Probabilistic flood loss estimation for residential buildings in Europe

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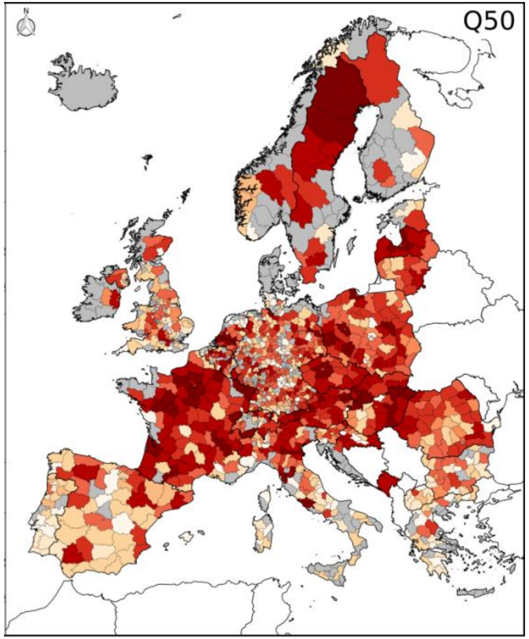
Introduction and research questions

European wide flood loss assessments are essential for governments to:

- support climate change adaptation policies (Van Renssen, 2013)
- manage the European Union solidarity fund (Hochrainer et al., 2010)
- comply with the European Flood Directive (EU, 2007)

Furthermore the (re-)insurance sector relies on flood loss estimations to calculate premiums.

Flood loss is often estimated by simple stage-damage-curves and lacks adequate uncertainty information.



With our research we aim to:

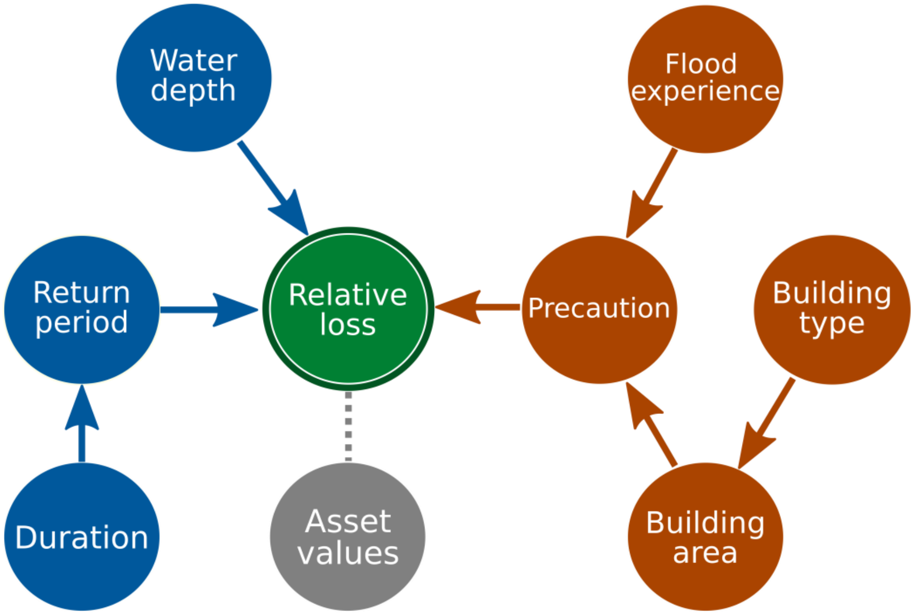
- provide Europe-wide probabilistic flood loss estimations with inherent uncertainty quantification
- identify the drivers that contribute to flood loss changes in the present and under future climate conditions
- make innovative modelling approaches more accessible

Features of BN-FLEMOps

Bayesian **N**etwork – **F**lood **L**oss

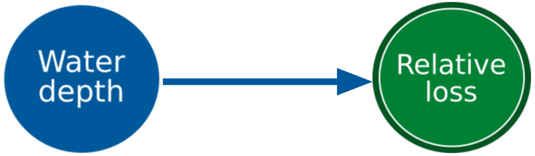
Estimation **Mo**del for the **p**rivate **s**ector

