**Torrential hazard,
mitigation works and residual risks:
how can we manage changes over
time?**

Vulnerability of elements at risk – assessment approaches from an Austrian perspective

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Point of departure: Risk

- UN/DRR:
  - The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

- DRR community:
  - Risk = Hazard x Vulnerability (older approach)
  - Risk = Hazard x Exposure x Vulnerability (newer approach)

  - $R = f\,(p_{Scenario}, \text{Value}_{Object}, \text{Vulnerability}_{Object})$

https://www.undrr.org/terminology/disaster-risk

Vulnerability: Different approaches in science

- The most important:

NATURAL SCIENCES: The degree of loss to a given element or set of elements within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss).

SOCIAL SCIENCES: The characteristics of a person or a group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard.

- Where vulnerable people and places are located and who in a place is vulnerable (Liverman 1990)

Image source: Municipality of Martell (left), Oxfam (right)

Vulnerability: Different approaches in science

- The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (UN/DRR 2023).

DIMENSIONS	
Physical	Refers to conditions of physical assets – including built-up areas, infrastructure, and open spaces that can be affected by natural hazards
Social	Refers to human welfare including mental and physical health, both at an individual and collective level
Economic	Refers to the financial value and/or productive capacity
Environmental	Refers to all ecological and bio-physical systems and their different functions
Institutional	Refers both organizational form and function as well as guiding legal and cultural rules

Papathoma-Köhle, M.; Thaler, T.; Fuchs, S. (2021). An institutional approach to vulnerability: evidence from natural hazard management in Europe. *Environmental Research Letters* 16(4), 044056. https://doi.org/10.1088/1748-9326/abe88c

Why vulnerability in DRR?

- To improve the quality of risk assessments;
- to better compare different risks;
- to better evaluate different options in risk management;
- to improve cost-effectiveness of protection measures;
- to better understand the impact and thus the socio-economic context of hazards, and to develop and implement adaptation measures in accordance with
  - political,
  - administrative, and
  - economic

  management strategies according to political, administrative and economic requirements.

Vulnerability: the physical dimension

Physical	Refers to conditions of physical assets – including built-up areas, infrastructure, and open spaces that can be affected by natural hazards

Most common definition in natural sciences:
The degree of loss to a given element at risk or set of such elements resulting from the occurrence of a phenomenon of a given magnitude and expressed on a scale from 0 (no loss) to 1 (total loss).

Image source: Getty (Slovenia and Greece 2023)

Physical vulnerability: Assessment methods

- **Empirical methods:** analysis of observed consequences (data on loss needed)
- **Analytical methods:**
  - Hazard parameters (e.g. pressure) and effect on elements at risk
  - Numerical models and computer simulation

- **Qualitative** methods (e.g. indicator-based index)
- **Semi-quantitative** methods (e.g. matrices)
- **Quantitative** methods (curves)

Papathoma-Köhle, M.; Gems, B.; Sturm, M.; Fuchs, S. (2017). Matrices, curves and indicators: a review of approaches to assess physical vulnerability to debris flows. *Earth-Science Reviews* 171, 272-288. doi: https://doi.org/10.1016/j.earscirev.2017.06.007

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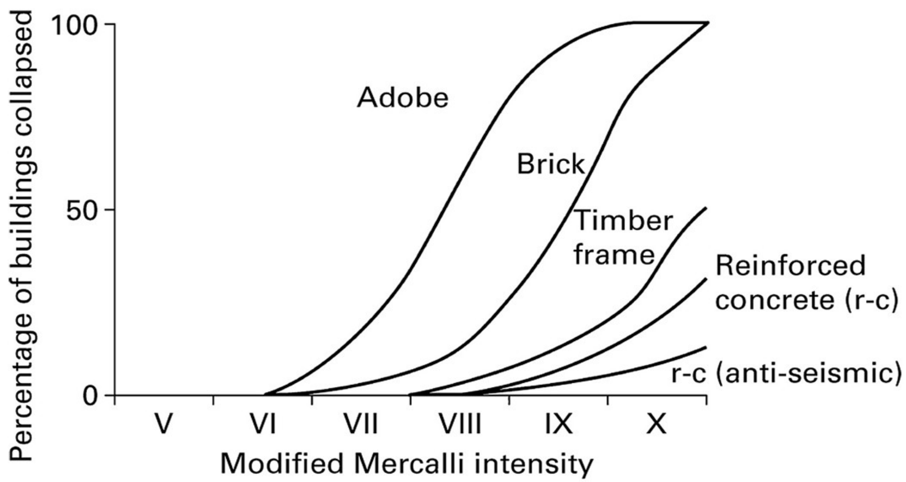
Physical vulnerability: Assessment methods

- **Quantitative** methods (curves)

Vulnerability curve:
Linking hazard magnitude/intensity to the potential degree of loss, based on observed data and/or event documentation. Results can be directly used in risk equation. Can also be used as predictive model for future events

- Basic idea: the higher the hazard magnitude is the higher the loss will be.



