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Understanding and managing Black Swans

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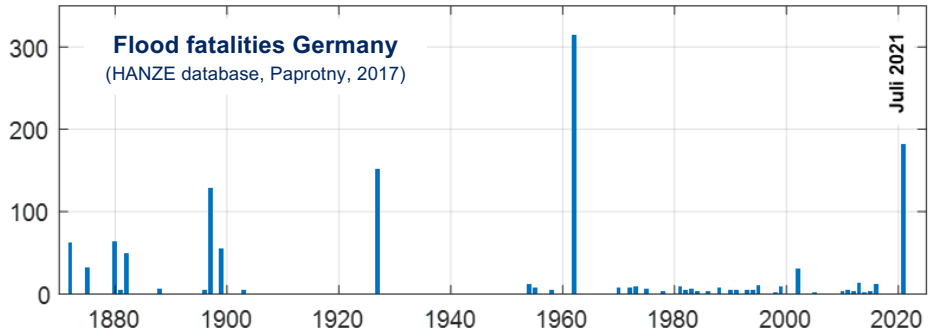
We are regularly surprised: Example July 2021

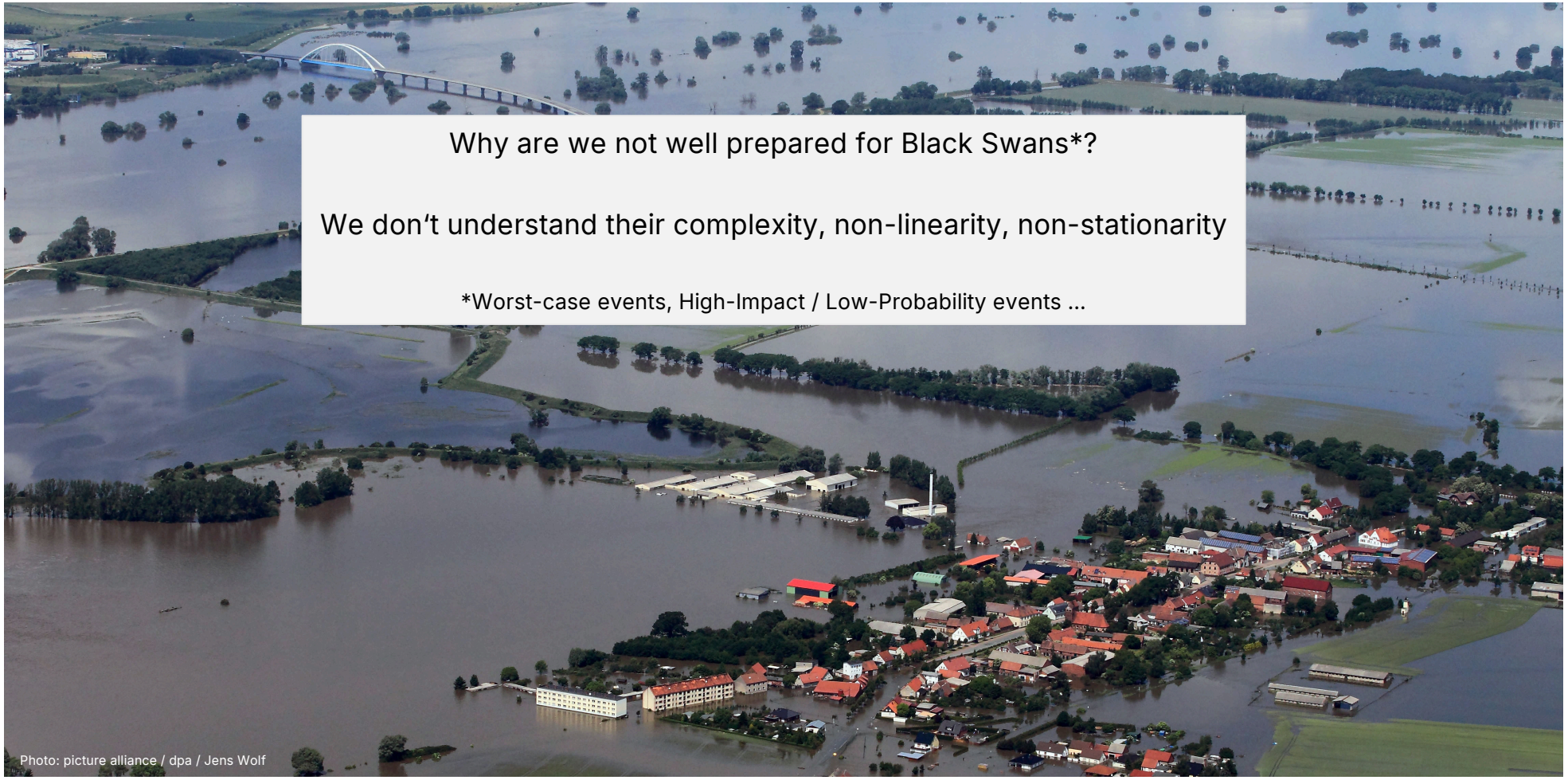


Widespread damage and loss:

- €46 billion damage
- 240 fatalities in Germany and Belgium
- Failure of critical infrastructure: Transport, electricity, water supply and waste water treatment etc.
- …

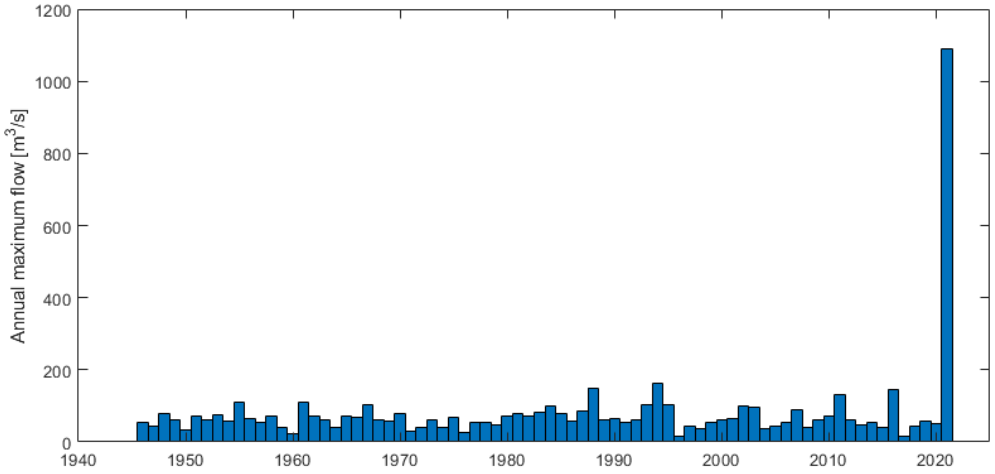
Locations of fatalities:

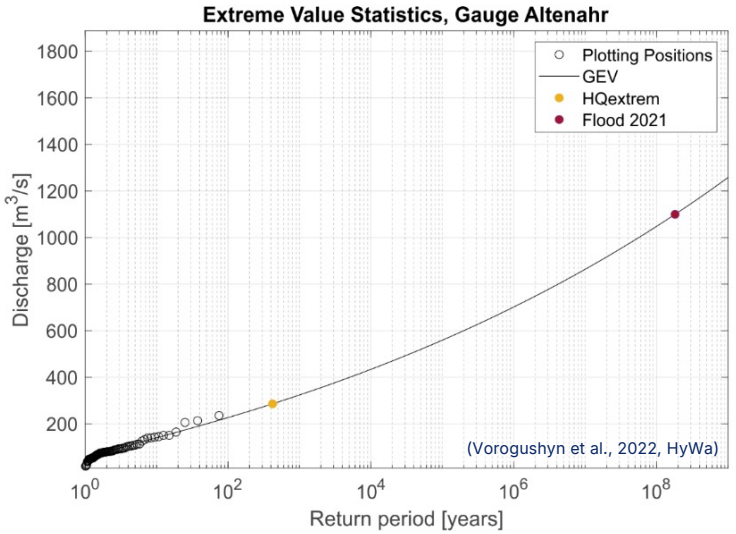
- Inside flood hazard zones: 30%
- Outside flood hazard zones: 58%
- Location unclear: 12%


Why are we not well prepared for Black Swans*?
We don‘t understand their complexity, non-linearity, non-stationarity
*Worst-case events, High-Impact / Low-Probability events ...
Photo: picture alliance / dpa / Jens Wolf

Extremes may not be the large version of small floods

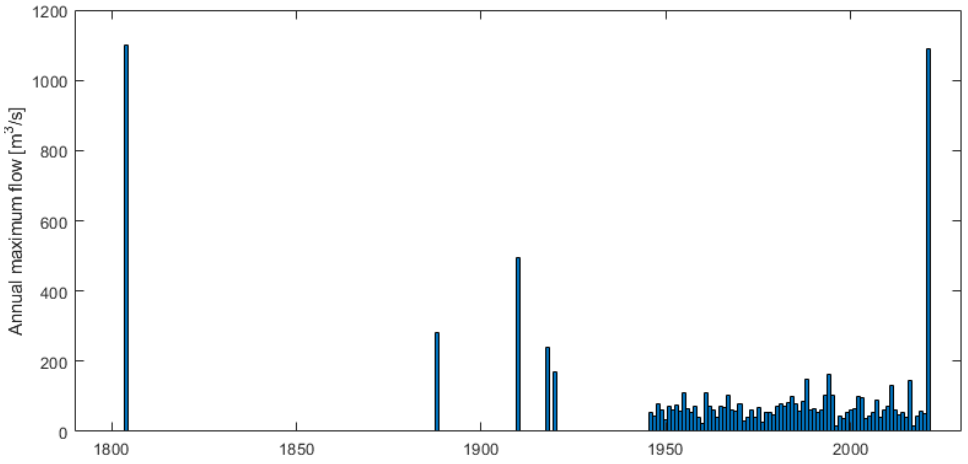
- Ahr, gauge Altenahr: Annual maxima 1947 – 2020
- Extreme value statistics: Return period of 2021: ~200 * 10^6 years (GEV shape = 0.06)

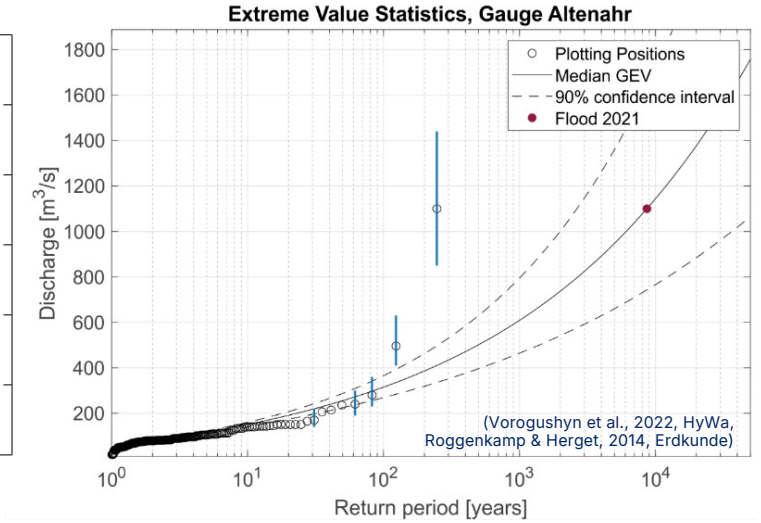




Extremes may not be the large version of small floods

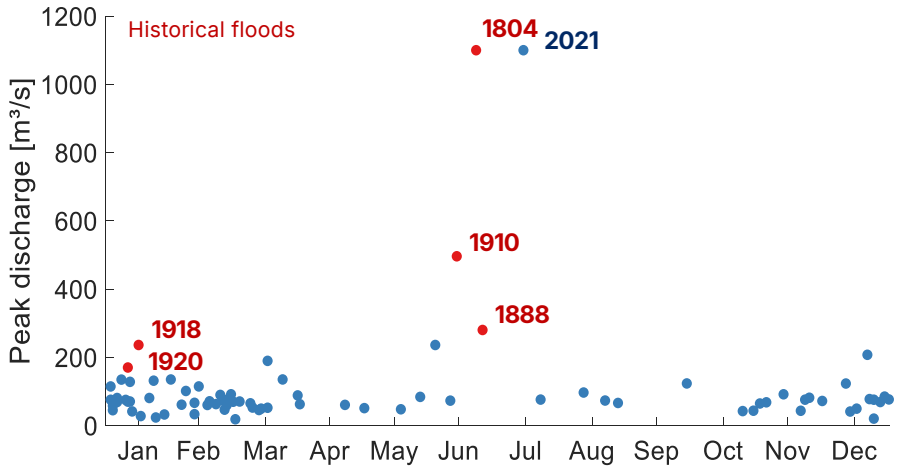
- Consideration of 5 historical floods in extreme value statistics
- Return period of 2021: ~8.000 years (GEV shape = 0.26)