- Direct loss to private buildings
- Multi-variable model for better damage process representation
- Probabilistic results provide uncertainty information for e.g. decision-making
- Transferable in location, scale and time
- Predictions are possible with incomplete input data



Probabilistic flood loss estimation

Simplified node probability table



class	P(wd)
1	0.0
2	0.0
3	0.0
4	0.0
5	0.0
6	0.0
7	**1.0**
8	0.0
9	0.0
10	0.0

class	P(rloss|wd=7)
1	0.001
2	0.005
3	0.013
4	0.022
5	0.034
6	0.156
7	0.683
8	0.051
9	0.025
10	0.010

$$P(X_i, \ldots, X_n) = \prod_{i=1}^{n} P(X_i \mid parents(X_i))$$

Equation for the joint probability distribution in BNs

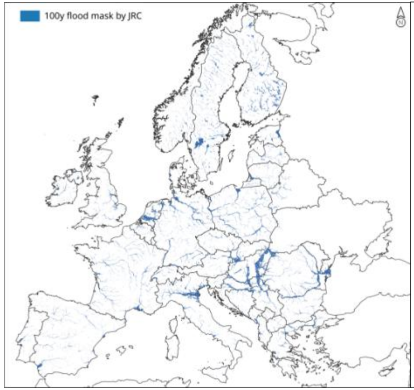
- BN-FLEMOps uses discretized variables
- Joint probability distributions are represented as node probability tables (example on the left)
- These tables contain the conditional probabilities for each node and their associated child node(s)

←The example on the left shows a simplified node probability table for an example of the BN where only water depth information is available to estimate relative loss

Consistent European input data

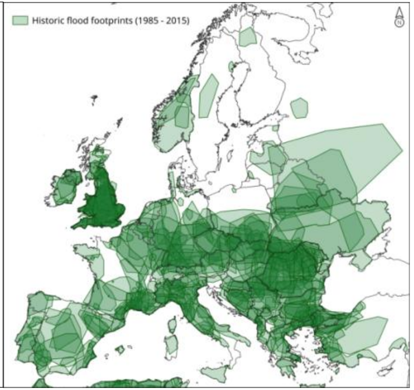
Water depth

Return period



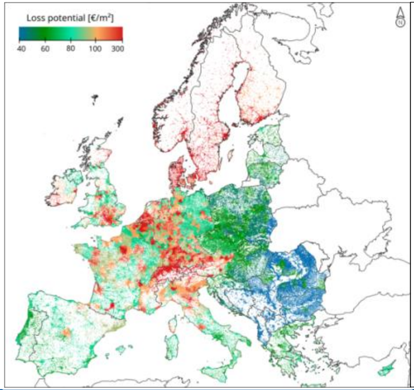
Continent-wide undefended flood hazard maps for present and future climate scenarios. Based on Lisflood-FP (Alfieri et al.2014)

Number of historic flood events in the past 25 years derived from the DFO-Catalogue to describe an areas flood experience (Brakenridge 2018)



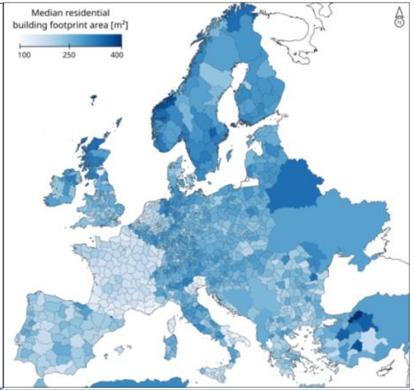
Flood experience

Asset values



European asset map with values of residential buildings in [€/m²] mapped on CORINE (Huizinga et al. 2017; Lüdtke et al. 2019)

Building footprint area distributions per NUTS-3 region extracted from residential building geometries in OSM (OSM contributors 2019)



