Risk-based Procedure for Design and Verification of Dam Safety

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4th International Symposium on Flood Defence
May 6-8, 2008 in Toronto, Ontario, Canada

Risk management of extreme flood events

Introduction

Concept

Study areas

Modules

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Overview

- Introduction (RIMAX and Objectives)
- Proposed Concept
    - Types of considered failure
    - Comprehensive procedure
- Study Areas
- Modules of RIBADD (M1 – M6)
- Conclusion

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RIMAX

- Project is part of the program on

  "Risk Management of Extreme Flood Events (RIMAX)"

- Aim of RIMAX:
  - To develop and implement improved instruments of flood risk management
  - Extreme flood events in river basins with a return period of more than a 100 years and a highly destructive potential

funded by
Bundesministerium für Bildung und Forschung

project management organisation
Projektträger Jülich Forschungszentrum Jülich GmbH
Projektträger Forschungszentrum Karlsruhe (PTKA)

rimax Risk management of extreme flood events

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Objectives

- Development of a risk-based procedure for design of a dam and verification of dam safety
- Combining traditional with risk-based components
- Scientifically validated and practicable
- Application to several case studies
- Support further developments of design standards
- Integration into a Flood Risk Management

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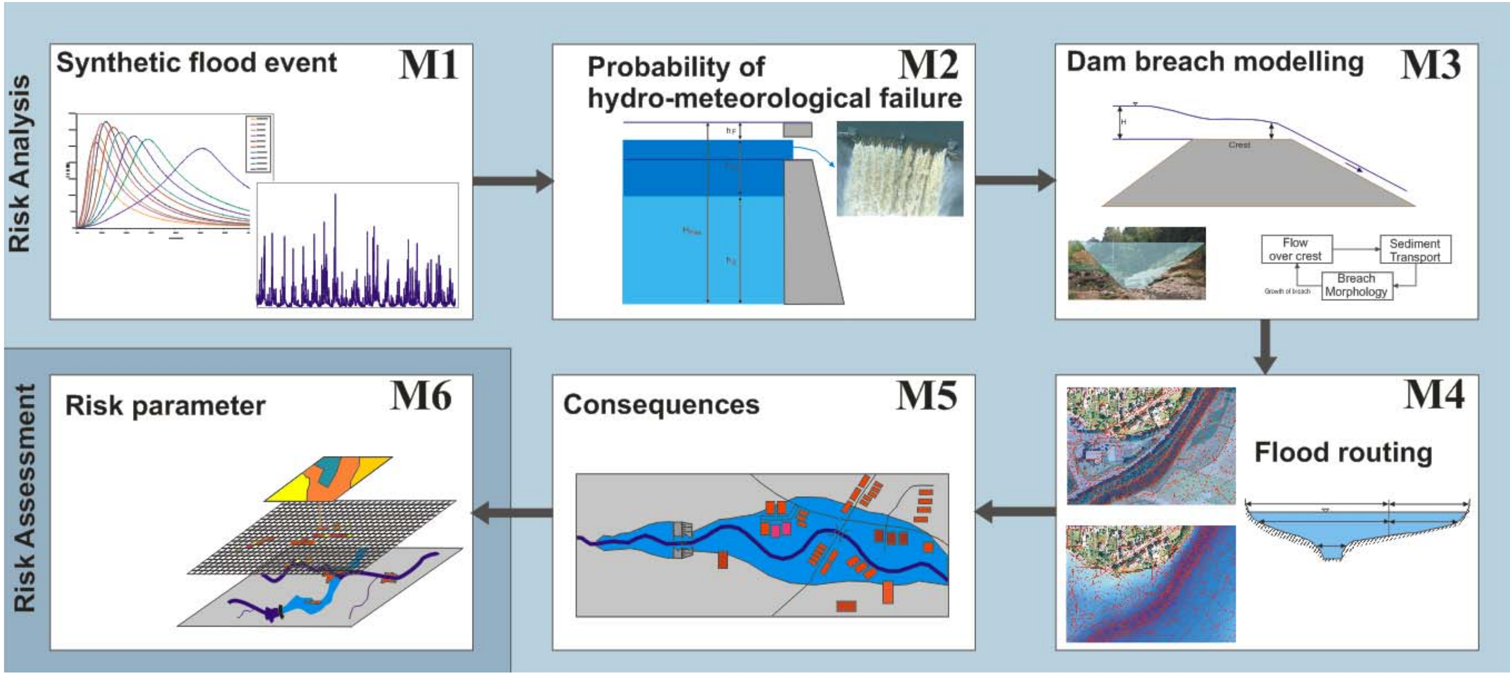
Failure Types (caused by flood loads) and corresponding probabilities of failure P_F

- Large spillway discharges → $P_{F,A}$
- Overtopping without dam breaching → $P_{F,B}$
- Overtopping with dam breaching → $P_{F,C}$
- $P_{F,A} > P_{F,B} > P_{F,C}$


Failure type A: Spillway damages in Saxony (2002)

RIBADD (Risk-Based Design of Dams)

- Estimation of Failure Probabilities (M1, M2)
- Potential Dam Breaching (M3)
- Flood Wave Modelling (M4)
- Damage analysis (M5) and Risk Assessment (M6)



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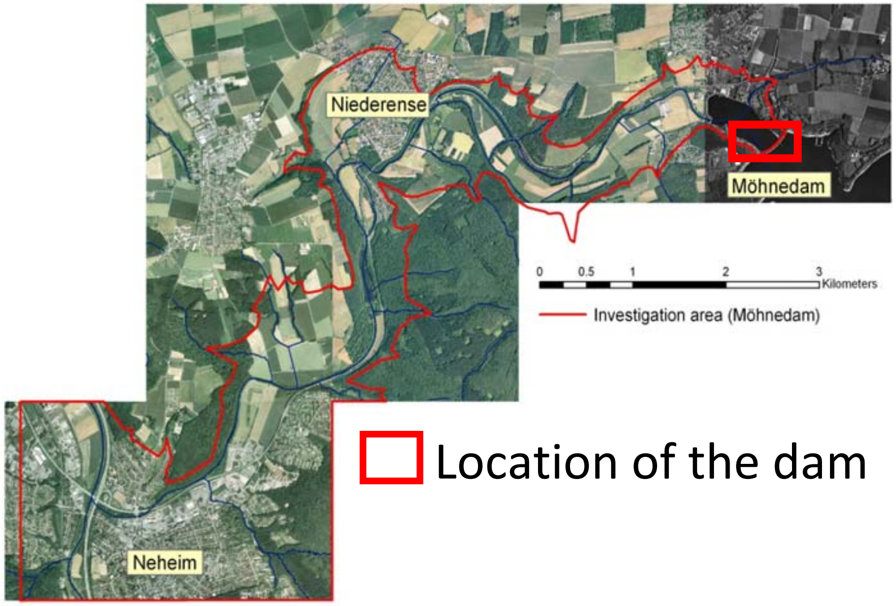
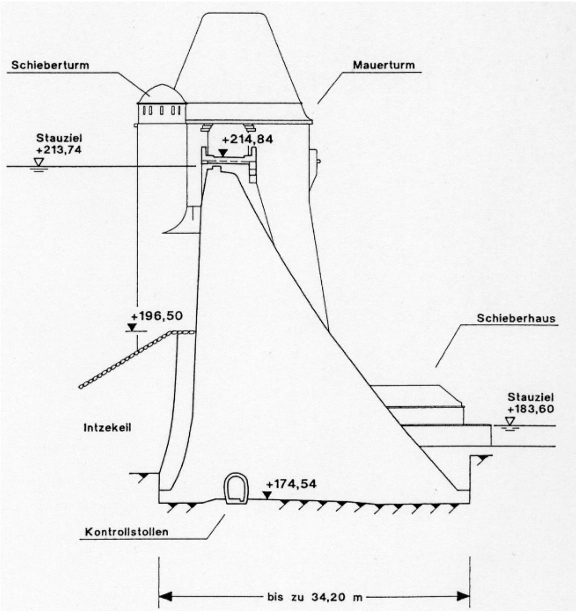
Study area 1: Möhne Dam





Cross-section view

- arch-gravity dam
- catchment area: 436 km²
- height: 40.3 m; crest length: 650 m
- capacity 134.5 hm³

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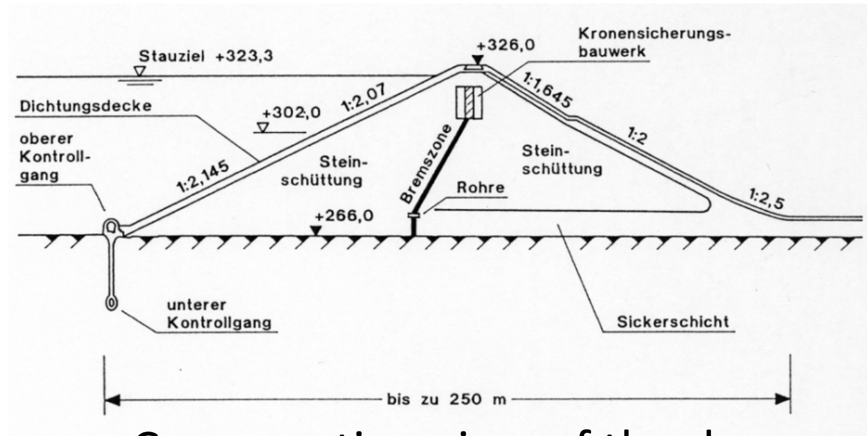
Study area 2: Henne Dam

Location of the dam



Cross-section view of the dam

- rockfill dam
- catchment area: 98 km²
- height: 59 m; crest length: 376 m
- capacity 38.4 hm³

