FLOODS, WATER SCARCITY AND EXTREME EVENTS
2023

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In search of the risk associated with dam failures

a tale of efficient computing and meta-modelling to implement an integrated probabilistic framework

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Lisbon, 2023.10.19

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Why risk?

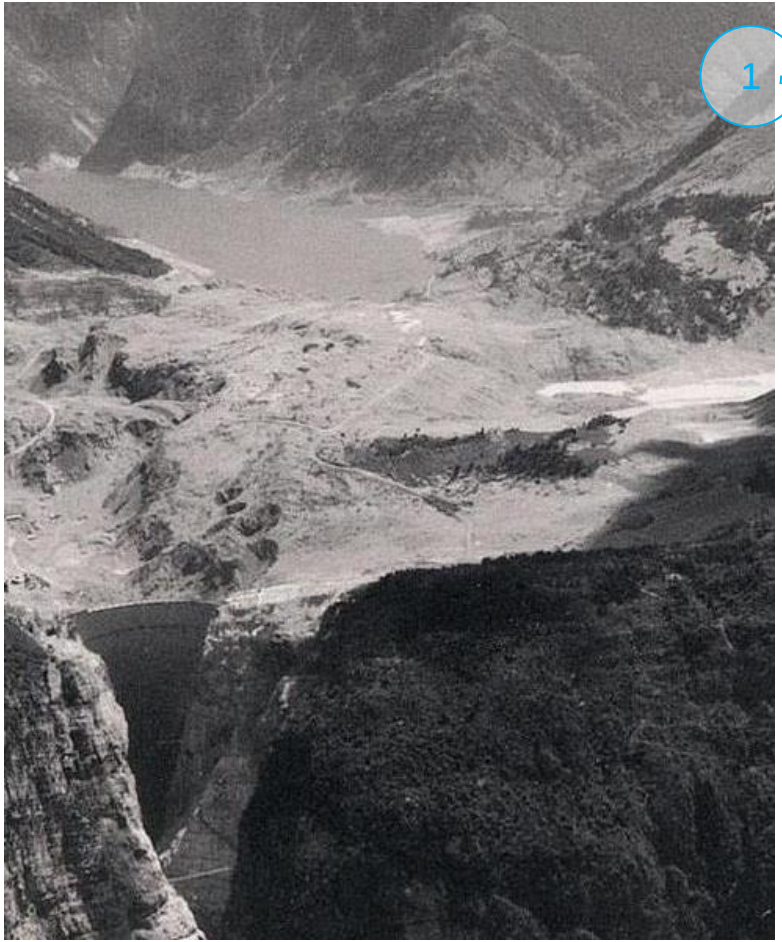
Is the quest to quantify risk worthwhile?

June 2013. Marquartstein

https://commons.wikimedia.org/wiki/File:Brücke_Über_die_Tiroler_Ache_in_Marquartstein,_Hochwasser_Juni_2013.jpg

Why risk?

Motivation and core message



Why risk?

Challenges and application to large dams. Why probability matters.

- There are several definitions of risk. Keeping it simple:

$$Risk = Probability \cdot Loss$$

- Large dams are built not to fail.
  - Design is based on deterministic cases (e.g., Probable Maximum Flood, Maximum Credible Earthquake).

$$R_{design\ flood} = P_{design\ flood} \cdot L_{design\ flood} \approx 0$$

  - Risk is part of design, of course, but not explicitly / strictly.

$$R_{floods} = \int P_{flood} \cdot L_{flood} = ?$$

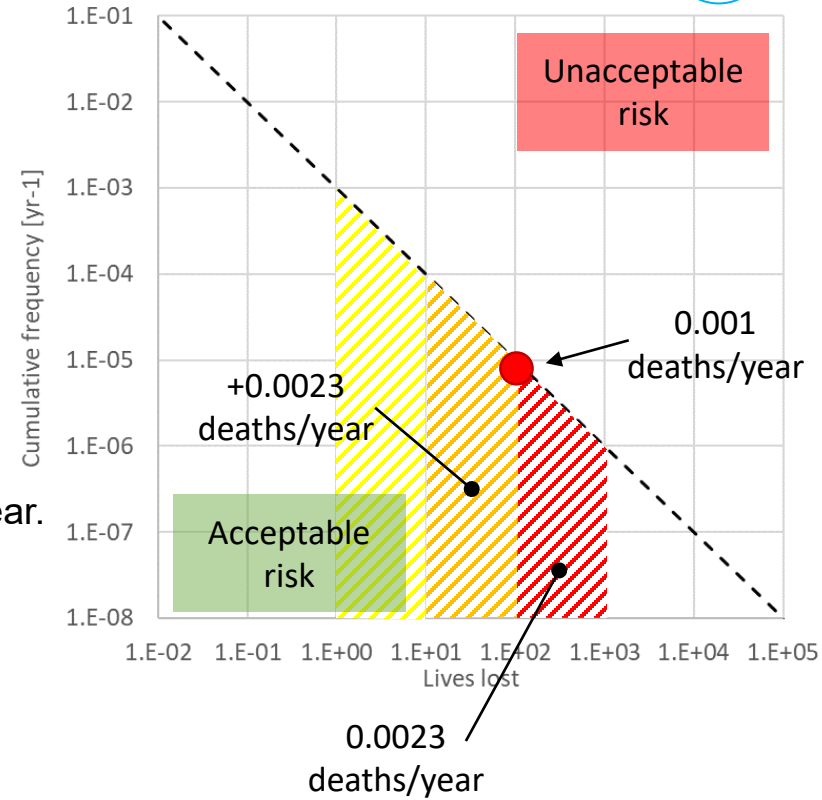
- In reality:

$$R_{dam} = \int P_{failure} \cdot L_{failure} = \text{Something hopefully very small.}$$

Why risk?

Challenges and application to large dams. Why probability matters.

- An example F-N curve.
  - $P(X \geq N) = \frac{0.001}{N}$
  - $T_{1\ death}$ = 1000 years
  - Valid from N=1 to 1000 (people at risk).
  - The design “event” also has a risk of 0.001 deaths/year. (as do all other events along the diagonal).
  - $p(N) = \frac{0.001}{N^2}$
  - Risk $= \int_1^b N \cdot p(N)\, dN = 0.001 \cdot \ln(b)$
  - The total risk is 7 times greater (0.0069 deaths/year).



Is it worth to quantify it?

Yes! – A personal view

- To a hydrologist, uncertainty and risk are omnipresent, inescapable.

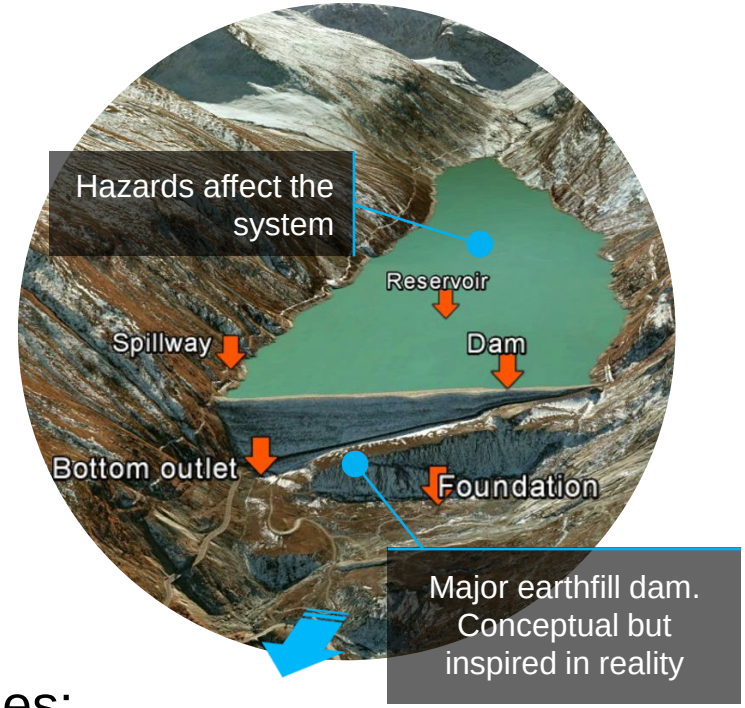
- Uncertainty is too often just politely ignored:

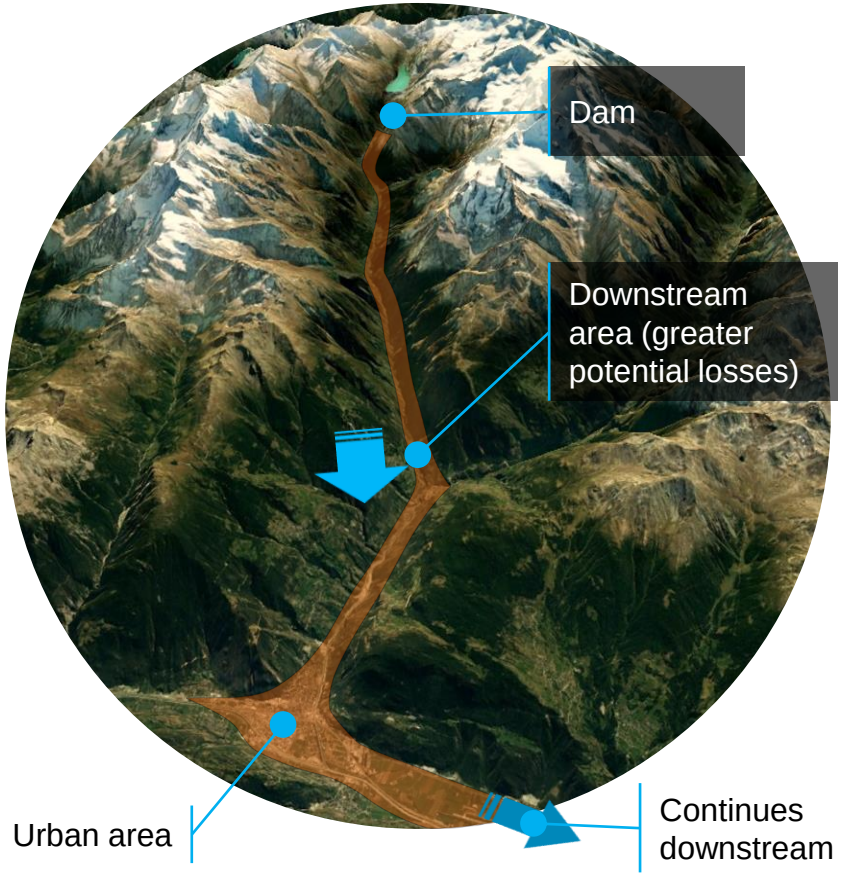
Some processes and phenomena are sufficiently understood and monitored for uncertainty to lose practical relevance.