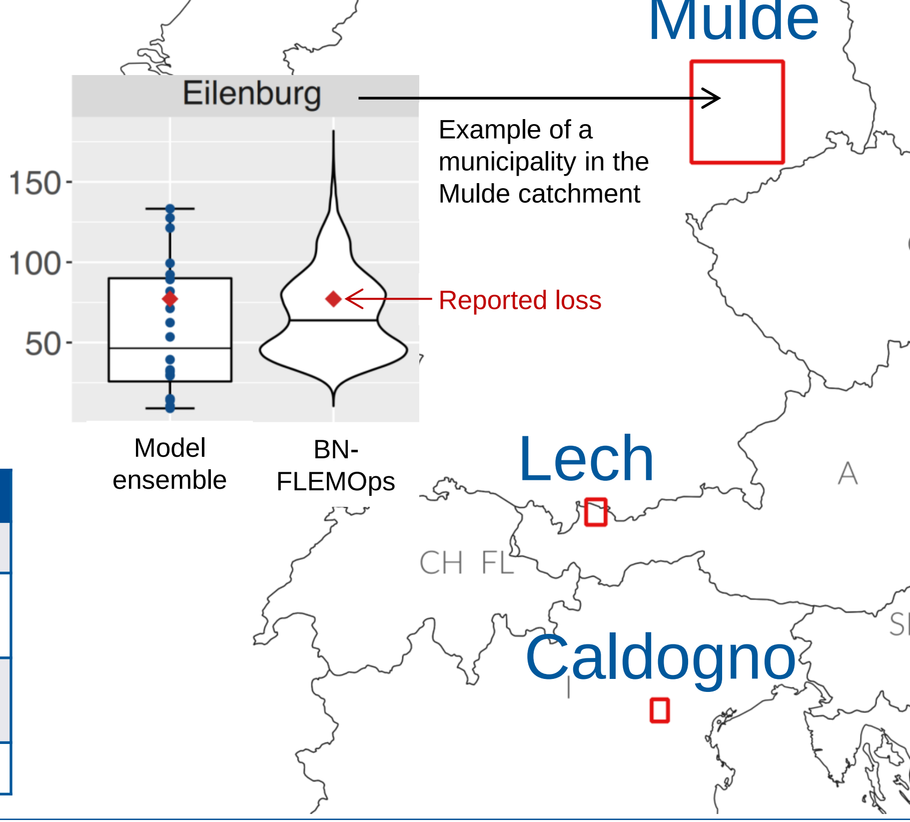
Building area

Validation in case studies

Validation of the BN-FLEMOps was performed by estimating flood loss for historic events in 3 case studies in Italy, Austria and Germany (Lüdtke et al. 2019).

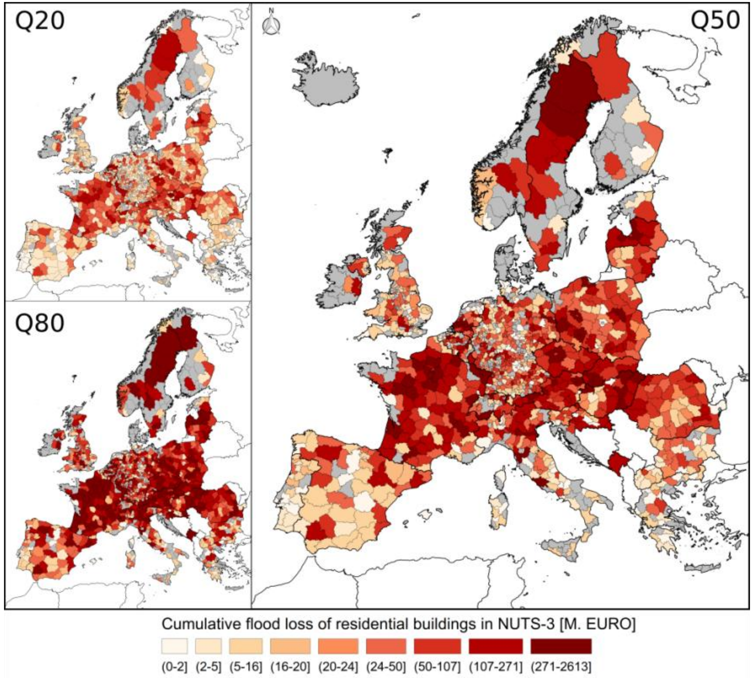
In a comparison with 20 flood loss models we were able to show that BN-FLEMOps outperforms a model ensemble. It requires less data and setup work than an ensemble and provides probabilistic results with inherent uncertainty information (Steinhausen et al. *in review*).