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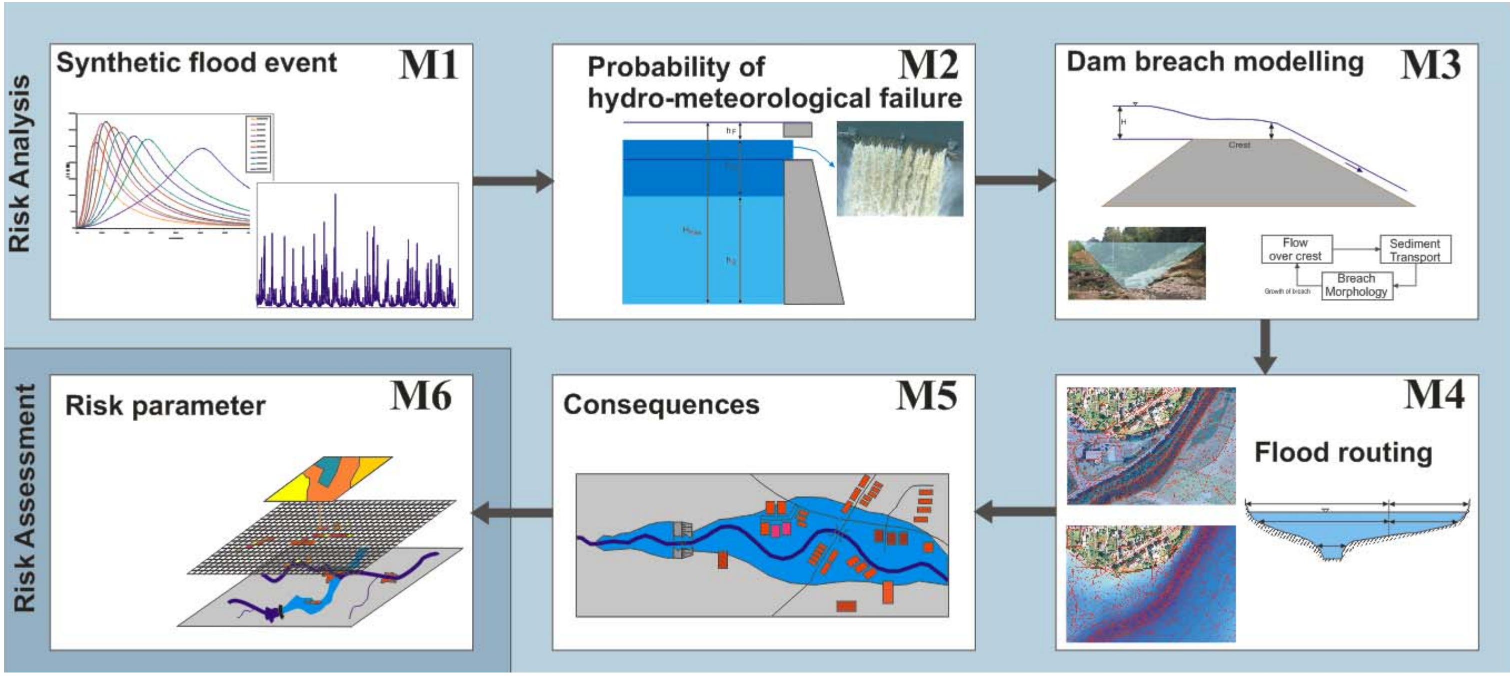
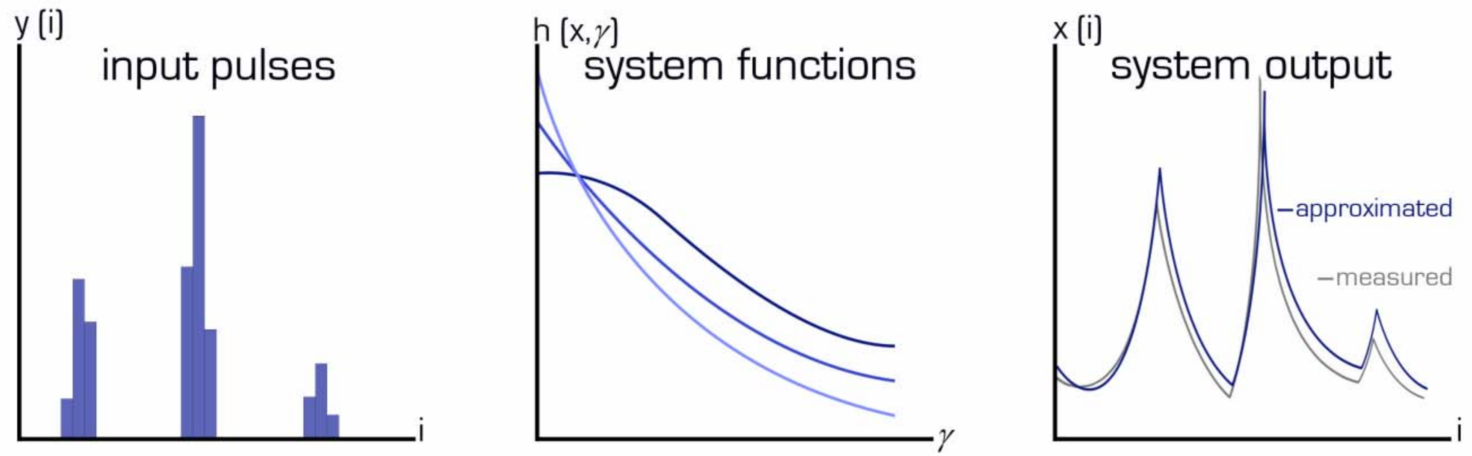


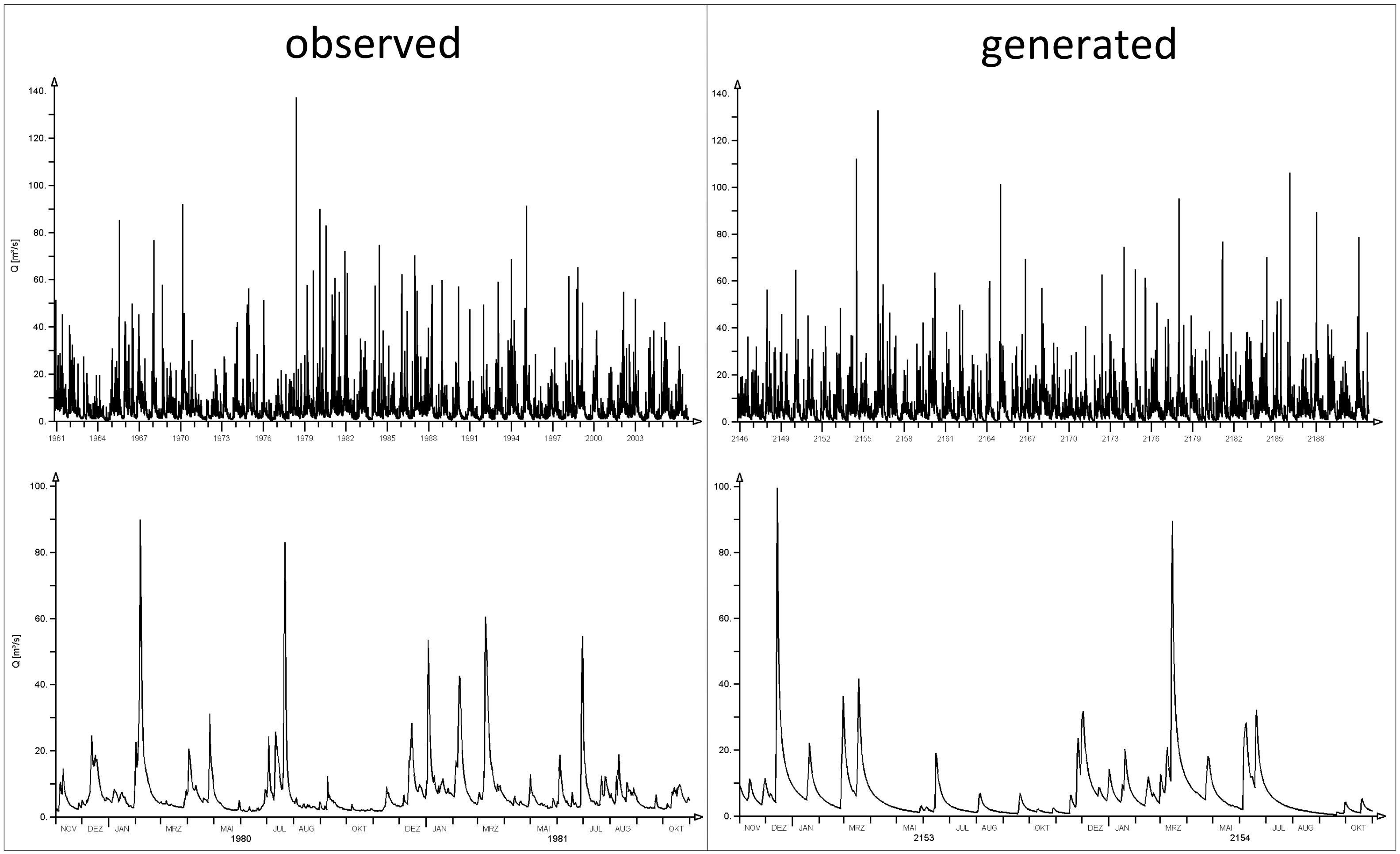
M1: Synthetic Flood Event

- Usage of a stochastic model
- Calibrated for two study areas
- Observed daily flows (46 years) were used
- Artificial series of reservoir inflow



M1: Synthetic Flood Event

- Reservoir inflows at the Möhne Dam



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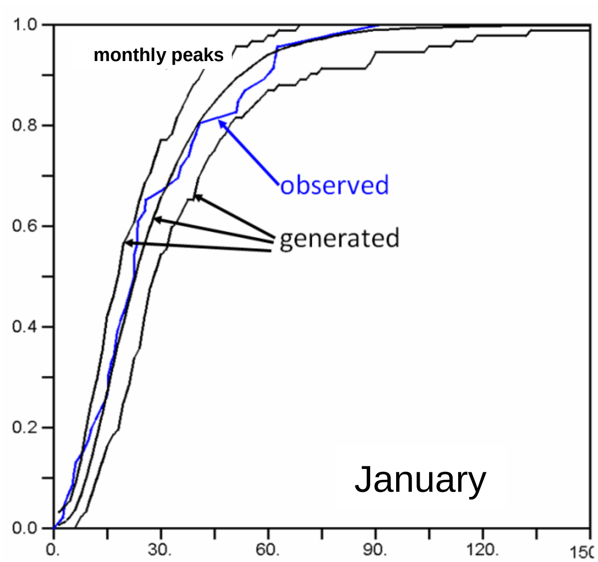
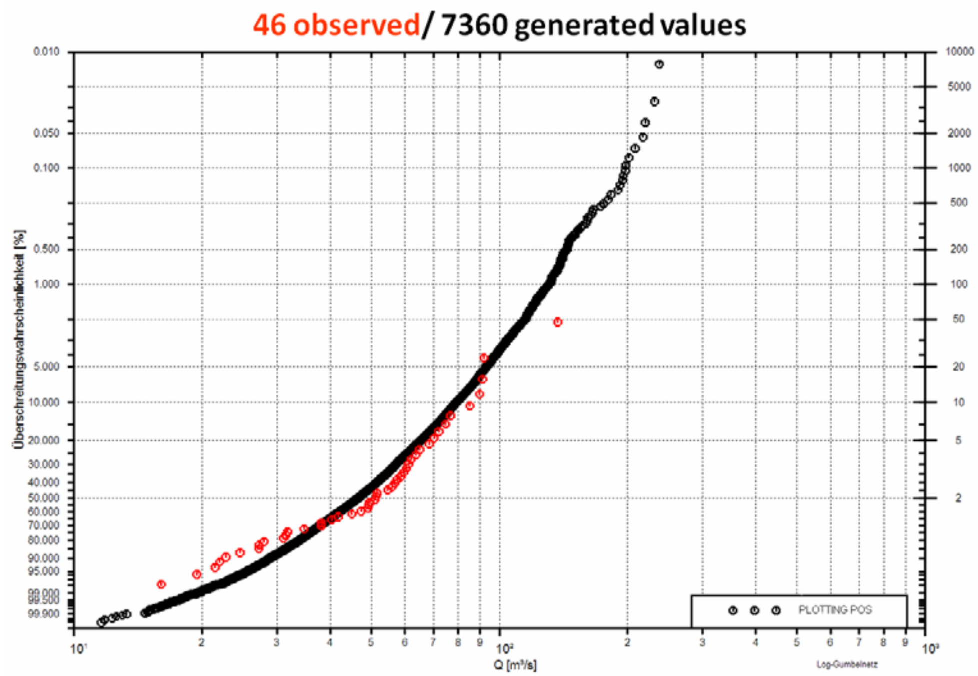
M1: Synthetic Flood Event