Stein and Stein 2014

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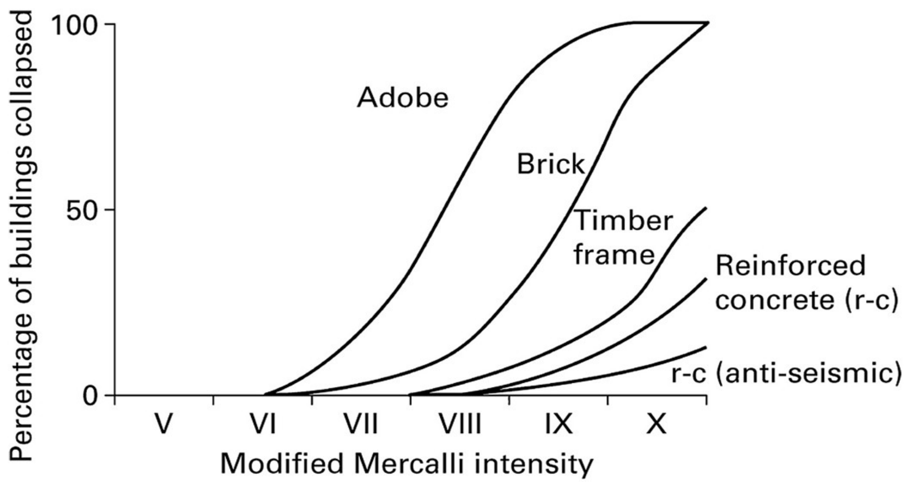
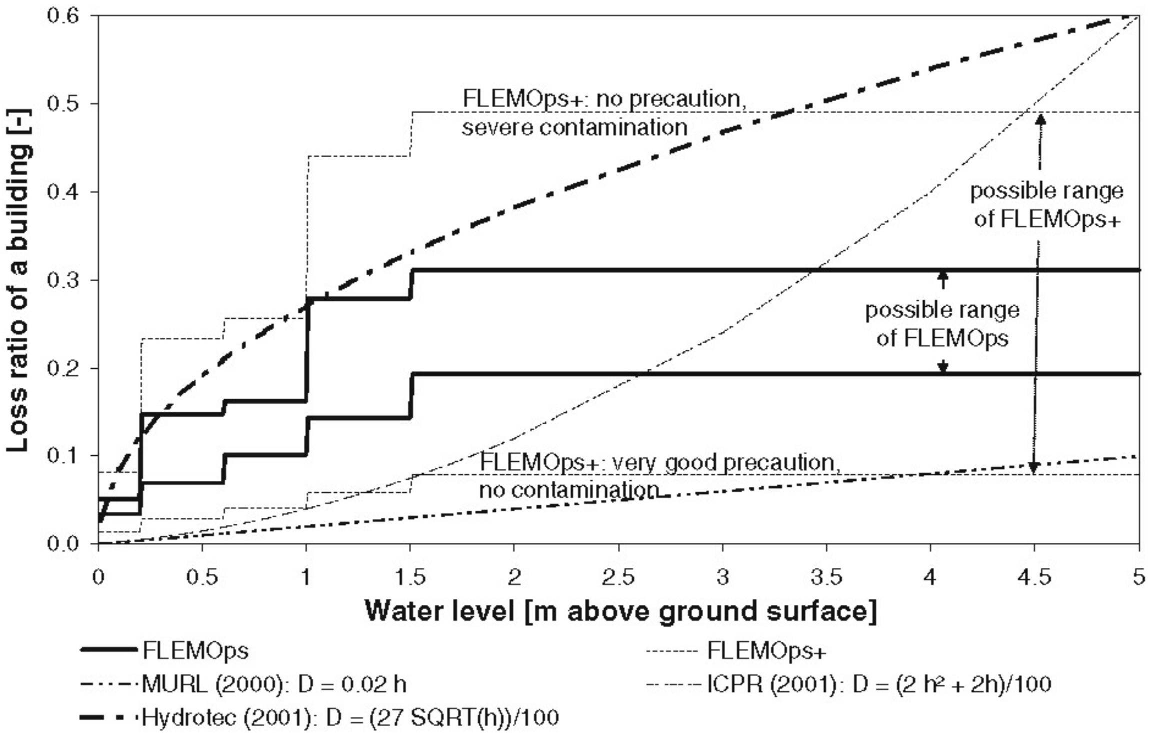


Stein and Stein 2014

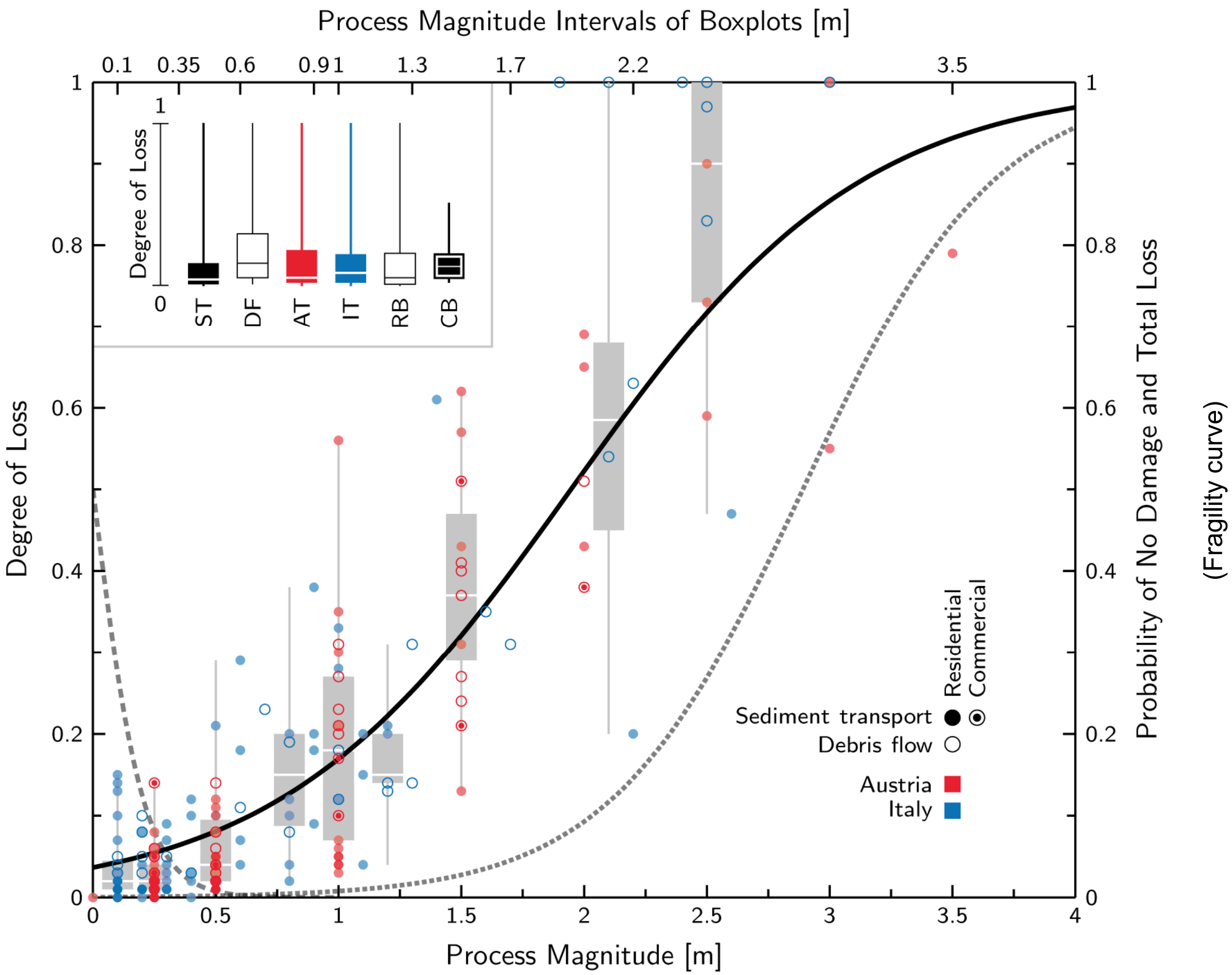
Physical vulnerability: Vulnerability curves for floods

