Flood scenarios, imprecise probabilities and multi-criteria decision making in polder planning

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Flood scenarios, imprecise probabilities and multi-criteria decision making in polder planning

1. **Introduction**
2. Case Study
3. Characterisation of uncertainties of hydrological loads by scenarios
4. Decision support
5. Summary

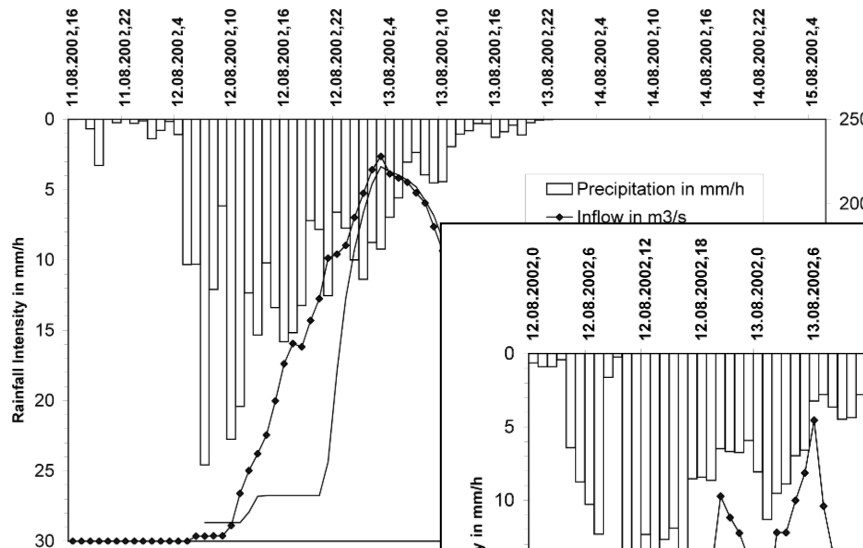
CONFERENCE THEMES and TOPICS

- Theme A1 : How can we identify and quantify water-related changes due to direct human interventions (analysis of long-time past records, future developments);
- Theme A2 : How can we identify and quantify water-related changes due to climate change (analysis of long-time past records, future developments);
- Theme B : How can we discriminate among impacts of direct human interventions and impacts caused by climate change, and how can we quantify the impacts;
- Theme C : How can we quantify/ predict changes in water-related hazards;

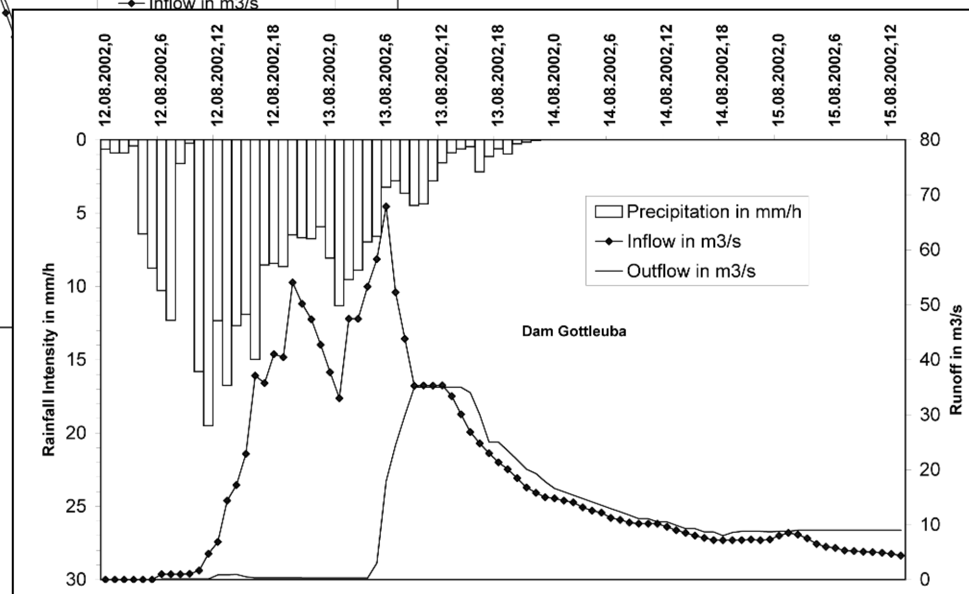
- Theme D : How can we adapt to / mitigate water-related hazards? - resilient and **robust** ways to adapt to water-related disasters.

„robust“: „capable of performing without failure under a wide range of conditions”

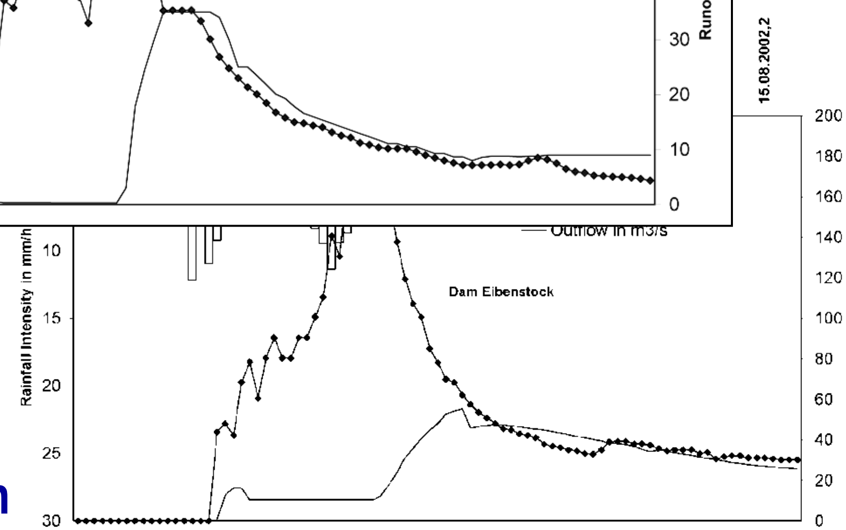
Hydrological Risk of flood protection by technical retention



No flood protection



Flood protection by technical retention facilities depends on characteristics of events!



Full flood protection

From Safety to Risk-Oriented Approaches

Safety-oriented Approach

Choice of a design flood Q_{design} (e. g. 100 year flood)

↓

Design
Technical flood control fully functional for $Q \leq Q_{design}$

↓

Assumption: No risk of failure for $Q \leq Q_{design}$ and negligible risks beyond Q_{design}

Risk-oriented Approach

100 % safety can not be achieved by technical measures

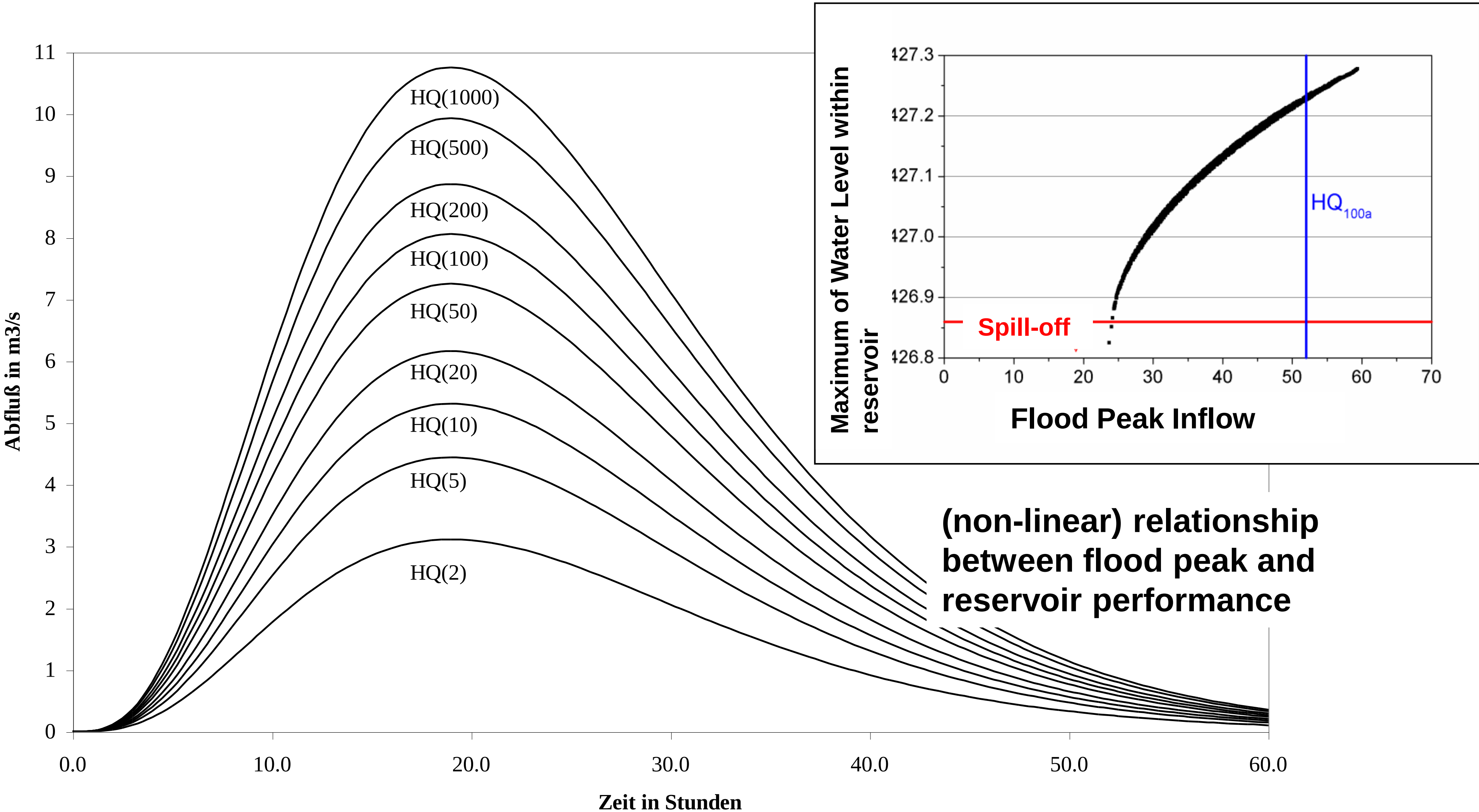
↓

Risk of failure
Hydrological Risk
Operational &Technical Risks

↓

Risk Management is required

Design Floods based on standardized and scaled Kozeny-hydrographs for different return periods



(non-linear) relationship between flood peak and reservoir performance

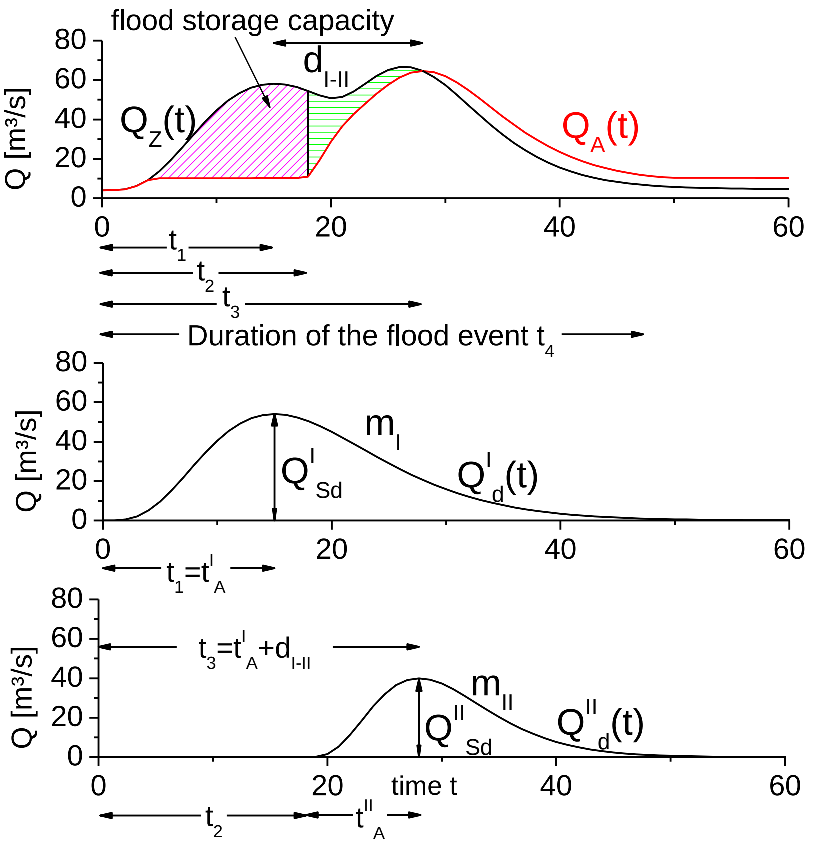
More complex design floods:

Stochastic generation of hydrographs with two peaks, derived from overlaying of two Kozeny-Curves

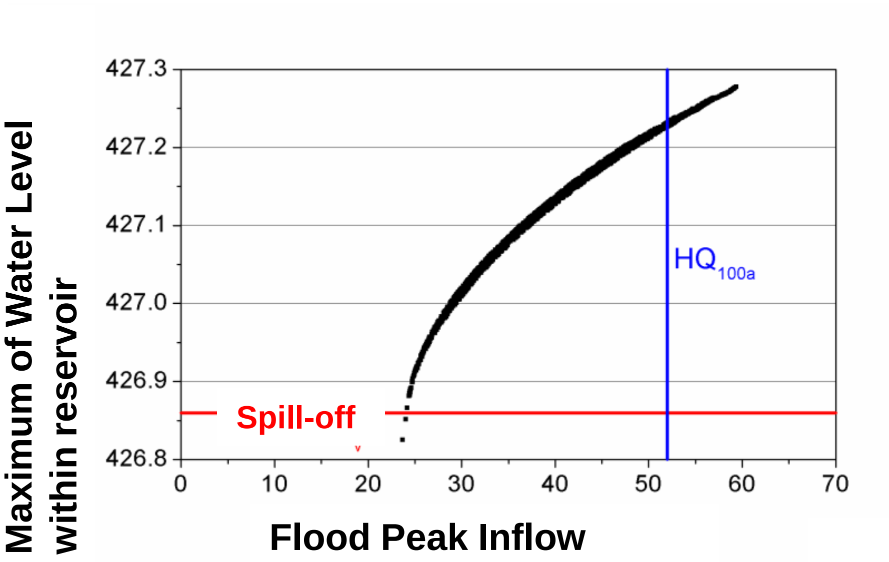
$$Q_Z(t) = Q_d^I(t) + Q_d^{II}(t) + Q_B(t)$$

Parameters:

- Q^I_{sd}, Q^{II}_{sd}: **Peaks of single flood waves**
- m_I, m_{II}: **shape parameter of flood waves**
- t^I_A, t^{II}_A: **time to peak**
- d_{I-II}: **temporal distance between the overlaying floods**
- t_2: **lag time until begin of the second flood wave**
- t_3: **total time span until second peak occurs**