- Reservoir inflows at the Möhne Dam
- Validation of Model Performance



frequency distribution
of monthly peaks



frequency distribution
of annual peaks

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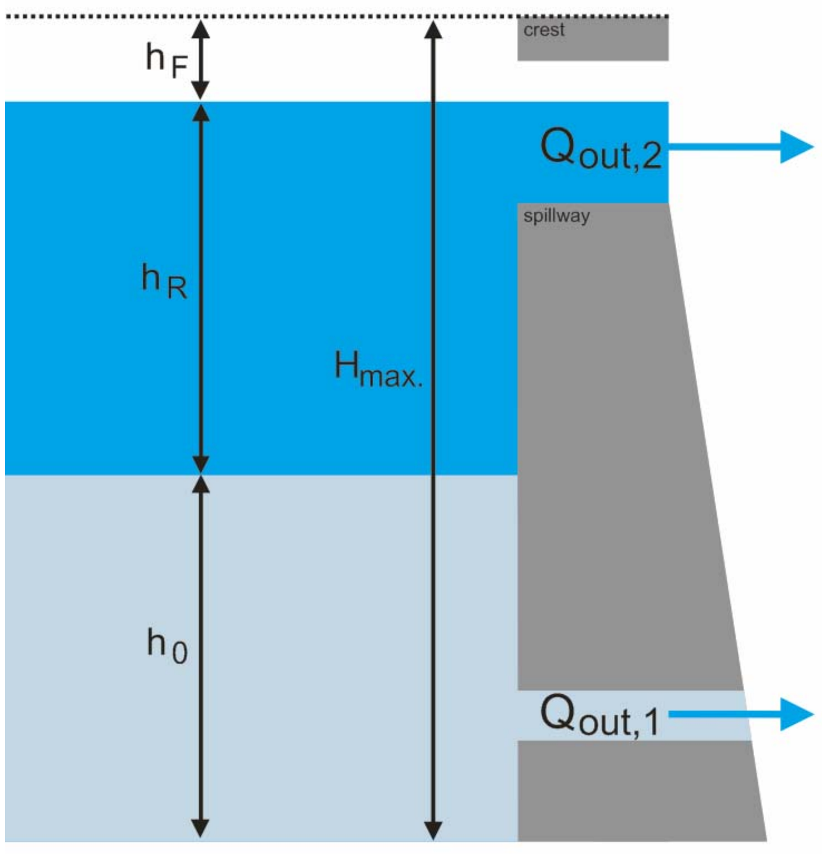
M2: Probability of hydro-meteorological failure

$$P_F = P(h_0 + h_R + h_f > b)$$
$$= \iiint f_{h_0}(h_0) \cdot d_{h_0} \cdot f_{h_R}(h_R) \cdot d_{h_R} \cdot f_{h_F}(h_F) \cdot d_{h_F}$$



Risk management of extreme flood events

M2: Probability of hydro-meteorological failure

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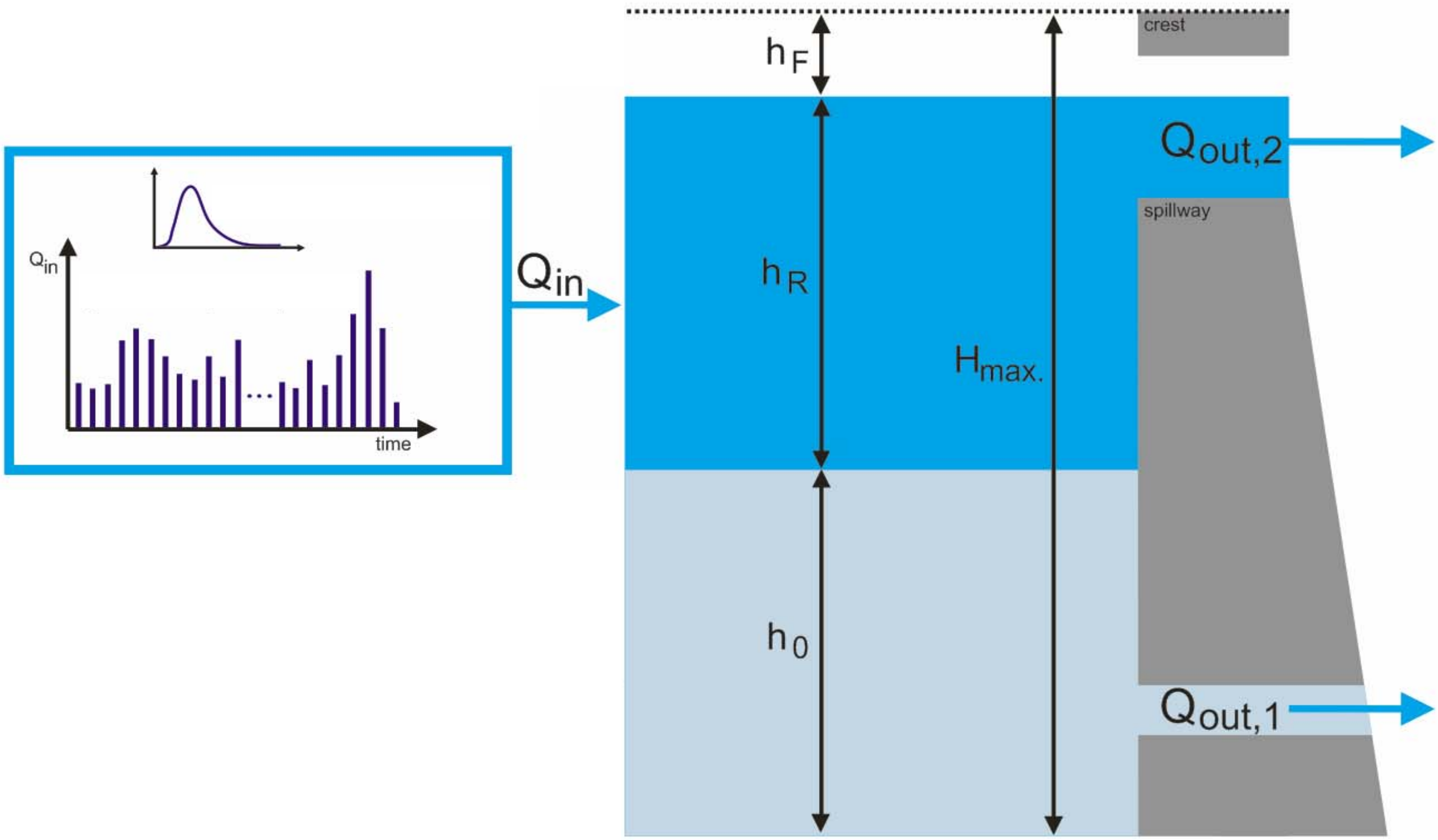

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M2: Probability of hydro-meteorological failure

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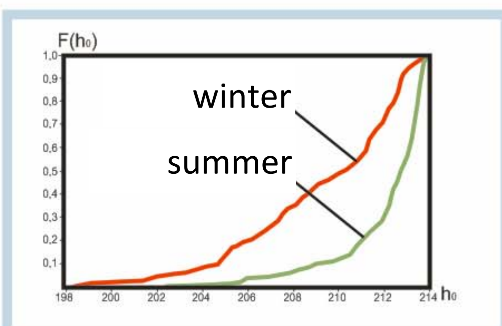
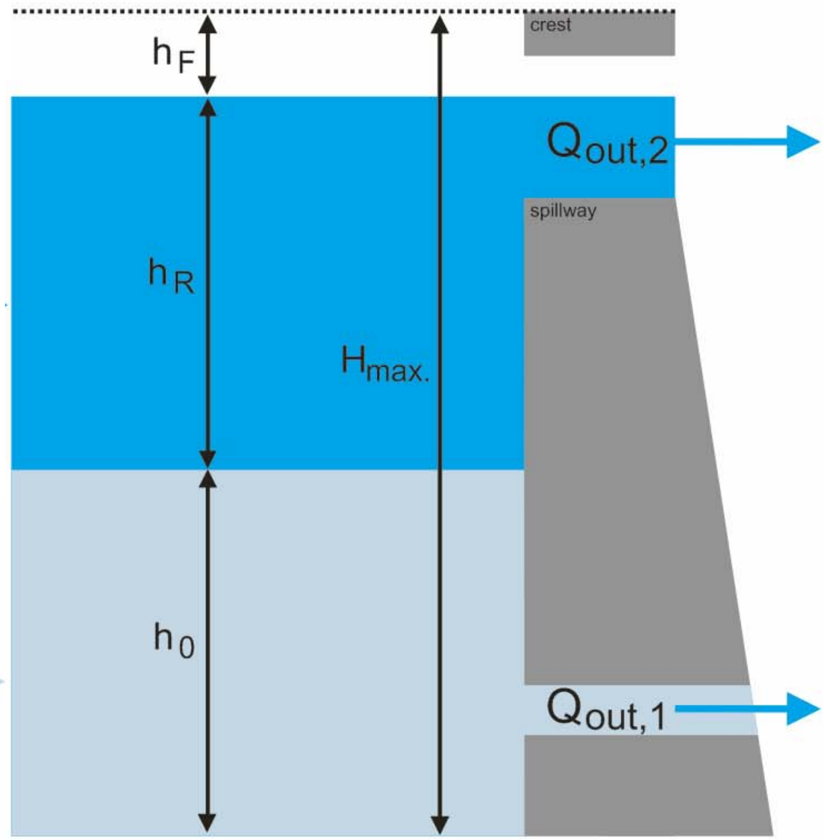
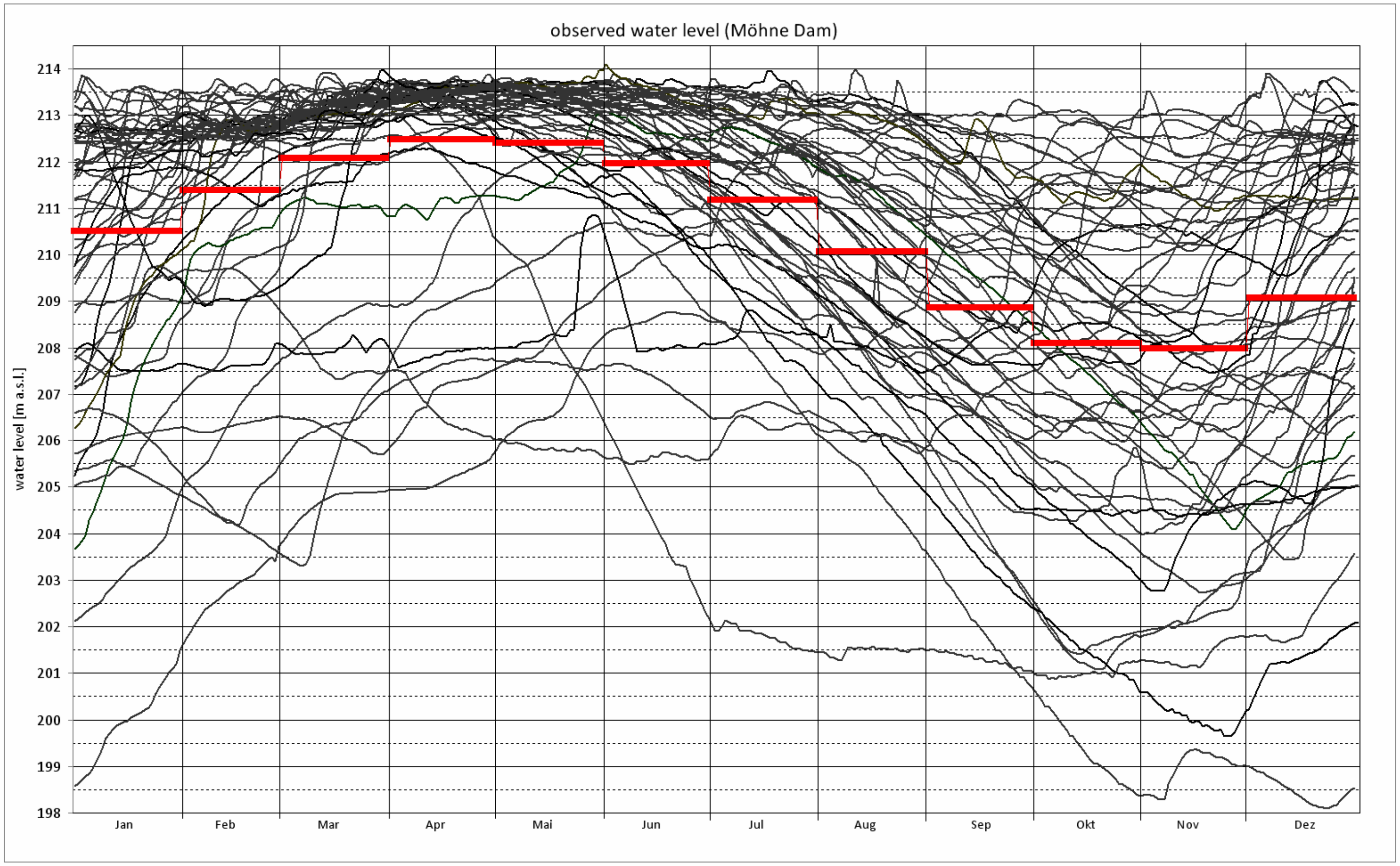