- FLEMOps damage curve for residential buildings (based on a statistical analysis of the August 2022 flooding along the Elbe river), and comparison with other damage curves (MURL 2000; Hydrotec 2001; ICPR 2001).



Apel 2009

Physical vulnerability: Vulnerability curves for torrential flooding



Fuchs et al. 2019

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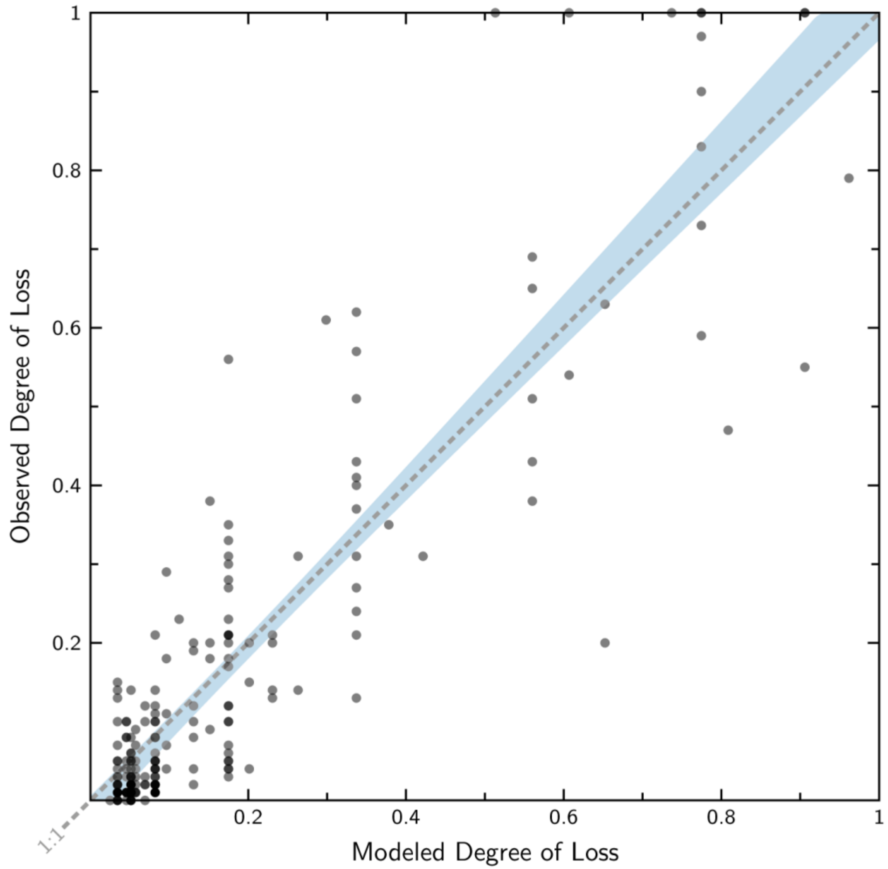
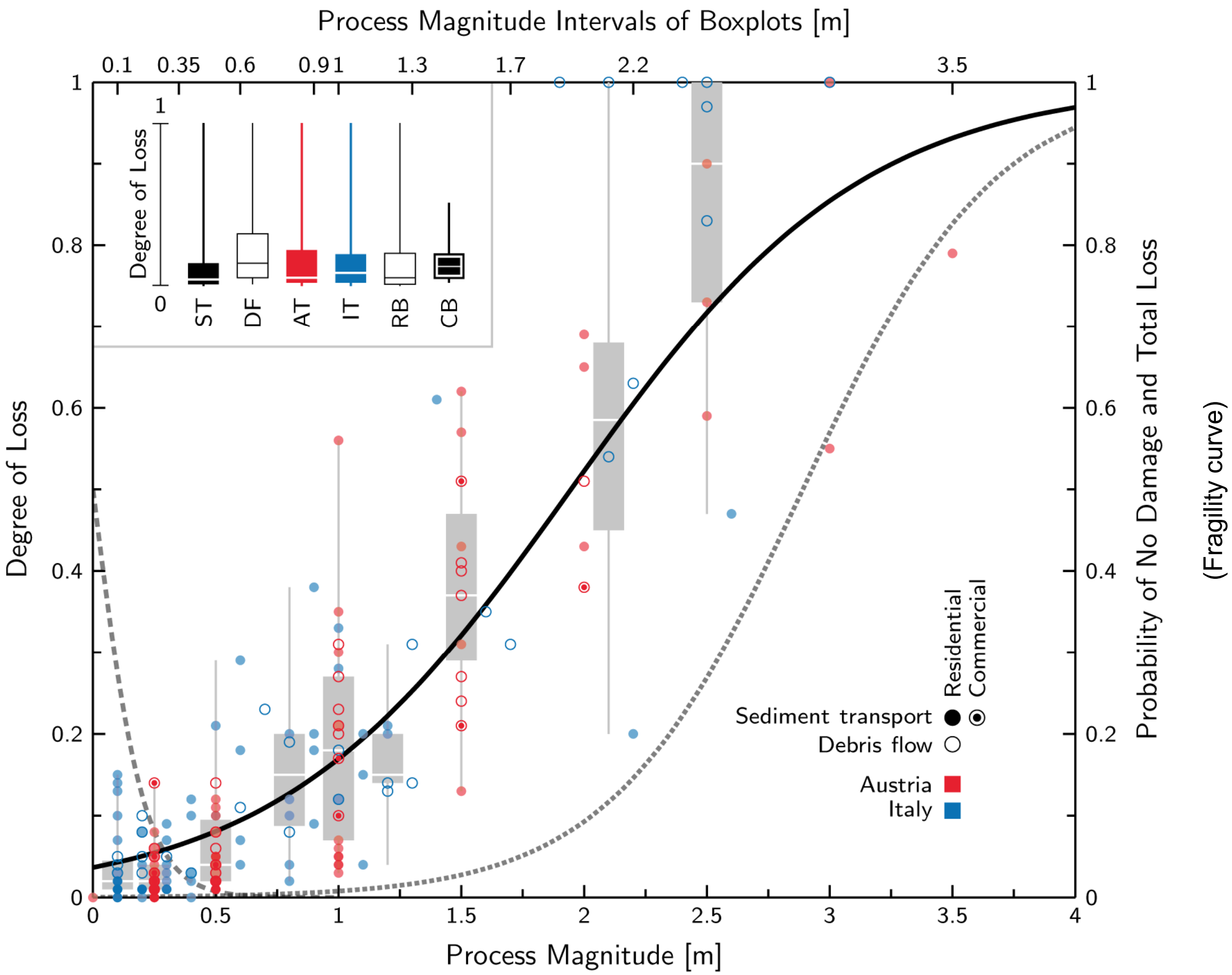