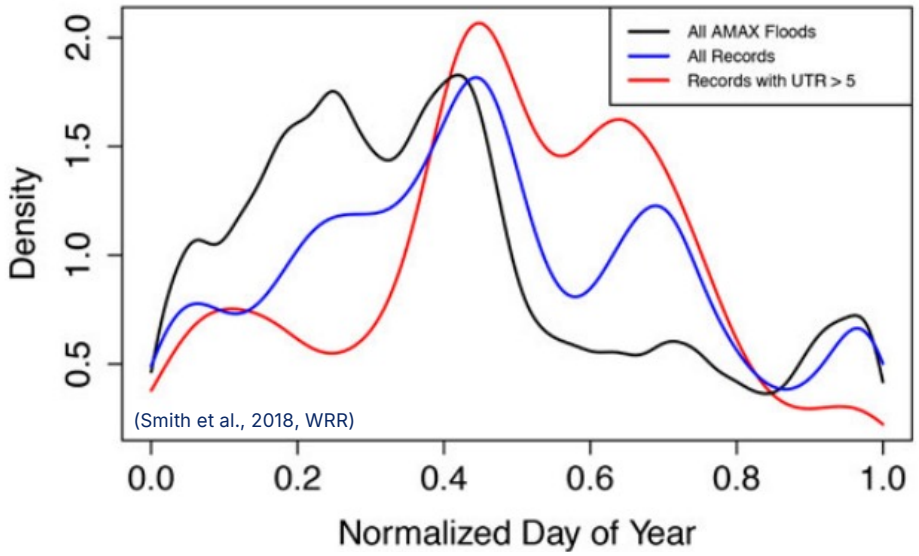
Extremes may not be the large version of small floods

Ahr: Seasonal distribution of annual maximum streamflow



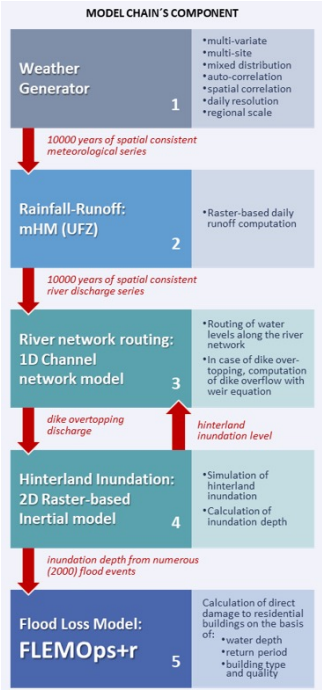
Annual maximum flows for 8,900 US catchments:

- Fundamental difference in seasonality between record floods and broader flood population.
- Flood peaks may reflect mixtures of flood agents.

