Summer Course 2022

"NATURE-BASED SOLUTIONS (NBS) TO CONFRONT WATER EXTREMES IN EUROPE: DESIGN AND MODELLING TOOLS"

(Within the project TRITON; https://triton.wasser.tum.de/)

General course I – Hydrology and Flood Risk Management

Prof. Dr.-Ing. Markus Disse

Chair of Hydrology and River Basin Management

Technical University of Munich

Athens, 05.09.2022, 09:30-11:00

Outline

- Introduction
- Flood Risk – Definition and General Concepts
- Flood Protection Measures
- Flood Chain Uncertainties

Introduction

Flood Risk is…

Likelihood
of the runoff event

X

Severity
of the runoff event

Flood Risk – a combination of ...

Likelihood
of a flood event

&

unfavourable **consequences / damages** for:

- human health
- environment
- cultural heritage
- economy
- significant tangible assets

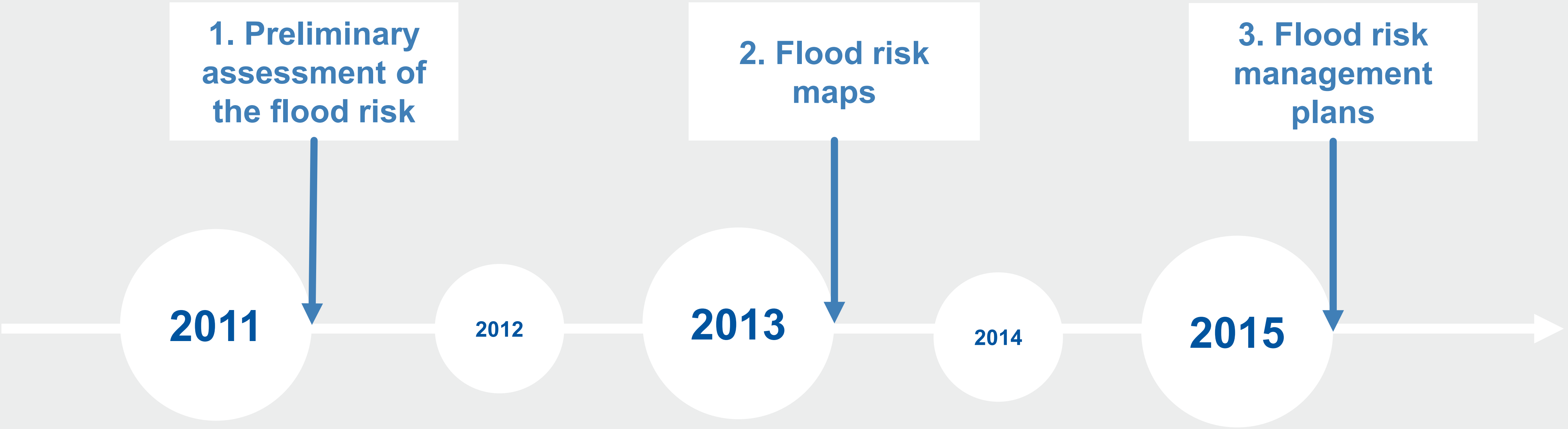
Source: § 73 German Water Management Act