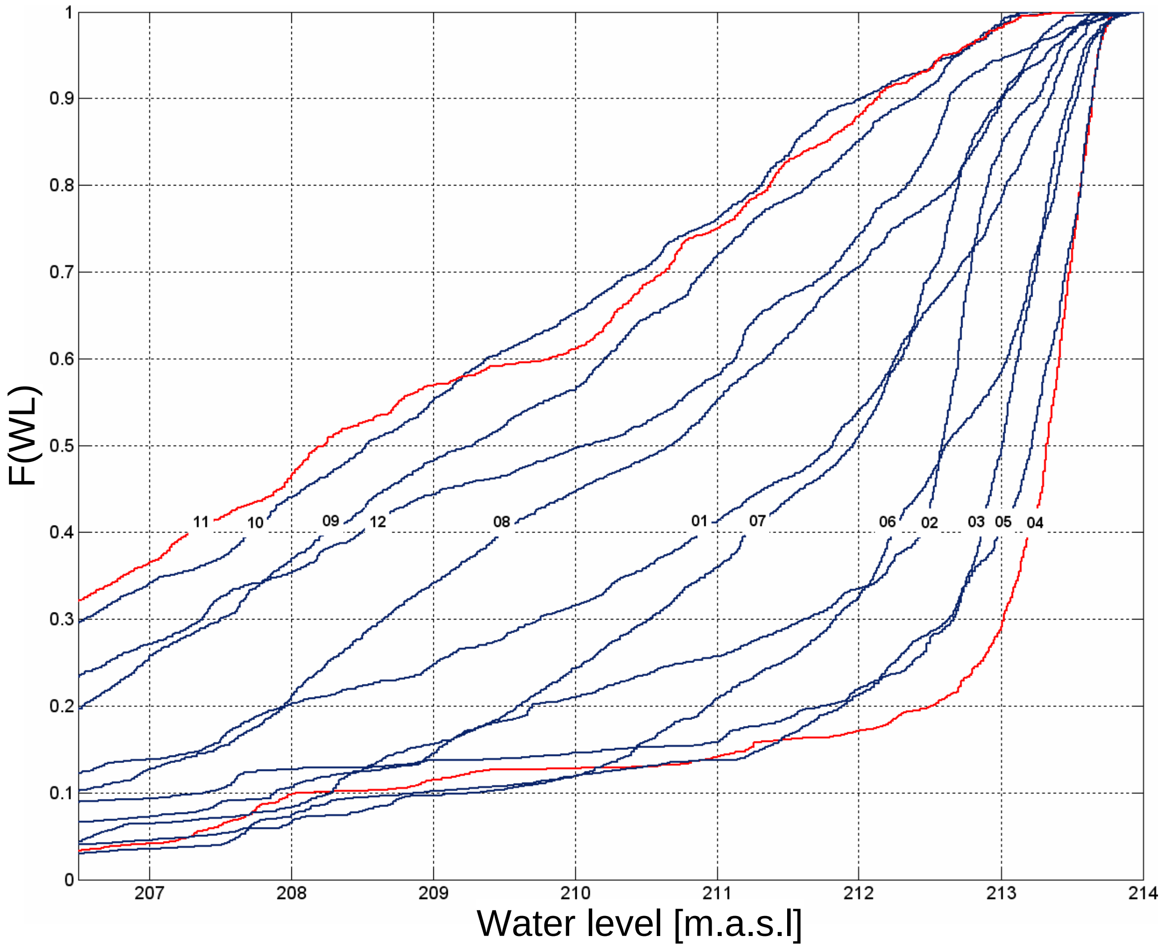


M2: Probability of hydro-meteorological failure



Historical data of measured daily water levels

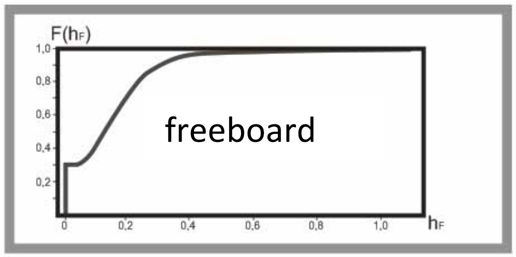
M2: Probability of hydro-meteorological failure

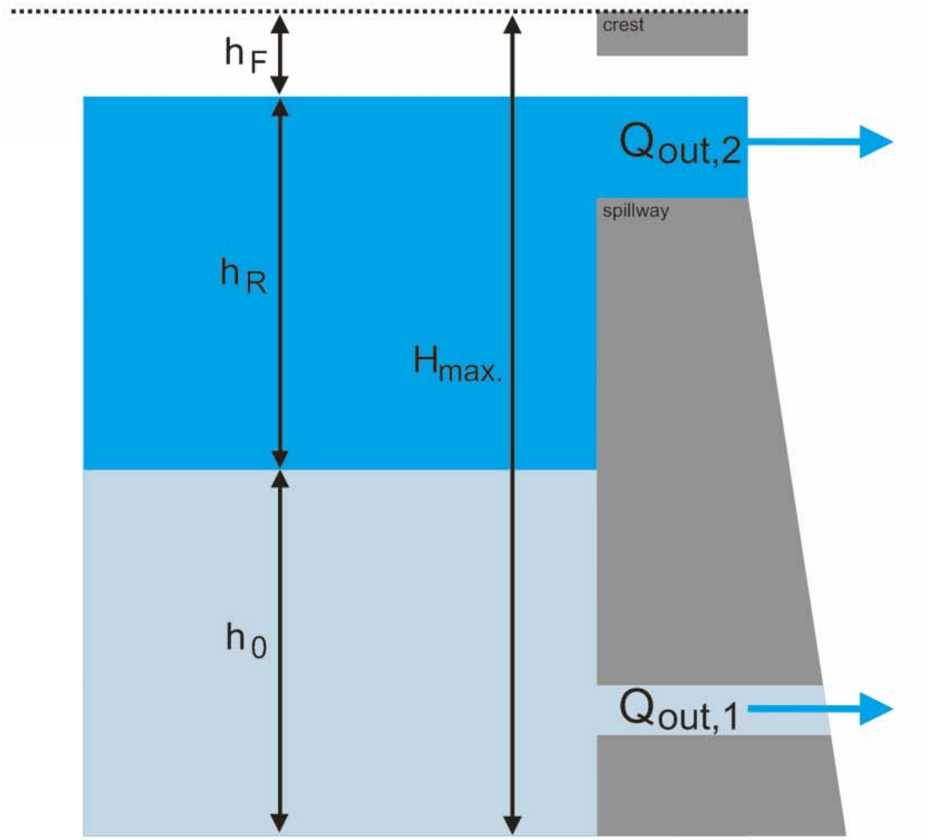


Empirical cumulative density functions for every month

M2: Probability of hydro-meteorological failure

$$P_F = P(h_0 + h_R + \boxed{h_f} > b)$$
$$= \iiint f_{h_0}(h_0)\cdot d_{h_0} \cdot f_{h_R}(h_R)\cdot d_{h_R} \cdot \boxed{f_{h_F}(h_F)\cdot d_{h_F}}$$





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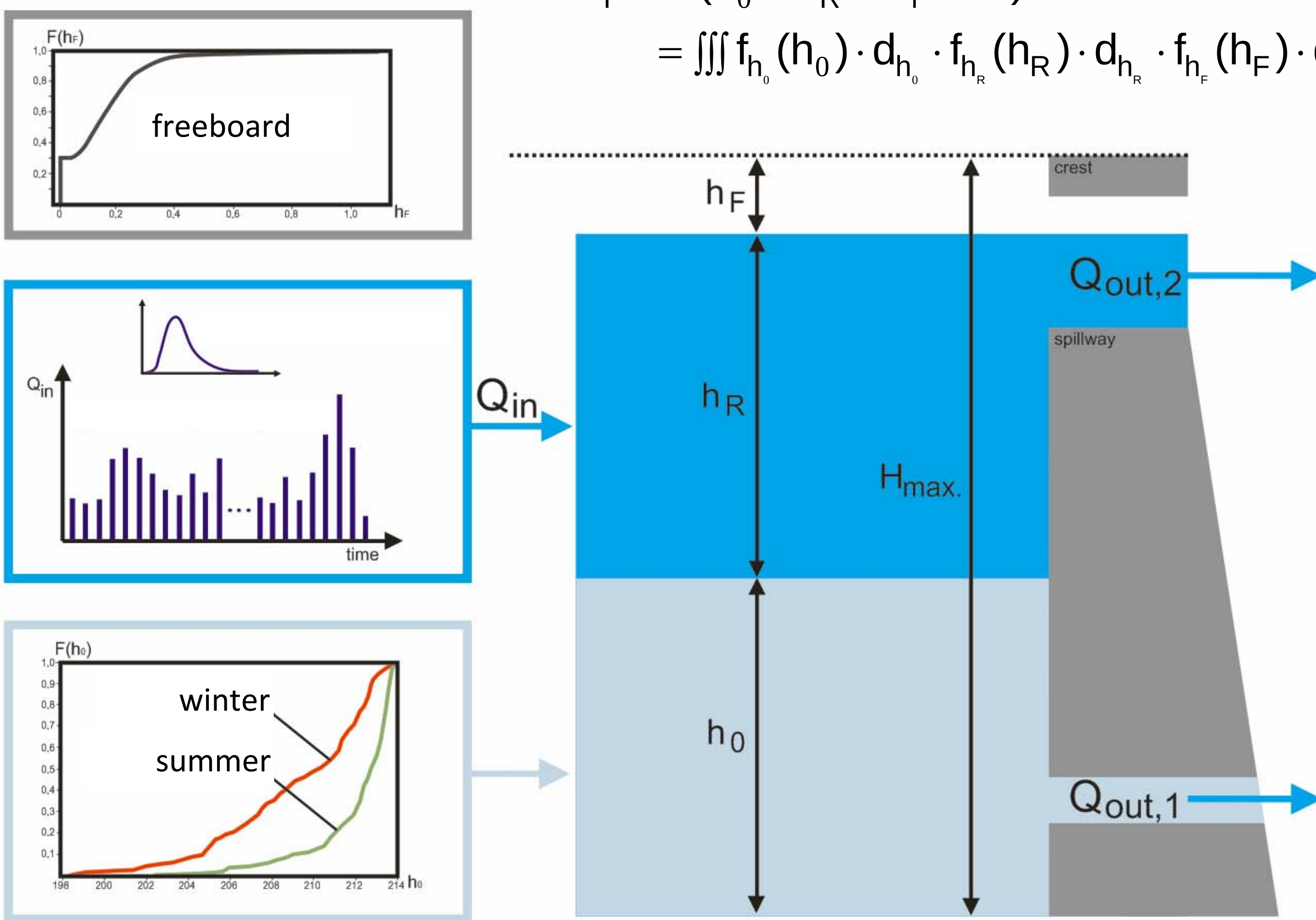
M2: Probability of hydro-meteorological failure