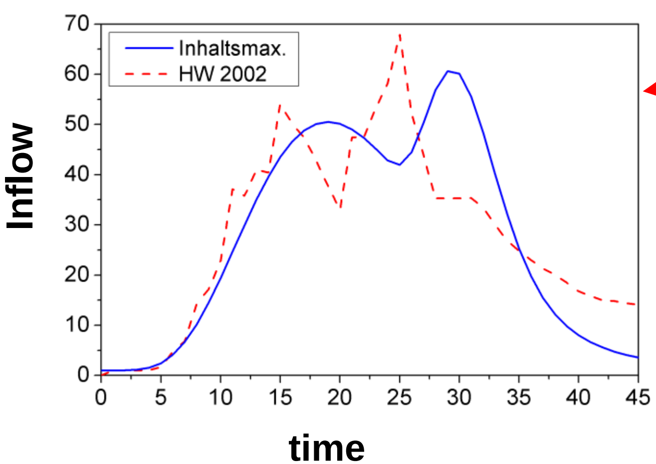


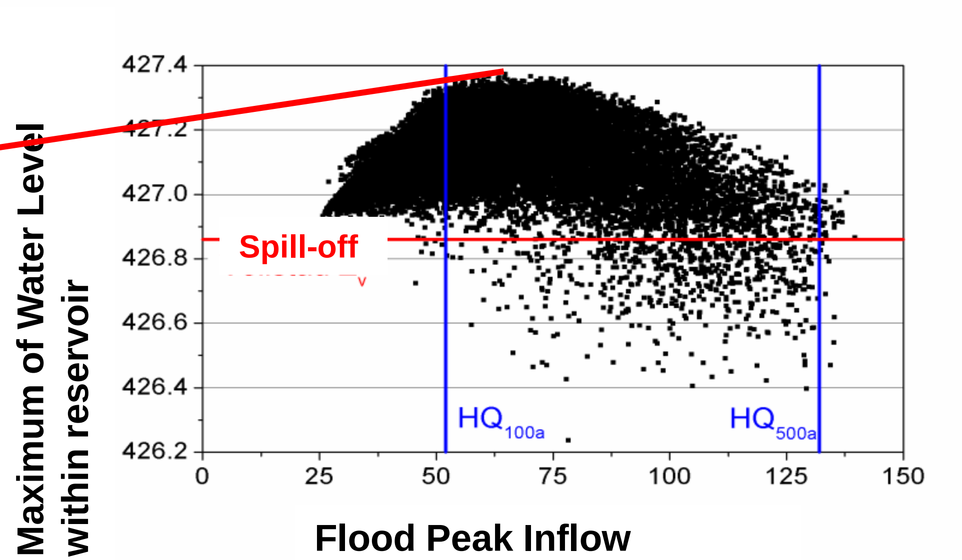
Monte- Carlo- Simulations of Hydrographs resulting from a design rainfall with duration D=24 h and a return periode of 1000 years(Reservoir Gottleuba, Germany) (Klein, 2009)



Simulation of hydrographs with one peak

Simulation of hydrographs with two peaks





➔ **more complex relationships between flood peaks and resulting storage content of the reservoir**

Flood scenarios, imprecise probabilities and multi-criteria decision making in polder planning

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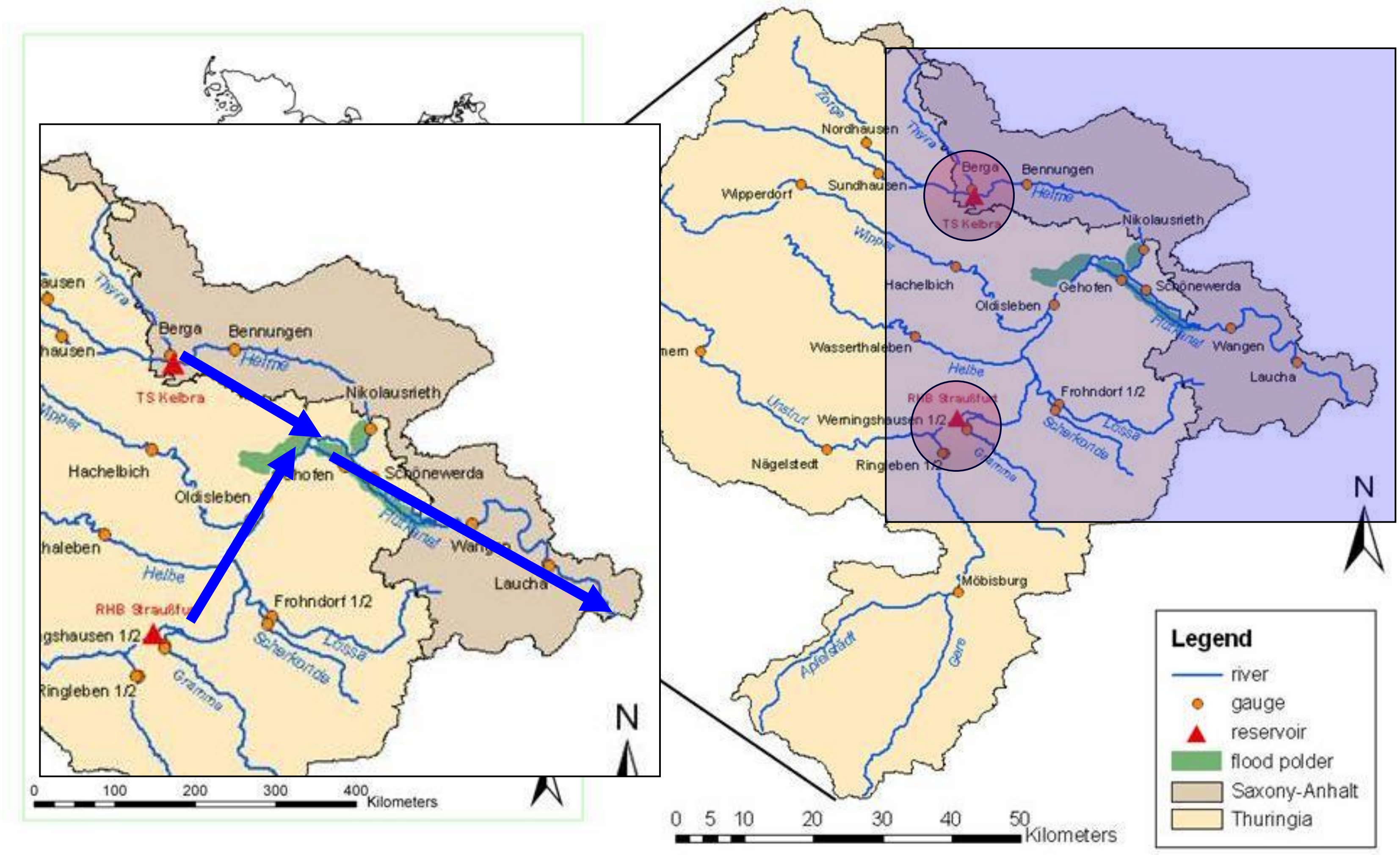
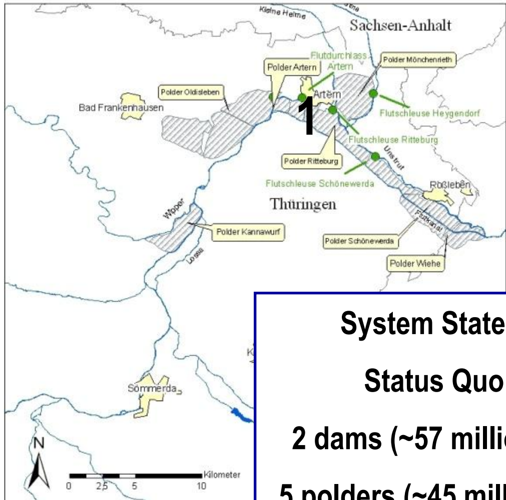
Considering complex flood risks in planning of flood retention systems

Unstrut River Basin in Germany, 6343 km^2



6 Different System States of the Technical Flood Control System

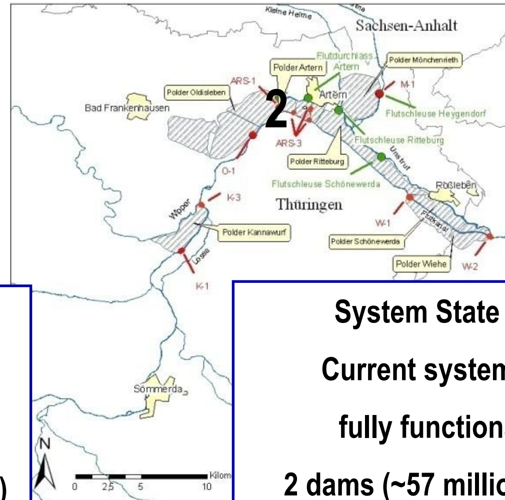


System State 1:

Status Quo:

2 dams (~57 million m^3)

5 polders (~45 million m^3)



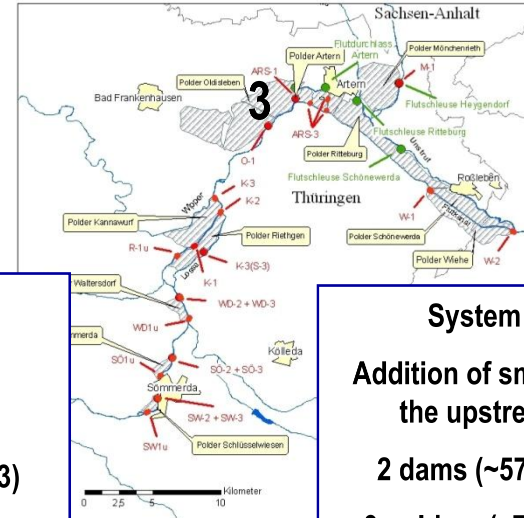
System State 2:

Current system is

fully functional

2 dams (~57 million m3)

5 polders (~45 million m3)

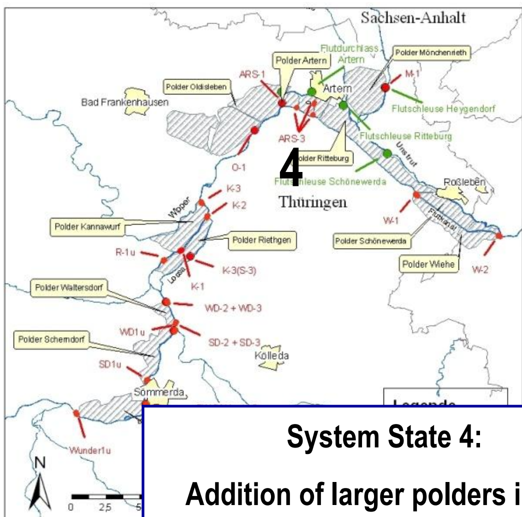


System State 3:

Addition of small polders in the upstream region

2 dams (~57 million m3)

9 polders (~77 million m3)

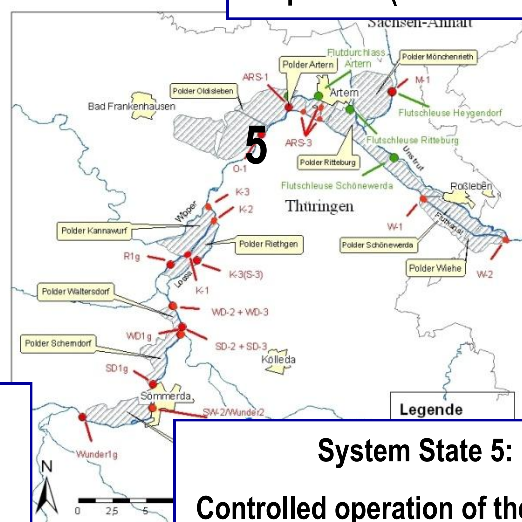


System State 4:

Addition of larger polders in the upstream region

2 dams (~57 million m3)

9 polders (~85 million m3)

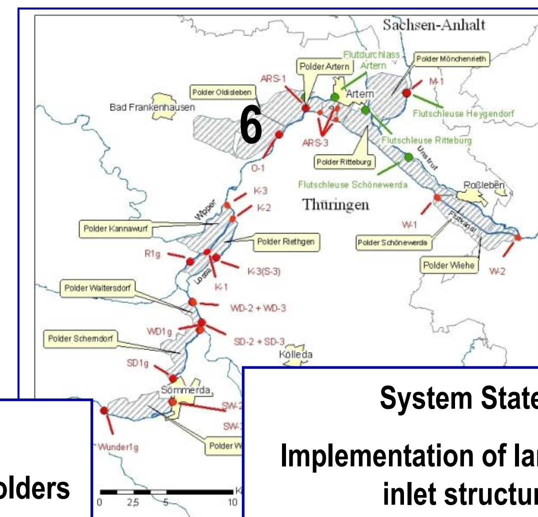


System State 5:

Controlled operation of the polders

2 dams (~57 million m3)

9 polders (~85 million m3)



System State 6:

Implementation of larger polder inlet structures

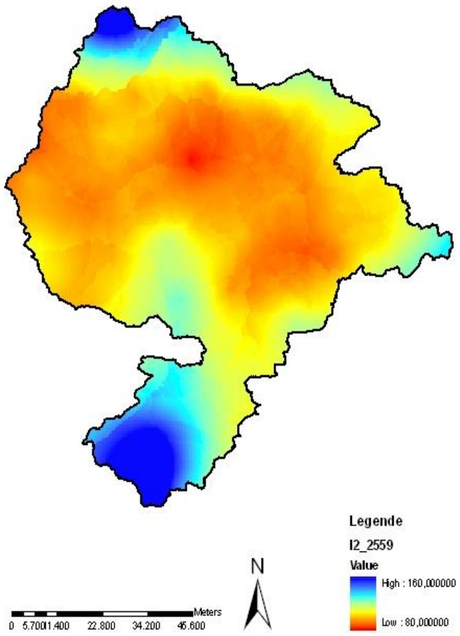
2 dams (~57 million m3)

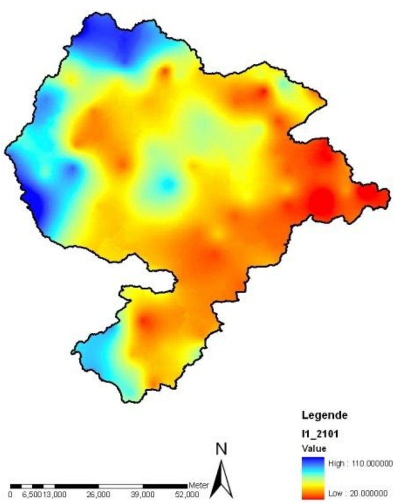
9 polders (~85 million m3)

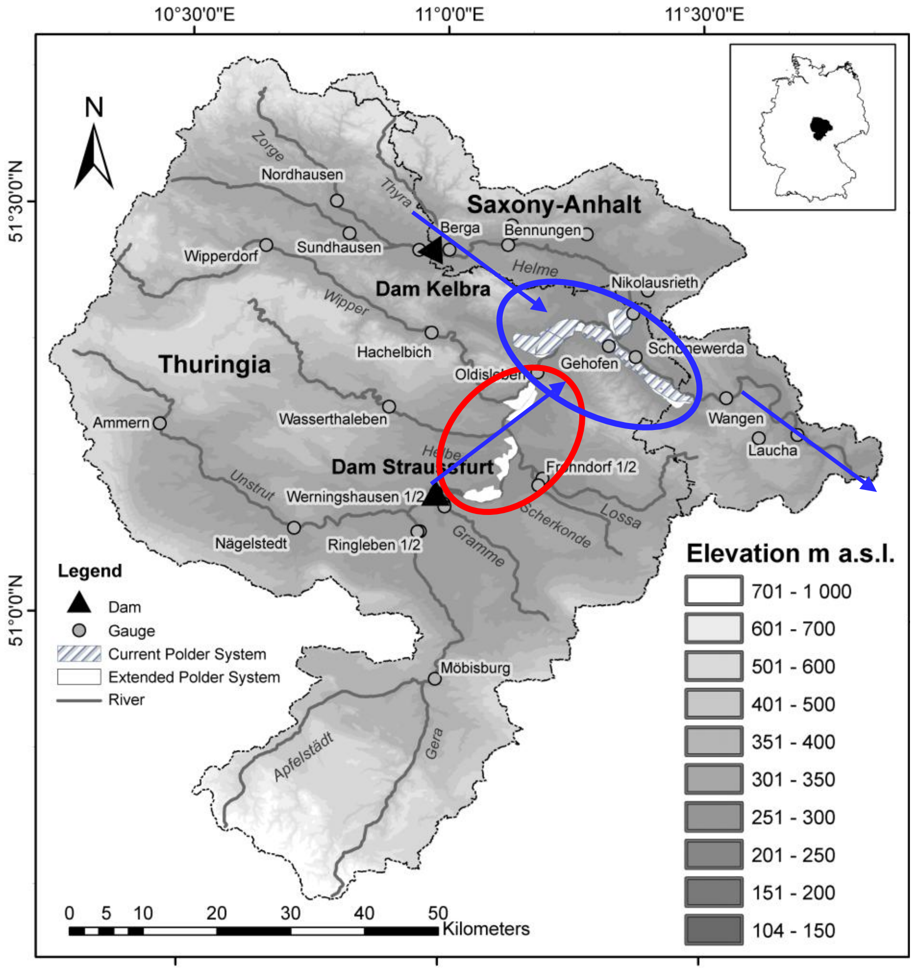
Spatial characteristics of hydrological loads and flood retention facilities