NATURAL RETENTION

TECHNICAL FLOOD PROTECTION

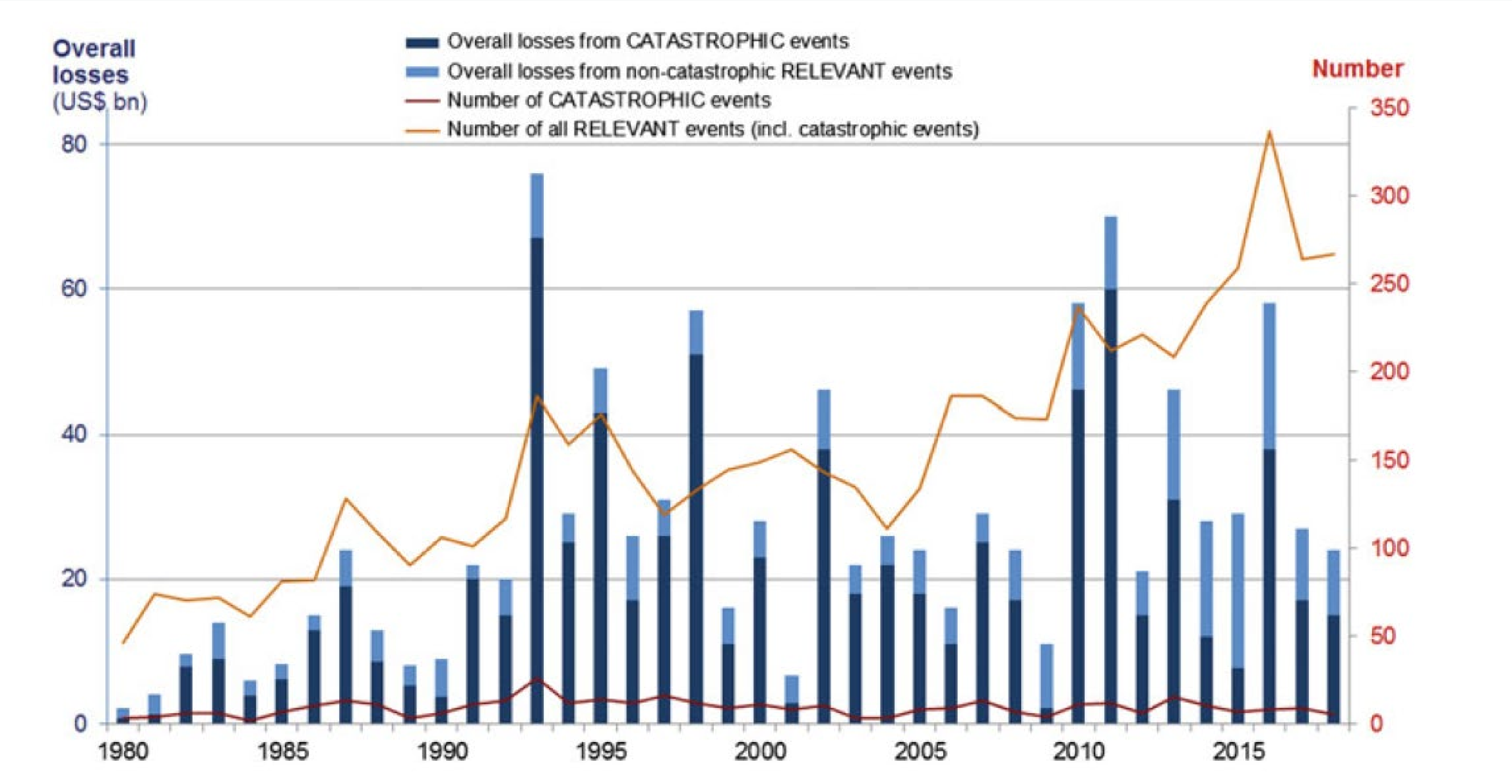
ADVANCED FLOOD PROTECTION

Modern Flood Protection



3 Steps of the Flood Risk Management Directive

… what it is all about



(Kron et al., 2021)

Loss Events worldwide (1980 – 2014)

- Water
- Fitness Check of the EU Water Legislation 2019
- Blueprint 2012
- River Basin Management
- Flood Risk Management
  - Introduction
  - About flood risk management
  - Floods Directive
  - Key documents
  - Links
- Water Scarcity, Droughts and Water Reuse

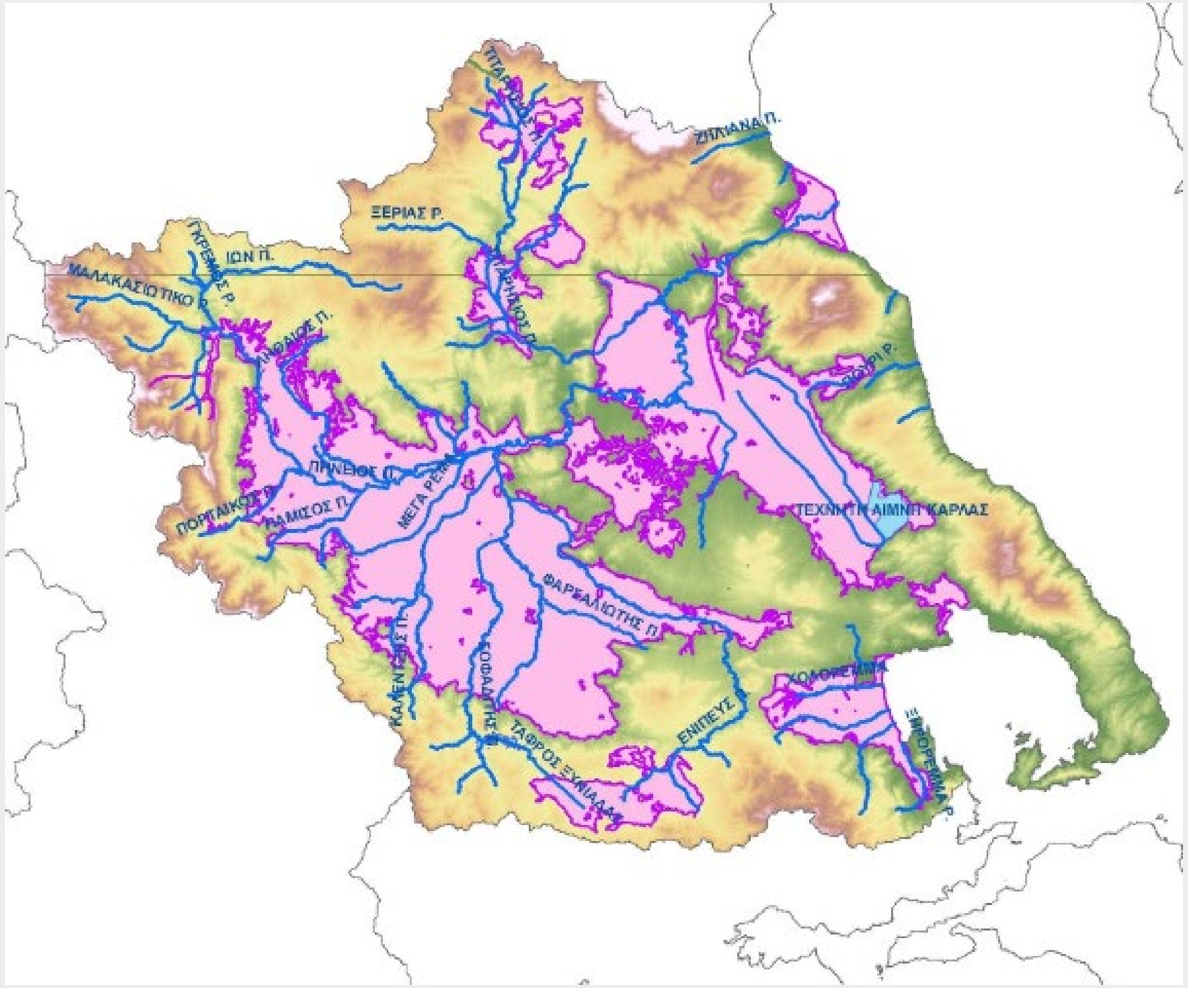
The EU Floods Directive

Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. This Directive now requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk. With this Directive also reinforces the rights of the public to access this information and to have a say in the planning process.

