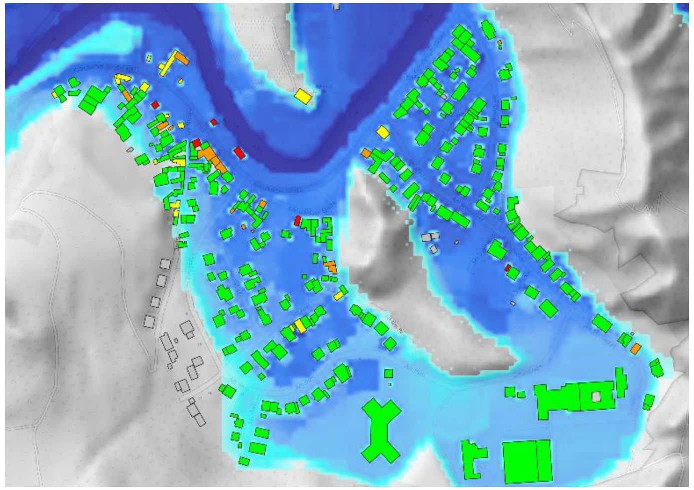
4. Simulative Flood Damage Modelling

Application of Monte Carlo Simulation in Altenburg

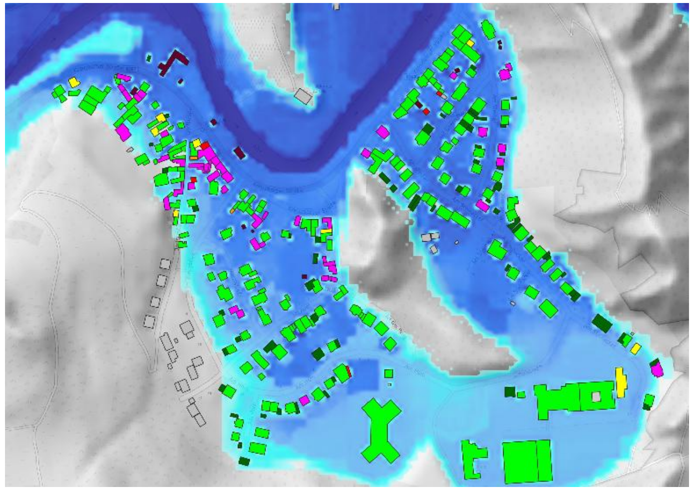
50%-Fractile



84%-Fractile



Observed damage grades



Damage grade D_i

D1 D2 D3 D4 D5 D6

Demolition (State 03/2022)