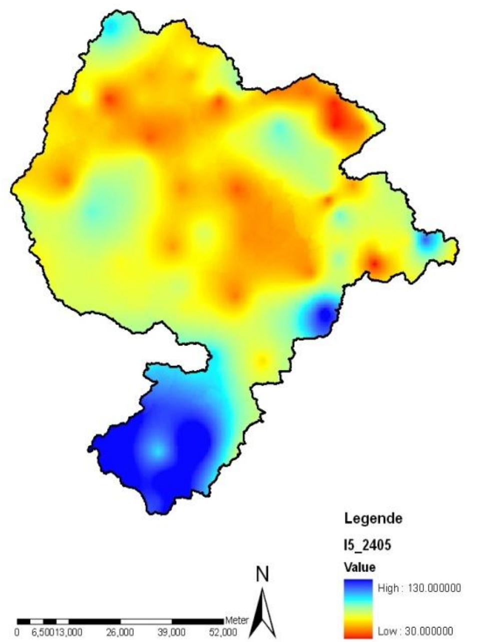
Flood protection depends on:

- spatial distribution of precipitation
- coincidences of floods in tributaries
- performances and interactions of flood retention facilities

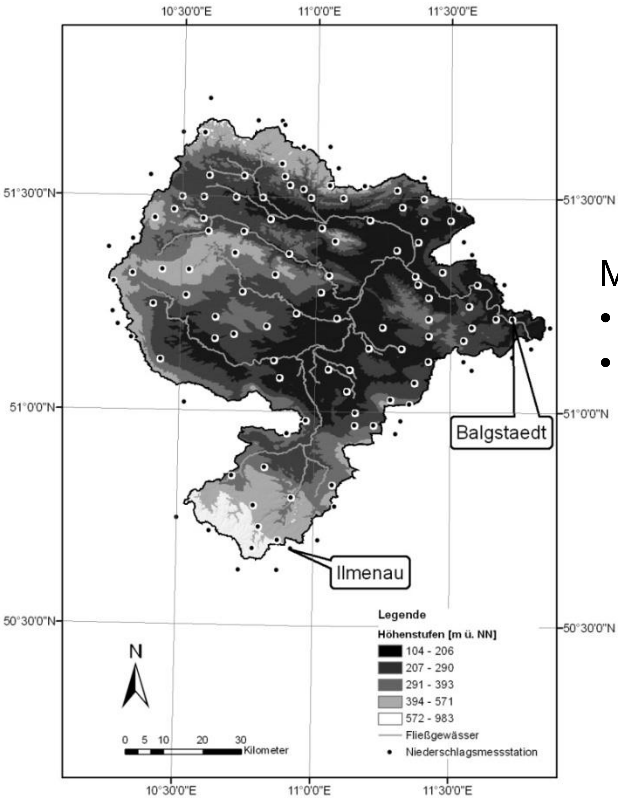




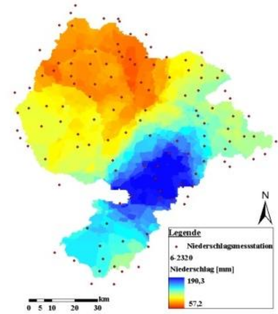


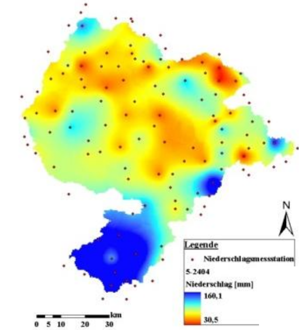


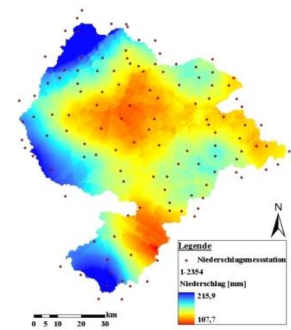
Flood scenarios: Coupling a stochastic generator of precipitation fields (Bárdossy & Plate (1992)) with a hydrological model



122 gauges precipitation



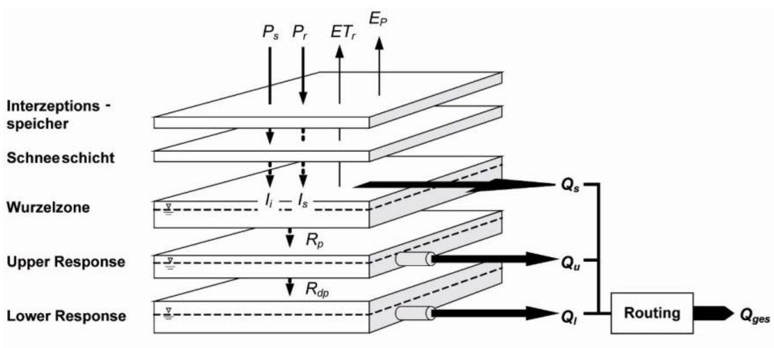




Mixed Distribution:

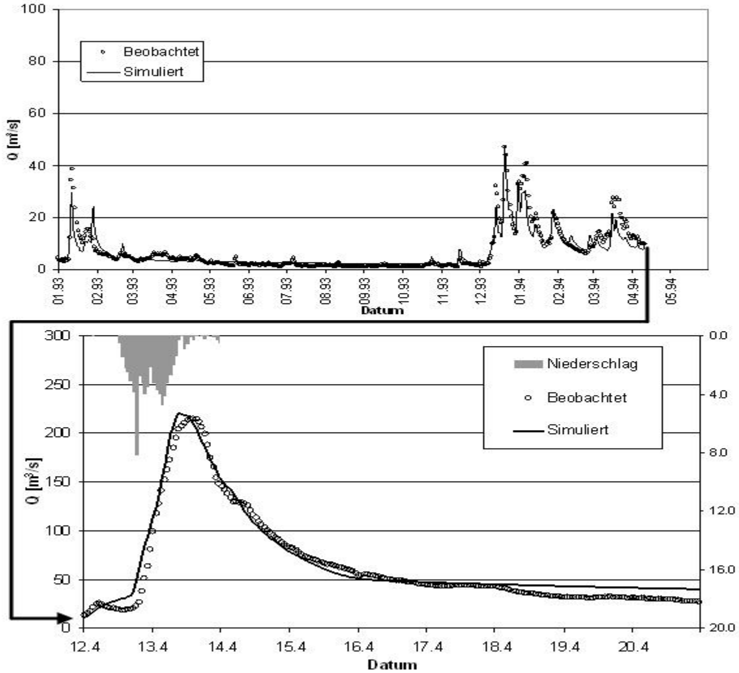
- Gamma-DF for small values,
- Generalized Pareto- DF for high values

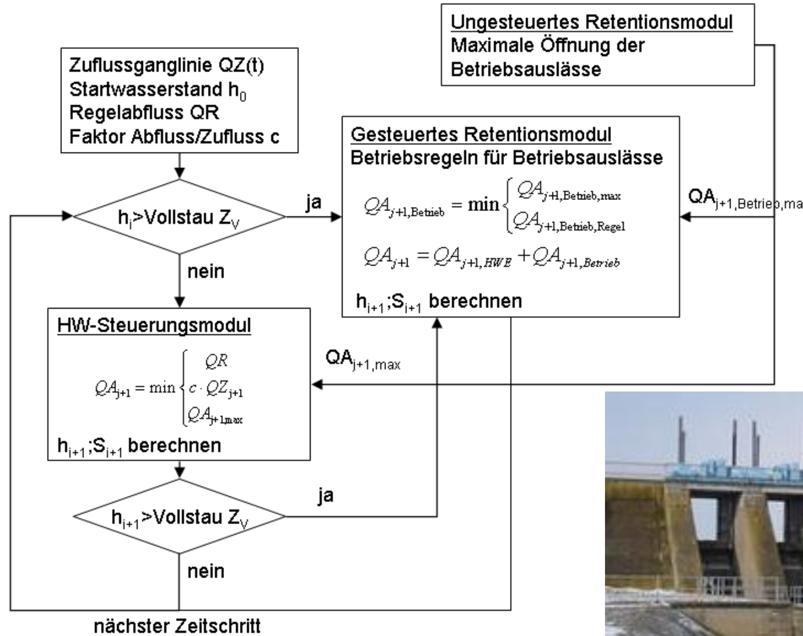
$$f(z,u) = \frac{\left[1-p(z,u)\right]h(z,u)+p(z,u)g(z,u)}{K(u)}$$

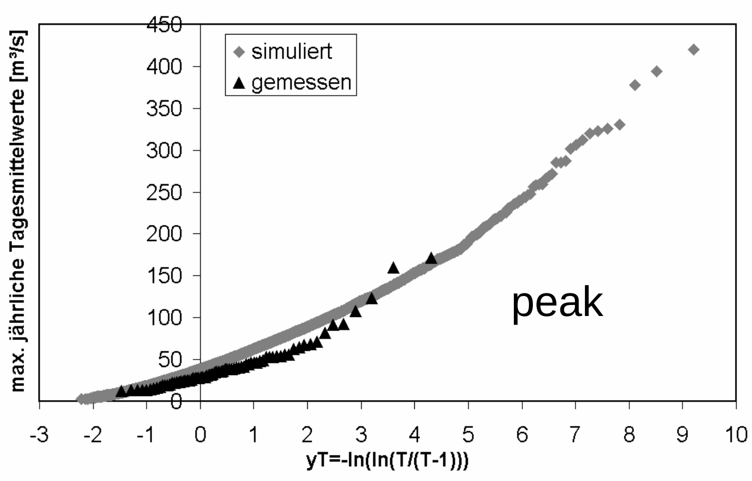


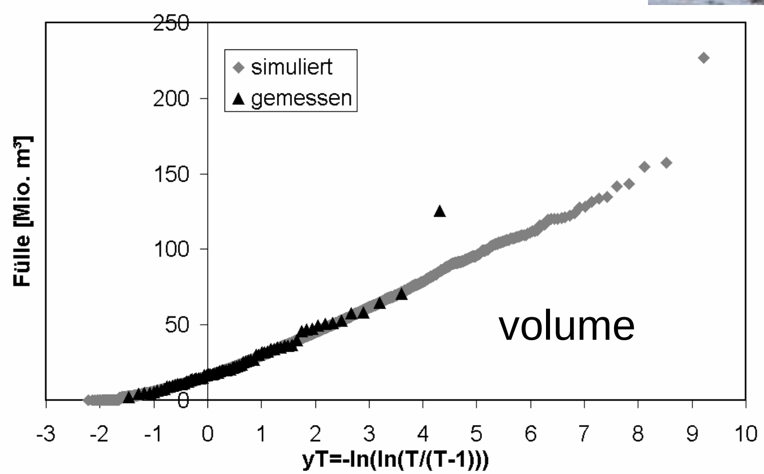
Simulation of 10 times 1.000 years runoff (daily values)

Transfer of simulated daily values into flood events, consideration of reservoirs



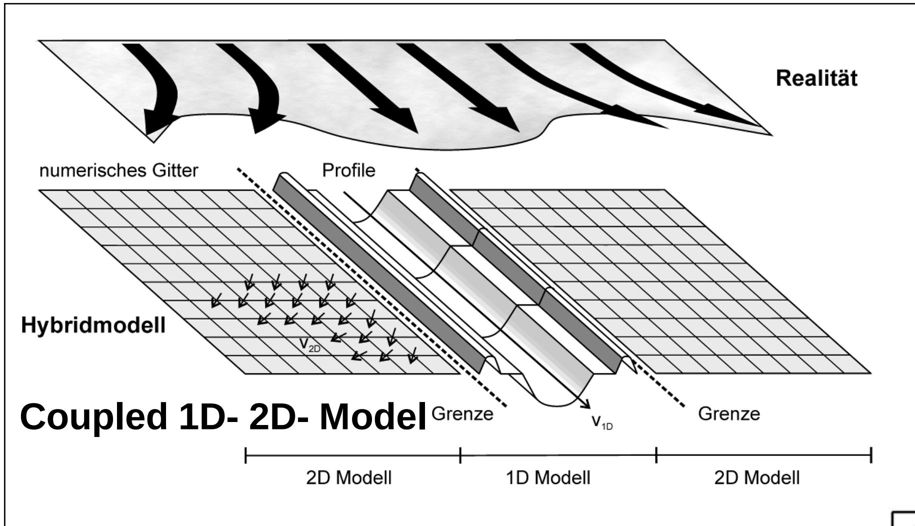




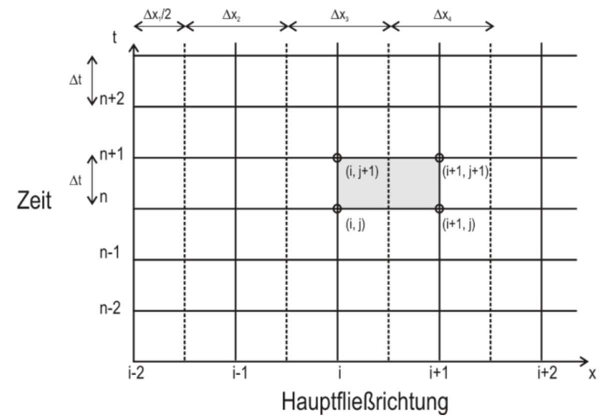


Flood statistics, derived from observed and simulated data

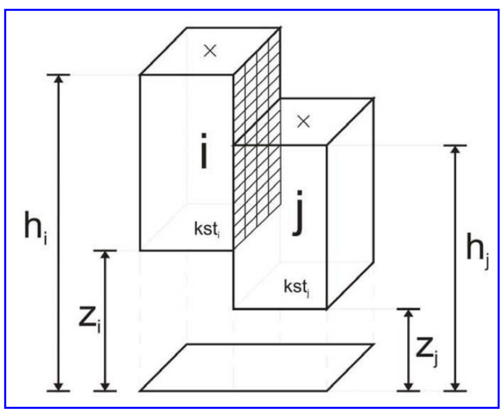
Impact analysis: Hydro-dynamic simulations of runoff, polder flooding and inundations (RWTH Aachen, Prof. Schüttrumpf)



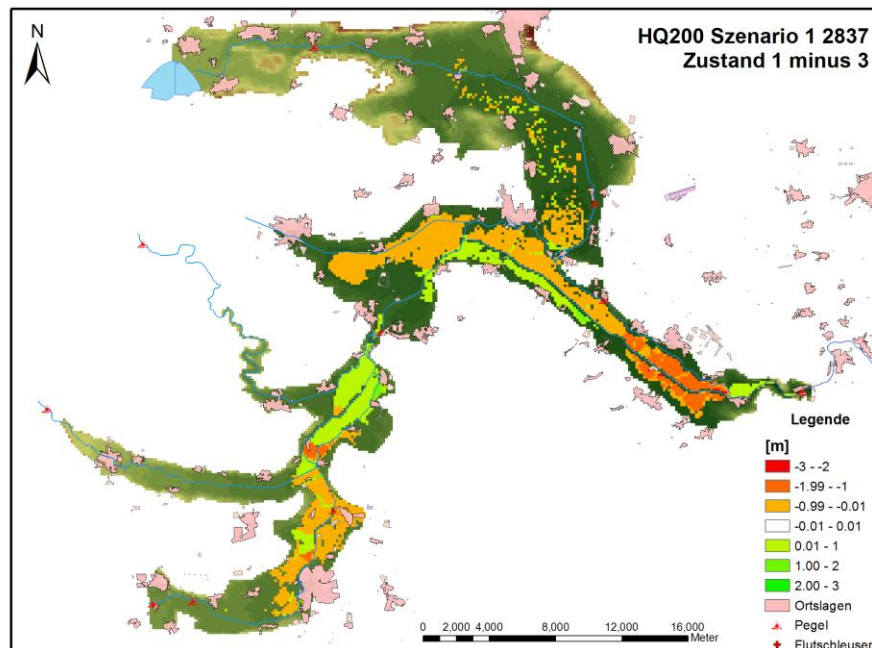
Coupled 1D- 2D- Model



implicid 4-point discretisation scheme



„Storage-Cell"-Approach



Selection of flood scenarios

Criteria	Characteristics
Performance of existing reservoirs	Flood Peak, Volume, Hydrograph
Interaction of tributaries	Distribution of runoff, Flood retention by polders and reservoirs
Spatially uneven distributed damages	Damages related to political units
Event-specific damages	Number of affected people, innundated areas, economic losses