- Challenge:
  - high spread in the observational data,
  - high spread in observed vs. modelled data.
  - Relatively few data available: need for better event documentation.

Fuchs et al. 2019

Physical vulnerability: Vulnerability curves for torrential flooding



Fuchs et al. 2019

Physical vulnerability: Assessment methods

- **Semi-quantitative** methods (e.g. matrices)

Vulnerability matrix:
Information expressing the combination of hazard levels (e.g. magnitude) and their impact on elements at risk by verbal expressions.

HAZARD / BUILDINGS VULNERABILITY	depth > 1m Displacement < 30 cm	depth > 1m Displacement > 30 cm	depth > 1m Displacement > 4 m
Position: **above or below the landslide** In the area potentially covered: **no** Type of foundation: **piles**	no damage	no damage	no damage
Position: **above, on or below the landslide** In the area potentially covered: **yes** Type of foundation: **piles**	partial damage	collapse	
Position: **above, on or below the landslide** In the area potentially covered: **yes** Type of foundation: **concrete bed**	partial damage	partial damage	collapse

Source: ARMONIA (FP6)

Physical vulnerability: Assessment methods

- **Qualitative** methods (e.g. indicator-based index)

Vulnerability indicator:
A variable which is an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of a system to a hazard impact.

Vulnerability indicators
- Selection
- Scoring

→

- Normalisation
- Weighting
- Aggregation

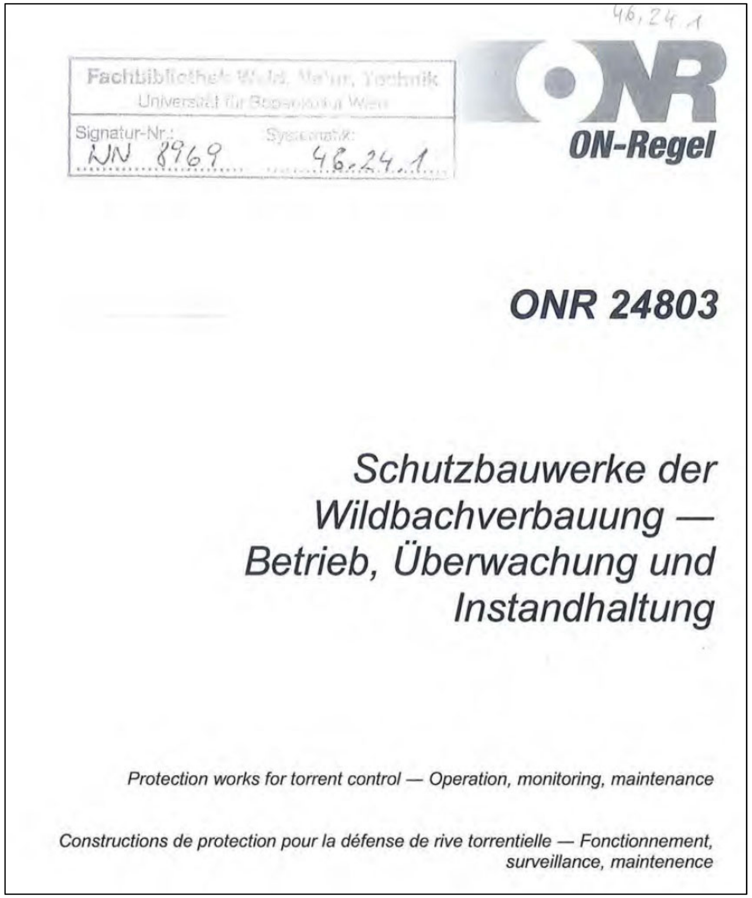
→

Vulnerability index

- Example on mitigation measures

Austrian Standard ONR 24803

- Provides a three-step procedure of vulnerability assessment, based on indicators.
- **Continuous monitoring** (LÜ) is used to determine the functional efficiency of the structures. It covers the visual detection of damage.
- The **inspection** (K) of the structure includes the survey of the state of preservation of the protective structure.
- The **detailed check** (P) of the structure has to provide a more detailed information about the state of preservation of protective structures.