https://ec.europa.eu/environment/water/flood_risk/flood_atlas/index.htm

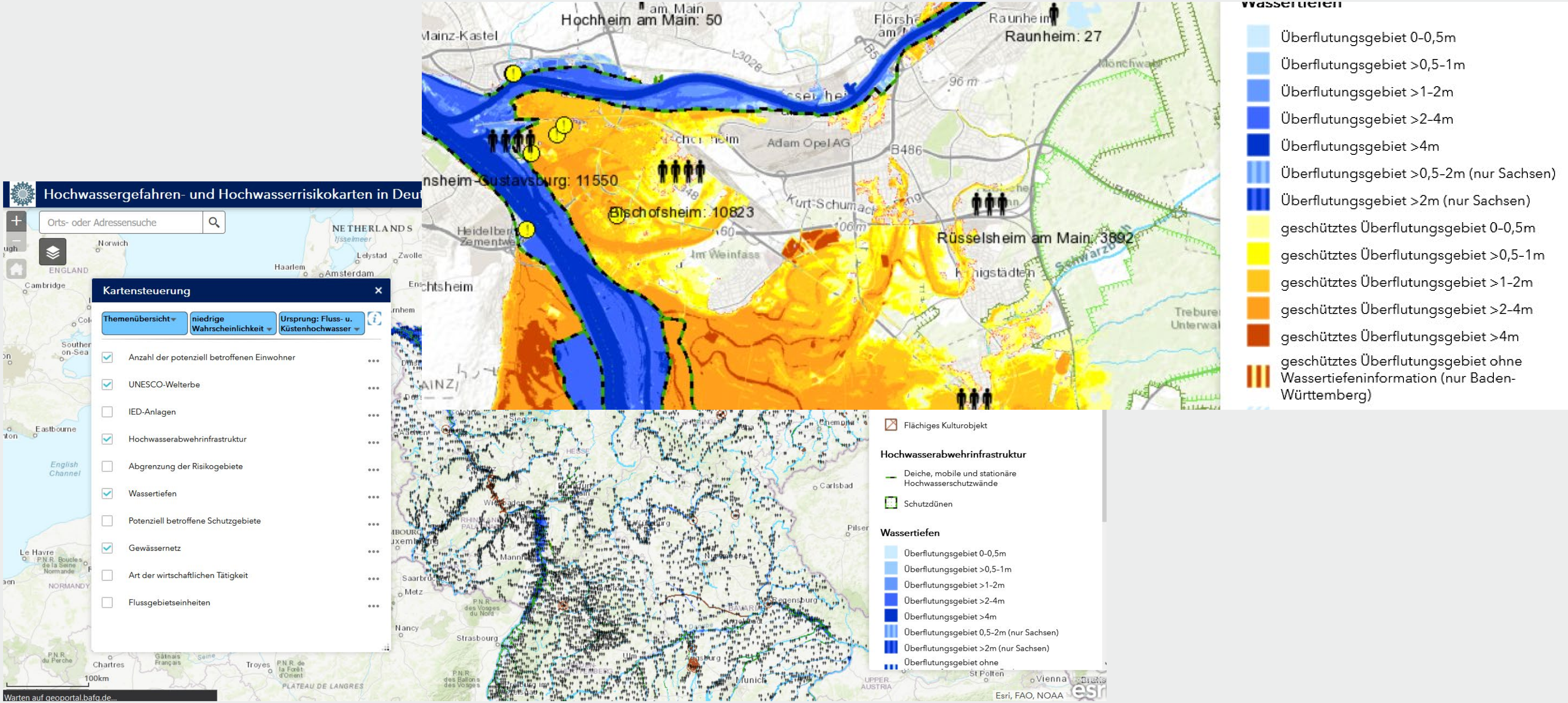
The EU Floods Directive Portal

Ref.: http://floods.ypeka.gr/index.php/ydatika-diamerismata



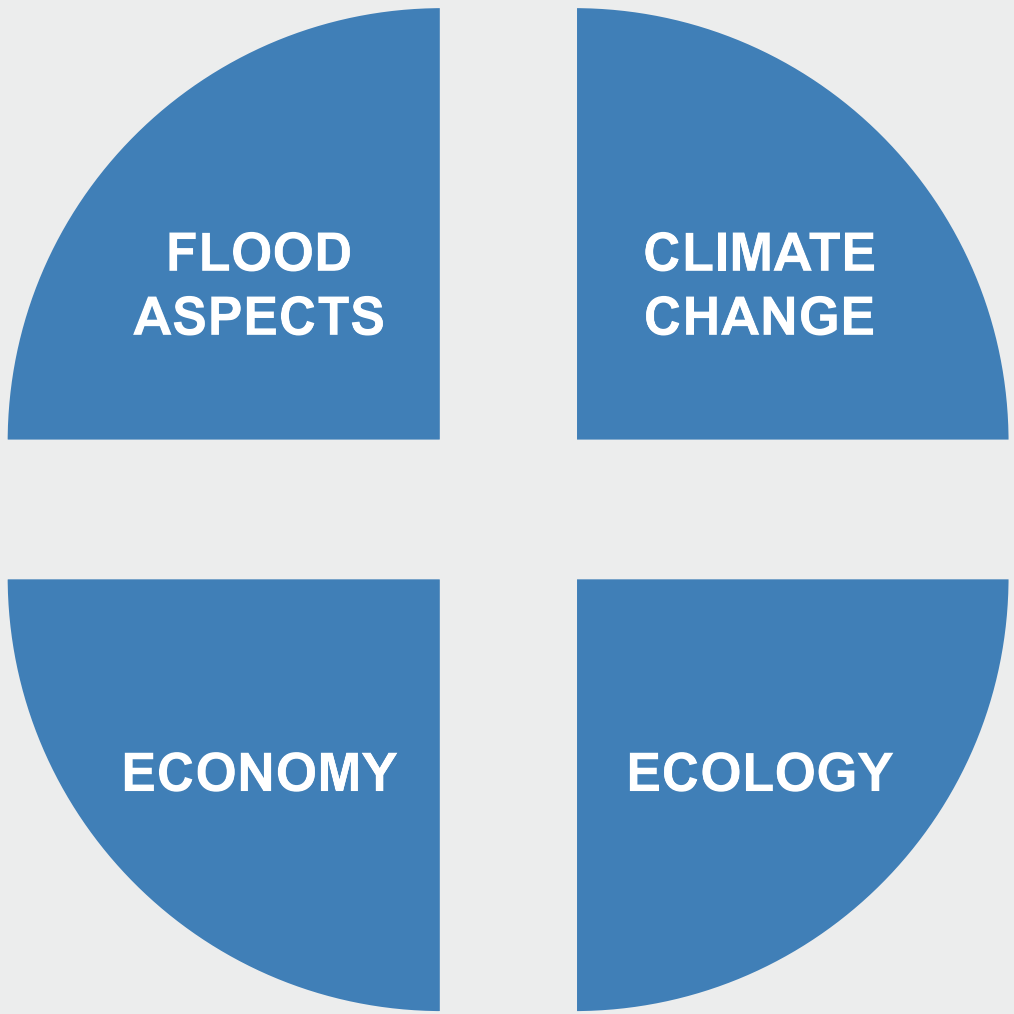