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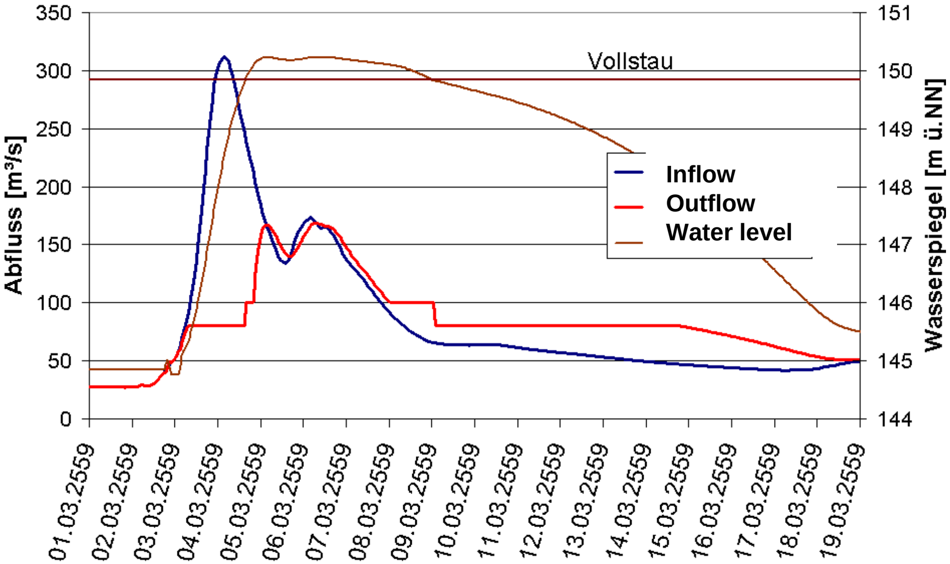
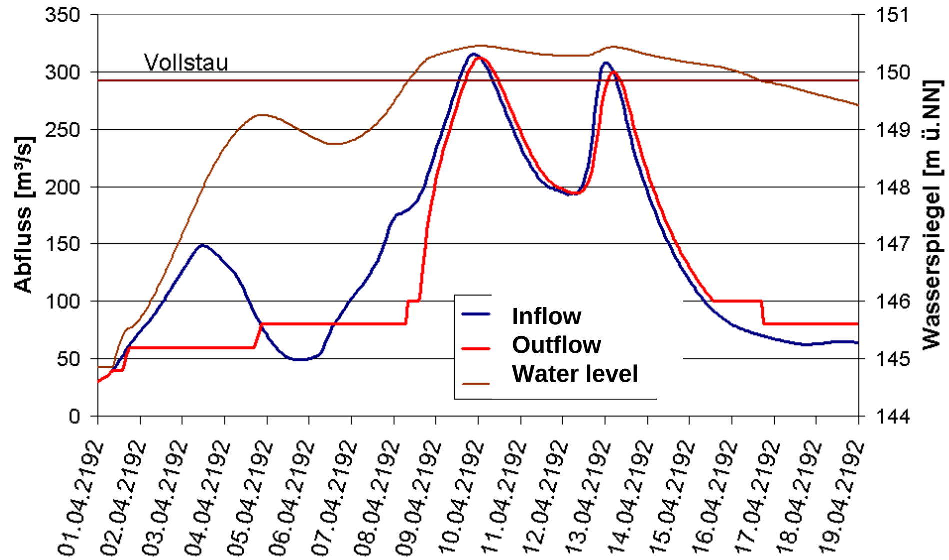
Scenarios to assess the performance of existing retention facilities

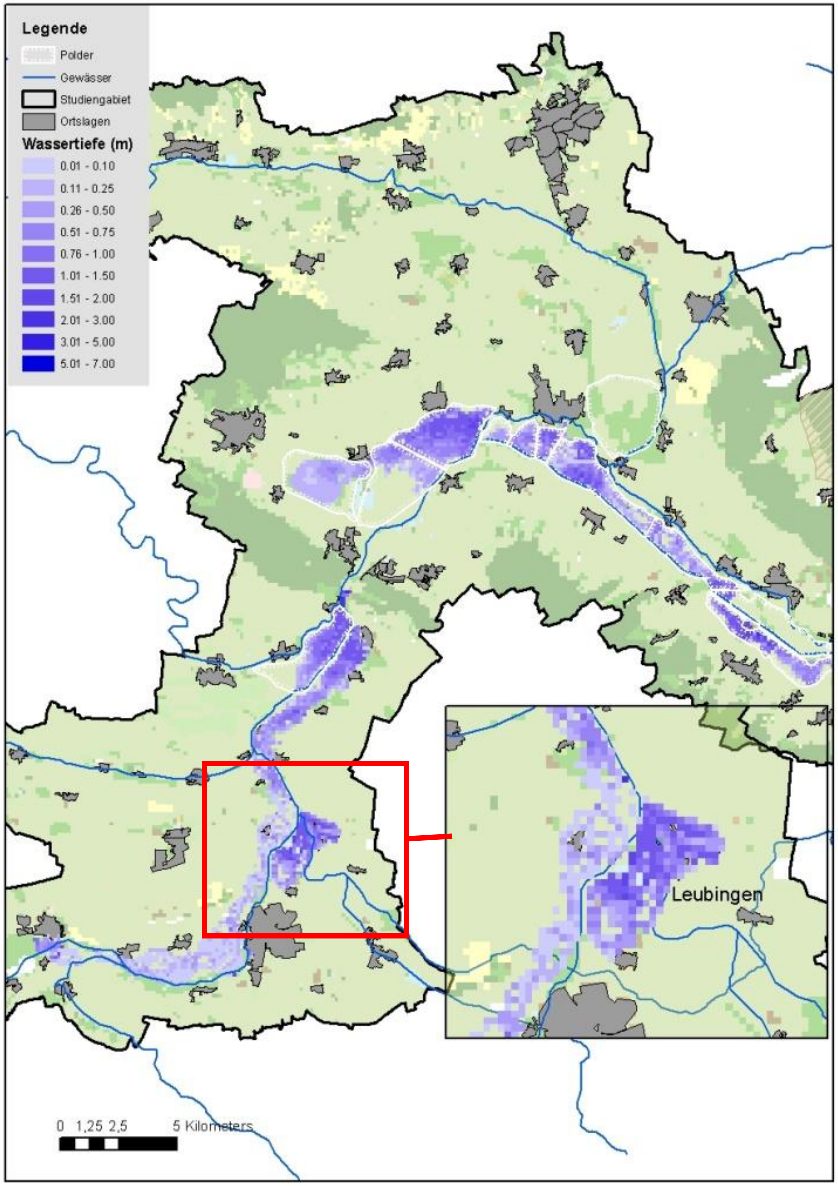
Example: Two 100- years floods with different volumes and shapes

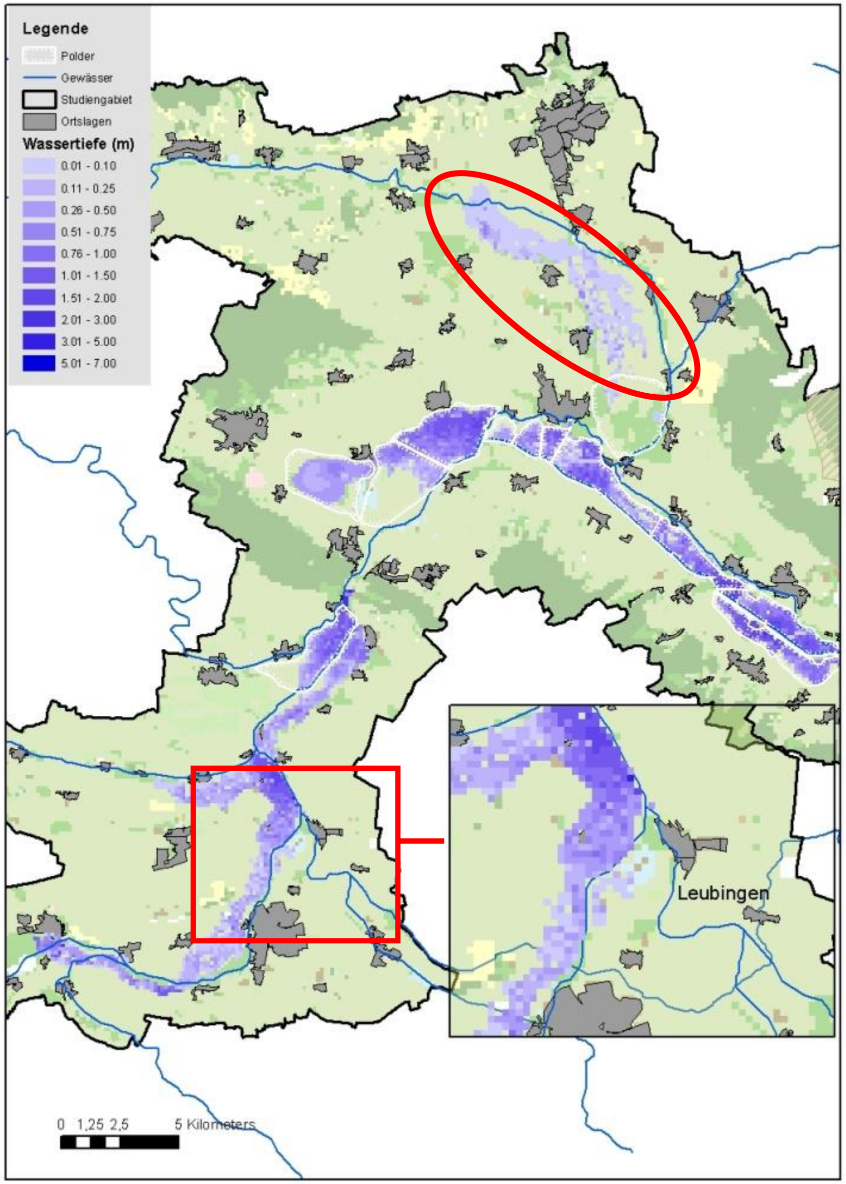
Reservoir Straussfurt





Differences between flooded areas resulting from two different floods with T=100 years



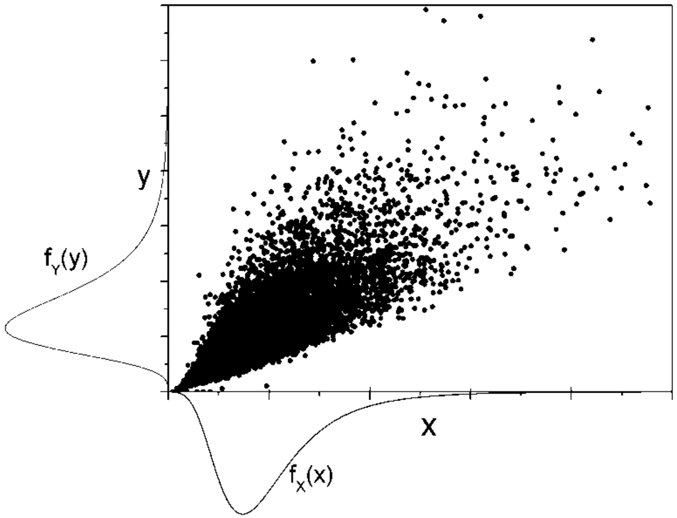


Bivariate Statistics with Copulas

Sklar- Theorem (1959):

$$F_{X,Y}(x,y) = C\left[F_X(x), F_Y(y)\right] = C(u,v)$$

$F_{X,Y}(x,y)$ bivariate Distribution Function
$F_X(x)$, $F_Y(y)$ Boundary distributions of random variables X and Y
C Copula- function describing interdependencies between X and Y independent from boundary distributions



$$C(u,v) = \varphi^{-1}\left(\varphi(u), \varphi(v)\right)$$

φ Generator

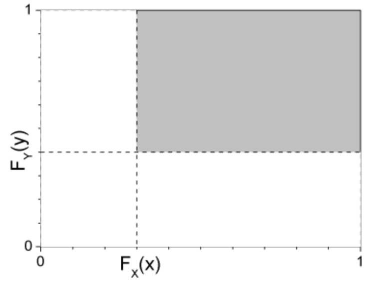
Bivariate Statistics with Copulas

Non-exceedance Probability of x **and** y

$$P\left(X \le x, Y \le y\right) = F_{X,Y}\left(x,y\right) = C\left[F_X\left(x\right), F_Y\left(y\right)\right]$$

Exceedance Probability of x **and** y

$$P\left(X > x \wedge Y > y\right) = 1 - F_X\left(x\right) - F_Y\left(y\right) + F_{X,Y}\left(x,y\right)$$
$$= 1 - F_X\left(x\right) - F_Y\left(y\right) + C\left(F_X\left(x\right), F_Y\left(y\right)\right)$$

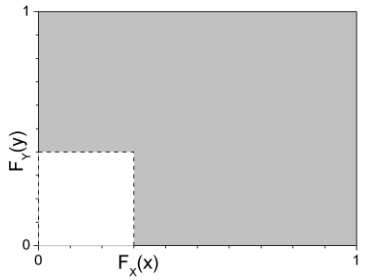


Return Periode

$$T^{\wedge}_{X,Y} = \frac{1}{P(X \ge x \wedge Y \ge y)} = \frac{1}{1 - F_X\left(x\right) - F_Y\left(y\right) + C\left[F_X\left(x\right), F_Y\left(y\right)\right]} > Max\left[T_X, T_Y\right]$$

Exceedance Probability of x **or** y :

$$P\left(X > x \vee Y > y\right) = 1 - F_{X,Y}\left(x,y\right) = 1 - C\left(F_X\left(x\right), F_Y\left(y\right)\right)$$

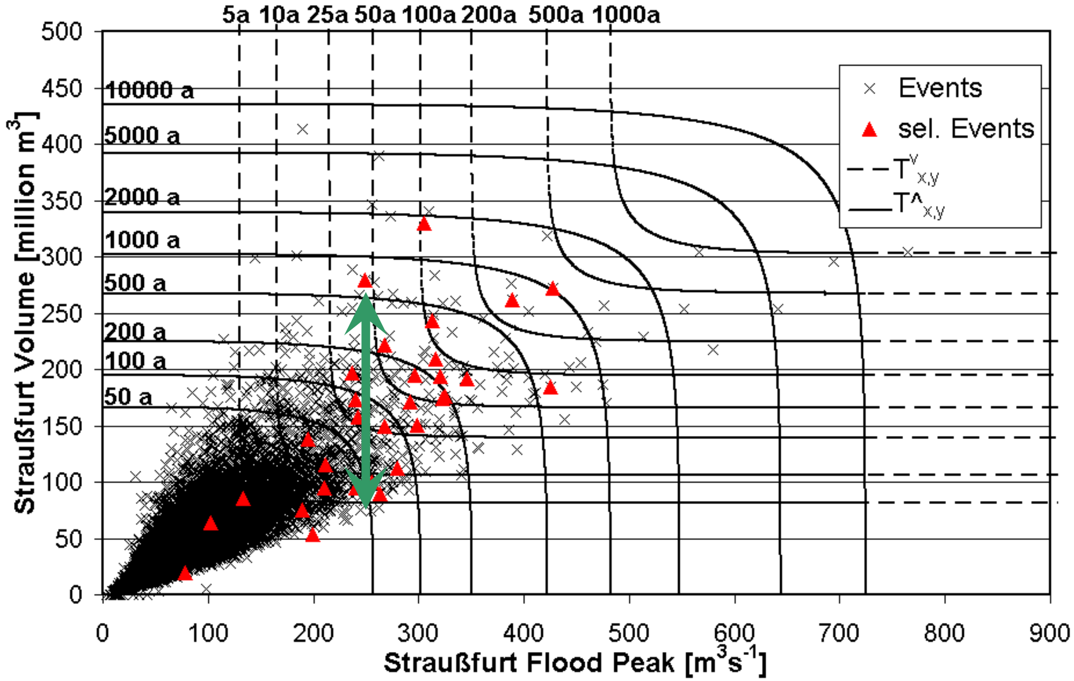


Return Periode

$$T^{\vee}_{X,Y} = \frac{1}{P(X \ge x \vee Y \ge y)} = \frac{1}{1 - C\left[F_X\left(x\right), F_Y\left(y\right)\right]} < Min\left[T_X, T_Y\right]$$