Framing and evaluating uncertainty can be difficult, both conceptually and practically (required data and computational power).

Historically, considering uncertainty with precision was simply not practical in many applications. The inertia of this mindset endures.

How to do it?





- Challenges:
  - Complexity.
  - Computationally demanding > millions of simulations are required.

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The failure

Estimating failure rates and how failures may occur

Failure | probability and characteristics

Dam-break wave | Many possibilities for each failure

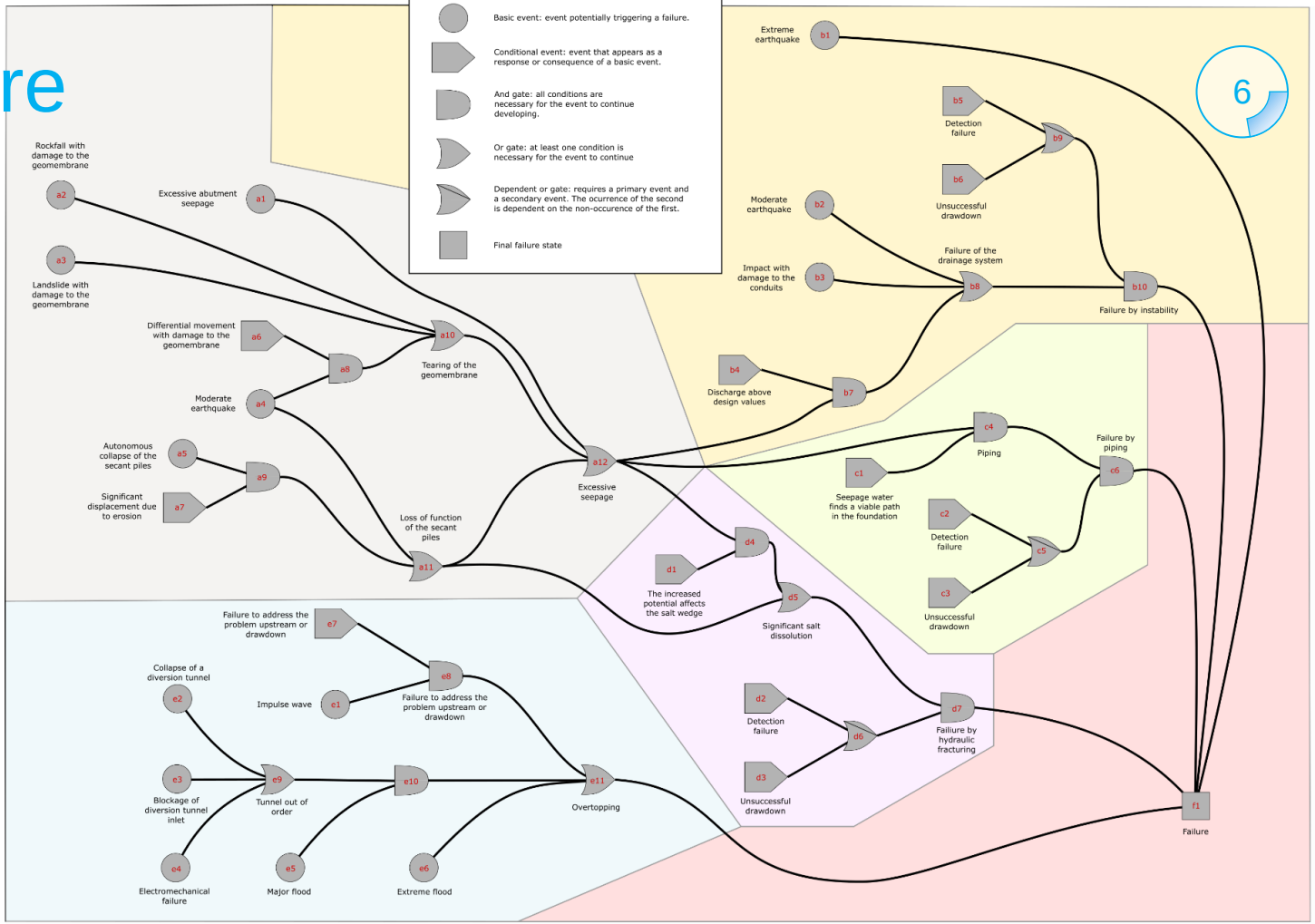
Loss estimation | Buildings, infrastructure and people

Zeuzier dam, Switzerland

The failure

Event tree analysis

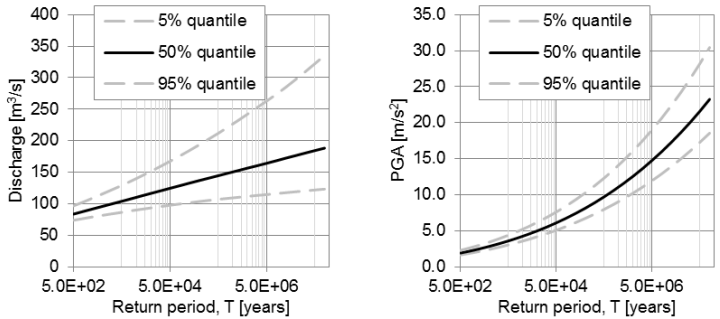
- Example of a real event tree analysis for a large dam.
- Subjective.
- Relies on imagination.



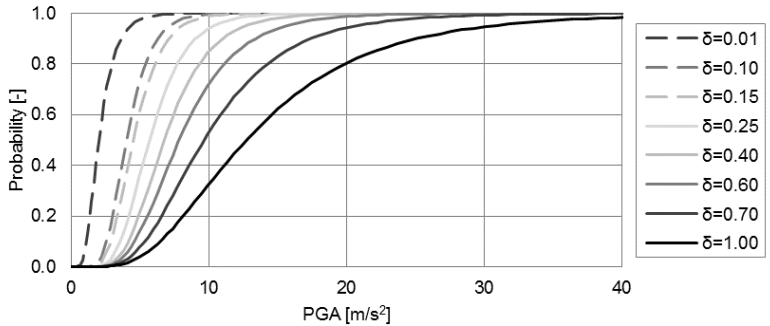
The failure

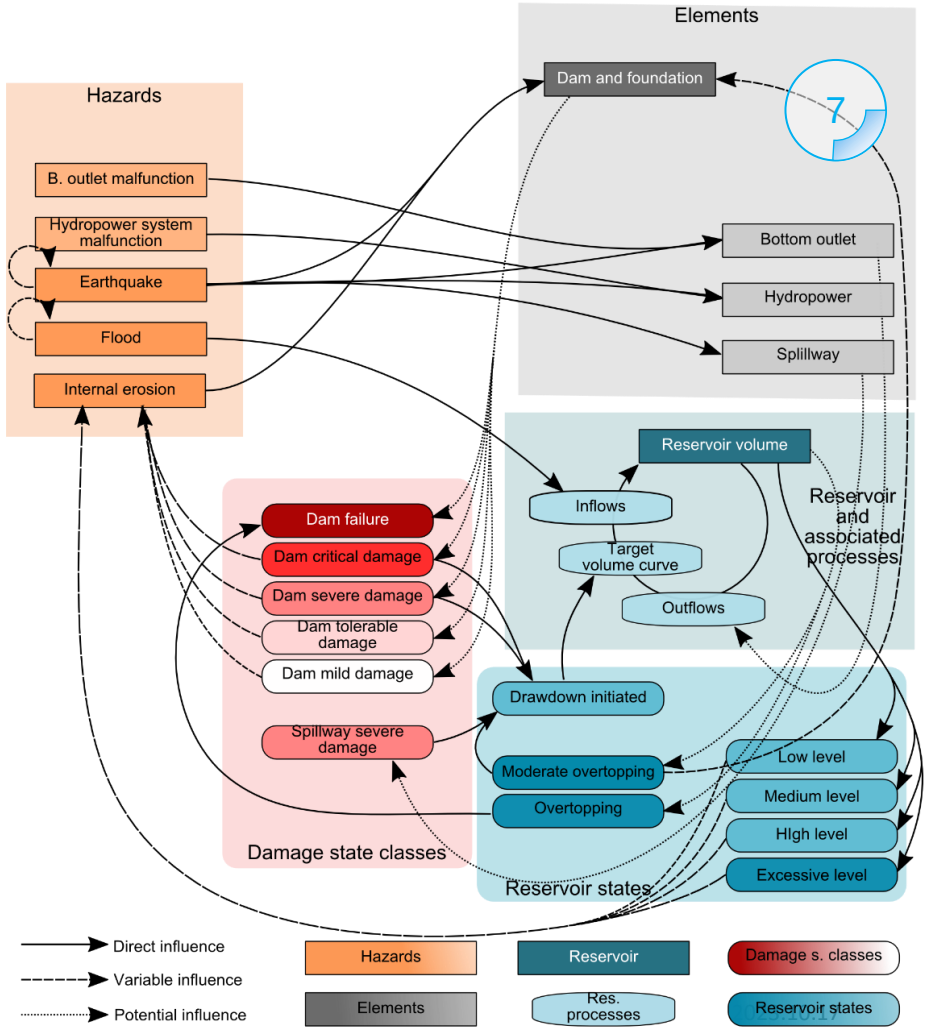
Estimating failure rates and how failures may occur