https://floods.ypeka.gr/

Greek Portal for Flood Risk Maps



https://geoportal.bafg.de/karten/HWRM_Aktuell/

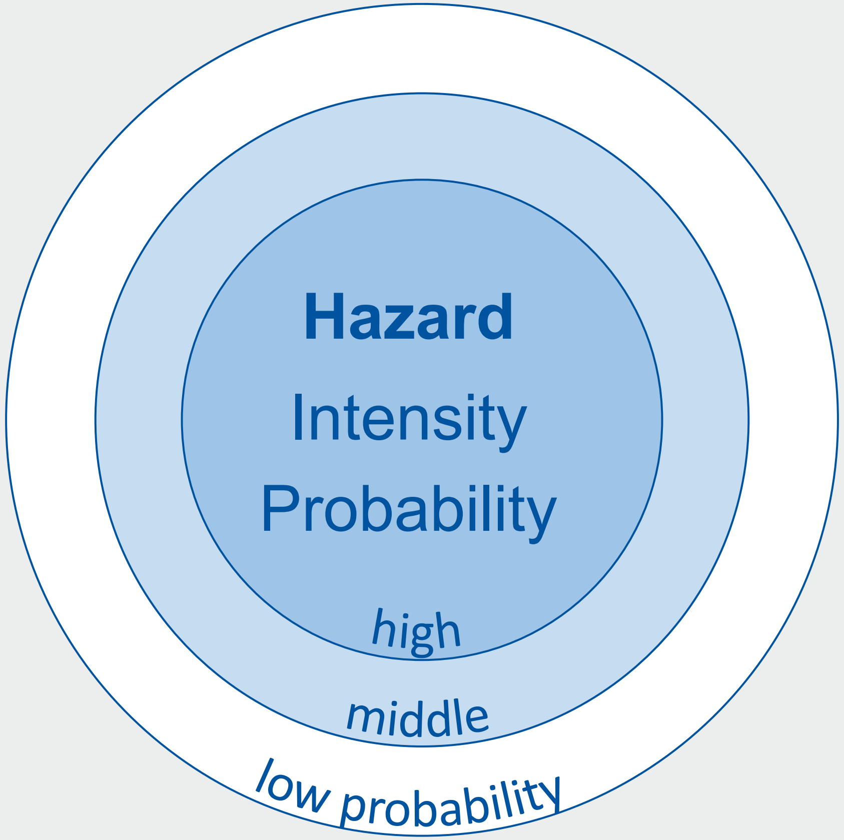
German Portal for Flood Risk Maps



EG Flood Management Directive & EU Water Framework Directive