Bivariate Analysis: Flood Peak-Volume at dam sites

Joint return periods:

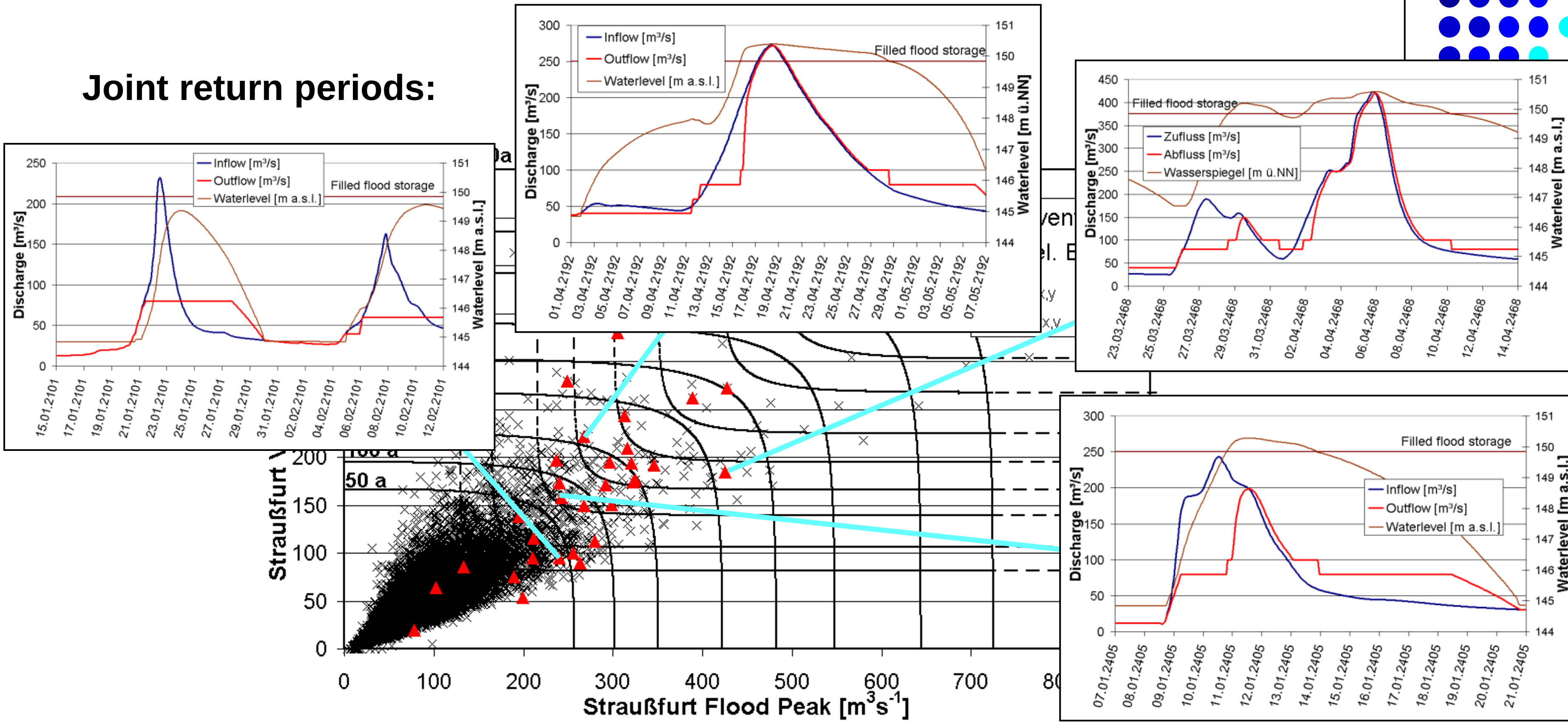


➔ A large variety of different hydrological scenarios has to be considered in design

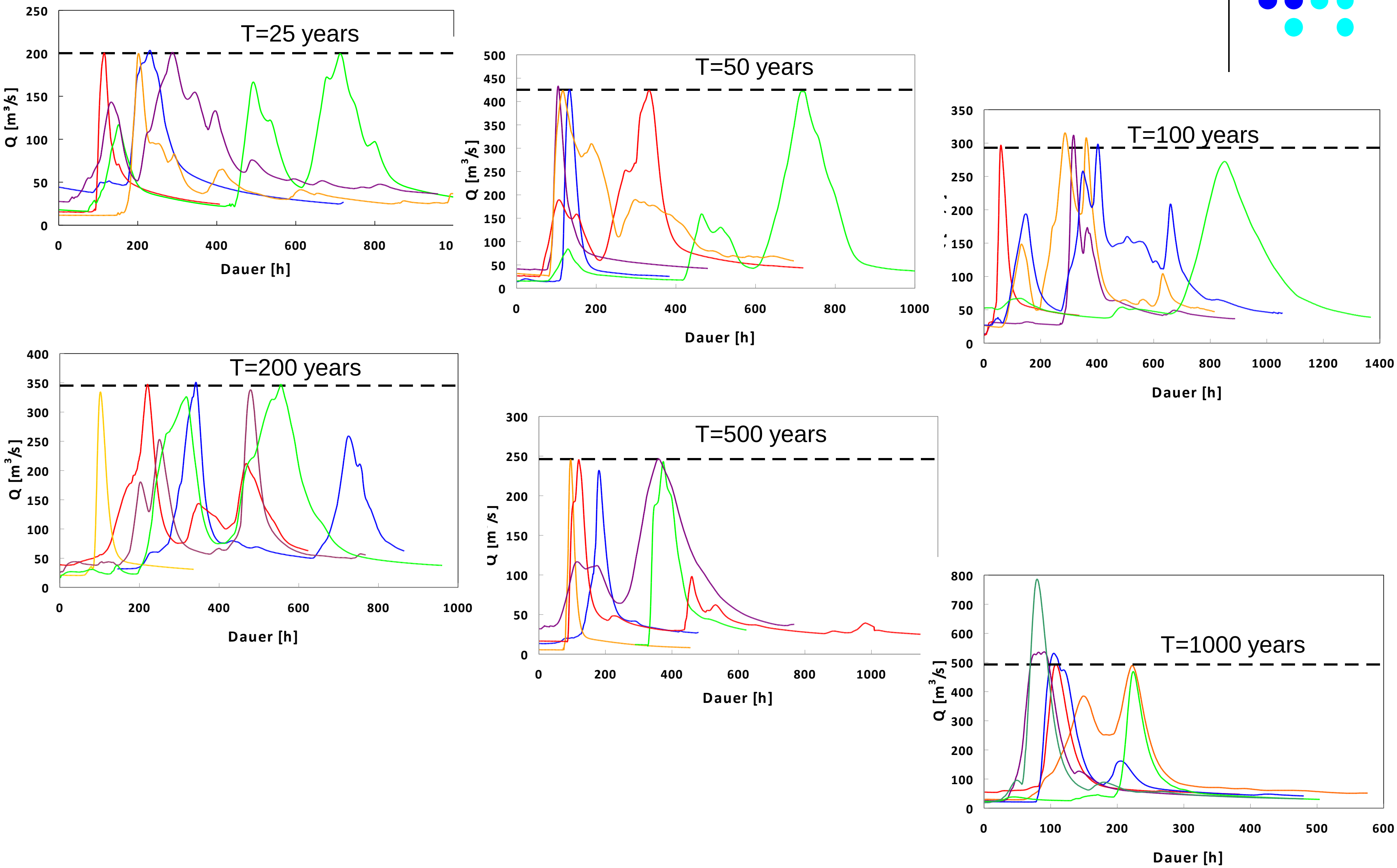
E.g. return period of flood peak of about 250 years at reservoir Straußfurt, the corresponding return periods of the flood volumes ranges between 50 and 500 years

Bivariate Analysis: Flood Peak-Volume at dam sites

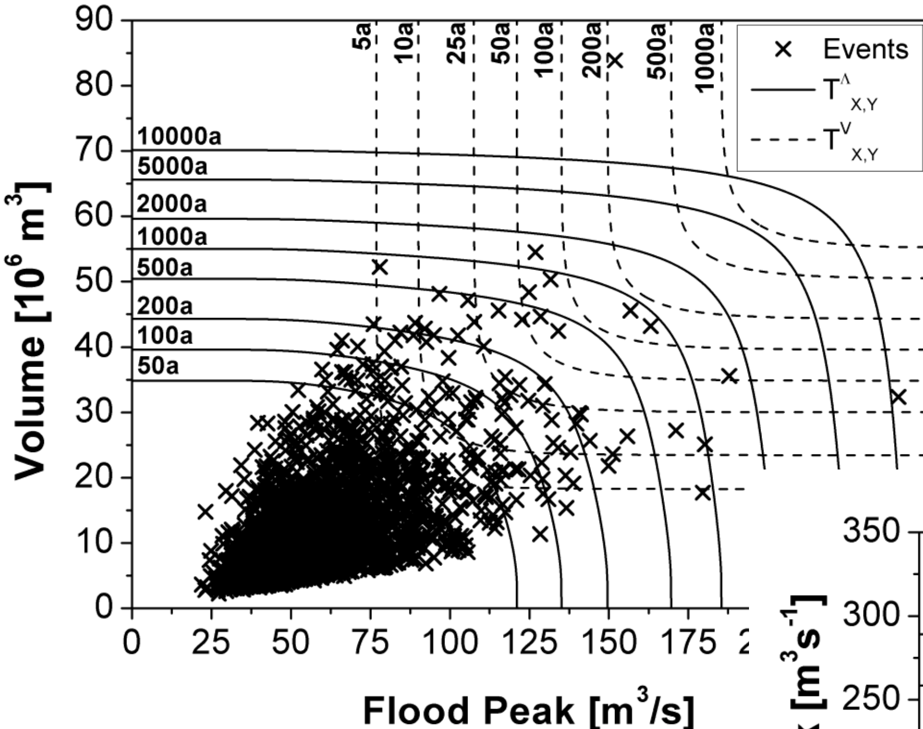
Joint return periods:

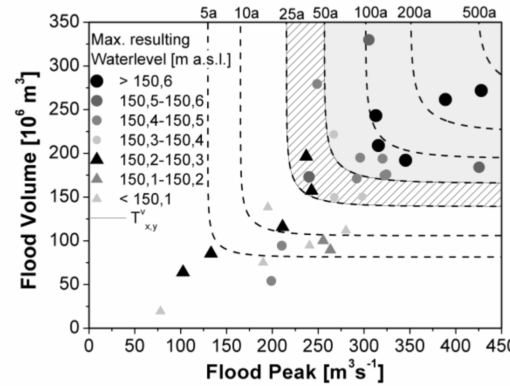


Hydrological Scenarios of different return periodes

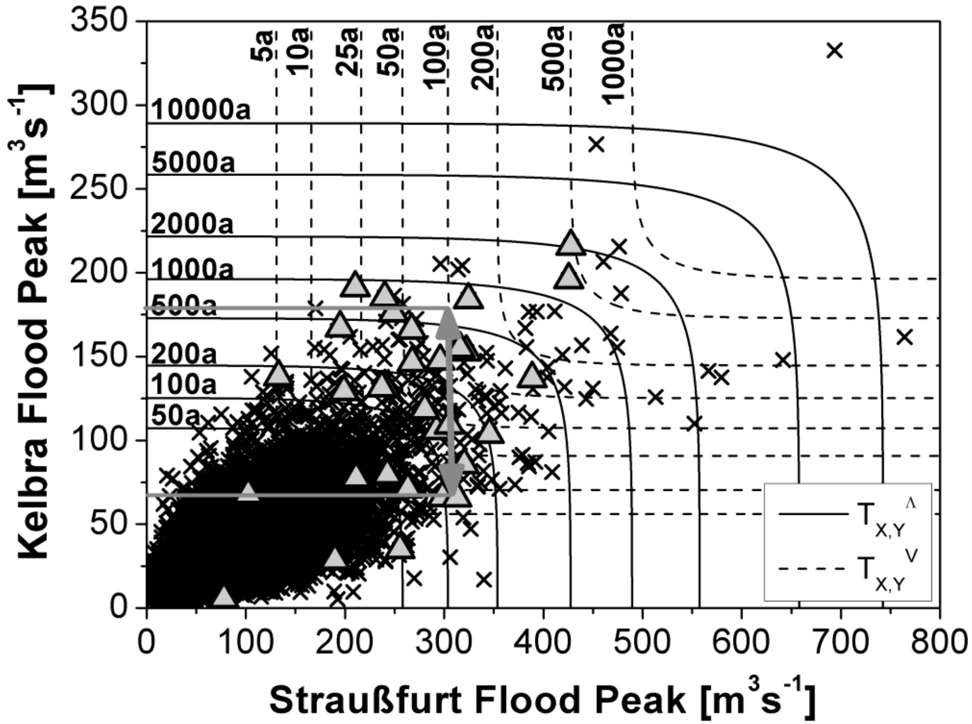


Utilization of Copulas





Performance of single reservoirs



Interactions of tributaries

Multivariate statistical characteristics of Flood Scenarios

T Peak

Compared with statistics from observed data

HQ100	Szenario				
	HQ100_ 2192_3	HQ100_ 2192_8	HQ100_ 2206	HQ100_ [illegible]	HQ100_ [illegible]
HQ $_S$ [m³/s]	315	[illegible]	[illegible]	[illegible]	[illegible]
HQ $_K$ [m³/s]	206	[illegible]	129	17	193
Vol.$_S$ [Mio. m³]	279	[illegible]	[illegible]	[illegible]	197
Vol.$_K$ [Mio. m³]	148	[illegible]	[illegible]	[illegible]	76
$T^{\wedge}_{HQ\_S, Vol\_S}$ [years]	681	236	[illegible]	[illegible]	[illegible]
$T^{V}_{HQ\_S, Vol\_S}$ [years]	44	55	[illegible]	[illegible]	34
$T^{\wedge}_{HQ\_K, Vol\_K}$ [years]	3861	2025	[illegible]	2	203
$T^{V}_{HQ\_K, Vol\_K}$ [years]	532	371	[illegible]	[illegible]	47
$T^{\wedge}_{HQ\_S,K}$ [years]	578	440	[illegible]	[illegible]	146
$T^{V}_{HQ\_S,K}$ [years]	43	57	131	2	34

Derived from coupled models: „Imprecise probabilities“

Copula- T(Peak **and** Volume) Reservoir Straussfurt

Copula- T T(Peak **or** Volume) Reservoir Straussfurt

Copula- T(Peak **and** Volume Reservoir Kelbra)

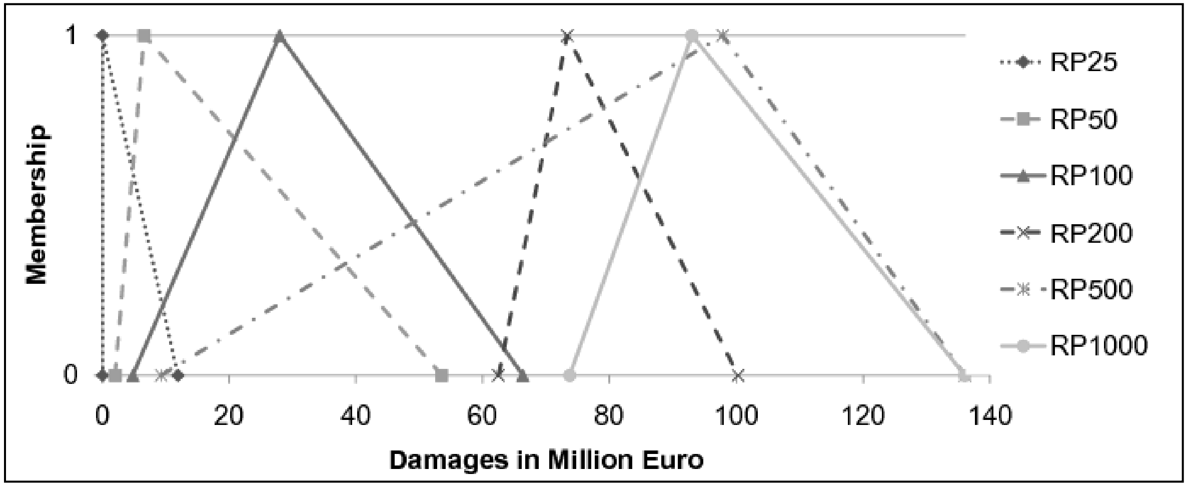
Copula- T(Peak **or** Volume Reservoir Kelbra)