Hazard characterization



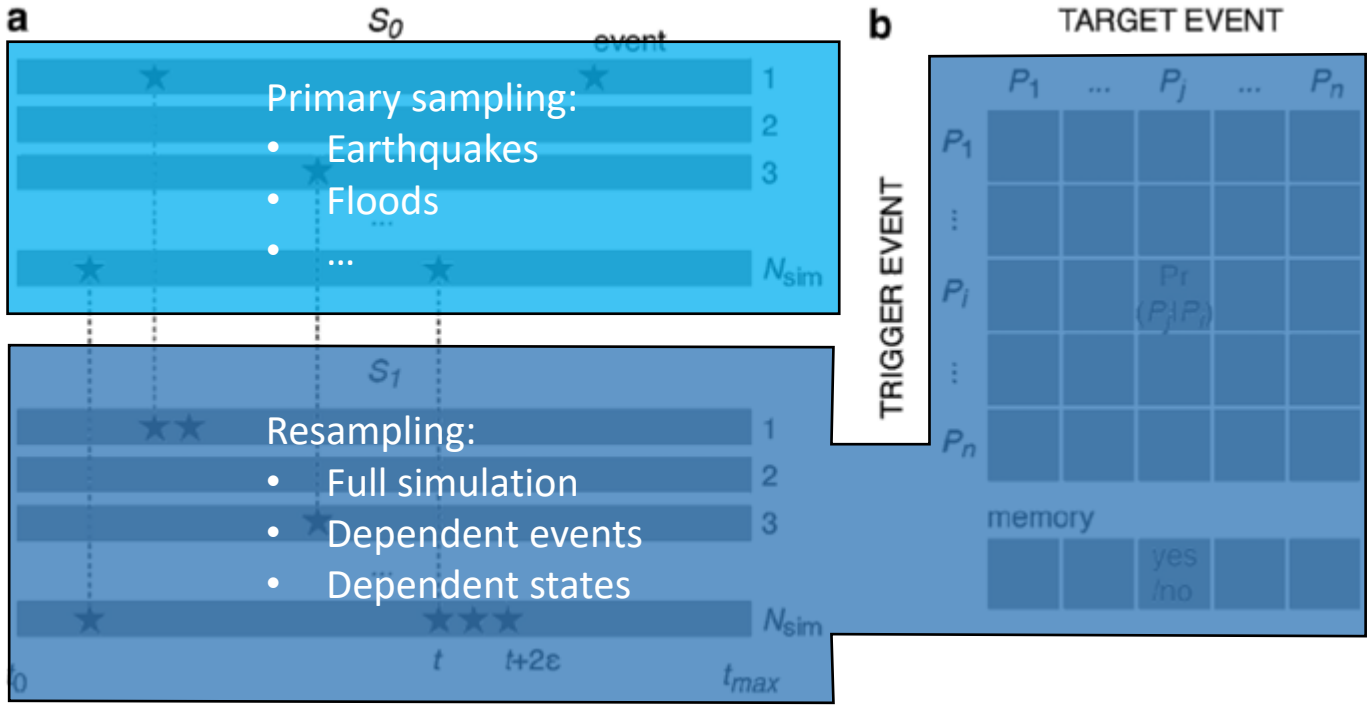
Element characterization





The failure

Estimating failure rates and how failures may occur



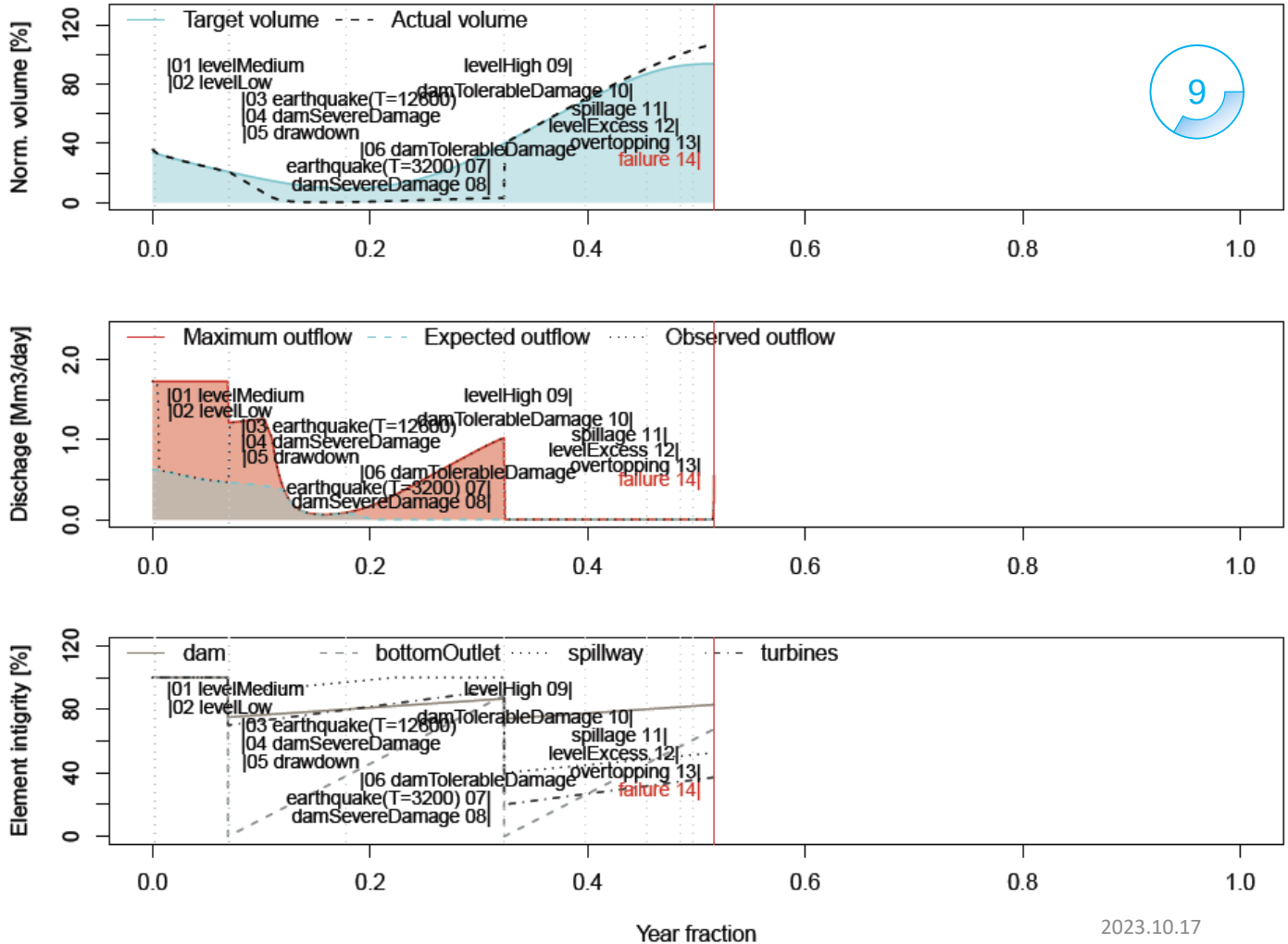
Generic Multi-Risk (GenMR)

See Mignan, A., S. Wiemer and D. Giardini (2014) The quantification of low-probability–highconsequences events: part I. A generic multi-risk approach Nat. Hazards, 73

The failure

Estimating failure rates and how failures may occur

- The full story of thousands of failures.



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The dam-break wave

Generation and propagation downstream

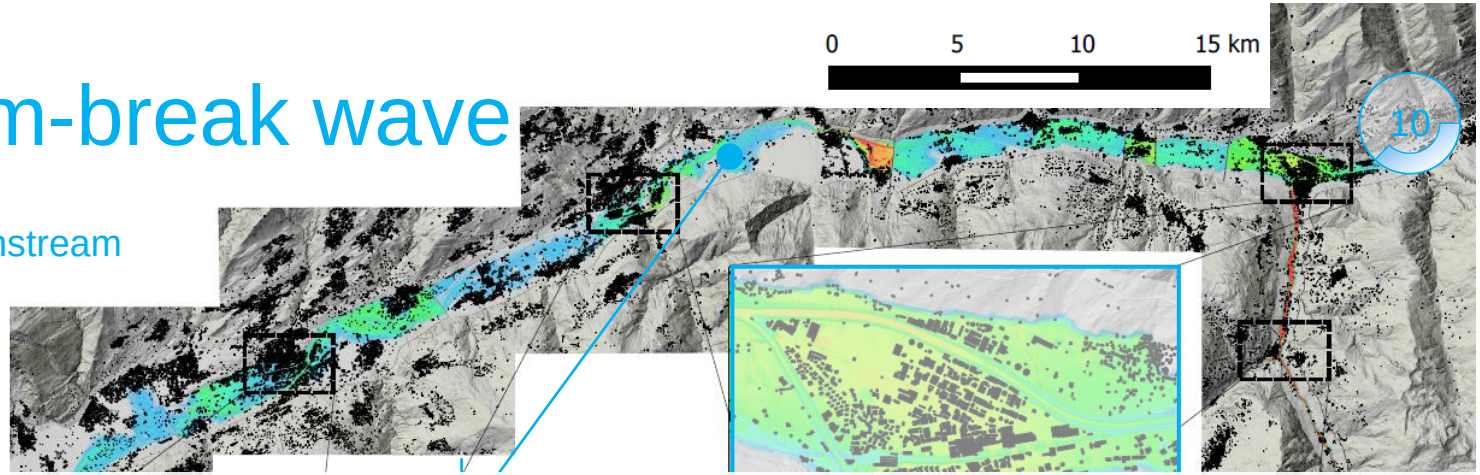
Failure | probability and characteristics