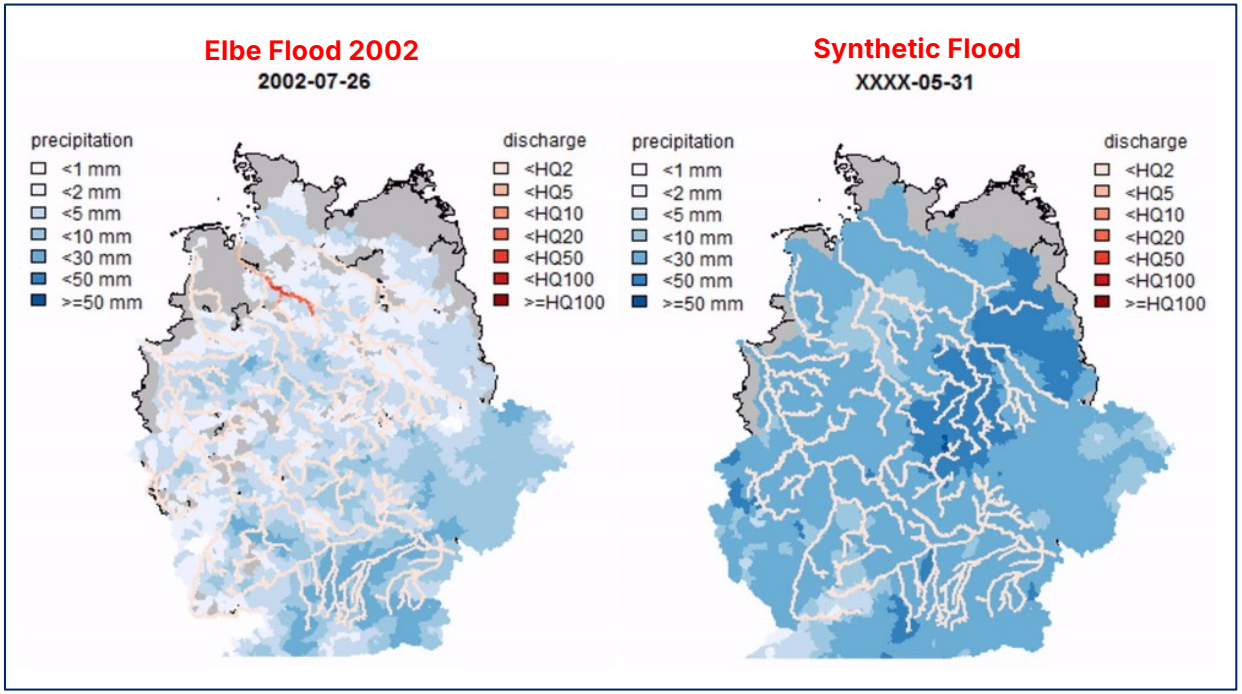


Process-based stochastic simulation

Model chain

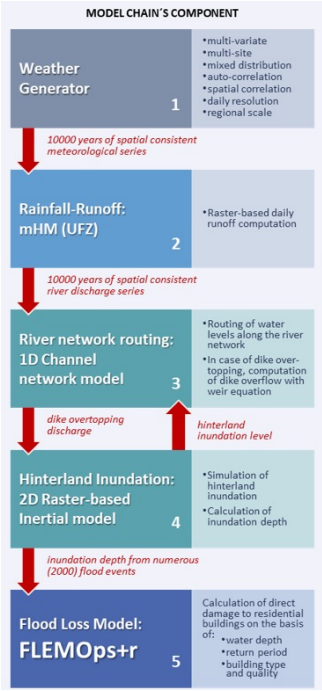


Observed and synthetic extreme events



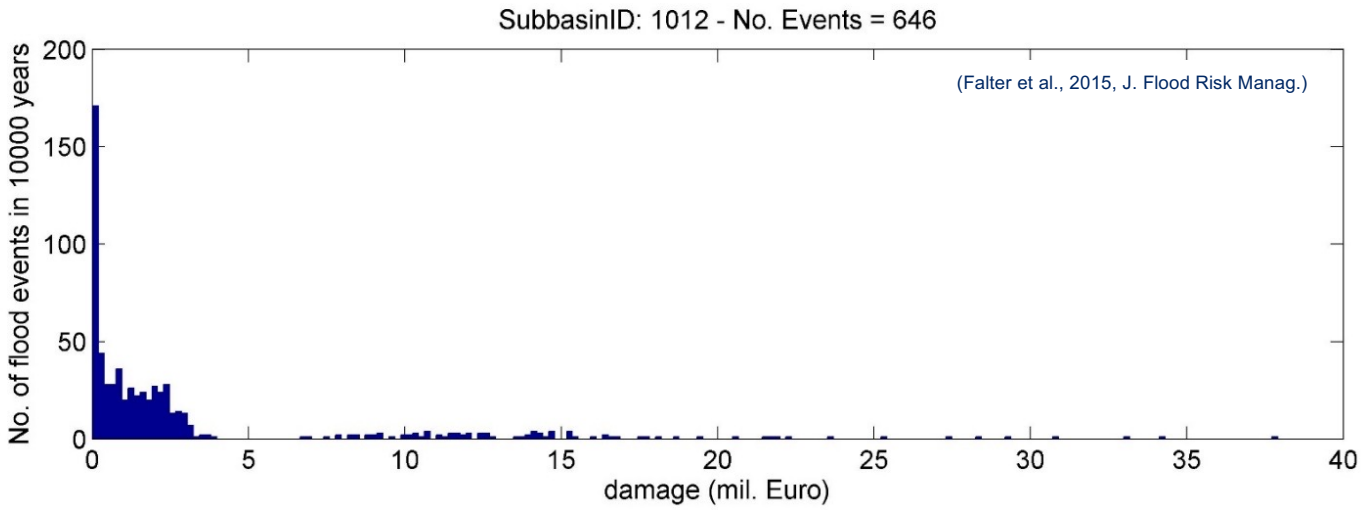
Process-based stochastic simulation

Model chain



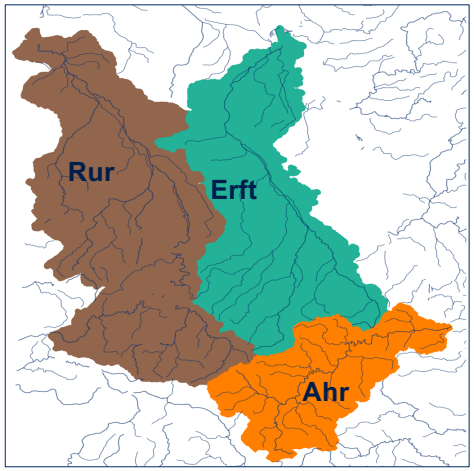
10,000 years of synthetic daily data:

- > 1,000 inundation events