Copula- T(Peak Kelbra **and** Straussfurt)

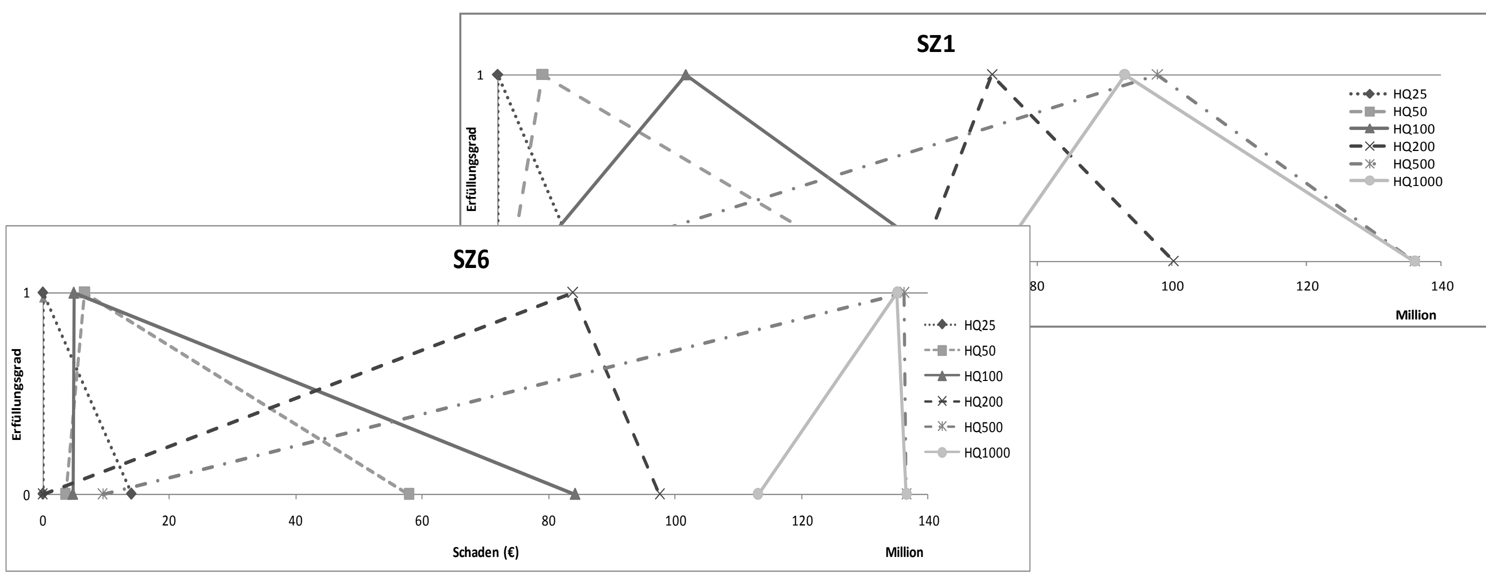
Copula- T(Peak Kelbra **or** Straussfurt)

Plausibility of Impact Assessments of Flood Scenarios

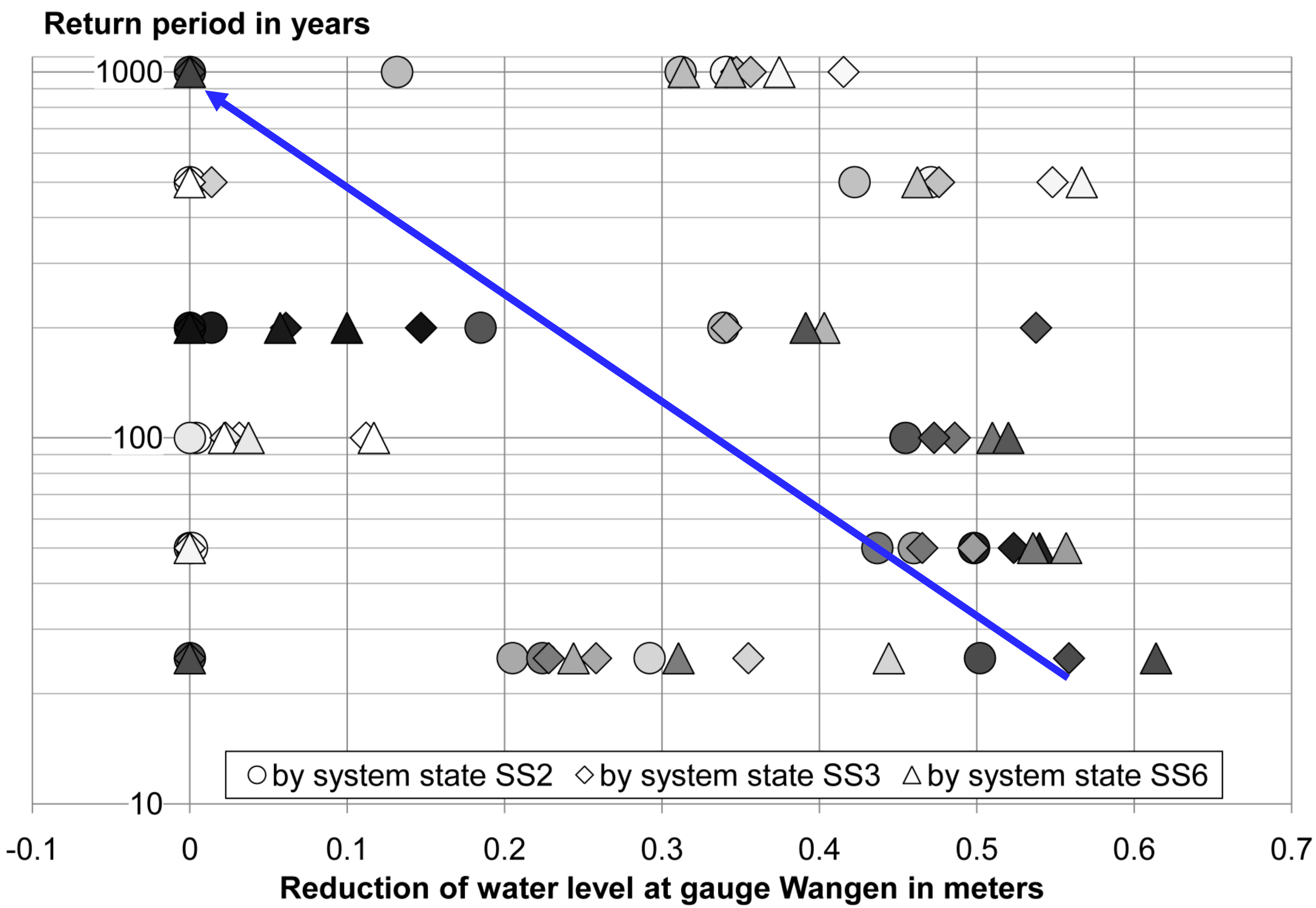
$$P_{Plausibility} = \begin{cases} \mathrm{Min}\left(\frac{T_{Copula}}{T_{Peak}};\frac{2\cdot T_{Peak}-T_{Copula}}{T_{Copula}}\right), & \forall T_{Copula}\in\left[0;\ 2\cdot T_{Peak}\right] \\ 0, & \forall T_{Copula}\notin\left[0;\ 2\cdot T_{Peak}\right] \end{cases}$$



Resulting from the assessments of plausibilty of floods the impacts of measures (e.g. damages) can be fuzzyfied)



Effectiveness of flood retention: Reduction of the flood peak at the basin outlet



Plausibility is depicted in colour intensity: highly plausible events are black; implausible events are white

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4. Decision support
5. Summary

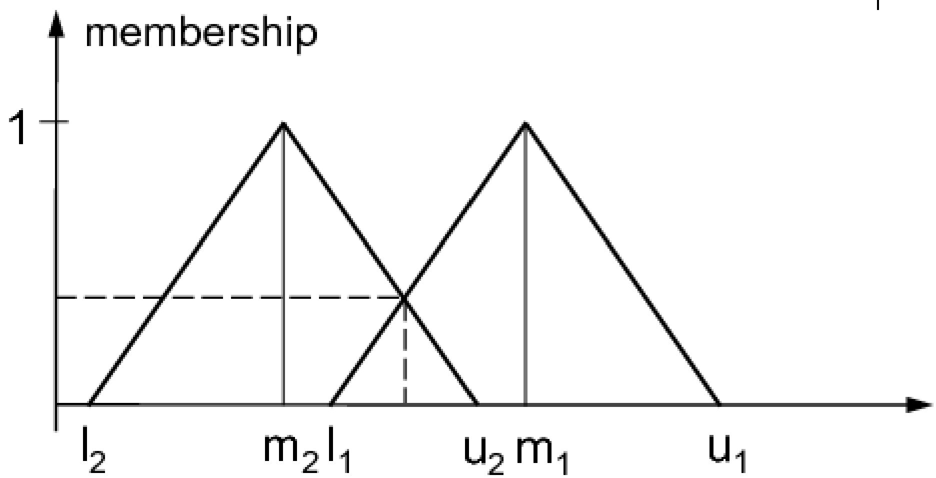
Possibility that a certain state of the system (SS1 to SS6) would result in higher economic damages than all other alternatives, differentiated by return periods (RP in years)

Intersection $V(F_2 > F_1)$:

$$1 \quad if \; m_2 \geq m_1 \quad or \quad 0 \quad if \; l_1 \geq u_2$$

in all other cases.

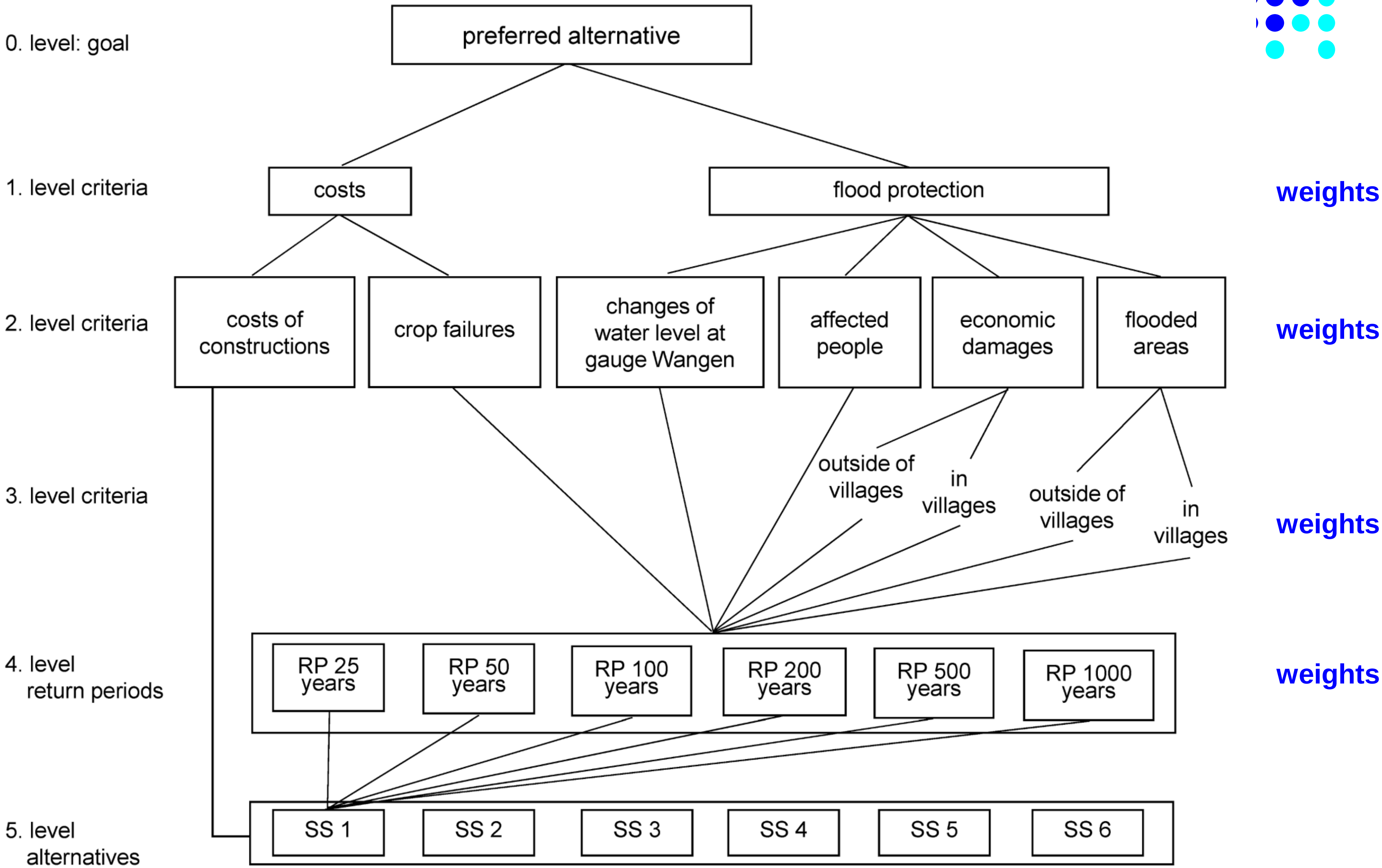
$$\frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}$$



SS	T=25 yrs	T=50 yrs	T=100 yrs	T=200 yrs	T=500 yrs	T=1000 yrs
1	0.167	0.167	0.196	0.095	0.144	0.085
2	0.167	0.167	0.196	0.082	0.142	0.085
3	0.167	0.167	0.151	0.116	0.152	0.106
4	0.167	0.167	0.153	**0.237**	0.188	**0.242**
5	0.167	0.167	0.152	**0.234**	0.187	**0.239**
6	0.167	0.167	0.152	**0.236**	0.187	**0.243**

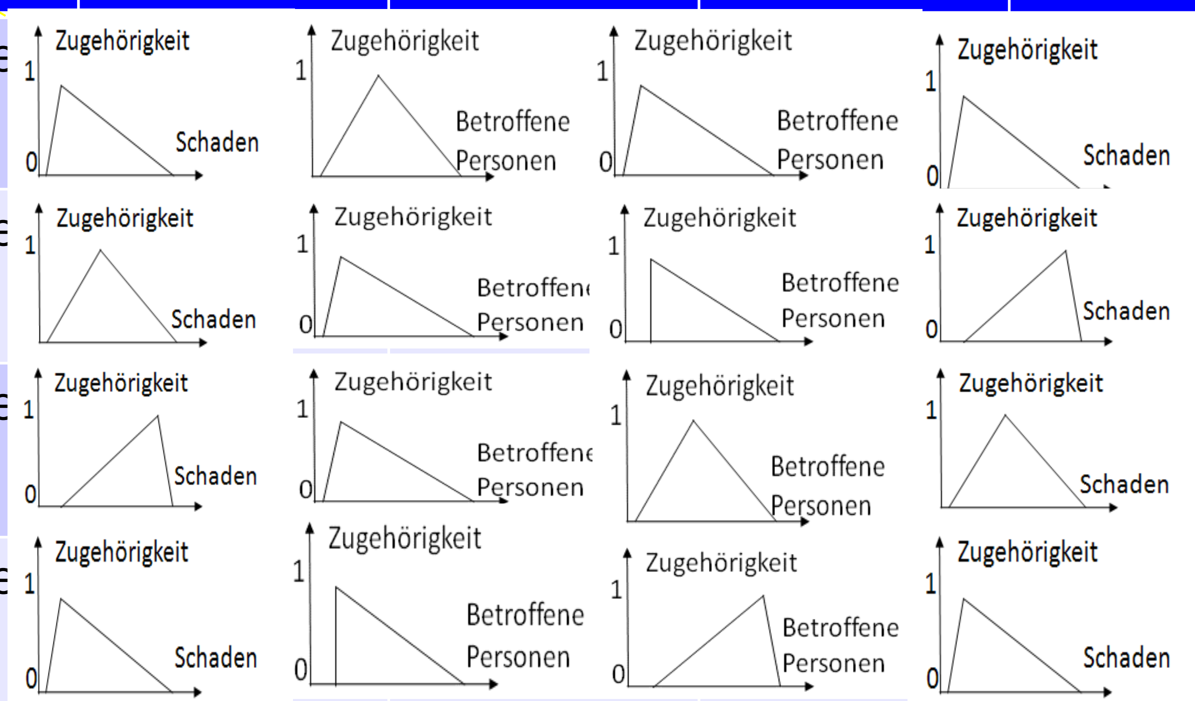
Hierarchic structure of the F-AHP approach