$$P_F = P(h_0 + h_R + h_f > b) = \iiint f_{h_0}(h_0)\cdot d_{h_0} \cdot f_{h_R}(h_R)\cdot d_{h_R} \cdot f_{h_F}(h_F)\cdot d_{h_F}$$



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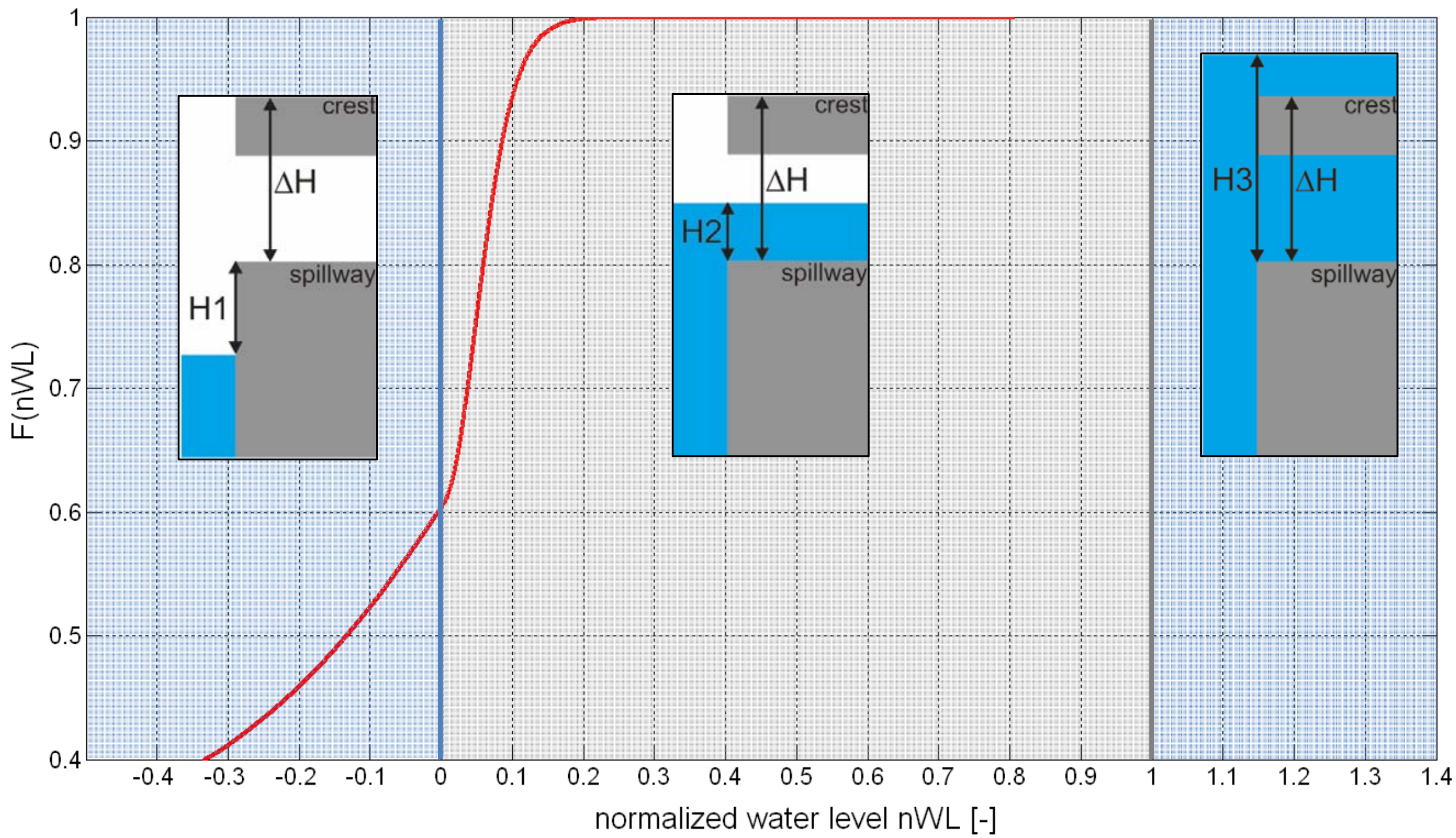
M2: Probability of hydro-meteorological failure

- Results of a scenario with different operating rules



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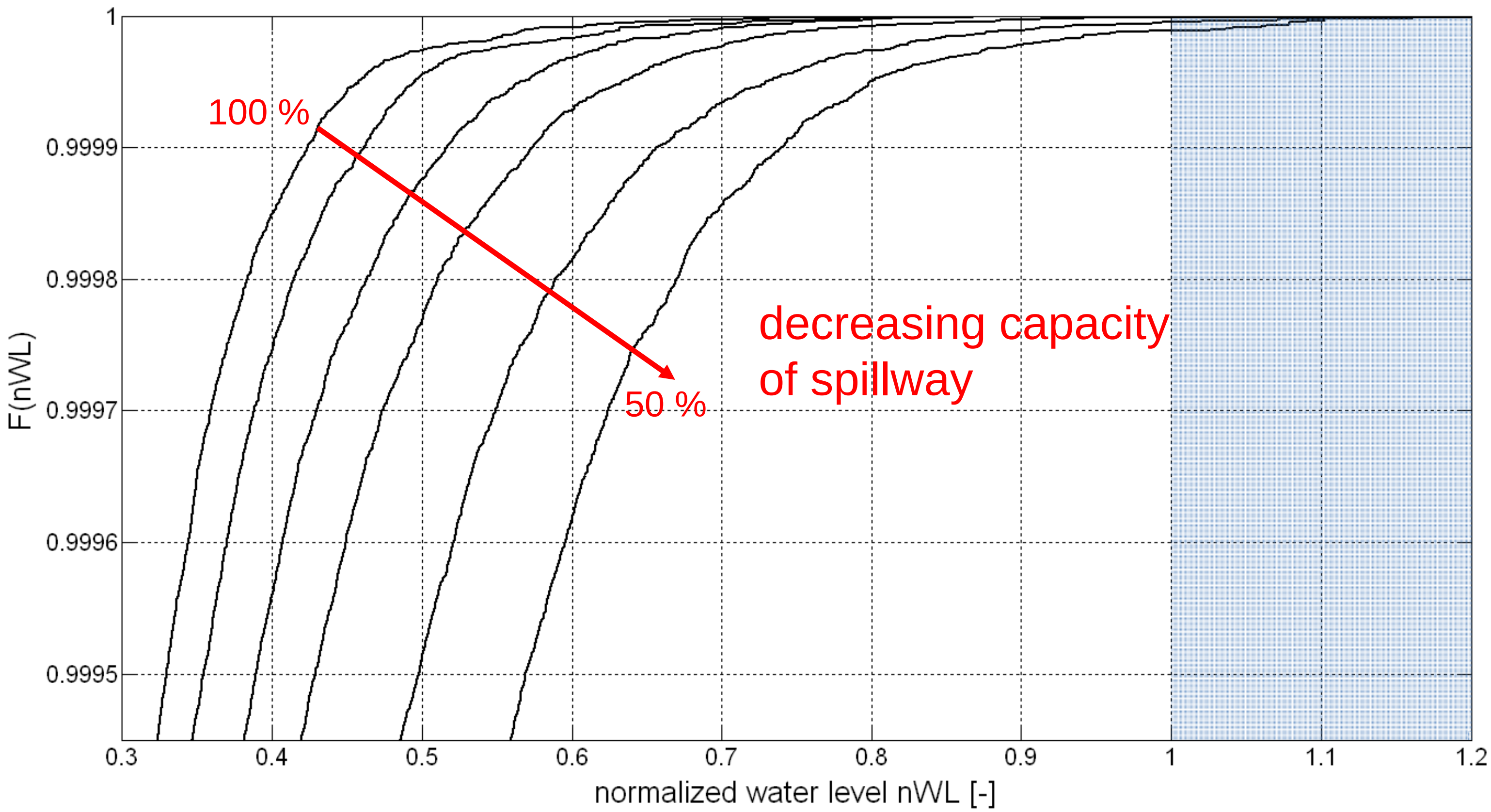
M2: Probability of hydro-meteorological failure