Dam-break wave | Many possibilities for each failure

Loss estimation | Buildings, infrastructure and people

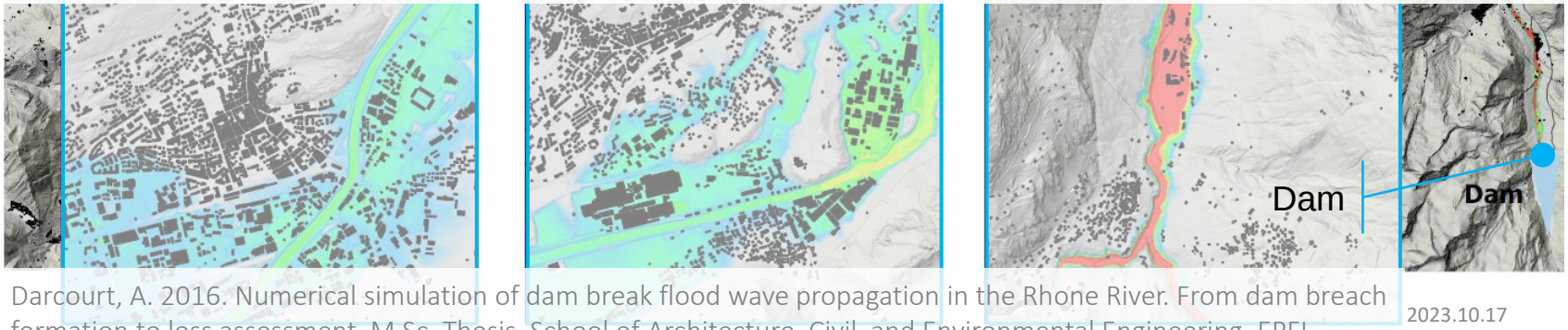
The dam-break wave

Generation and propagation downstream



~100 km domain

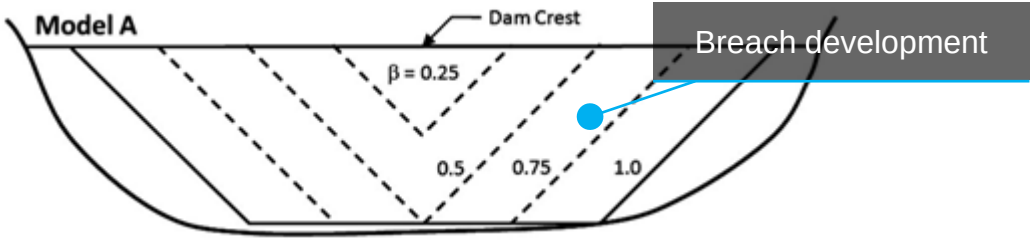
Simulations at this scale take long to run:



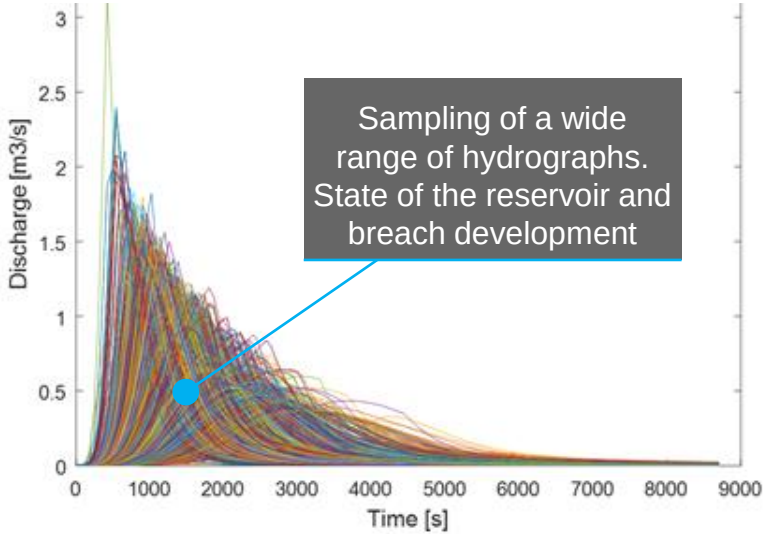
Darcourt, A. 2016. Numerical simulation of dam break flood wave propagation in the Rhone River. From dam breach formation to loss assessment. M.Sc. Thesis. School of Architecture, Civil, and Environmental Engineering, EPFL.

The dam-break wave

Generation and propagation downstream

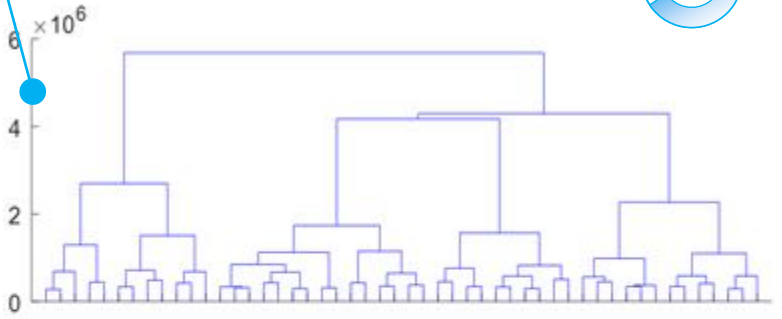


Breach development

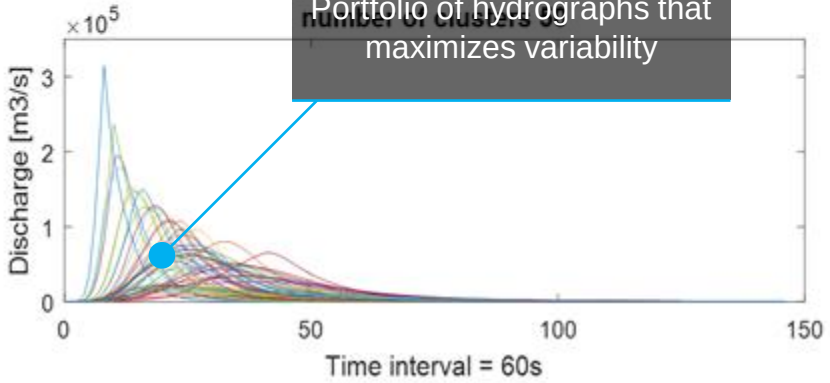


Sampling of a wide range of hydrographs. State of the reservoir and breach development

Amount of variability lost



Portfolio of hydrographs that maximizes variability



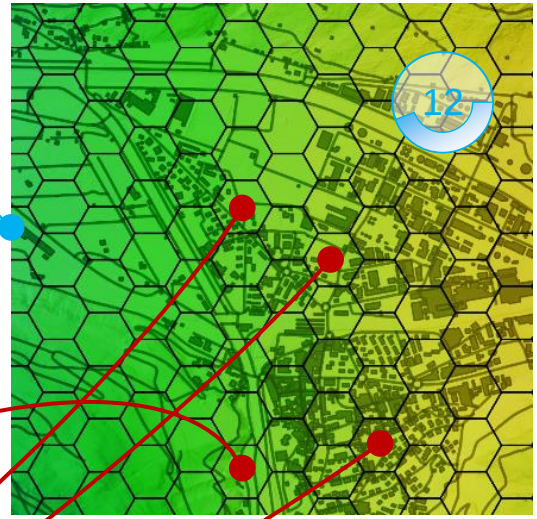
Froehlich, D. C. 2008. Embankment Dam Breach Parameters and Their Uncertainties. Journal of Hydraulic Engineering doi:10.1061/(ASCE)0733-9429(2008)134:12(1708).

The dam-break wave

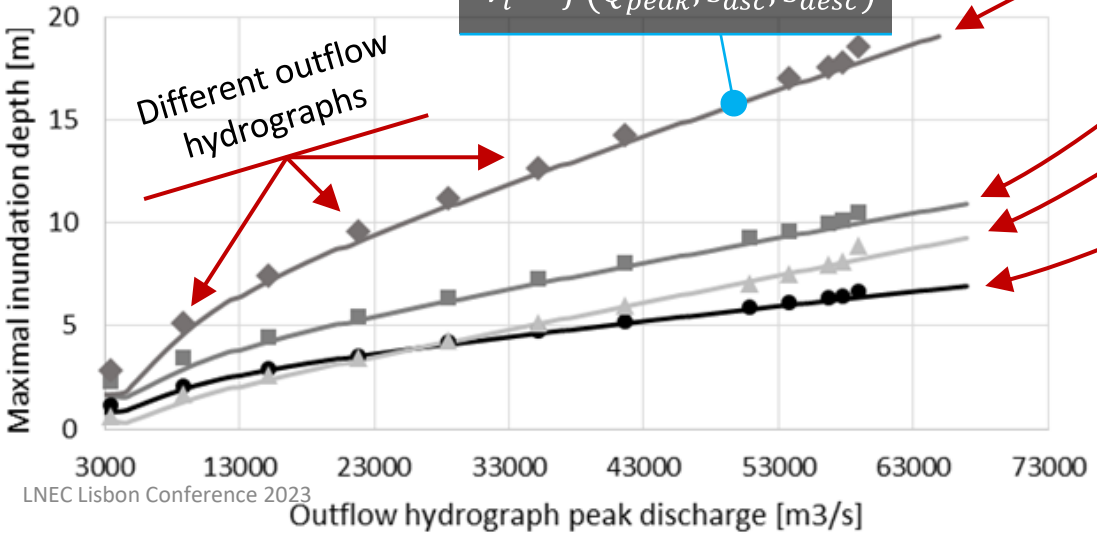
Generation and propagation downstream

- ML meta-modelling can be used:
  - To overcome the computational difficulties;
  - To incorporate epistemic and aleatoric uncertainty.

Location-wise interpolation



$$\nu_l = f(Q_{peak}, s_{asc}, s_{desc})$$



- Any "good" general-purpose regression model would do. Support-vector regression was chosen in this case.

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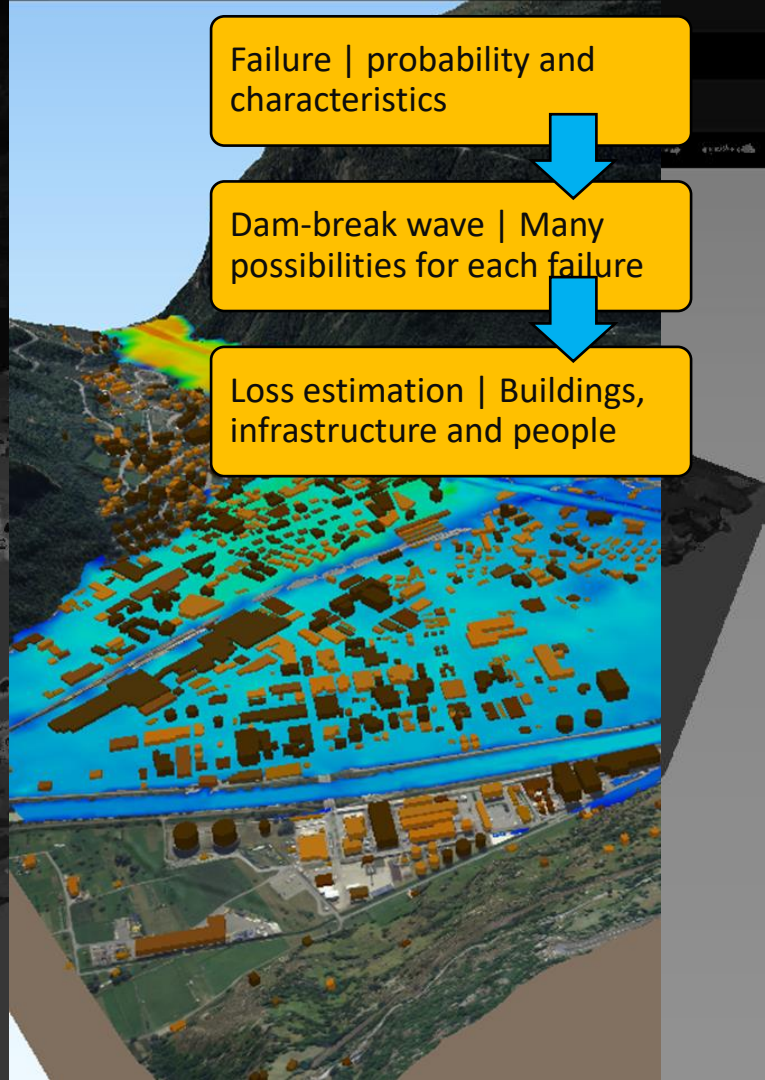
The losses

Loss estimation and results

Failure | probability and characteristics

Dam-break wave | Many possibilities for each failure

Loss estimation | Buildings, infrastructure and people



The losses

Loss estimation and results

- Tangible losses:
  - Computed for every dam-break wave using fragility curves.
  - Different building types and responses.