- Incl. unfavourable superposition of hazard, exposure and vulnerability



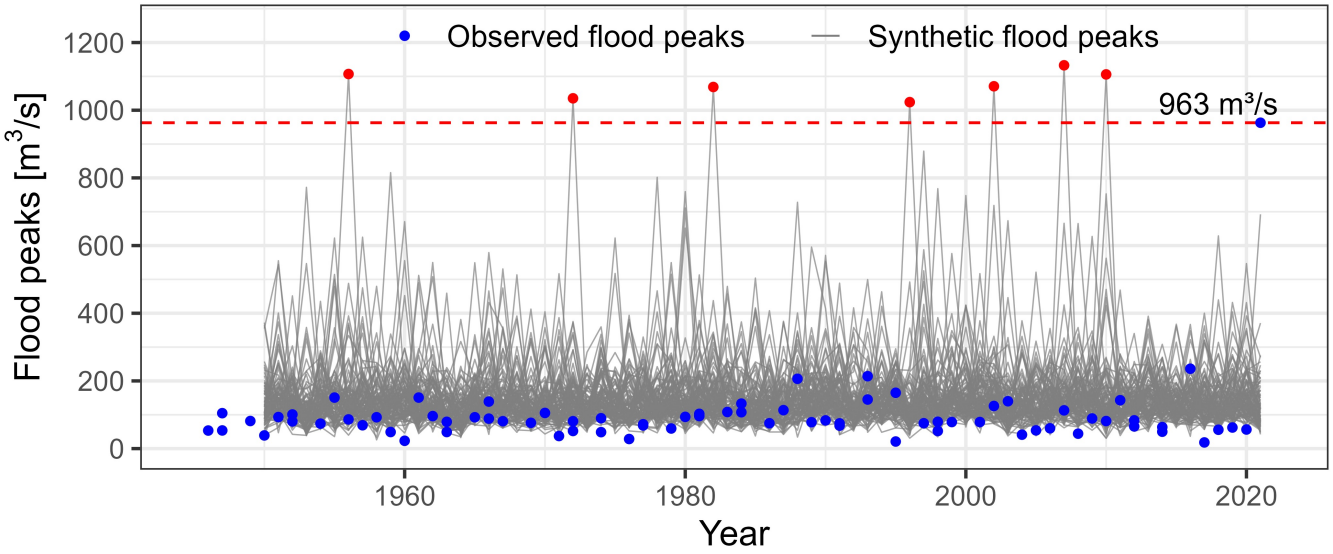
Process-based stochastic simulation

Flood model chain for Rur, Erft, Ahr



Long-term simulation with flood model chain:

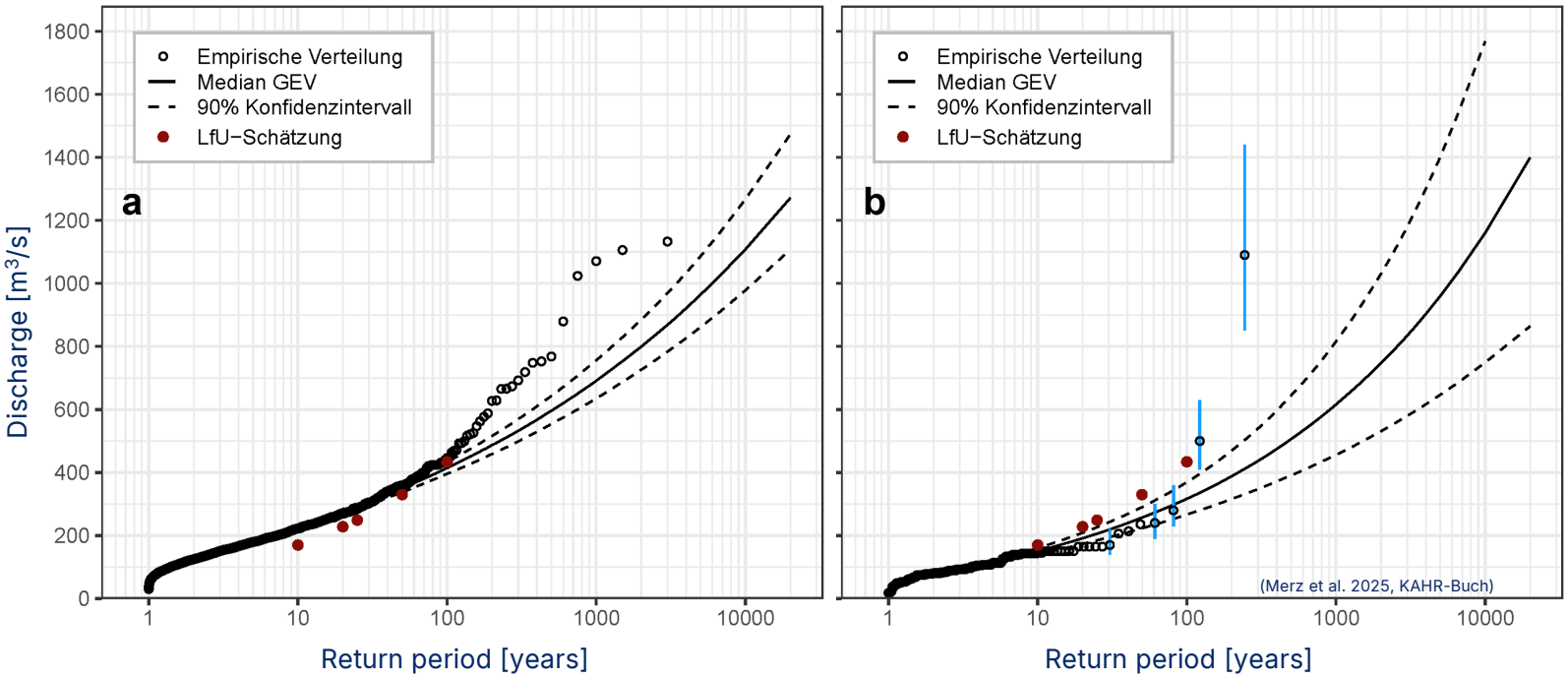
- 72 years (1950-2021) x 100 realisations = 7,200 years of hourly data
- 7 events > 2021: Return period of 2021: ~1,000 years