Flood Risk – Definition and General Concepts

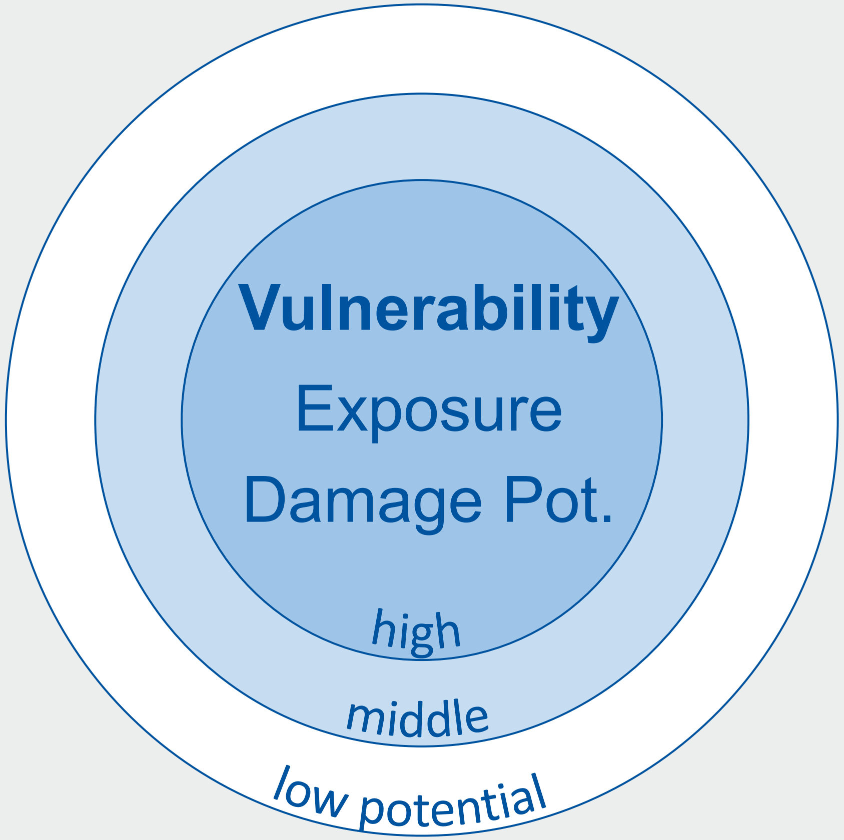
Definition of Flood Hazard



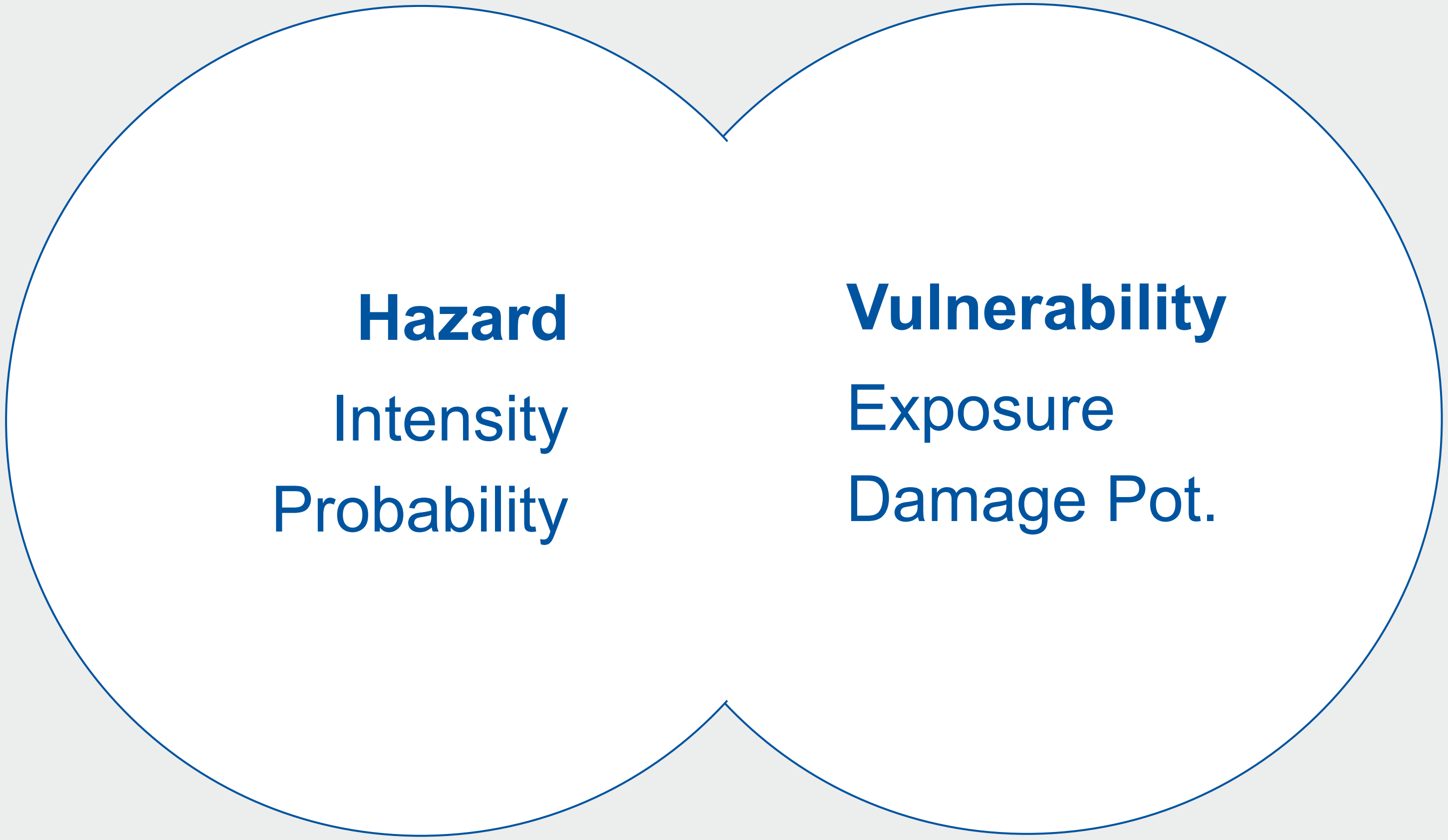
StMUV (2014)

Definition of Vulnerability

(Wolfgang Rattay/Reuters)