MATSim
Multi-Agent Transport Simulation

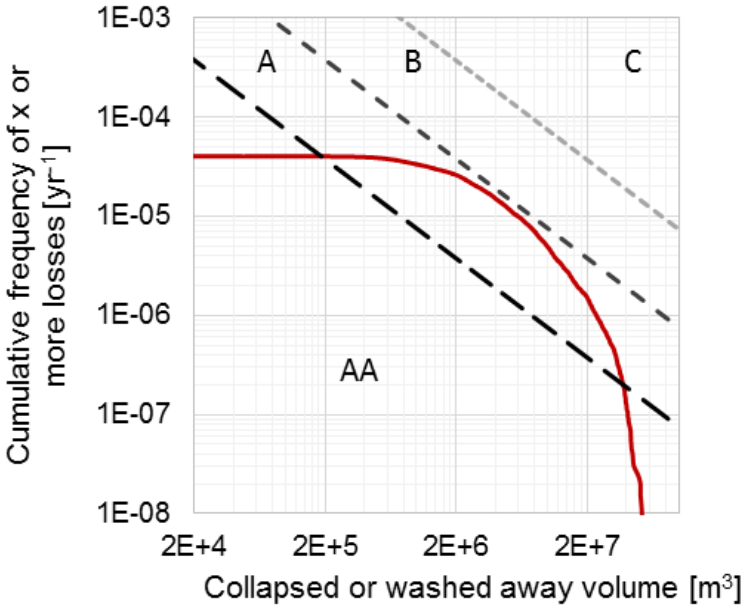
- Intangible losses:
  - Micro-simulation of the evacuation area.
  - The evacuation of individuals is simulated for every dam-break wave.

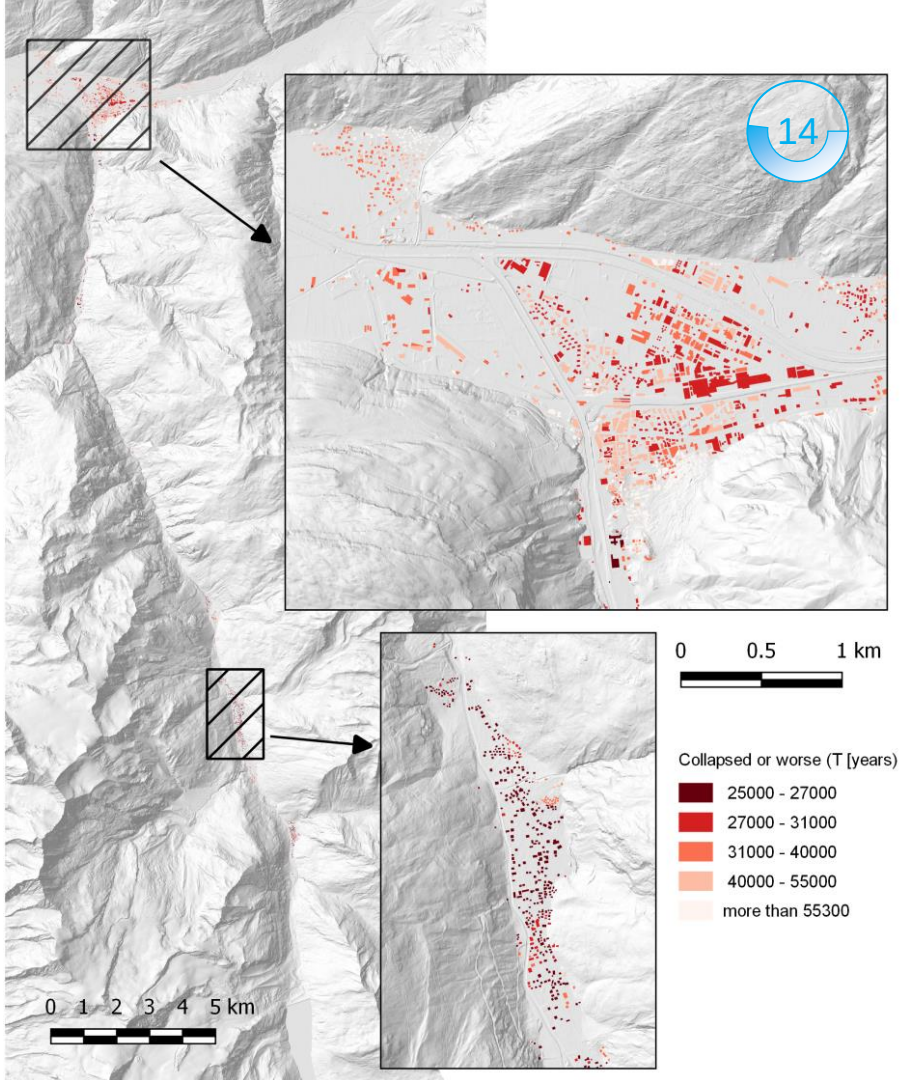
(For intangible losses see) Dia, A. D. 2017. Quantitative dam break flood risk mitigation assessment based on microsimulation techniques: an application to the Mattmark Dam in Switzerland. M.Sc. Thesis. School of Architecture, Civil, and Environmental Engineering, EPFL.