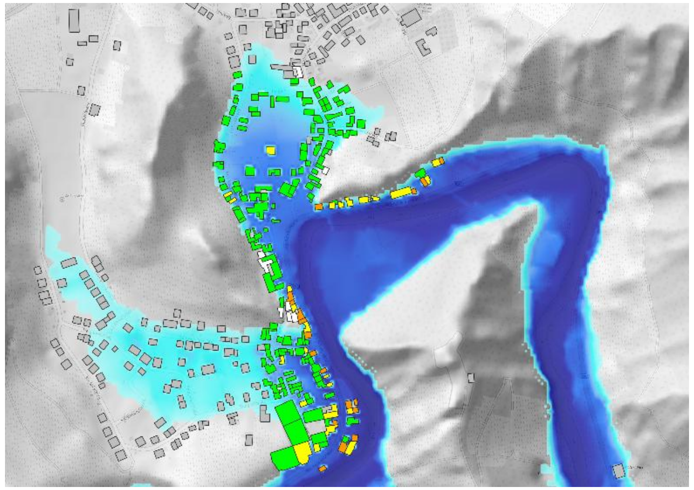
Not affected/ not considered

Water level

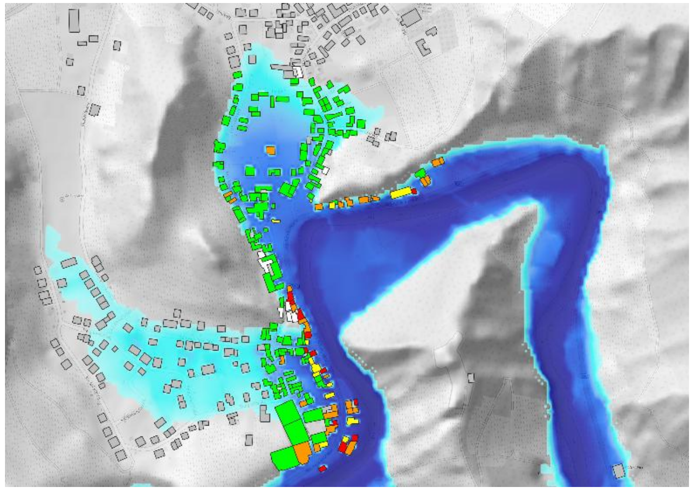
0 5 10 m

Application of Monte Carlo Simulation in Mayschoss

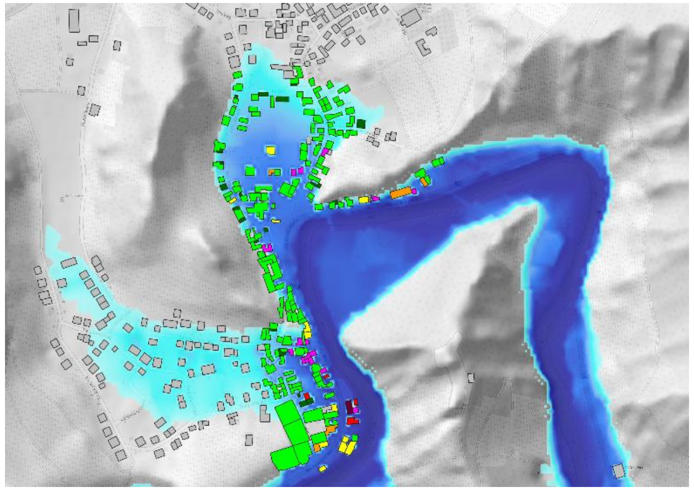
50%-Fractile



84%-Fractile



Observed damage grades



Damage grade D_i

D1 D2 D3 D4 D5 D6

Demolition (State 03/2022)

Not affected/ not considered

Water level

0 5 10 m

Error Analysis of the Simulations for Residential Buildings

Investigation area	No.	50 % fractile			84 % fractile			Mean		
		ME	MAE	RMSE	ME	MAE	RMSE	ME	MAE	RMSE
Altenahr	59	0.49	0.73	1.24	0.19	0.69	1.14	0.40	0.71	1.14
Altenburg	171	0.05	0.15	0.47	-0.07	0.21	0.57	0.00	0.19	0.44
Laach	43	0.26	0.44	0.85	-0.37	0.70	1.06	0.09	0.51	0.78
Marienthal	43	0.42	0.51	1.03	0.19	0.56	1.06	0.29	0.53	0.98
Mayschoß	146	-0.10	0.30	0.71	-0.31	0.46	0.95	-0.13	0.35	0.70
Reimerzhoven	23	-0.48	0.48	0.81	-1.00	1.00	1.37	-0.50	0.55	0.78
Schuld	138	-0.33	0.62	1.00	-0.76	0.96	1.40	-0.41	0.70	0.98
Combined	623	-0.01	0.40	0.83	-0.29	0.57	1.04	-0.08	0.45	0.80

ME - Mean Error MAE - Mean Absolute Error RMSE - Root Mean Square Error

5. Conclusions

- The presented fragility functions enable a simulative damage prognosis considering water level, flow velocity and the vulnerability of building types,
- A realistic re-interpretation of the real observed structural damages from the 2021 flood in the Ahr Valley is carried out,

→Successful validation of the fragility functions also for floods with high flow velocities,

→Possible application for emergency and disaster management.

6. Outlook

- Incorporation of the damage data from the Ahr Valley (extension of the data base),
- Comparison of simulated and actual losses in the Ahr Valley considering the range of scatter in subsequent studies due to the non-availability of reliable loss data from the investigation areas,
- Future considerations of the complete uncertainty chain,

→ New application possibilities in the context of cost-benefit analyses.