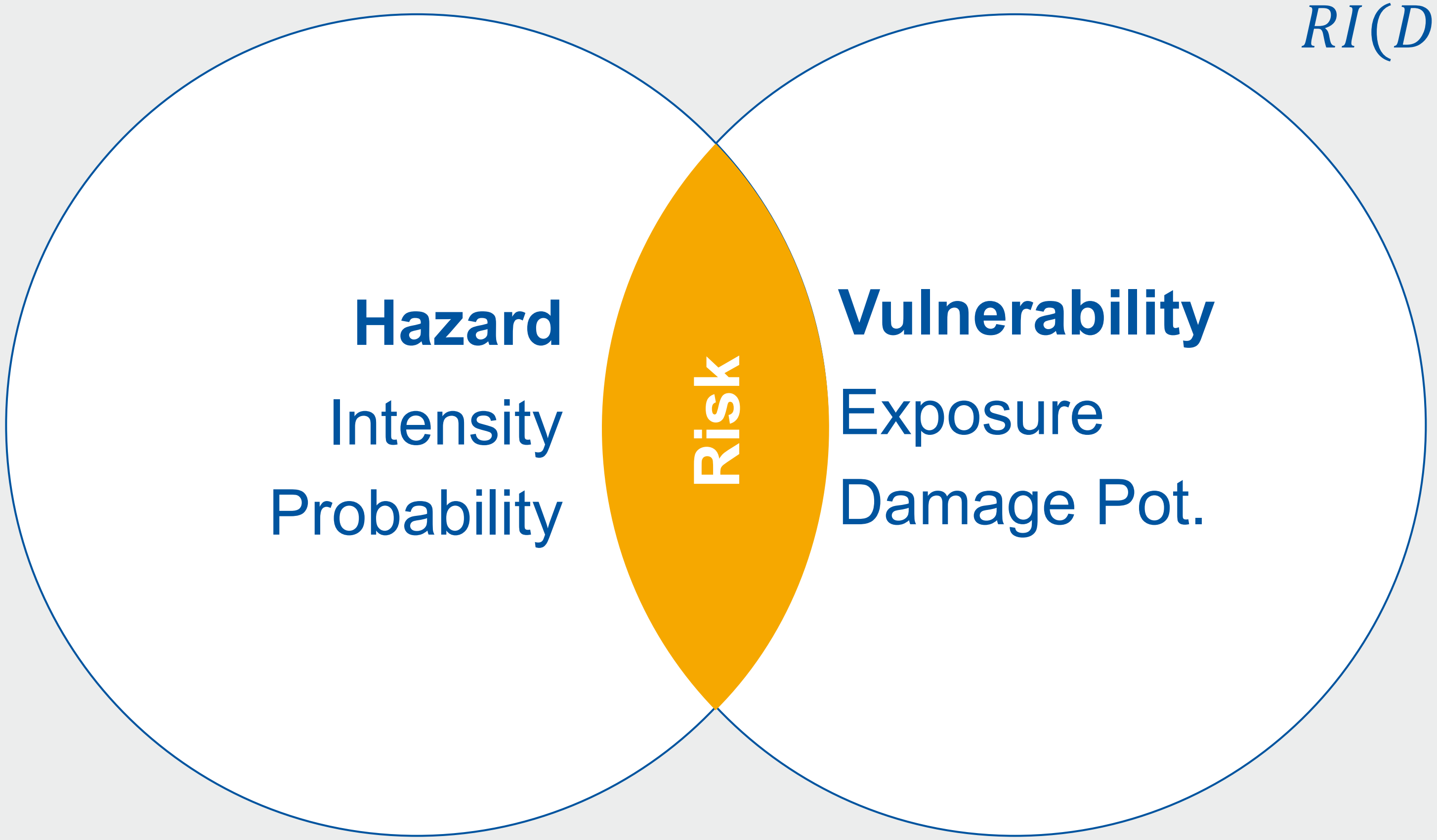


Definition of Flood Risk



Patt und Jüpner (2013)

Definition of Flood Risk



$$RI(\vec{D}) = \sum_{j} n_j * k_j * \int_0^{\infty} \varphi_j(u) * f_u(u) * du$$

D = measure (scenario)
n = number of elements at risk
k = maximum damage due to event u
$\varphi_j(u)$= relative vulnerability
$f_u(u)$= probability densitity function of event u
j = category index

$$RI(\vec{D}) = \sum_{(u)} Pr(u) * C(u)$$

Pr = exceedance probability
C = consequence (cost)

Assessment with flood hazard and flood risk maps

Structural and non-structural flood protection

Flood Management Measures

All planned actions or structures

- Aim to reduce the effect of floods
- Preventive and protective measures
- Take into account contingencies: failure of system components

Structural (traditional)

Flood pathway control

Separate river and population

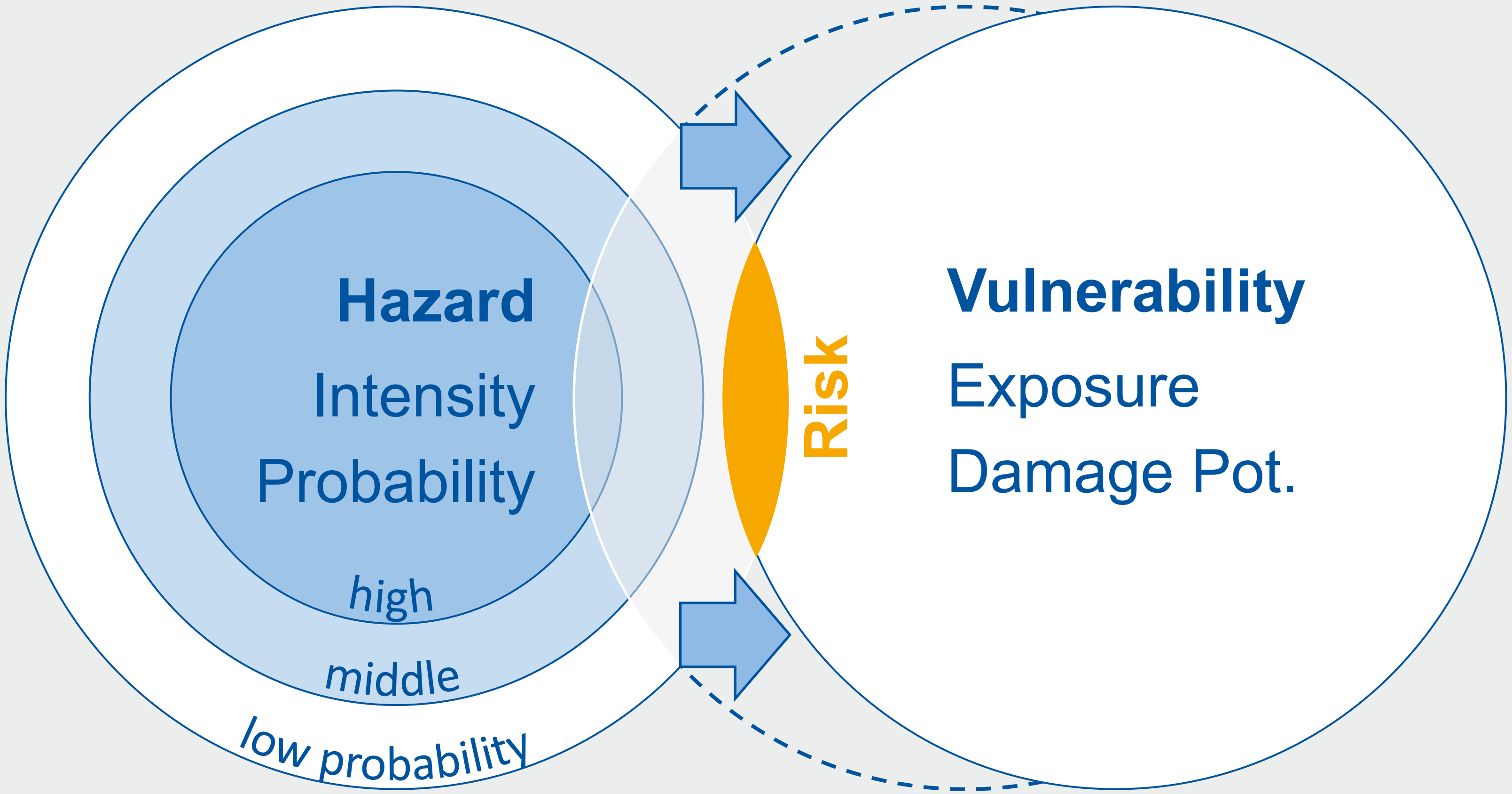
dams, dykes, retention basins, channelization, …