The losses

Loss estimation and results

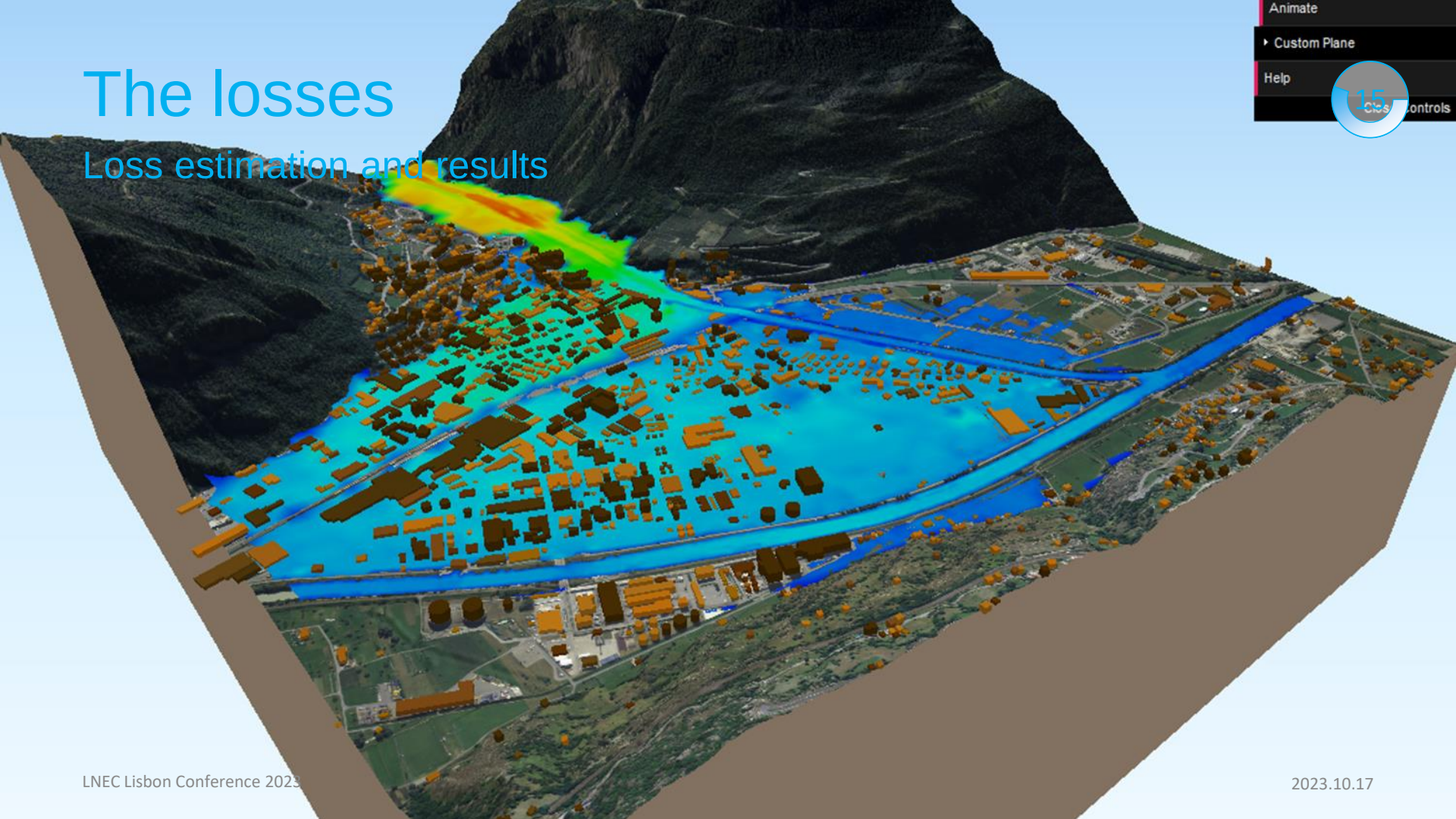
- A full depiction of the risk profile





The losses

Loss estimation and results



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Findings

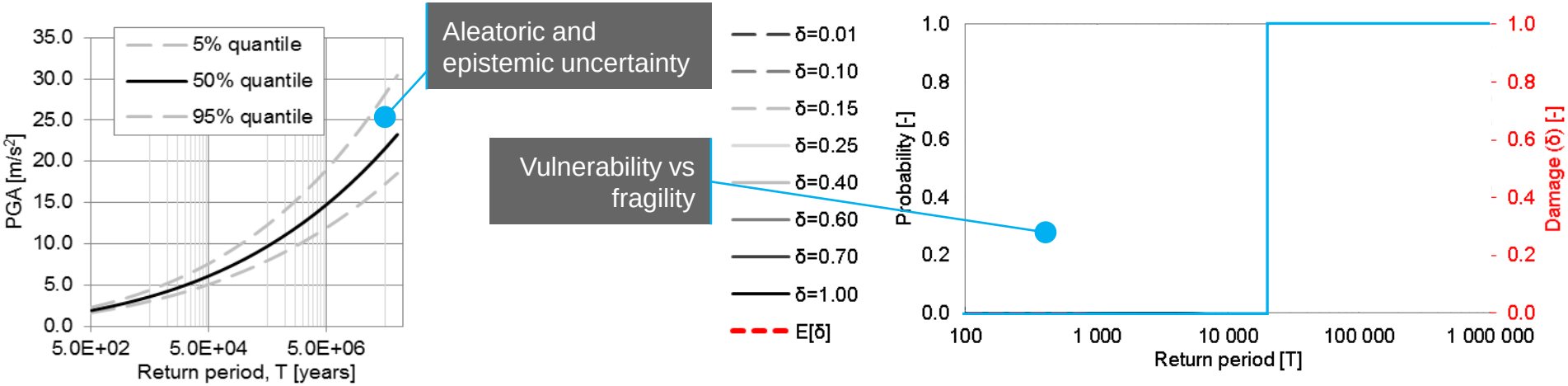
Back to the importance of uncertainty

Sebzor, Tajikistan

Findings

The importance of uncertainty

(R)	reference case	▪ Extreme probability distributions used to model hazard intensity ▪ Vulnerability is used to model element responses
(REu)	reference case plus epistemic uncertainty	▪ Lack of knowledge about the laws governing hazard intensity is included
(REuF)	reference case plus epistemic uncertainty and fragility	▪ Uncertainty is considered also in element responses



Findings

The importance of uncertainty

(R)	reference case	▪ Extreme probability distributions used to model hazard intensity ▪ Vulnerability is used to model element responses
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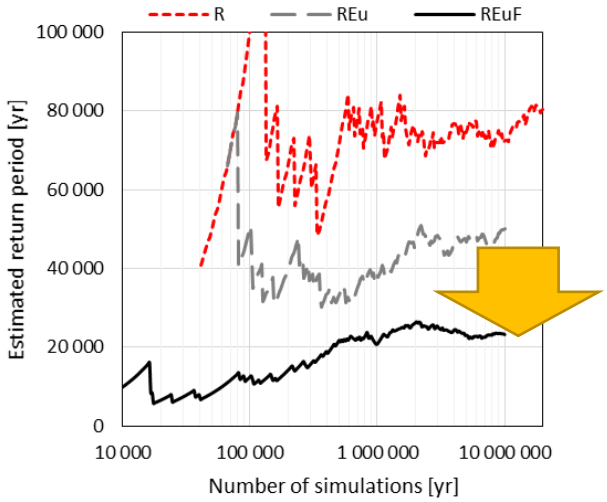
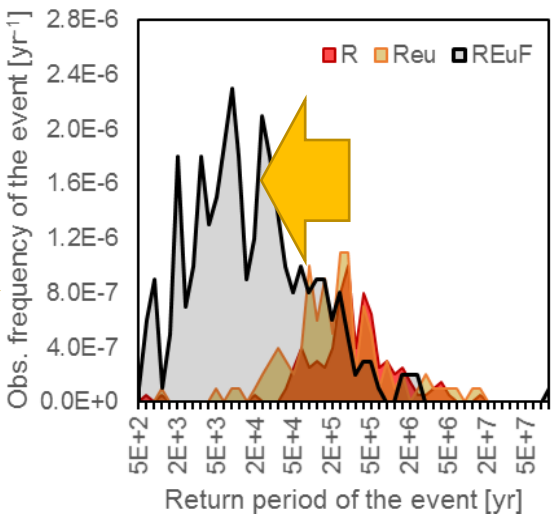




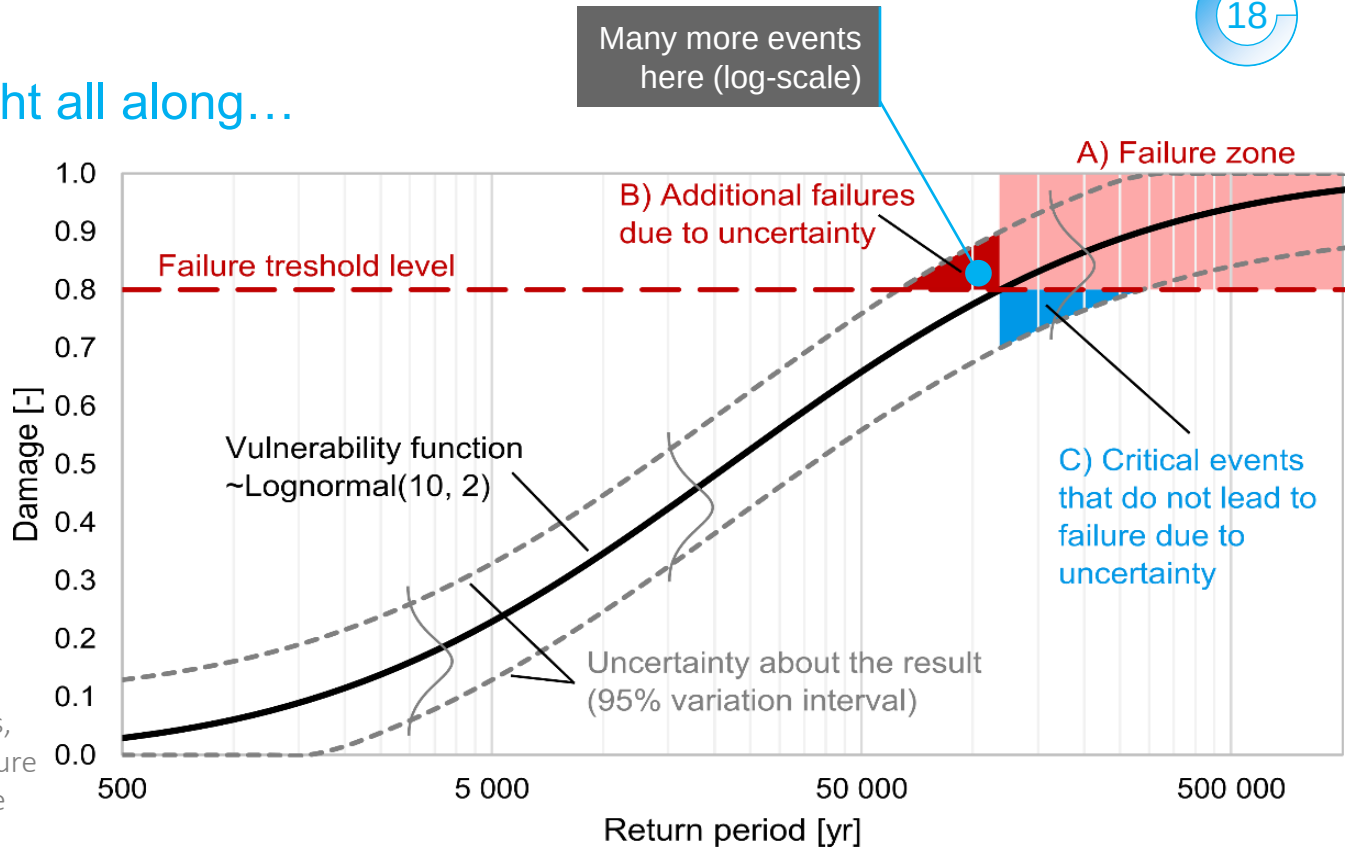
See Matos, J.P., Mignan, A. and Schleiss, A.J.: The role of uncertainty in dam failure frequency estimates: a conceptual case study. Proceedings of the 26th International Commission on Large Dams World Congress, Vienna, 2018.

Findings

Pessimists had it right all along…

Uncertainty does matter.

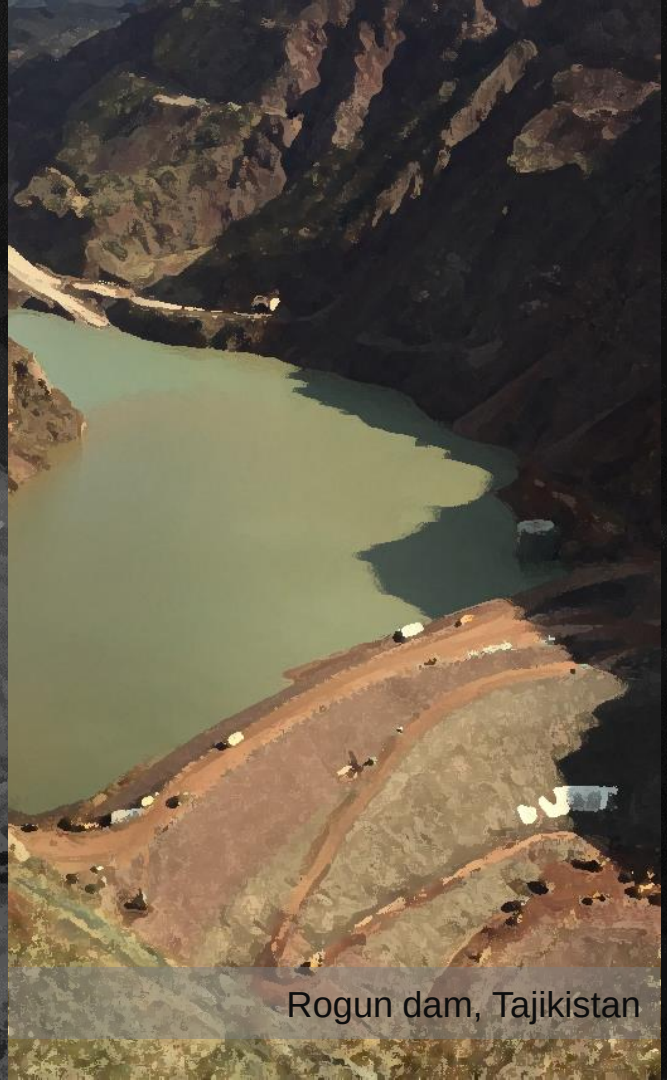
There are more chances of being unlucky than lucky



See Matos, J.P., Mignan, A. and Schleiss, A.J.: The role of uncertainty in dam failure frequency estimates: a conceptual case study. Proceedings of the 26th International Commission on Large Dams World Congress, Vienna, 2018.