- Results of a scenario with varying capacities of spillway



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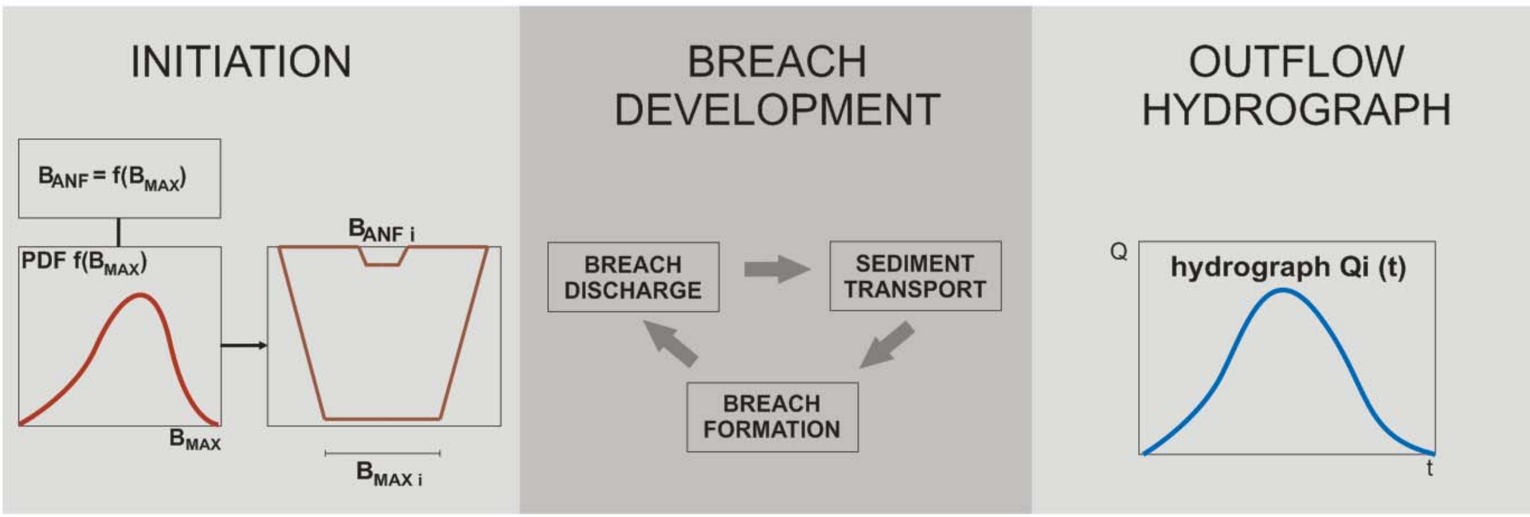
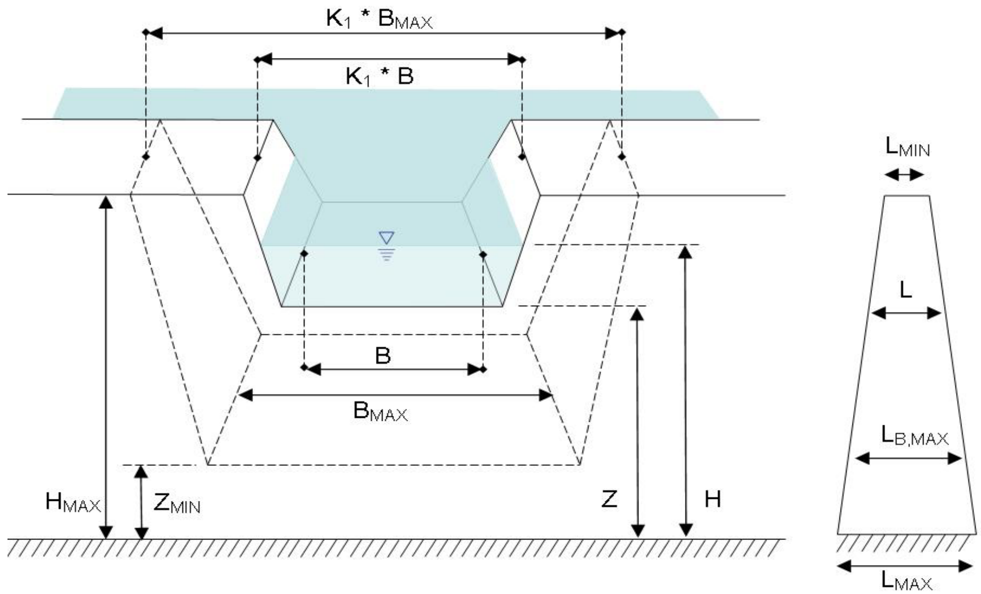
M3: Dam breach modelling

- Models vary in complexity and basis
- A simplified dam breach model was developed
- Estimating the discharge by combining stochastic, parametric and physical based models
- Outflow hydrograph by using MCS

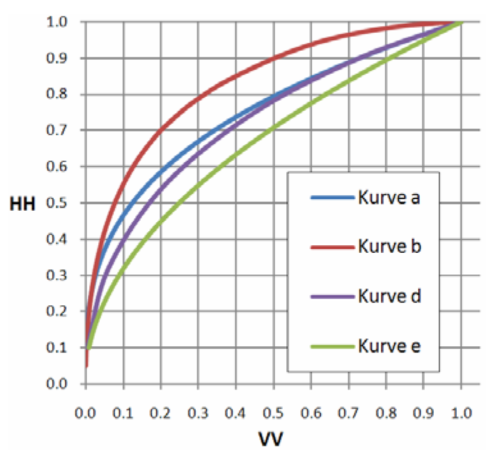


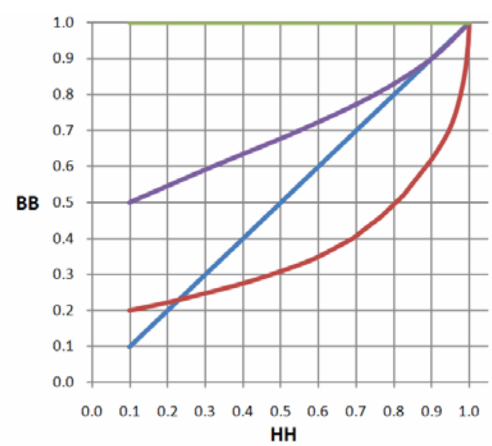
M3: Dam breach modelling



Breach formation

- Probability density function for B_{MAX}





- Parametric breach curves

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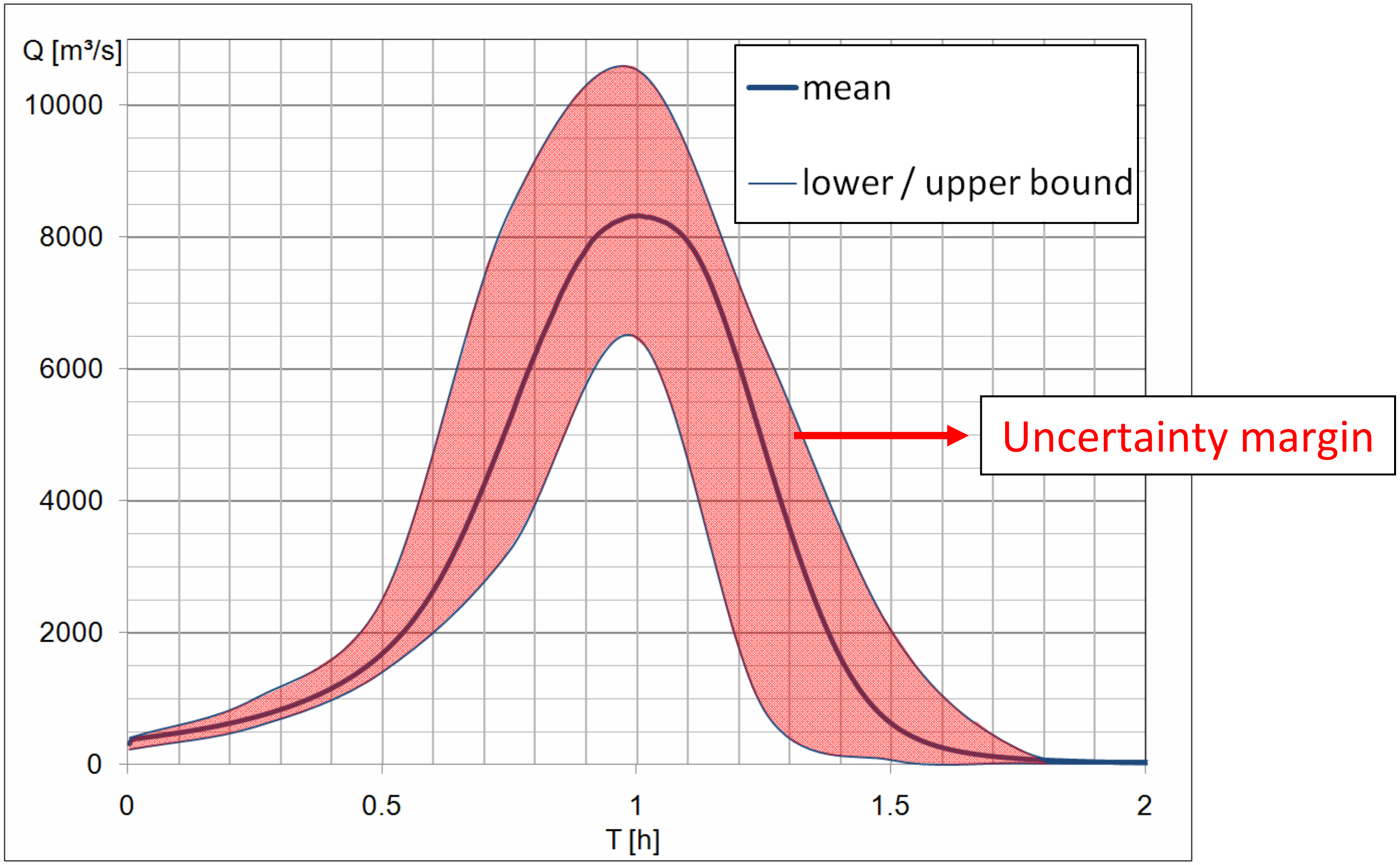
M3: Dam breach modelling

- Stochastic Outflow Hydrograph by using MCS
- $B_{max,1}$ = 50 m and $B_{max,2}$ = 90 m



M4: Flood Routing – hydrodynamic simulation

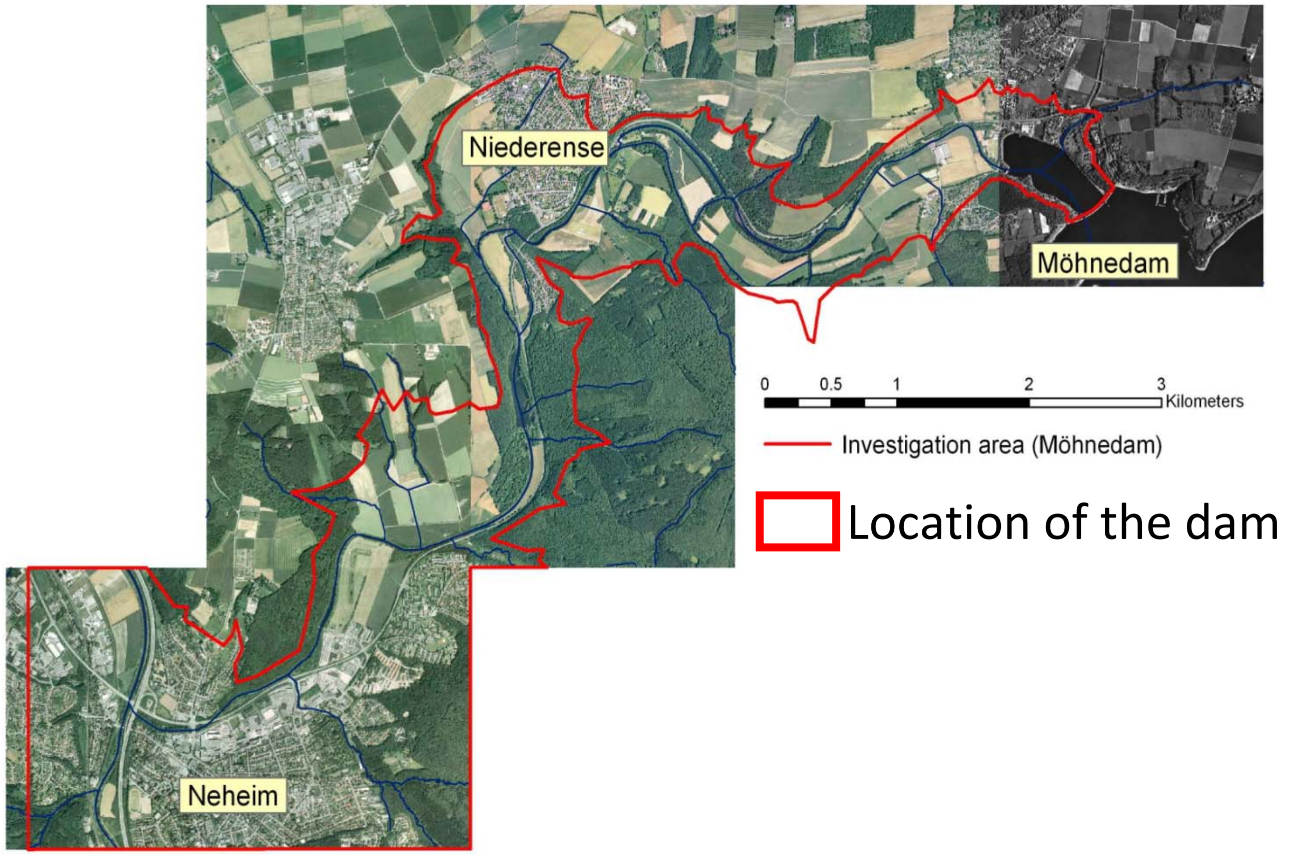
- Determination of flooded areas, maximum water depth and maximum velocities