Non-Structural (modern)

Learning to live with rivers

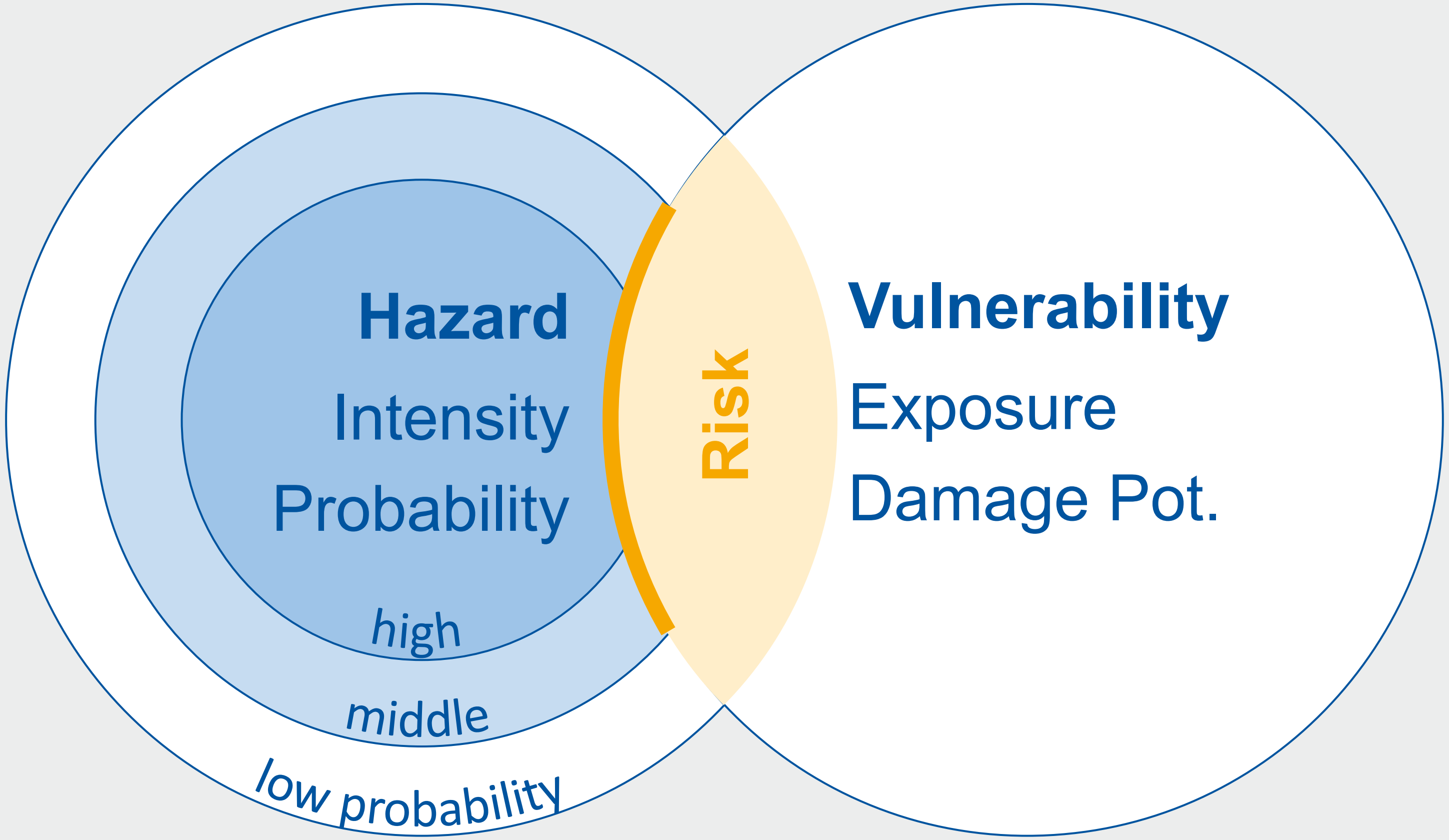
information, spatial planning, building regulations, strengthen retention capacity (river basin), …