ONR

ON-Regel

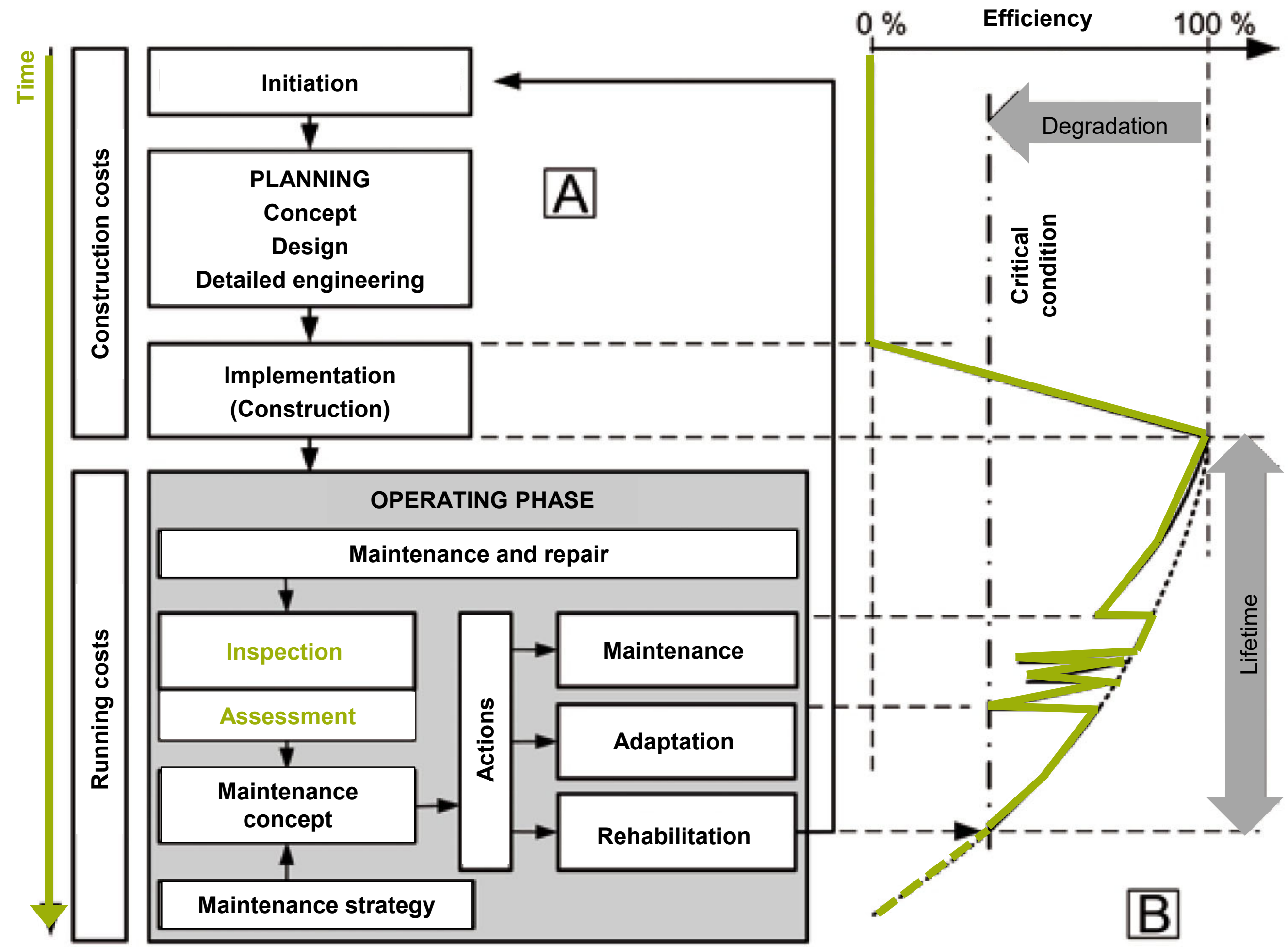
ONR 24803

Schutzbauwerke der Wildbachverbauung — Betrieb, Überwachung und Instandhaltung

Protection works for torrent control — Operation, monitoring, maintenance

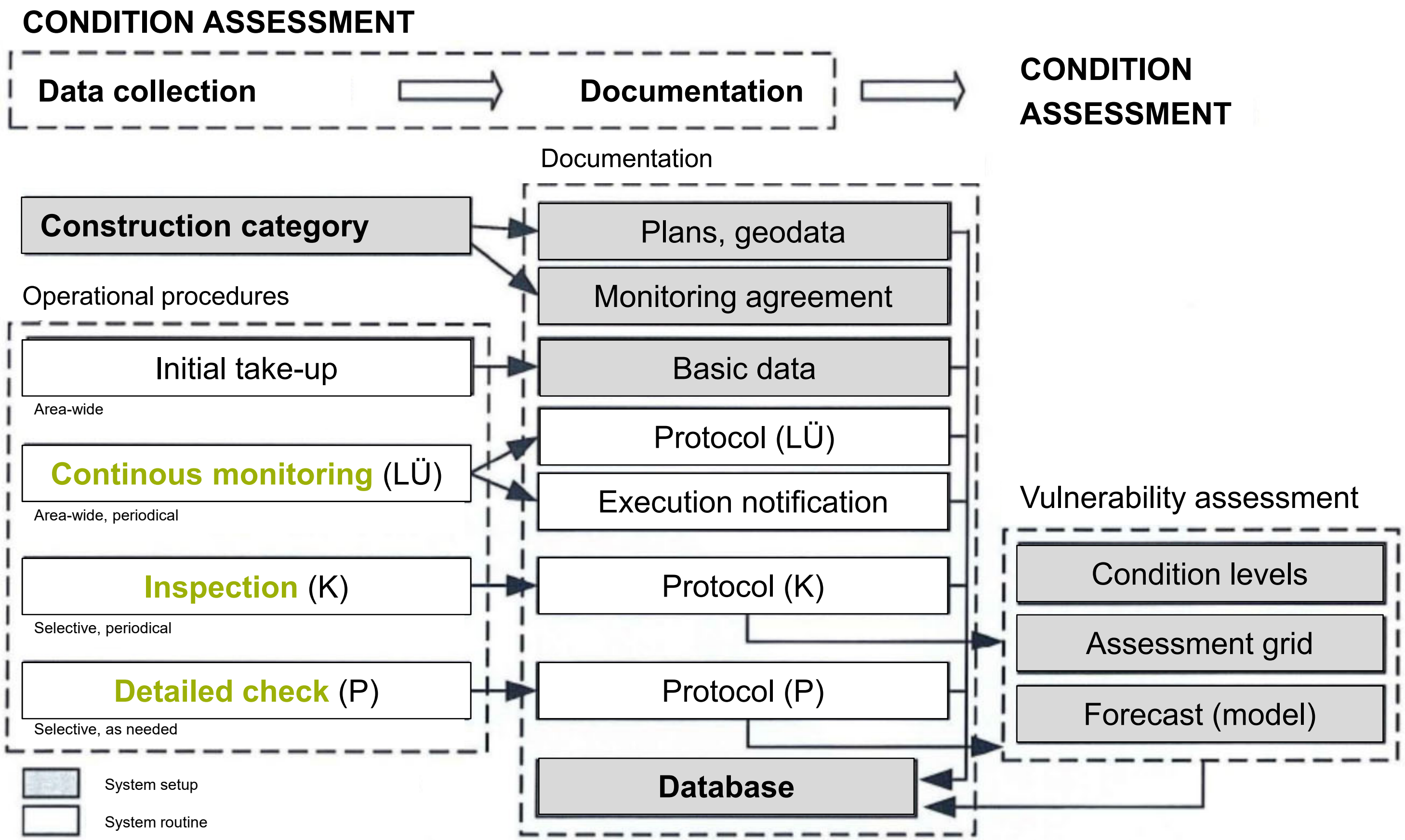
Constructions de protection pour la défense de rive torrentielle — Fonctionnement, surveillance, maintenence

Technical mitigation: general principles

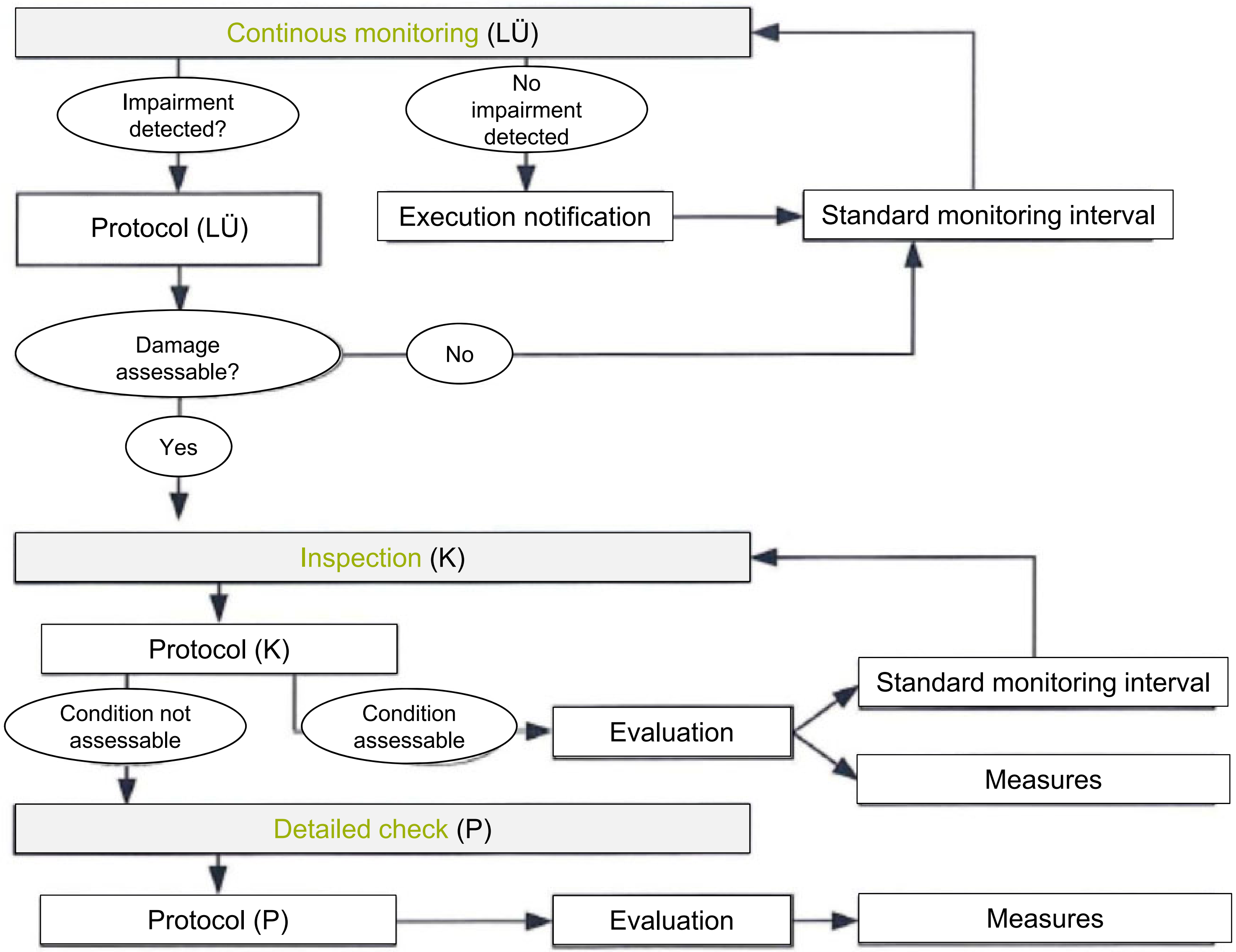


Suda 2013, adapted

Technical mitigation: vulnerability assessment



ONR 24803


Continous monitoring (LÜ)
Impairment detected?
No impairment detected
Protocol (LÜ)
Execution notification
Standard monitoring interval
Damage assessable?
No
Yes
Inspection (K)
Protocol (K)
Standard monitoring interval
Condition not assessable
Condition assessable
Evaluation
Measures
Detailed check (P)
Protocol (P)
Evaluation
Measures