AHP: Analytical Hierarchic Programming

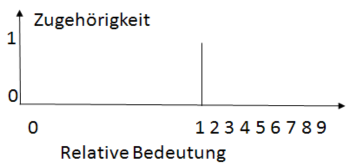
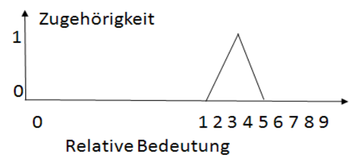
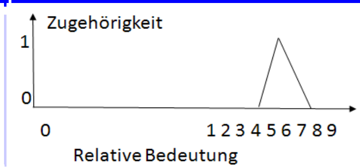
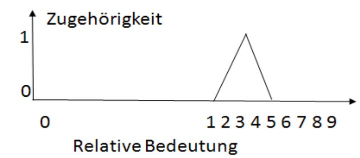
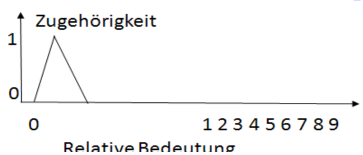
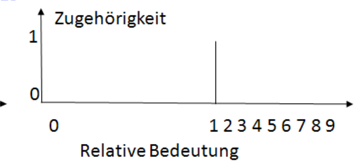
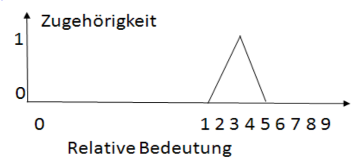
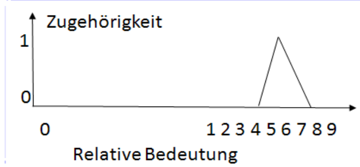
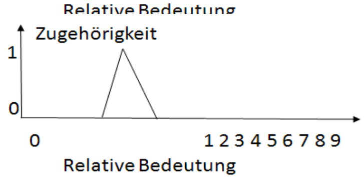
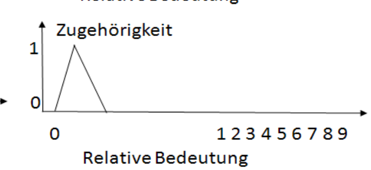
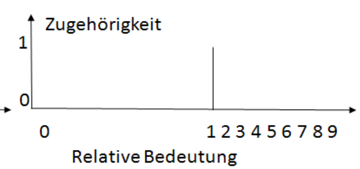
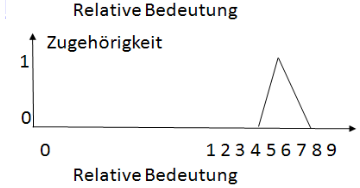
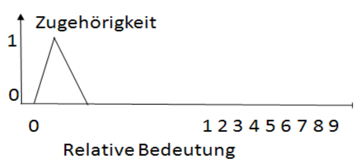
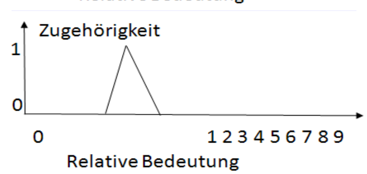
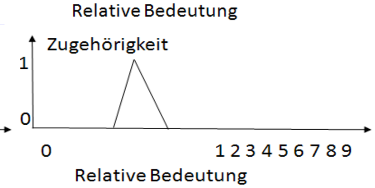
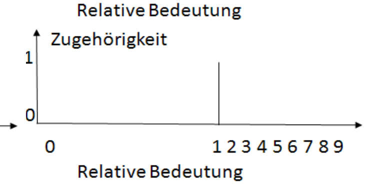


Fuzzyfied Impacts of Planning Alternatives

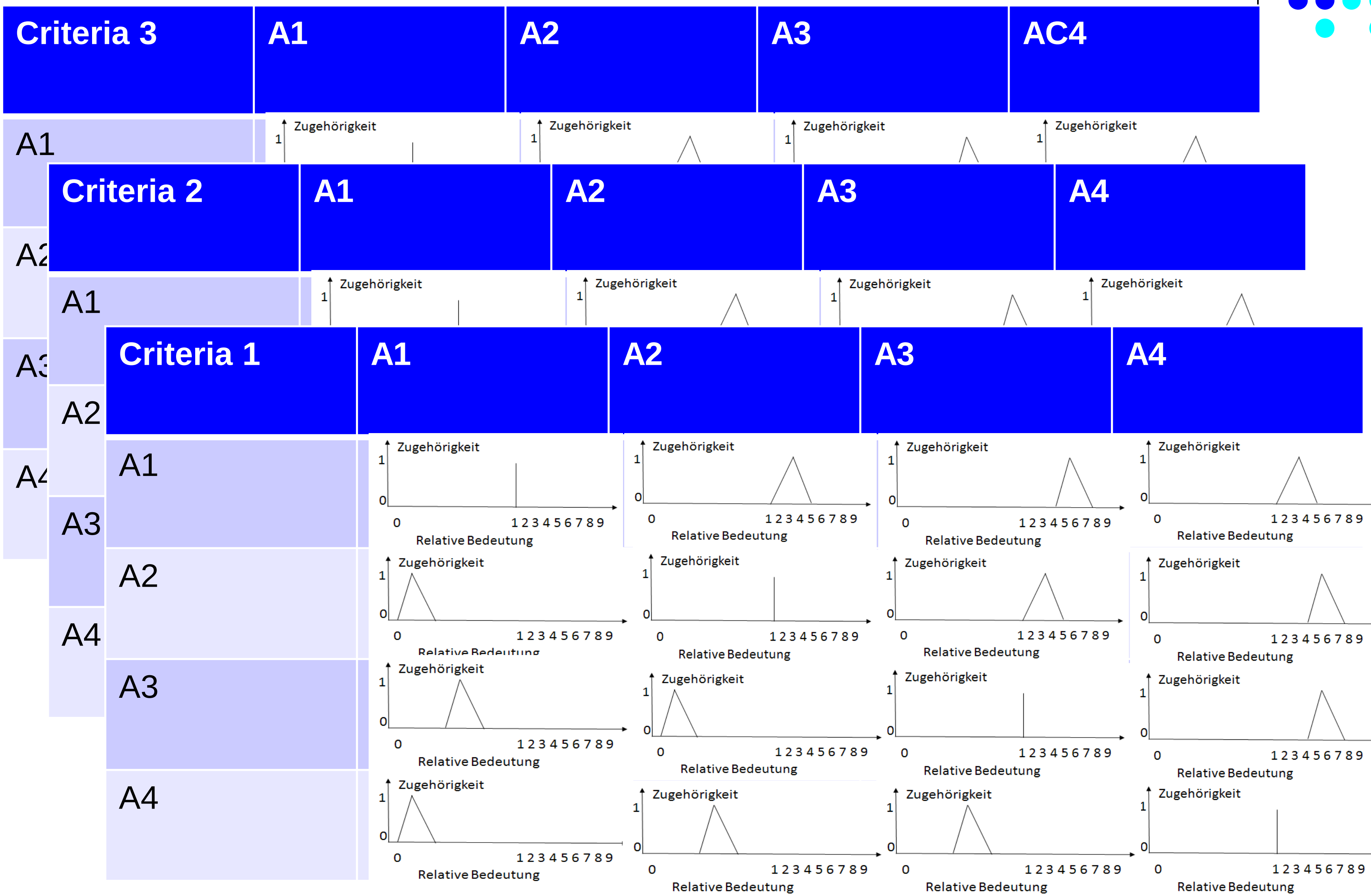
Criteria / Alternatives	K1	K2	K3	K4
Alternative				
Alternative				
Alternative				
Alternative				



Relative Importance of Criteria for Decision Maker

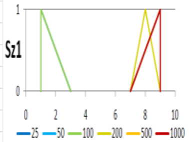
	Criteria 1	Criteria 2	Criteria 3	Criteria 4
Criteria1				
Criteria 2				
Criteria 3				
Criteria 4				

Intercomparison of Alternatives with regard to single criteria

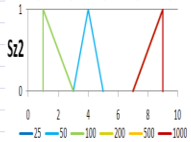


5. Ebene Alternativen

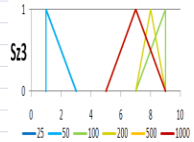
Normierte Werten für Ökonomische Schaden Außerhalb von Polder:



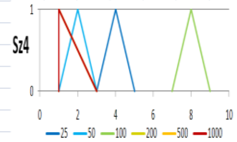
	Sz1
HQ 25	(1,1,3)
HQ 50	(7,9,9)
HQ100	(1,1,3)
HQ200	(7,8,9)
HQ500	(7,9,9)
HQ1000	(7,9,9)



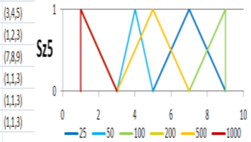
	Sz2
HQ 25	(7,9,9)
HQ 50	(3,4,5)
HQ100	(1,1,3)
HQ200	(7,9,9)
HQ500	(7,9,9)
HQ1000	(7,9,9)



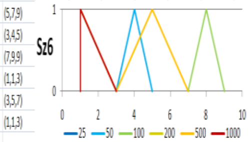
	Sz3
HQ 25	(1,1,3)
HQ 50	(1,1,3)
HQ100	(7,9,9)
HQ200	(7,8,9)
HQ500	(5,7,9)
HQ1000	(5,7,9)



	Sz4
HQ 25	(3,4,5)
HQ 50	(1,2,3)
HQ100	(7,8,9)
HQ200	(1,1,3)
HQ500	(1,1,3)
HQ1000	(1,1,3)



	Sz5
HQ 25	(5,7,9)
HQ 50	(3,4,5)
HQ100	(7,9,9)
HQ200	(1,1,3)
HQ500	(3,5,7)
HQ1000	(1,1,3)



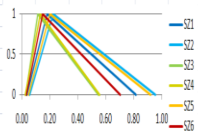
	Sz6
HQ 25	(3,4,5)
HQ 50	(3,4,5)
HQ100	(7,8,9)
HQ200	(1,1,3)
HQ500	(3,5,7)
HQ1000	(1,1,3)

4. Ebene Jährlichkeitsklassen

Fokus auf häufige HQ´s

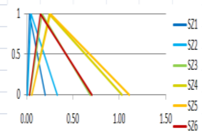
		COG:
HQ 25	(0.18,0.37,0.69)	0.411939
HQ 50	(0.13,0.27,0.56)	0.319946
HQ100	(0.08,0.18,0.41)	0.223697
HQ200	(0.04,0.1,0.27)	0.138702
HQ500	(0.02,0.05,0.16)	0.076432
HQ1000	(0.01,0.02,0.08)	0.037314

Ökonomische Schäden außerhalb von Ortschaften:



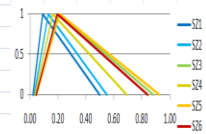
		COG:
SZ1	(0.04,0.18,0.82)	0.346667
SZ2	(0.06,0.22,0.95)	0.41
SZ3	(0.03,0.11,0.55)	0.23
SZ4	(0.03,0.13,0.56)	0.24
SZ5	(0.05,0.2,0.92)	0.39
SZ6	(0.03,0.15,0.7)	0.293333

Überschwemmte Fläche außerhalb von Polder:



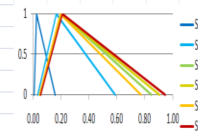
		COG:
SZ1	(0.01,0.03,0.2)	0.08
SZ2	(0.01,0.05,0.33)	0.13
SZ3	(0.04,0.17,0.69)	0.3
SZ4	(0.06,0.25,1.03)	0.446667
SZ5	(0.06,0.26,1.11)	0.476667
SZ6	(0.06,0.25,0.99)	0.433333

Betroffene Personen



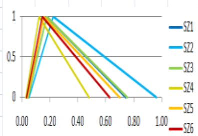
		COG:
SZ1	(0.02,0.09,0.5)	0.203333
SZ2	(0.03,0.13,0.55)	0.236667
SZ3	(0.05,0.21,0.88)	0.38
SZ4	(0.04,0.16,0.69)	0.296667
SZ5	(0.05,0.21,0.93)	0.396667
SZ6	(0.05,0.19,0.84)	0.36

Wasserstand Wangen:



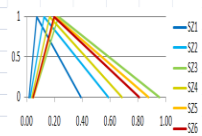
		COG:
SZ1	(0.01,0.02,0.16)	0.063333
SZ2	(0.03,0.16,0.59)	0.26
SZ3	(0.05,0.2,0.85)	0.366667
SZ4	(0.05,0.2,0.91)	0.386667
SZ5	(0.05,0.2,0.77)	0.34
SZ6	(0.05,0.21,0.95)	0.403333

Ökonomische Schaden innerhalb Ortschaften:



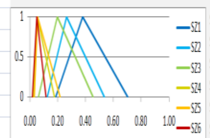
		COG:
SZ1	(0.04,0.18,0.74)	0.32
SZ2	(0.05,0.22,0.96)	0.41
SZ3	(0.04,0.18,0.75)	0.323333
SZ4	(0.03,0.12,0.48)	0.21
SZ5	(0.04,0.16,0.7)	0.3
SZ6	(0.03,0.14,0.63)	0.266667

Überschwemmte Fläche innerhalb von Ortschaften:



		COG:
SZ1	(0.02,0.07,0.39)	0.16
SZ2	(0.03,0.13,0.59)	0.25
SZ3	(0.05,0.23,0.96)	0.413333
SZ4	(0.04,0.17,0.69)	0.3
SZ5	(0.05,0.21,0.88)	0.38
SZ6	(0.05,0.2,0.81)	0.353333

Baukosten



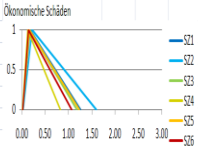
SZ1	(0.19,0.38,0.7)
SZ2	(0.12,0.26,0.54)
SZ3	(0.06,0.2,0.45)
SZ4	(0.03,0.05,0.18)
SZ5	(0.03,0.05,0.22)
SZ6	(0.02,0.05,0.12)

3. Kriterienebene (Lage der Schadensflächen)

In Ortschaften

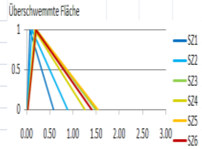
Außerhalb	(0.07,0.1,0.34)	0.172774
In Ortscha	(0.53,0.9,1.32)	0.915125

Ökonomische Schäden



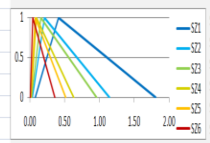
		COG:
SZ1	(0.03,0.18,1.26)	0.49
SZ2	(0.03,0.22,1.6)	0.616667
SZ3	(0.02,0.17,1.18)	0.456667
SZ4	(0.02,0.12,0.83)	0.323333
SZ5	(0.02,0.16,1.24)	0.473333
SZ6	(0.02,0.14,1.07)	0.41

Überschwemmte Fläche



		COG:
SZ1	(0.01,0.07,0.59)	0.223333
SZ2	(0.01,0.12,0.89)	0.34
SZ3	(0.03,0.22,1.5)	0.583333
SZ4	(0.02,0.17,1.26)	0.483333
SZ5	(0.03,0.21,1.54)	0.593333
SZ6	(0.03,0.2,1.41)	0.546667