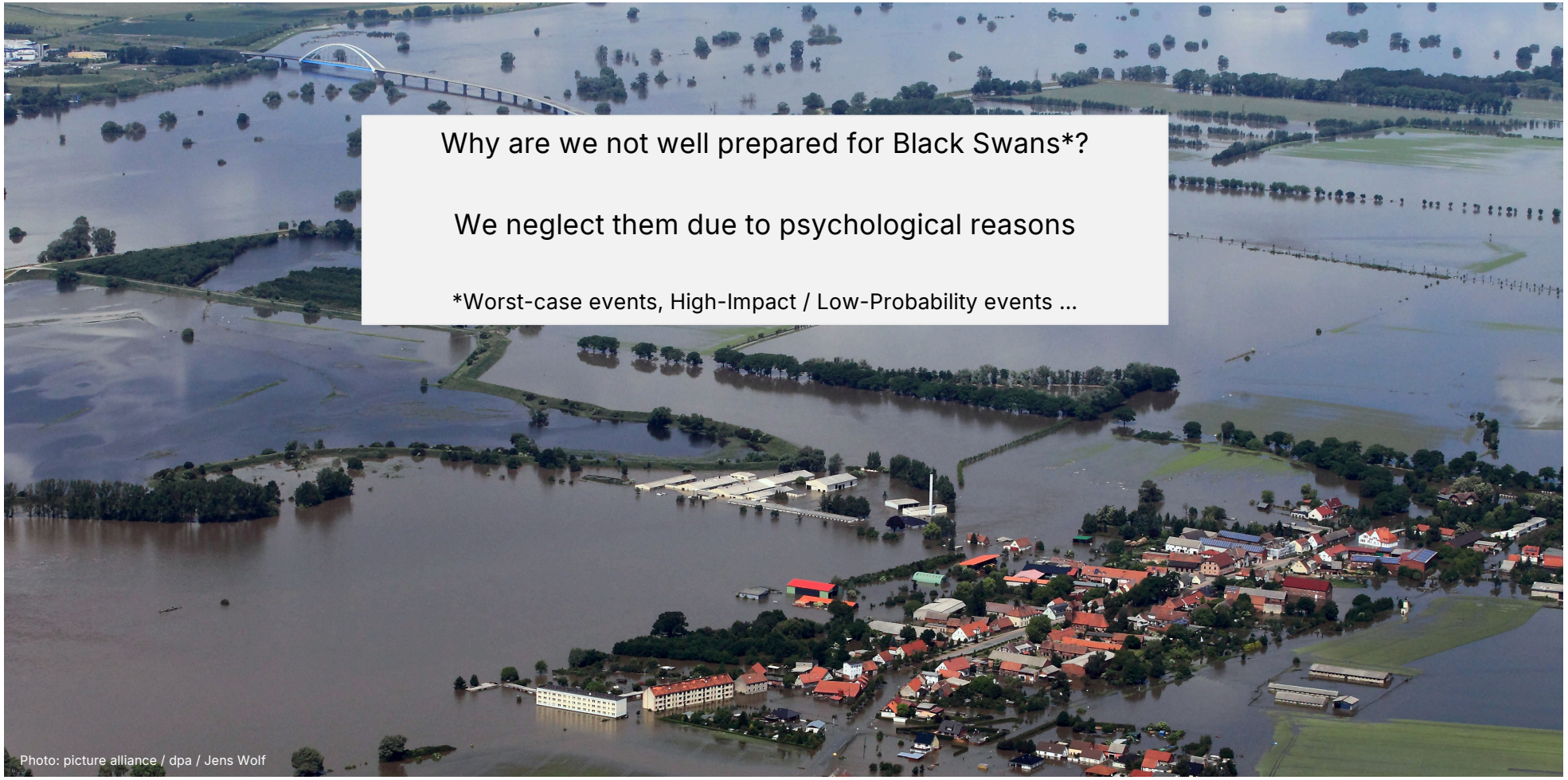


Process-based stochastic simulation

Observed climate and flood model chain
Return period 2021 ~ 10.000 years

Observed streamflow incl. historical events
Return period 2021 ~ 7.000 years




Why are we not well prepared for Black Swans*?
We neglect them due to psychological reasons
*Worst-case events, High-Impact / Low-Probability events ...
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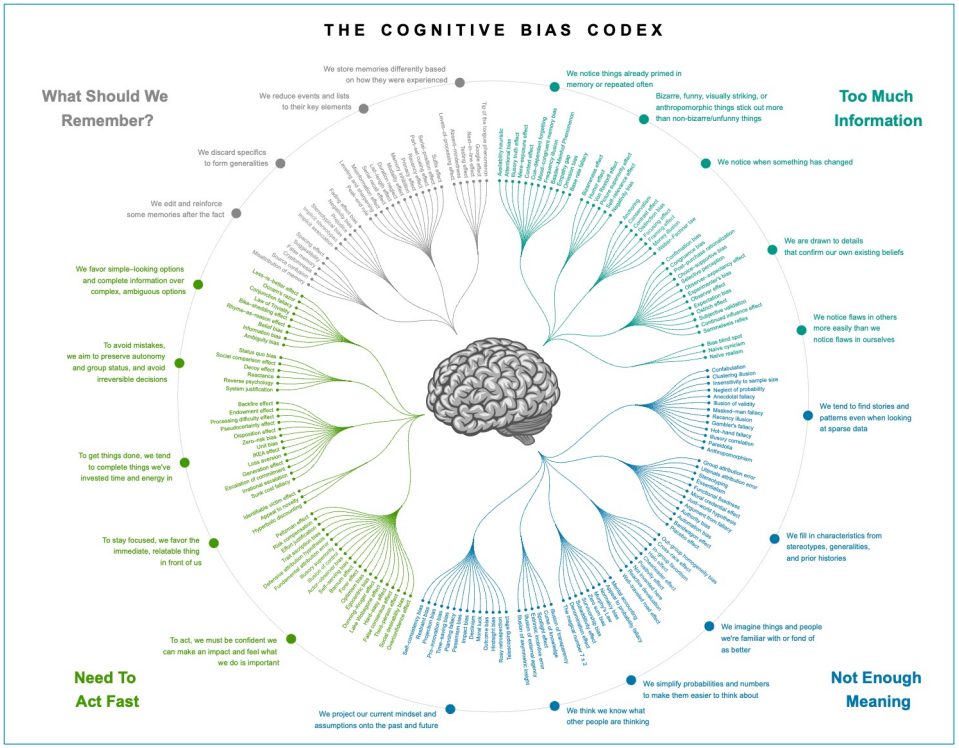
Extremes are ignored due to psychological reasons

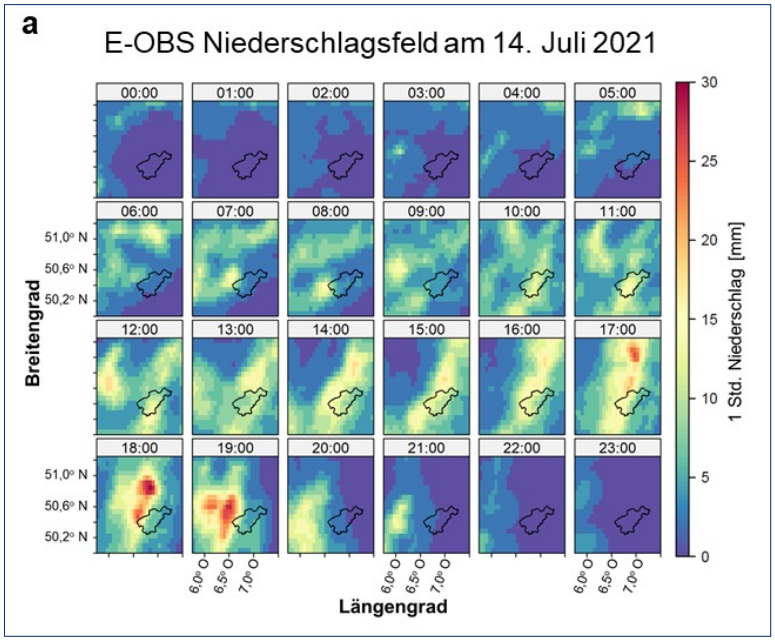
- People attach too small subjective probability to events they have not experienced.
- People perceive desirable events as more likely for themselves than for others.
- People cannot predict negative effects of severe flooding, when they have not experienced it (Siegrist & Gutscher, 2008).

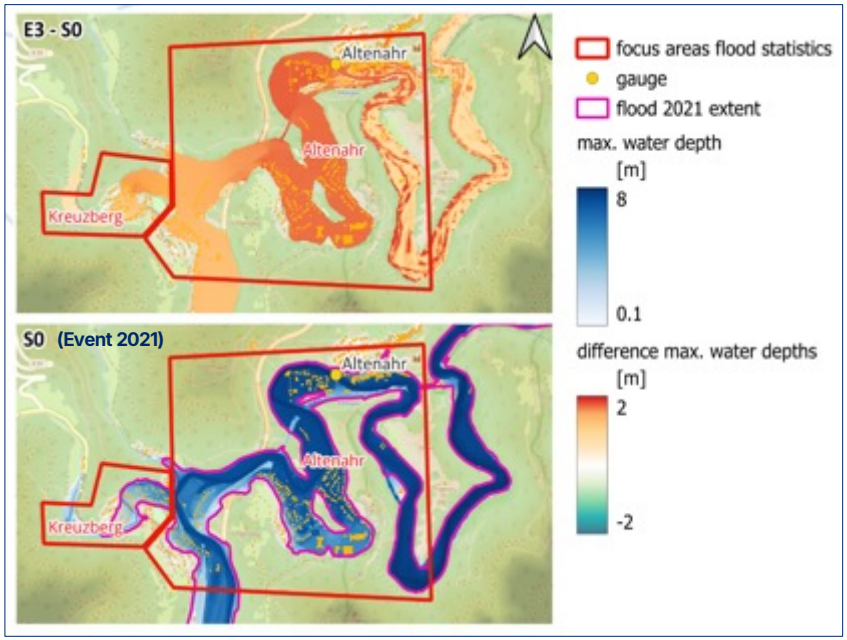


The Cognitive Bias Codex - 180+ biases, designed by John Manoogian III (jm3).png:, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=69756809

What if the event precipitation field had occurred 15 km towards the east?