Epilogue

Some considerations for the round table discussion

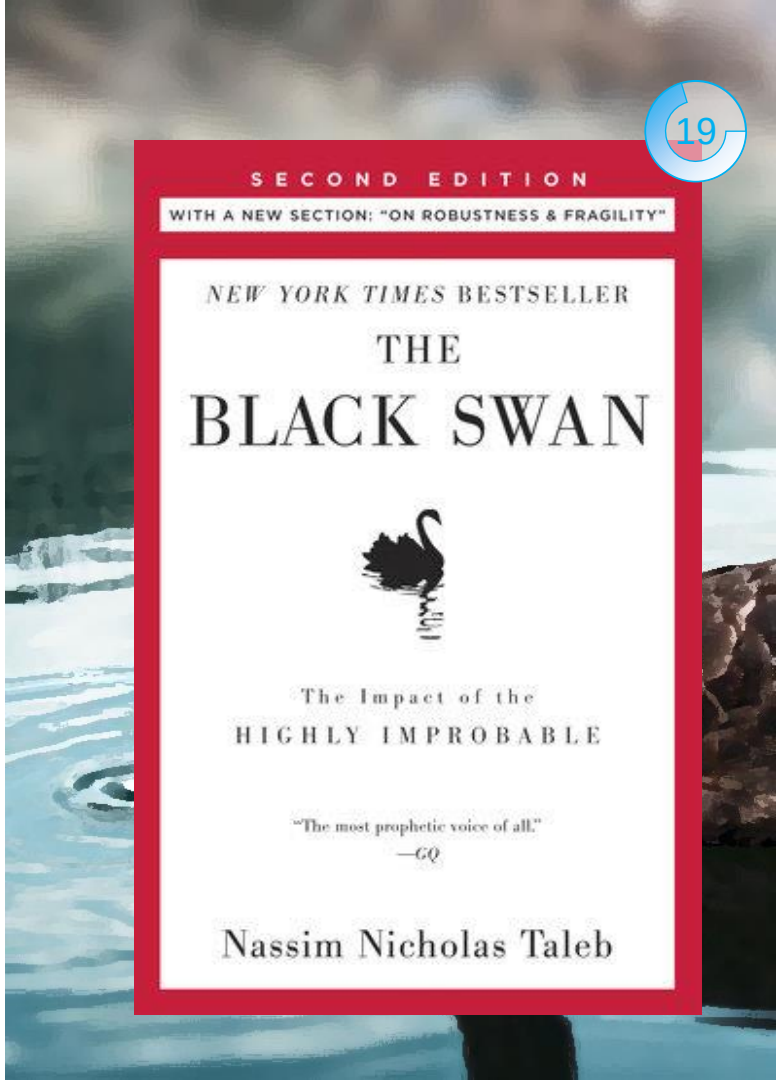


Rogun dam, Tajikistan

Handling risk is not easy

The illusion of total control is dangerous

- Black Swans
  - an event that comes as a surprise, has a major effect, and is often inappropriately rationalized after the fact with the benefit of hindsight.
- Some events cannot be predicted…



Handling risk is not easy

Risk is part of life

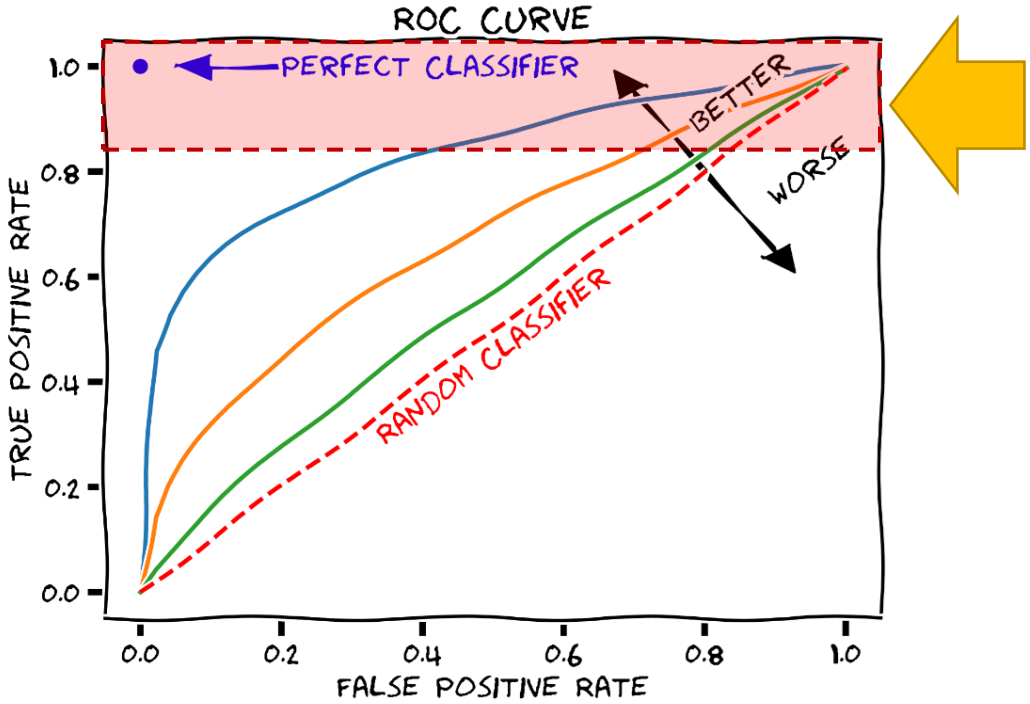
- 412 nuclear reactors in the world.
  - If they were designed for 10’000-year events, what would the average time between failures be?
- Large dams… more than 57’000!
- Designing for PMF and MCE are very good ideas.

Handling risk is not easy

No such thing as a free lunch

- Safety has very significant costs.
- The ROC curve as a decision framework.
- Difficult decisions should be taken before they are needed.

A flood is expected and it comes



A flood is expected and no flood comes.

Handling risk is not easy

Considerations about the 2021 floods in Belgium

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Europe's deadly floods leave scientists stunned

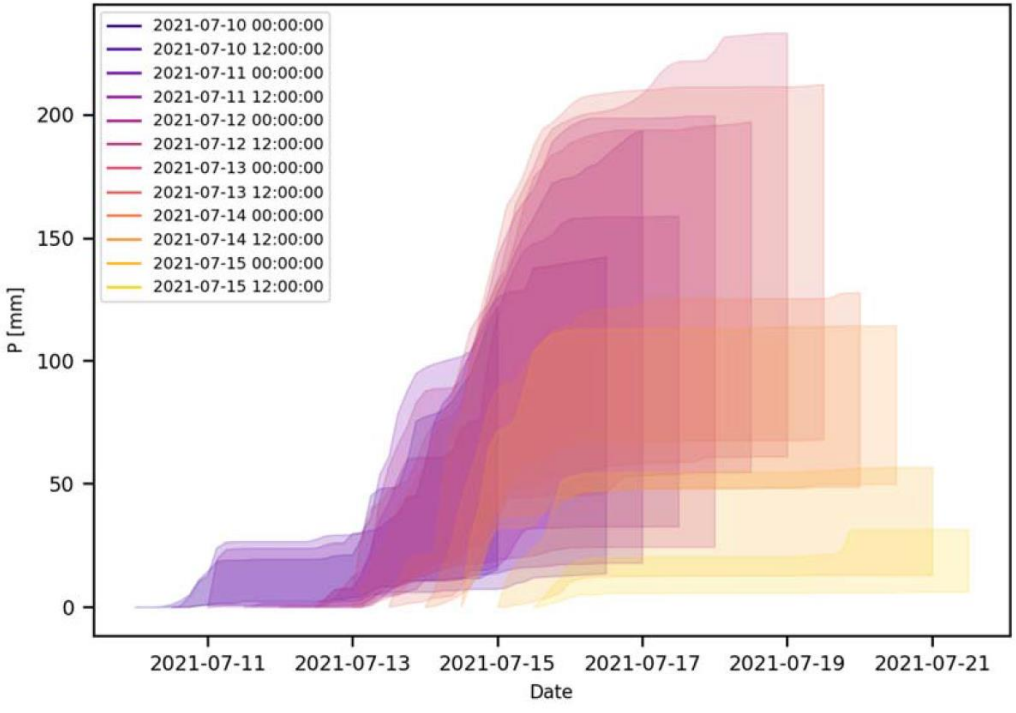
Despite improvements, flood forecasting sometimes fails to flag risks along smaller streams