Used 2-D hydrodynamic model (MeadFlow)

- Finite element method (FEM)
- St. Venant equations (complete or simplified)
- Steady and unsteady flow
- Automatic procedures for refinement of network
- Numerical stability
- Very short computation times

M4: Flood Routing – hydrodynamic simulation

- Determination of flooded areas, maximum water depth and maximum velocities



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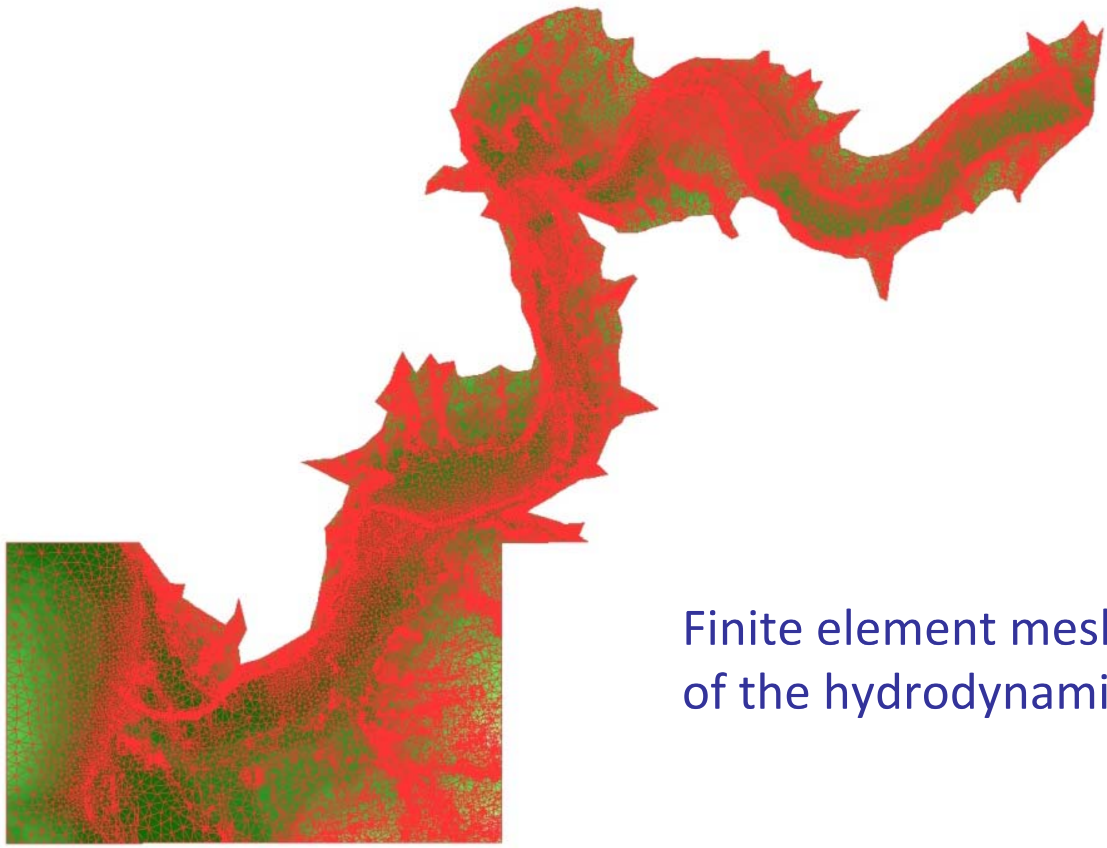
M4: Flood Routing – hydrodynamic simulation

- Determination of flooded areas, maximum water depth and maximum velocities



Finite element mesh
of the hydrodynamic model

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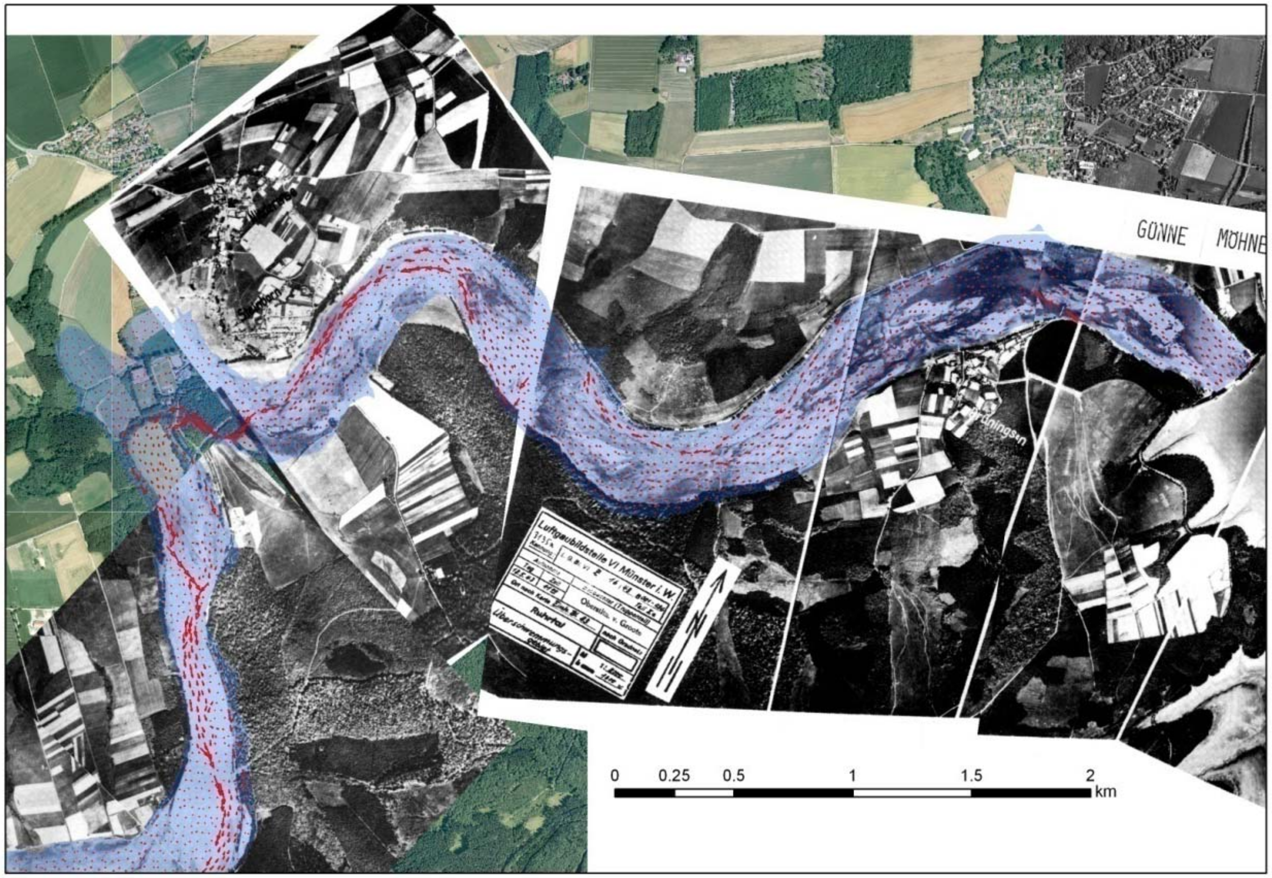
M4: Flood Routing – hydrodynamic simulation

- Verification of the model's applicability on the basis of the failure of the Möhne Dam during World War II



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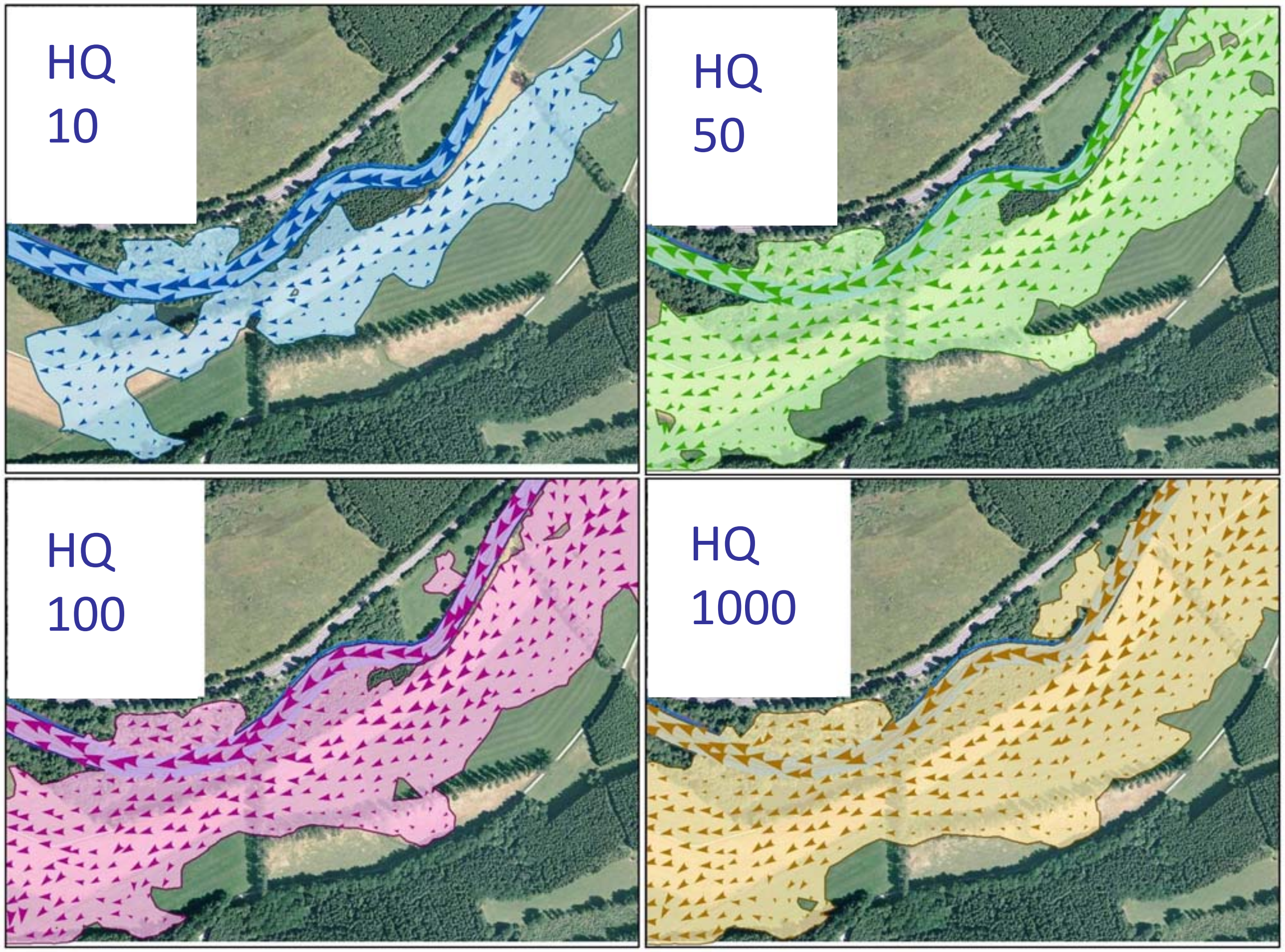
M4: Flood Routing – hydrodynamic simulation