Spatial counterfactuals of 2021 event

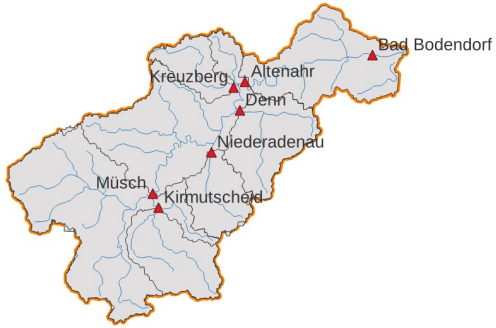


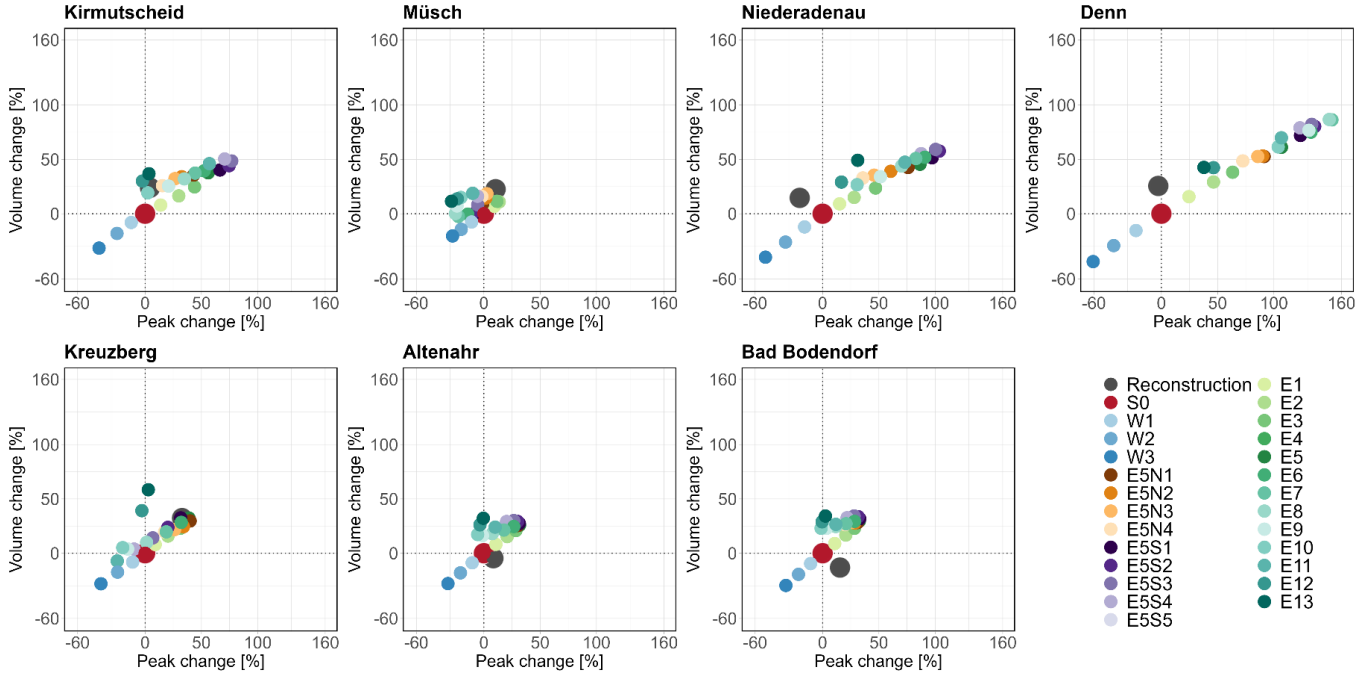


(Vorogushyn et al., 2025, NHESS)

Spatial counterfactuals of 2021 event

Relative change in flood peak and volume (24 spatial counterfactuals)





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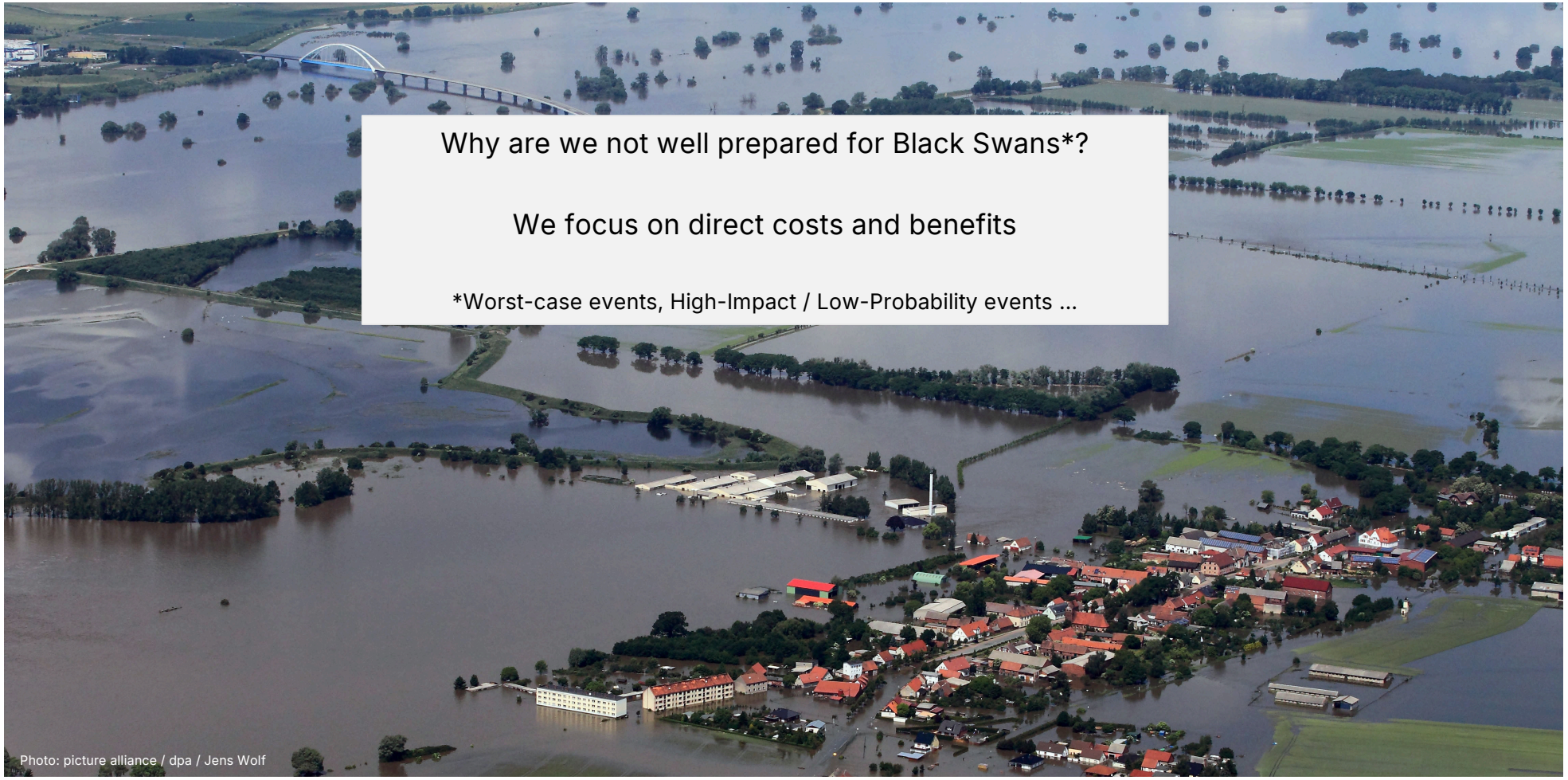
Why are we not well prepared for Black Swans*?
We focus on direct costs and benefits
*Worst-case events, High-Impact / Low-Probability events ...
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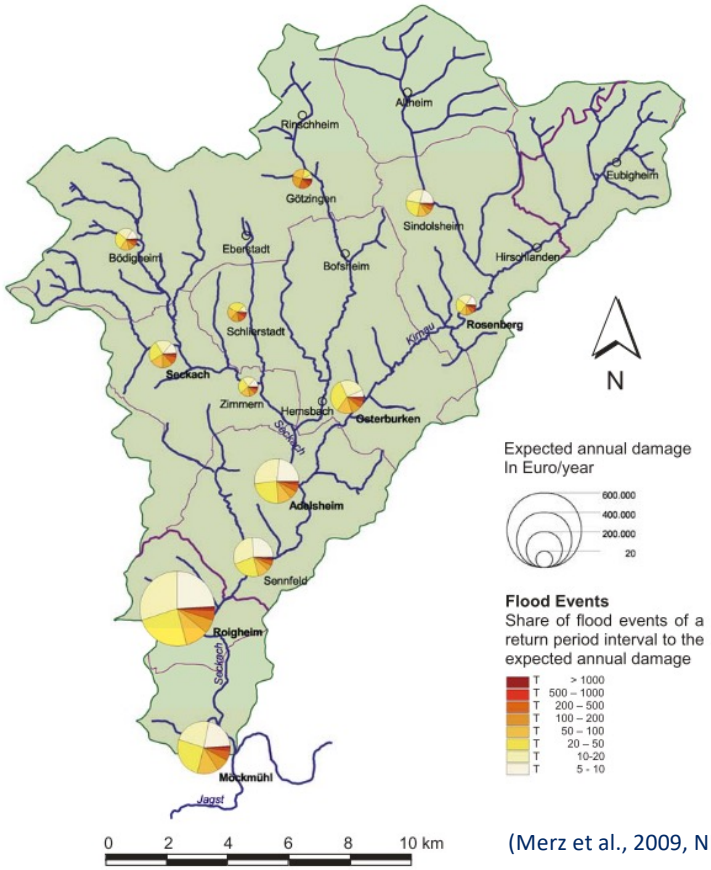
Extremes are underrated as we focus on direct economic costs and benefits