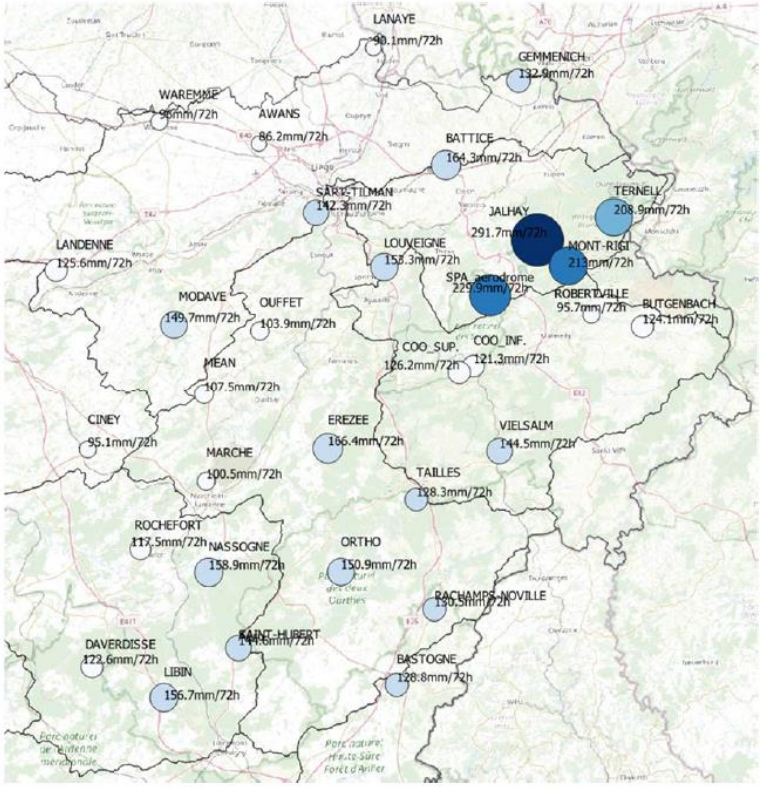
20 JUL 2021 • BY WARREN CORNWALL

SHARE:

Handling risk is not easy

Considerations about the 2021 floods in Belgium





Handling risk is not easy

Considerations about the 2021 floods in Belgium

The bottom outlet had to operate in the worst moment

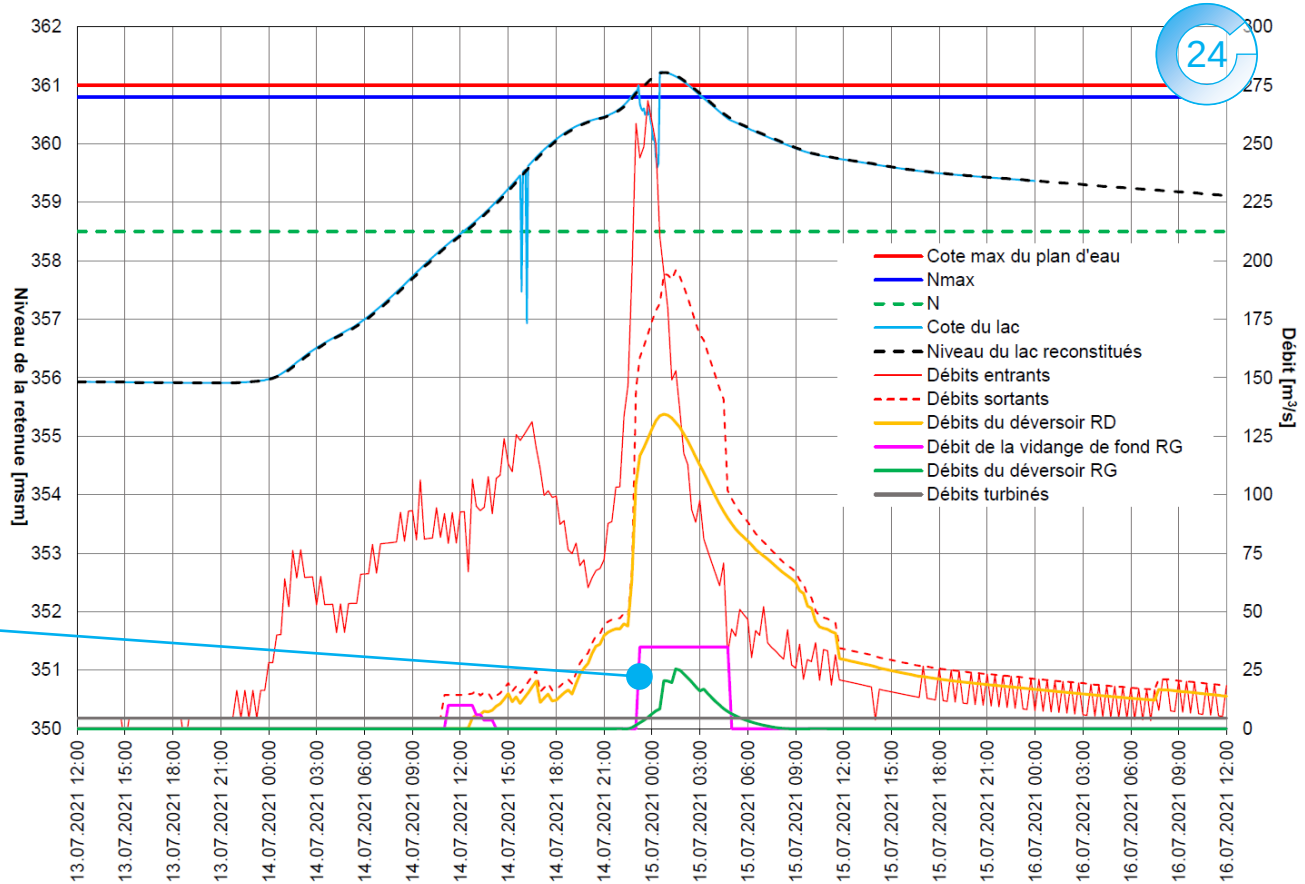


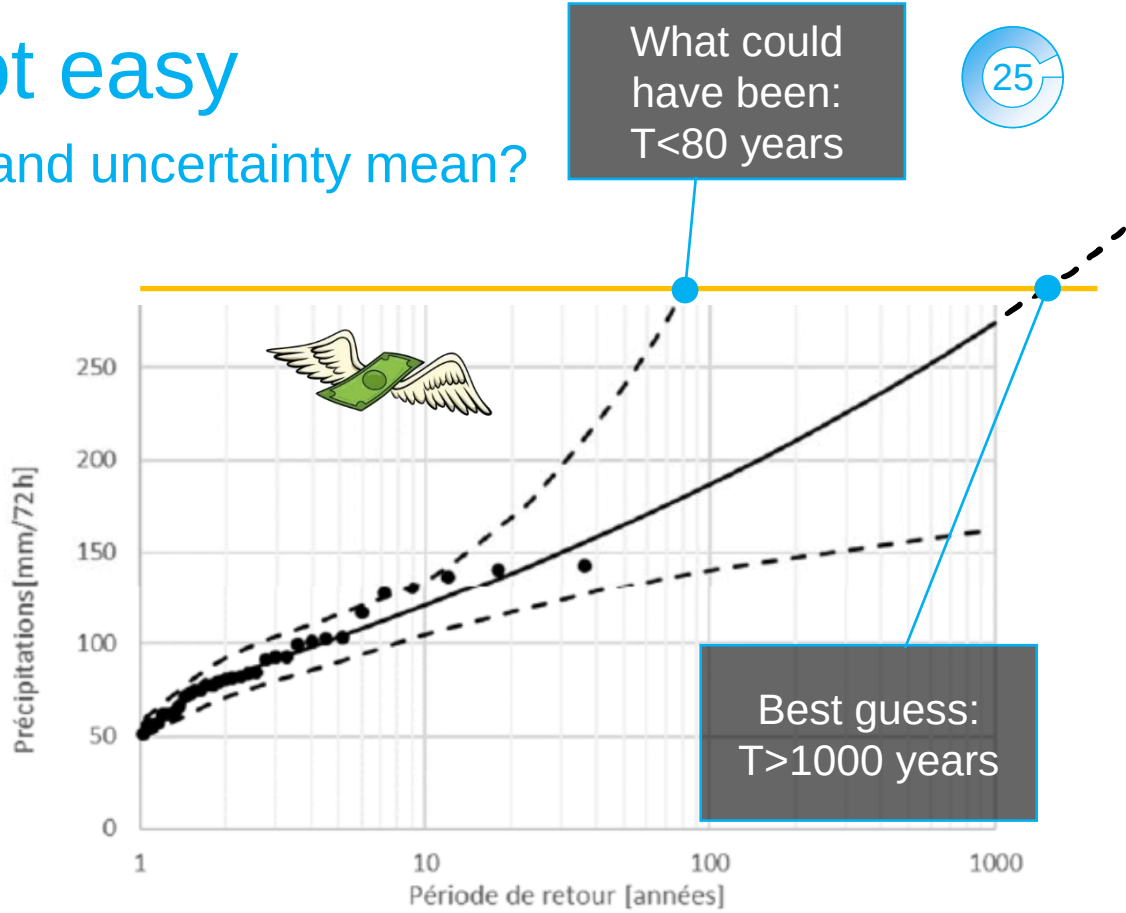
Figure 5-51 : Evolution du niveau du lac mesuré au barrage d'Eupen, des débits entrants reconstitués et des débits sortants calculés lors de la crue du 14 juillet 2021

Handling risk is not easy

Have we forgotten what risk and uncertainty mean?

- Climate change is a tremendous challenge. Often, quite convenient too.

- Uncertainty means: we do not know.
- It may be a good idea to overdesign.



Handling risk is not easy

It takes courage to act

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Libya floods: The flawe that increased Derna d

10 October

Libya floods

Flooding in Derna devastated residential areas, killing thousands

Dr Abdulwanis Ashour, a hydrologist and lecturer at Omar Al-Mukhtar University, told the BBC he had collected data on the condition of the Derna dams for a study published last year, which showed they were not prepared to withstand a storm like Daniel.

He said he had spent years studying the Derna dams and had discovered the presence of numerous cracks and fissures. In his research, he asserted that they would not be able to handle a large amount of rainfall and were at risk of collapse.

Biden backs Israel's account of Gaza hospital explosion
1 hour ago

What video, pictures and other evidence tell us about Gaza hospital blast
2 hours ago

Features

'Grab the children and leave': BBC reporter flees Israel bomb warning

Handling risk is not easy

It takes courage to act …and someone to listen

- On how decisions are made.
  - Roger Boisjoly and the o-rings that led to the disaster of the Challenger Space Shuttle (1986).
  - Low-probability high-consequence events are not easy to address.
  - Professionalism vs. personal interest (its not about corruption).

https://commons.wikimedia.org/wiki/File:Challenger_explosion.jpg

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2023

Thank you!

jose.matos@tecnico.ulisboa.pt

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