ONR 24803

Technical mitigation: vulnerability assessment

Effects on the mitigation system	**Effects on the protected areas**		
	High	Medium	Low
	Densely-settled areas, nucleus of population, important infrastructure, cross-regional transport axis, high personal risk	Loosely-settled areas, individual buildings, regional transport axis, medium personal risk	Auxiliary buildings, ancillary infrastructure, subsidary roads, low personal risk
High (Effects on the entire system, serial failure)	CC3	CC3	CC3
Medium	CC3	CC3	CC2
Low (Only local effects, no other mitigation measures affected)	CC3	CC2	CC1

- Consequence classes are defined as follows:
  - CC3: Serious effects for human life **or** considerable economic, social or environmental effects.
  - CC2: Medium effects for human life **and** considerable economic, social or environmental effects.
  - CC1: Low effects for human life **and** no/negligible economic, social or environmental effects.
- Key mitigation works are shaded in grey.

ONR 24803

Technical mitigation: vulnerability assessment

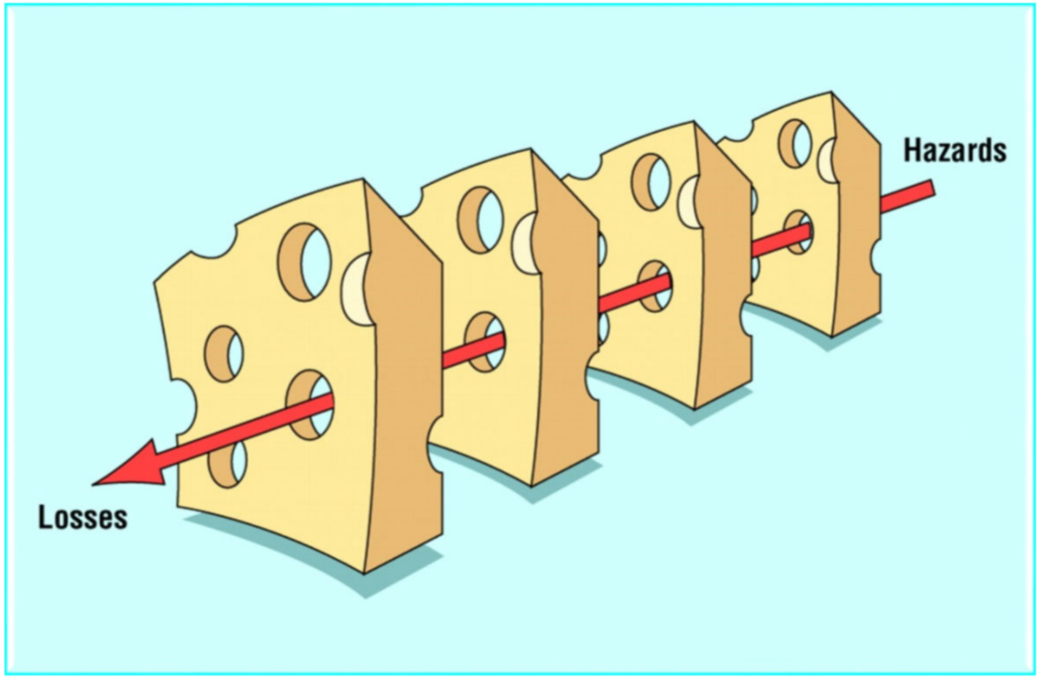
	Condition levels					
Level	Structural safety				Period of structural measures	
	Date of assessment	For next event (HQ30)	For next design event	Long-term	Standard migitation	Key mitigation
0	-	-	-	-	-	-
1	Given	Given	Given	Given	Not defined	Not defined
2	Given	Given	Given	Given	Not defined	Not defined
3	Given	Given	Given	Not given	Not defined	Not defined
4	Given	Given	Not given	Not given	Not defined	3 years
5	Given	Not given	Not given	Not given	2 years	1 year
6	Not given	Not given	Not given	Not given	2 years	1 year

- Levels for mitigation work condition:
  - 0 = Mitigation work is unnecessary
  - 1 = very good condition
  - 2 = good condition
  - 3 = sufficient condition
  - 4 = inadequate condition
  - 5 = poor condition
  - 6 = Mitigation work is destroyed