	Caldogno	Lech	Mulde
Reported loss [mil.€]	7.5	1.9	240
Estimated median loss [mil.€]	9.5	7.8	136
Interquartile range [mil.€]	4.0 – 18.5	3.6 - 3.4	87.1- 246.0
No. of data points	295	22	74



European application

100-year European flood loss map
(undefended scenario, reference climate)

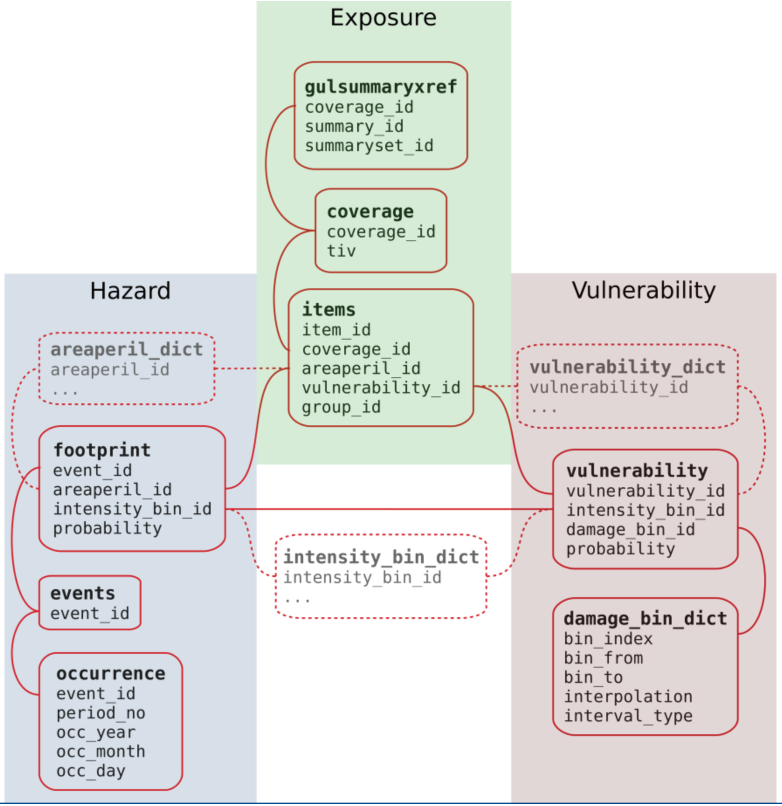


The map on the left shows the 20% quantile (Q20), the median (Q50) and the 80% quantile (Q80) of a flood loss estimation performed with BN-FLEMOps for a continent-wide 100-year flood scenario. Results are aggregated on the NUTS-3 level.

For this flood scenario, the highest flood losses are estimated in the flood plains of major European rivers, such as Rhine and Meuse, Danube, Seine, Loire, and Po. The flood scenario does not account for any flood protection infrastructure in place.

The total accumulated loss for residential buildings in Europe is estimated to 79.0 billion € (Q20 = 32.3; Q80 = 213.8) (Lüdtke et al. 2019).

OASIS-LMF implementation



The OASIS Loss Modelling Framework (LMF) is an open source platform for developing, deploying and executing catastrophe models to enable the “plug and play” of hazard and vulnerability modules (https://oasislmf.org/) .