- Application for reference scenarios and dam break waves



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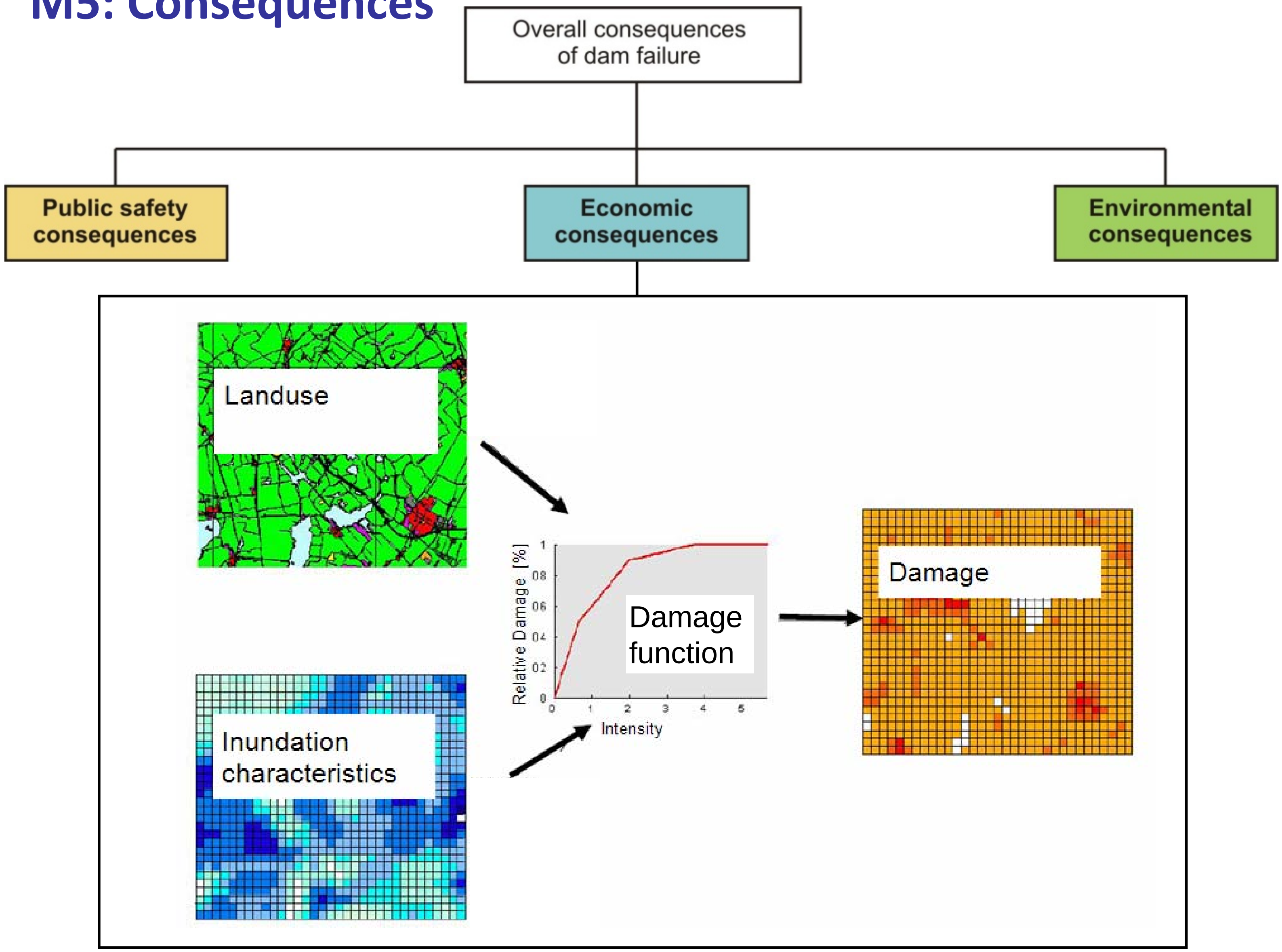
M5: Consequences



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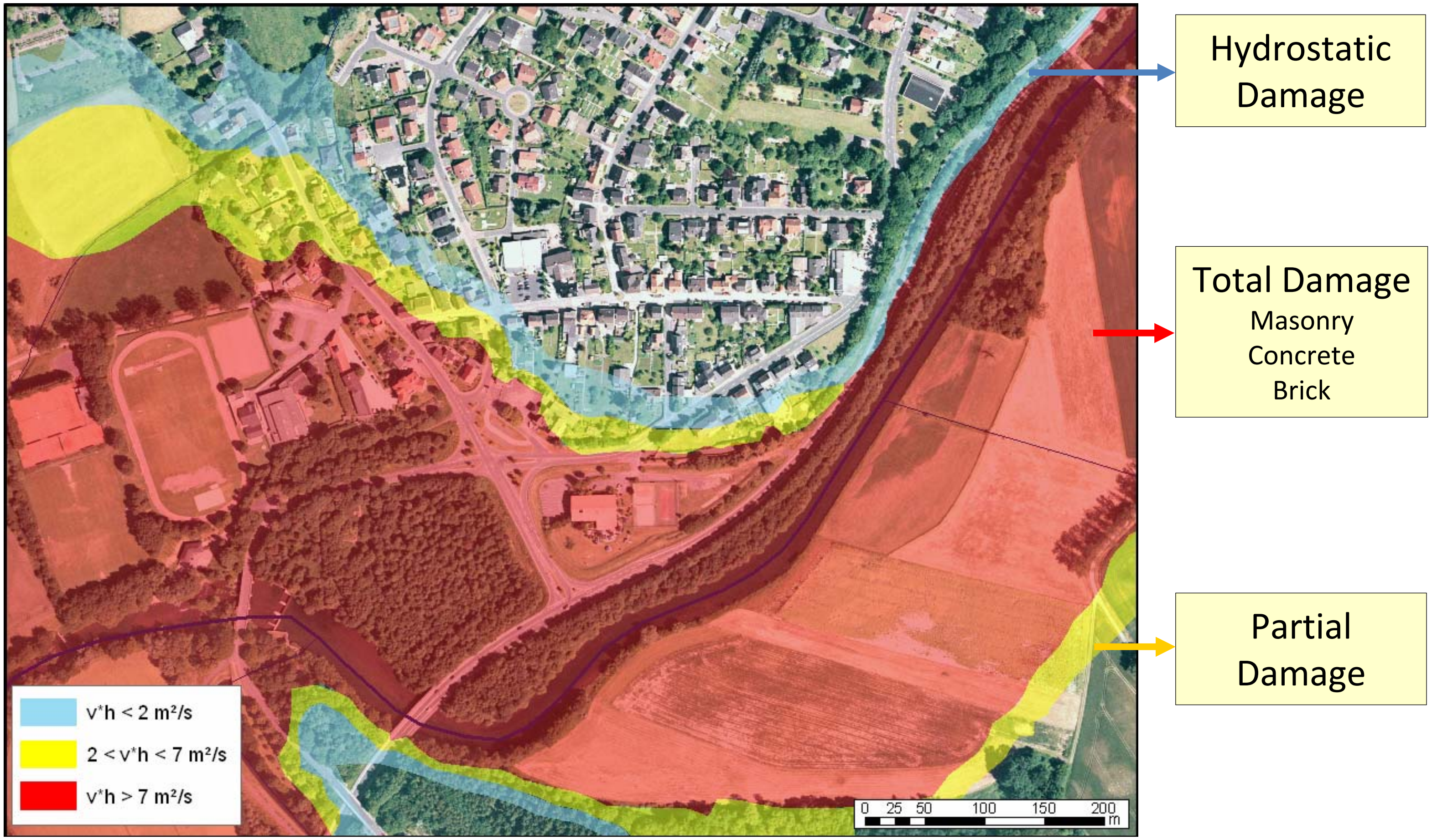
M5: Consequences

- Other damage criteria (flow velocity times water depth)
- Inundation – Partial Damage – Total Damage



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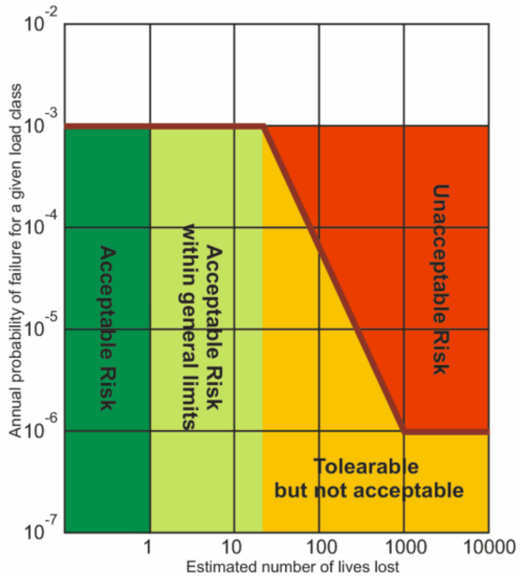
M6: Risk Parameters

- Failure probabilities
- Product of failure probability and potential damage

Probability → RISK ← Consequences

- People at risk (PAR)
- Subjective risk in the field of socio-economics and ecology
- Presentation of Risk in maps

  and Risk level graphs
- Acceptance limits ("Acceptable Risk")



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Conclusion - RIBADD

- With RIBADD a scientifically validated and practicable risk-based procedure for design and verification of dam safety was developed
- Cognitions from the application of RIBADD to several case studies will support further developments of design standards
- Safety evaluations of dams with respect to risk on a practicable and economically significant basis are possible through RIBADD
- RIBADD can be used as a part of an integrated flood risk management
- RIBADD provides tools for the selection of risk reduction measures like emergency plans

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