- Usual risk indicator: Expected Annual Damage (EAD)
- EAD-based design minimizes long-term, average damage

BUT:

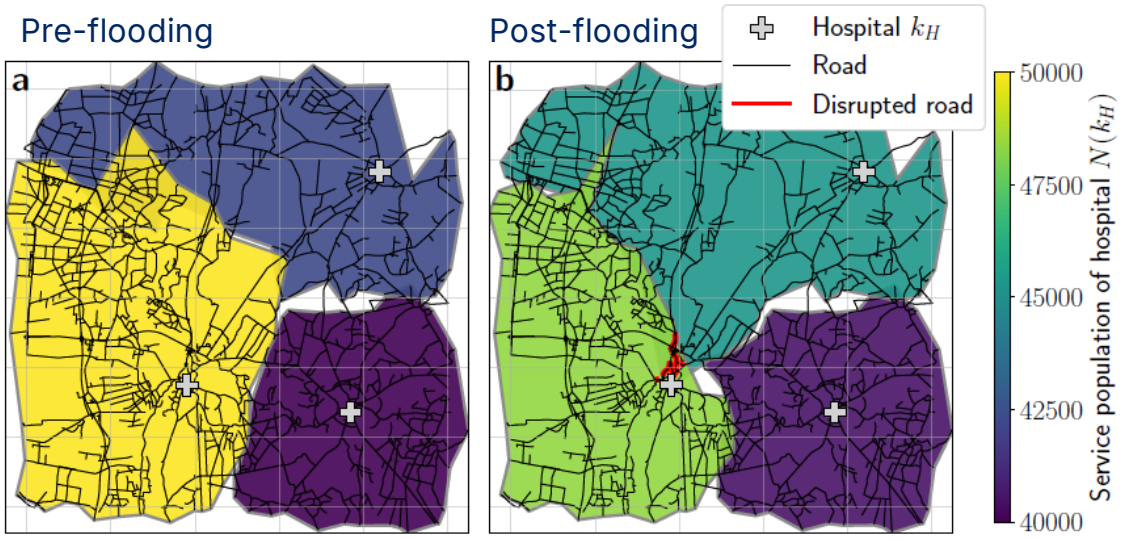
- Small contribution of extremes to EAD
- EAD ignores indirect and intangible consequences



(Merz et al., 2009, NHESS)

Flood-induced traffic changes and hospital access

Hospital service area and service population



(Wassmer et al., 2025, Nat. Com. Earth Env.)

- Germany-wide analysis of flood-induced traffic disruptions on hospitals
- 75 (of 2,475) hospitals at risk of patient surges beyond capacity
- 25 hospitals > 10 km from nearest inundation


Photo: picture alliance / dpa / Jens Wolf

Need to consider extremes beyond design events:

- Understand physical complexities of extremes
- Develop scenarios where people can relate to
- Consider indirect and intangible effects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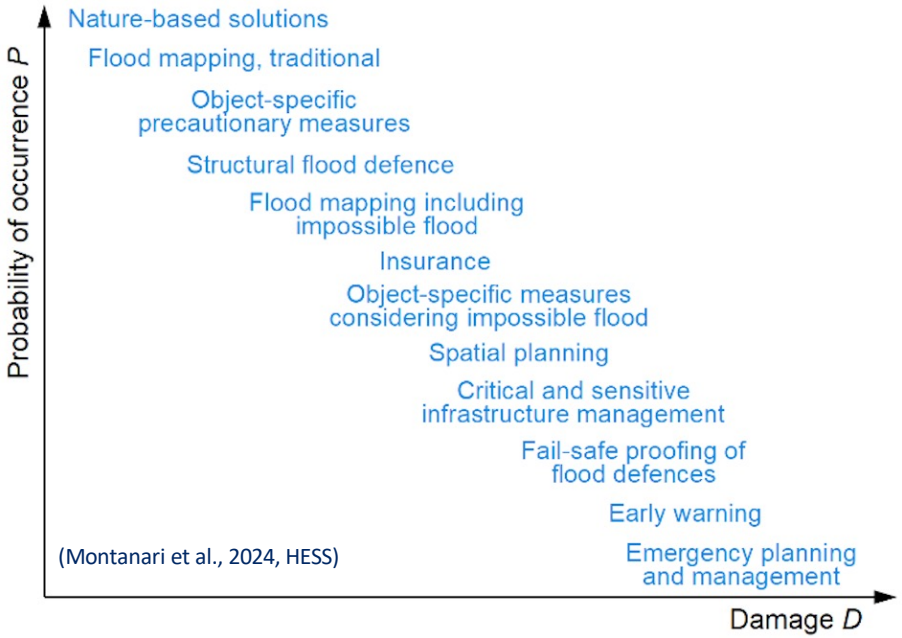
Better understanding which measures help when



(Montanari et al., 2024, HESS)