ONR 24803

Summary

- Multi-dimensional nature of vulnerability

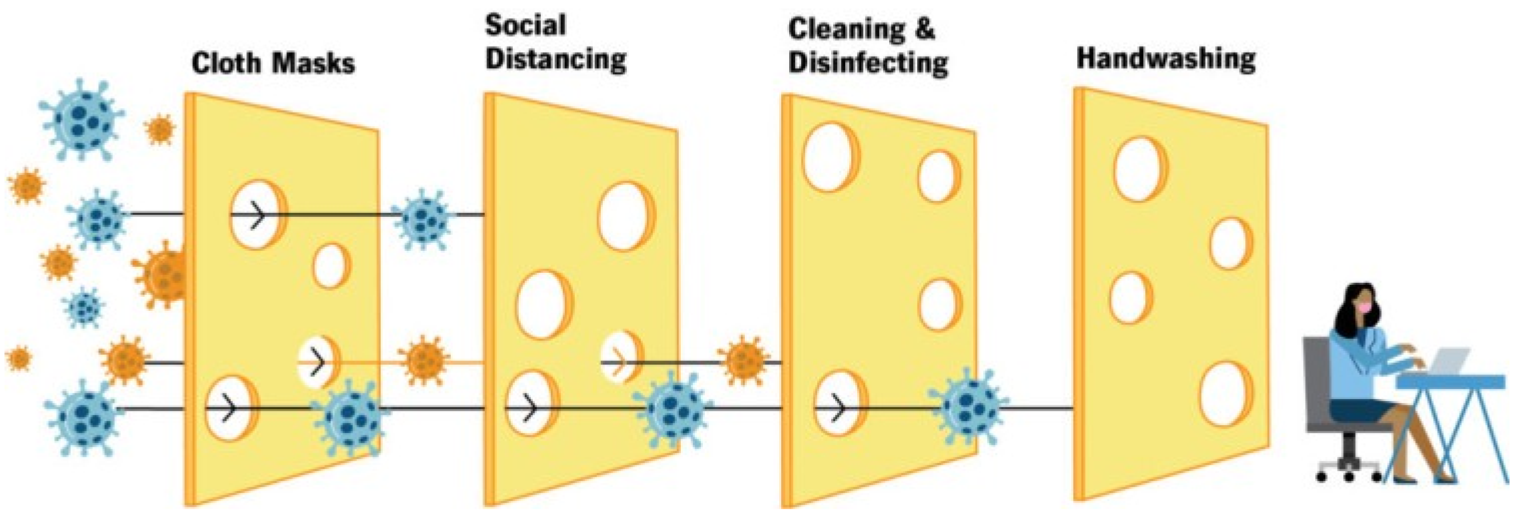


- Different conditions have to line up so that vulnerability becomes manifest.

Reason 1990, 2000

Summary

- Multi-dimensional nature of vulnerability



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Lindgren 2023: https://www.linkedin.com/pulse/layered-defenses-addressing-holes-how-swiss-cheese-model-sam-lindgren/

Summary

- Methods to assess physical vulnerability:
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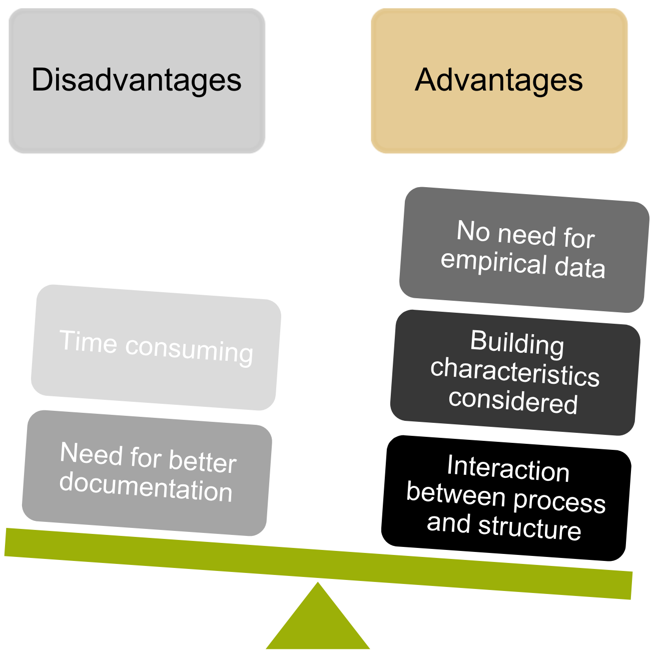
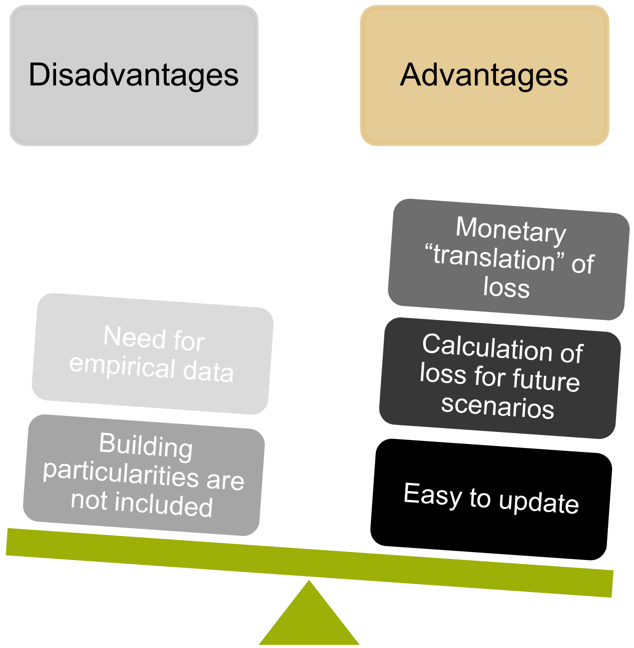


Vulnerability indicators



Vulnerability curves

Summary

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- Individual loss assessment methods available for hazards that occur regularly and can be assessed using defined magnitudes,
- …but knowledge gaps for rare events and cascading hazards (with extraordinary magnitudes);

- …spatial and temporal dynamics in exposure and thus risk are often not considered.

Summary

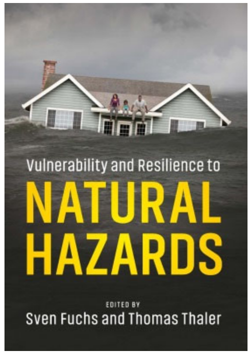
- Consider adaptation and mitigation:
  - Land-use planning
  - Local structural protection
  - Technical mitigation

- Consider other vulnerabilities:
  - Social (education, communication)
  - Economic (insurance systems)
  - Institutional (standards, law, and law enforcement)

Next steps – Research needs

- Validation of indices and curves with data from new events;
- More loss data (damage documentation) to also reduce the spread (e.g. floods);
- Better visual representation of results (how can practitioners and decision makers better use the results);
- Integration on indicators associated with the magnitude/intensity of the hazard;
- Scale issues (e.g. national vs. local level);
- Transferability of the methods to a different context (e.g. curves from the Alps to the Pyrenees).

References and further reading



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Further questions?

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