To make BN-FLEMOps easier to use and transfer new approaches from research into practice the model was implemented in the OASIS LMF.

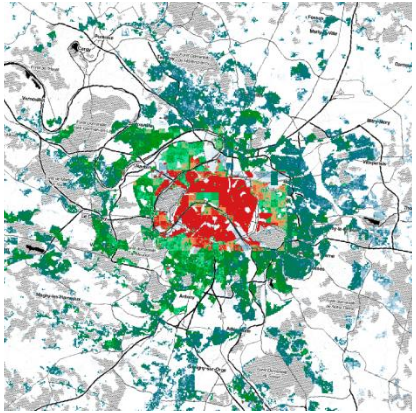
Data for the use of BN-FLEMOps are available on the OASIS HUB (https://oasishub.co/dataset/european-exposure-data-for-bn-flemo-models-gfz) (Steinhausen et al. 2020).

← The figure on the left shows the structure of compliant tables in the OASIS LMF

Summary and outlook

- The Bayesian Network methodologies of BN-FLEMOps produces probabilistic loss estimates
- BN-FLEMOps is validated in case studies and comparisons show good performance
- Consistent European input data enables continent-wide loss estimation
- First results show that urban areas along major rivers would suffer most of the 79.0 billion € estimated loss for residential buildings in Europe
- The OASIS LMF implementation makes BN-FLEMOps more accessible

- An improved asset methodology will be used for future loss estimations (figure below)
- Exposure scenarios for future climate conditions will be incorporated
- Adaptation by private precaution will be studied



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References and online resources

- Alfieri, L., Salamon, P., Bianchi, A., Neal, J., Bates, P., & Feyen, L. (2014). Advances in pan-European flood hazard mapping. Hydrological Processes, 28(13), 4067–4077. https://doi.org/10.1002/hyp.9947
- Brakenridge, G. R. (2018). Global active archive of large flood events. Retrieved from http://floodobservatory.colorado.edu/Archives/index.html
- EU, (European Union). directive 2007/60/EC of the European parliament and of the council of 23 October 2007 on the assessment and management of flood risks, 288 § (2007).
- Hochrainer, S., Linnerooth-Bayer, J., & Mechler, R. (2010). The European Union solidarity fund. Mitigation and Adaptation Strategies for Global Change, 15(7), 797–810. https://doi.org/10.1007/s11027-009-9209-2
- Huizinga, J., Moel, H. D., & Szewczyk, W. (2017). Global Flood Depth-Damage Functions Database with Guidelines. https://doi.org/10.2760/16510
- Lüdtke, S., Schröter, K., Steinhausen, M., Weise, L., Figueiredo, R. and Kreibich, H.(2019): A Consistent Approach for Probabilistic Residential Flood Loss Modeling in Europe, Water Resources Research, 55(12), 10616–10635, http://doi.org/10.1029/2019WR026213
- Lüdtke, Stefan; Steinhausen, Max; Schröter, Kai; Figueiredo, Rui; Kreibich, Heidi (2019): Pan-European probabilistic flood loss data for residential buildings. GFZ Data Services. http://doi.org/10.5880/GFZ.4.4.2019.002
- OSM contributors. (2018b). OpenStreetMap. Retrieved 30 November 2018, from https://www.openstreetmap.org/
- Van Renssen, S. (2013). EU adaptation policy sputters and starts. Nature Climate Change, 3(7), 614–615. https://doi.org/10.1038/nclimate1943
- Steinhausen, Max; Schröter, Kai; Lüdtke, Stefan; Drews, Martin (2020): European exposure data for BN-FLEMO models. V. 1.0. GFZ Data Services. http://doi.org/10.5880/GFZ.4.4.2020.001
- Steinhausen, Max; Schröter, Kai; Lüdtke, Stefan; Figueiredo, Rui; Kreibich, Heidi (*in review*): Das probabilistische Hochwasserschadensmodel für Wohngebäude BN-FLEMOps. Hydrologie und Wasserwirtschaft.