Schaden in Polder



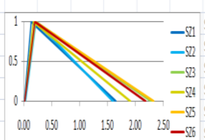
SZ1	(0.08,0.41,1.81)
SZ2	(0.08,0.41,1.81)
SZ3	(0.08,0.41,1.81)
SZ4	(0.08,0.41,1.81)
SZ5	(0.08,0.41,1.81)
SZ6	(0.08,0.41,1.81)

2. Kriterienebene

Überschwemmte Flächen

Ökonomisc	(0.05,0.08,0.29)	0.1431
Überschwe	(0.38,0.75,0.96)	0.696844
Betroffene	(0.05,0.08,0.29)	0.1431
Wasserstа	(0.05,0.08,0.29)	0.1431

Hochwasserschutzwirkung gesamt



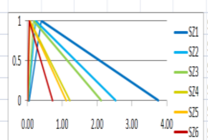
		COG:
SZ1	(0.01,0.08,1.12)	0.403333
SZ2	(0.01,0.13,1.65)	0.596667
SZ3	(0.02,0.22,2.28)	0.84
SZ4	(0.01,0.17,1.91)	0.696667
SZ5	(0.02,0.21,2.33)	0.853333
SZ6	(0.02,0.2,2.18)	0.8

2. Kriterienebene Kosten

Gleiche Gewichtung

Baukosten	(0.17,0.5,1.5)	0.722222
Fokus auf E	(0.17,0.5,1.5)	0.722222

Kosten



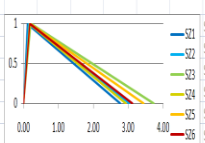
		COG:
SZ1	(0.05,0.4,3.76)	1.403333
SZ2	(0.03,0.24,2.54)	0.936667
SZ3	(0.02,0.18,2.12)	0.773333
SZ4	(0.01,0.08,1.22)	0.436667
SZ5	(0.01,0.06,1.11)	0.393333
SZ6	(0.01,0.05,0.72)	0.26

1. Kriterienebene

Fokus auf Hochwasserschutzwirkung

Hochwasse	(0.53,0.9,1.32)	0.915125
Kosten	(0.07,0.1,0.34)	0.172774

Ziel



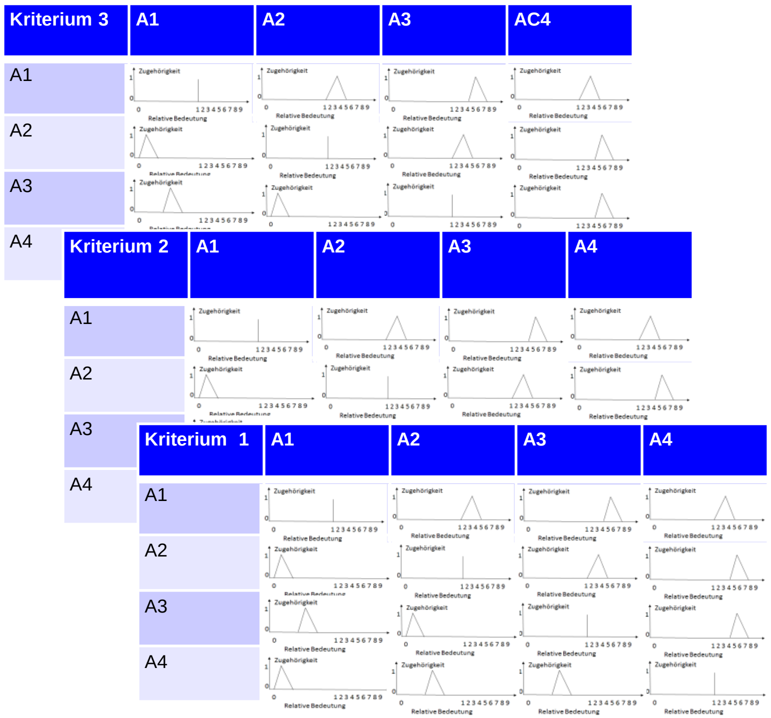
Gesamtergebnis

		COG:		Total Integral Value λ: 0	0.5	1
SZ1	(0.01,0.11,2.77)	0.963333	SZ1	0.06	0.75	1.44
SZ2	(0.01,0.14,3.05)	1.066667	SZ2	0.08	0.84	1.60
SZ3	(0.01,0.21,3.74)	1.32	SZ3	0.11	1.04	1.98
SZ4	(0.01,0.16,2.94)	1.036667	SZ4	0.09	0.82	1.55
SZ5	(0.01,0.19,3.45)	1.216667	SZ5	0.10	0.96	1.82
SZ6	(0.01,0.18,3.12)	1.103333	SZ6	0.10	0.87	1.65

User Interface DSS

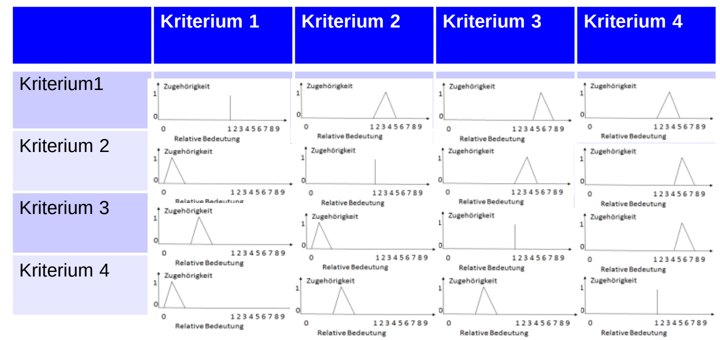
Fuzzy- AHP

Comparison of alternatives with several criteria



⊗

Fuzzyfied Matrix of the relative importance of the criteria for desicion makers



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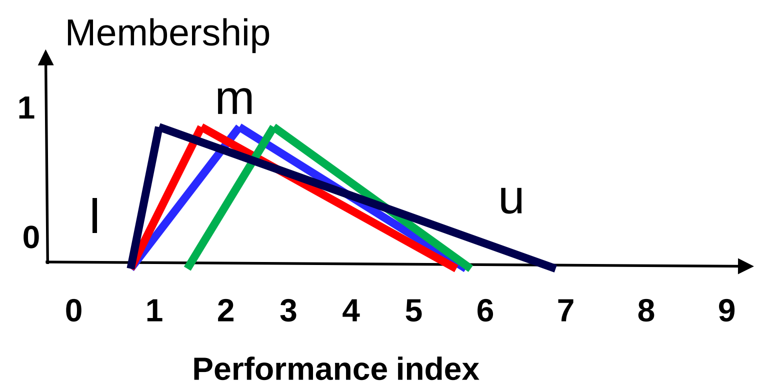
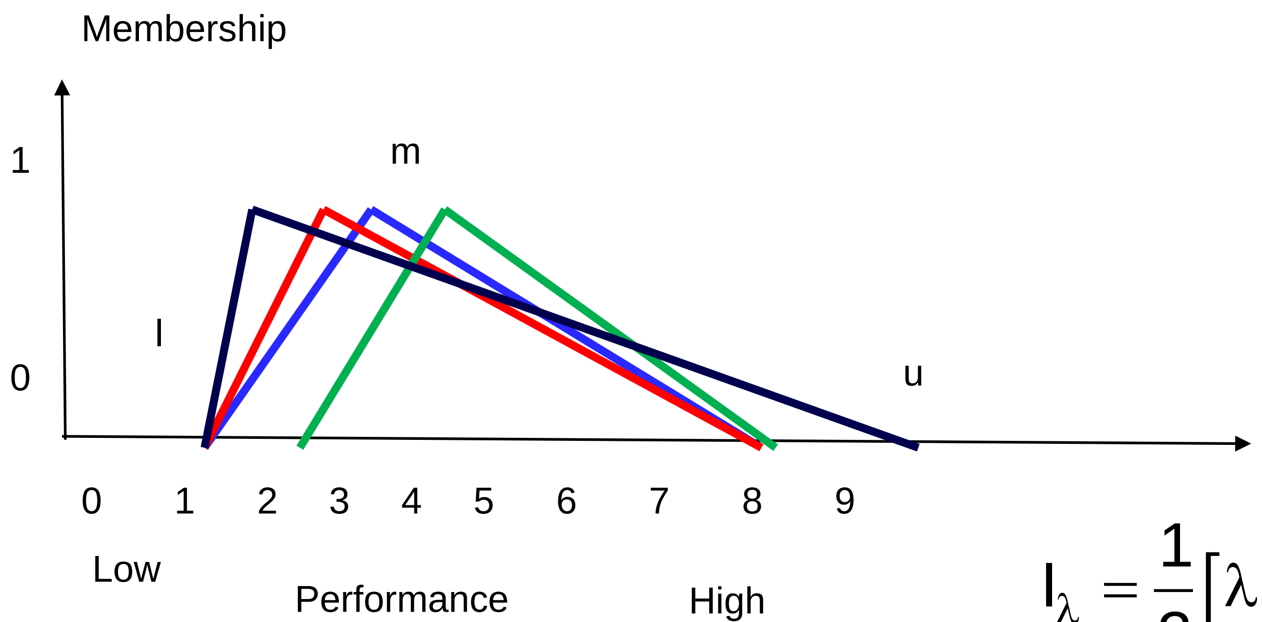


De-Fuzzyfication



$$I_\lambda = \frac{1}{2}[\lambda u + m + (1-\lambda) l]$$

λ Pessimism/ Optimism-Index
=1 optimistic, upper bound of performance
=0 pessimistic, lower bound of performance

Impact of the parameter λ on defuzzification of the results of FAHP

λ :	**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**
0	0.11	0.12	0.11	0.06	0.07	0.07
0.5	1.90	2.01	1.91	1.21	1.58	1.40
1	3.70	3.91	3.72	2.36	3.10	2.73

Results of the Fuzzy-AHP approach with focus on flood protection and equal weighting of damages at settlements and non-populated areas, Defuzzification with the Total Integrated Value (λ=0.5), optimal is the maximum (numbers printed in bold)

Main Goals	SS1	SS2	SS3	SS4	SS5	SS6
Reduction of flood peaks at the basin outlet						
all floods	1.11	1.27	**1.50**	1.15	1.25	1.19
frequent floods only	0.78	0.95	**1.06**	0.95	1.04	0.99
rare floods only	0.91	0.97	**1.19**	0.78	0.84	0.78
Damage reductions within the Unstrut basin upstreams of gauge Wangen						
all floods	1.90	**2.01**	1.91	1.21	1.58	1.40
frequent floods only	1.30	**1.47**	1.28	1.07	1.40	1.20
rare floods only	**1.55**	**1.55**	**1.55**	0.72	0.94	0.85
Combined goals: flood peak reduction, damage reduction, minimum of potential damage increases						
all floods	1.44	**1.57**	**1.57**	1.06	1.28	1.18
frequent floods only	1.01	**1.18**	1.07	0.91	1.10	0.99
rare floods only	1.16	1.20	**1.28**	0.67	0.80	0.75

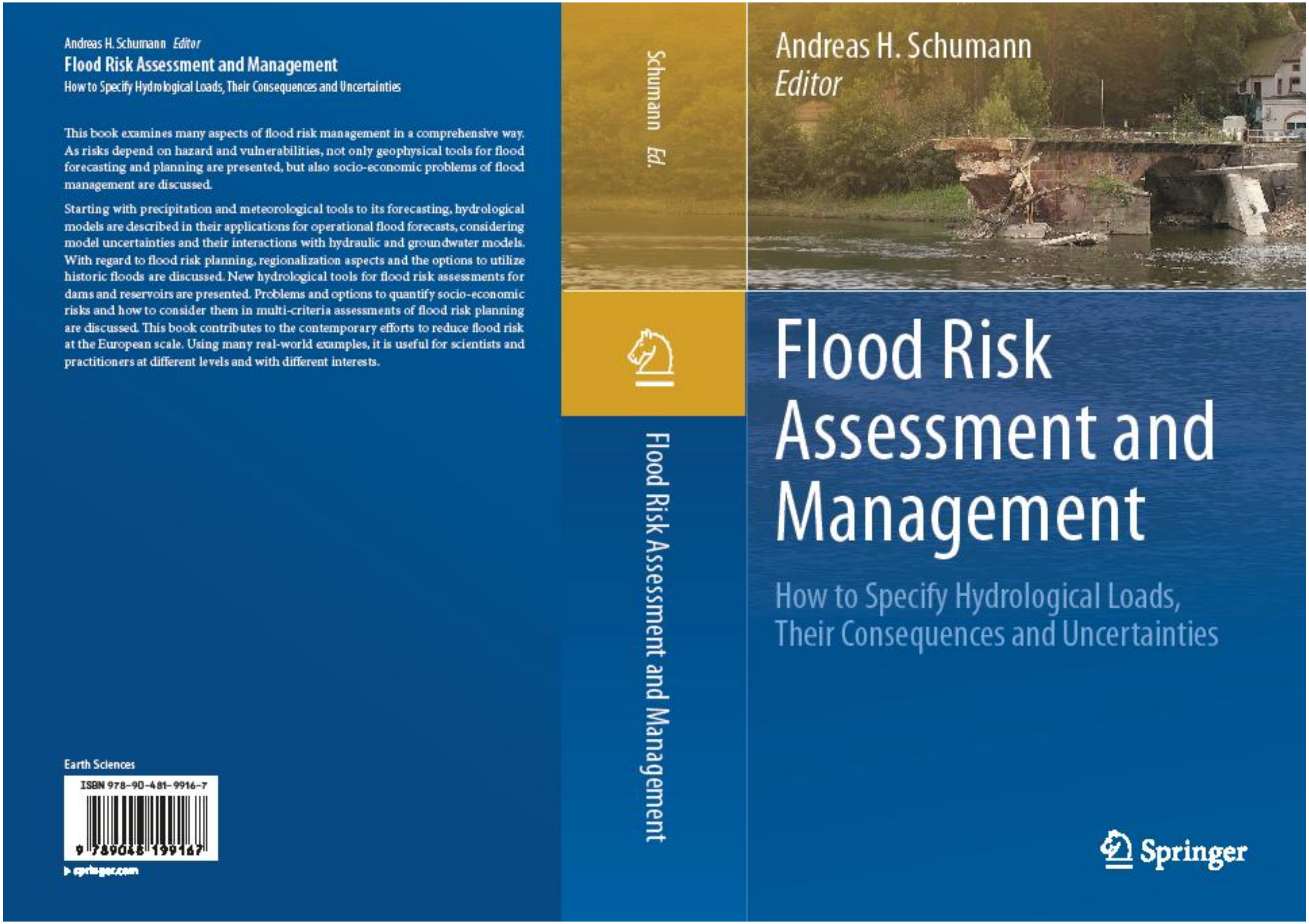
Summary

1. Risik- oriented planning and design demands the consideration of uncertainties of hydrological loads.

2. A variety of hydrological loads can be considered by scenarios, which should cover the range of possible circumstances.

3. The possibility of different hydrological loads can be characterised by multi-variate statistics. The data base is often insufficient to derive them. If stochastic-deterministic simulations are used to generate such a data base, the results are uncertain as well as the probabilities derived from these data.

4. The uncertainty of simulated data should be considered in decision making, e.g. by fuzzy sets.


Andreas H. Schumann Editor
Flood Risk Assessment and Management
How to Specify Hydrological Loads, Their Consequences and Uncertainties
This book examines many aspects of flood risk management in a comprehensive way. As risks depend on hazard and vulnerabilities, not only geophysical tools for flood forecasting and planning are presented, but also socio-economic problems of flood management are discussed.
Starting with precipitation and meteorological tools to its forecasting, hydrological models are described in their applications for operational flood forecasts, considering model uncertainties and their interactions with hydraulic and groundwater models. With regard to flood risk planning, regionalization aspects and the options to utilize historic floods are discussed. New hydrological tools for flood risk assessments for dams and reservoirs are presented. Problems and options to quantify socio-economic risks and how to consider them in multi-criteria assessments of flood risk planning are discussed. This book contributes to the contemporary efforts to reduce flood risk at the European scale. Using many real-world examples, it is useful for scientists and practitioners at different levels and with different interests.
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It is certain that nothing is certain but even this is not certain.

Ringelnatz

Thank you for your attention !