Avoidance



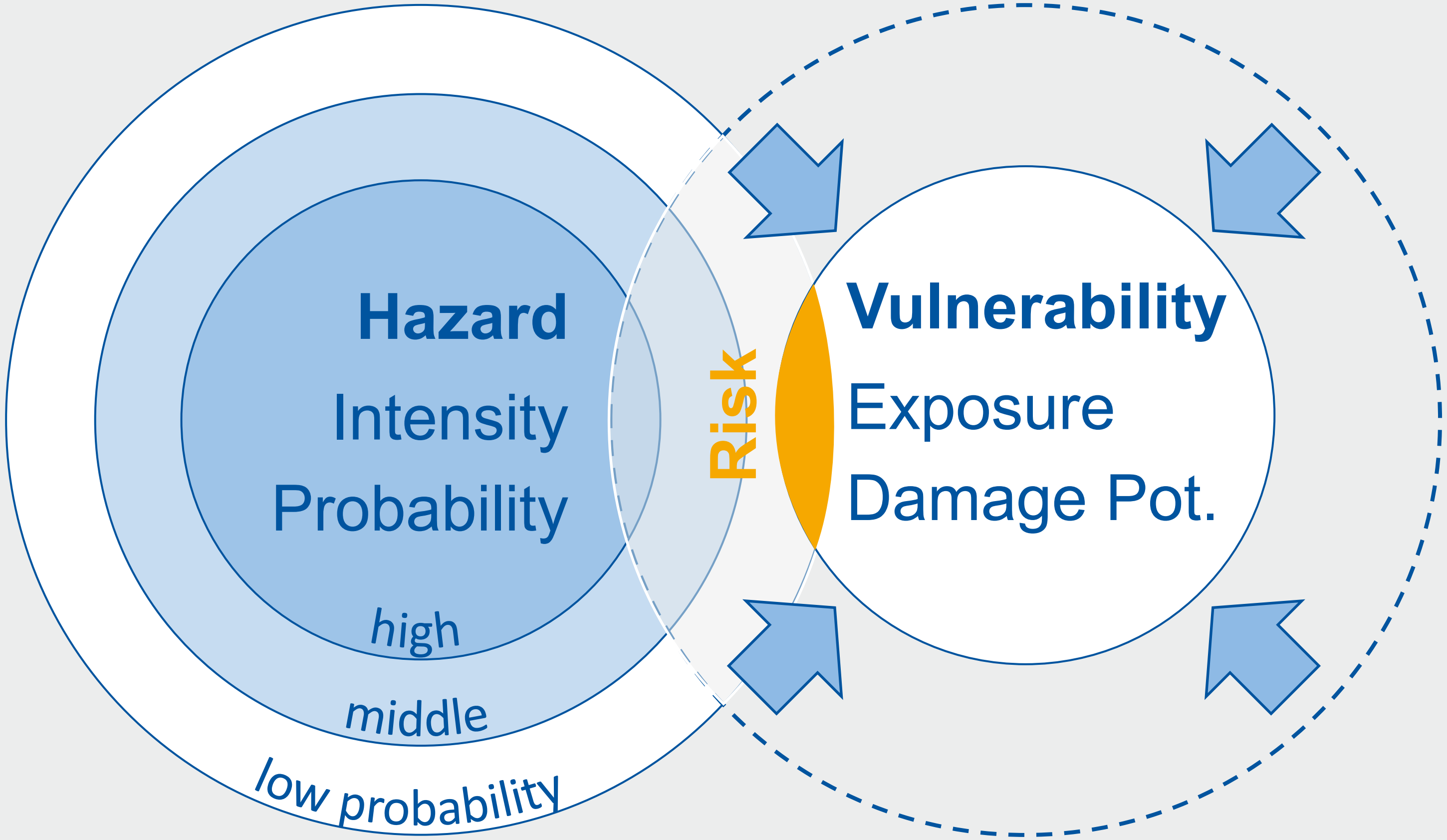
Removal of vulnerable objects out of the risk zone

Resistance



Flood protection by technical measures for a defined exceedance probability

Alleviation



Reduced vulnerability through resilient design

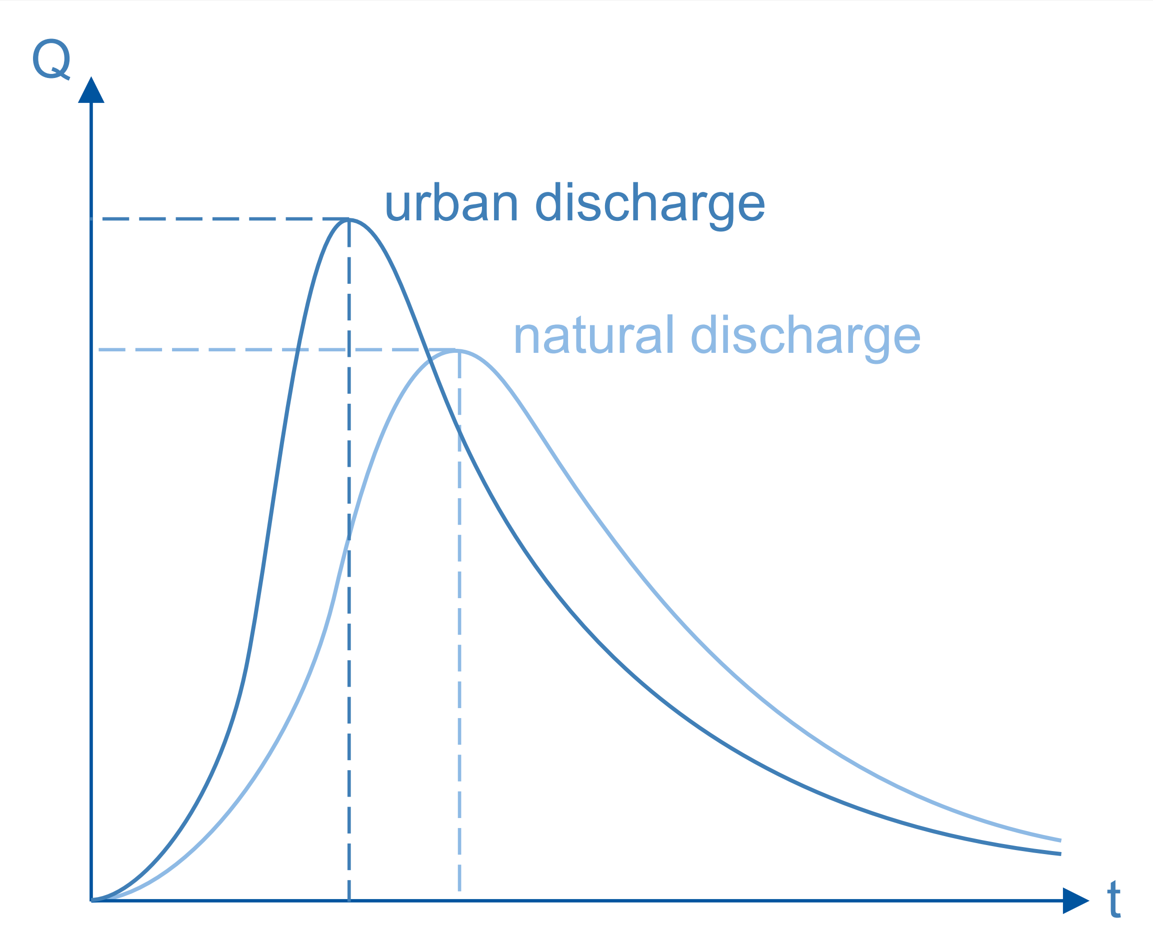
Increasing Flood Risk in Urban Areas

Climate Change

- more frequent and intensive heavy precipitation events
- rise of sea level

Urbanization

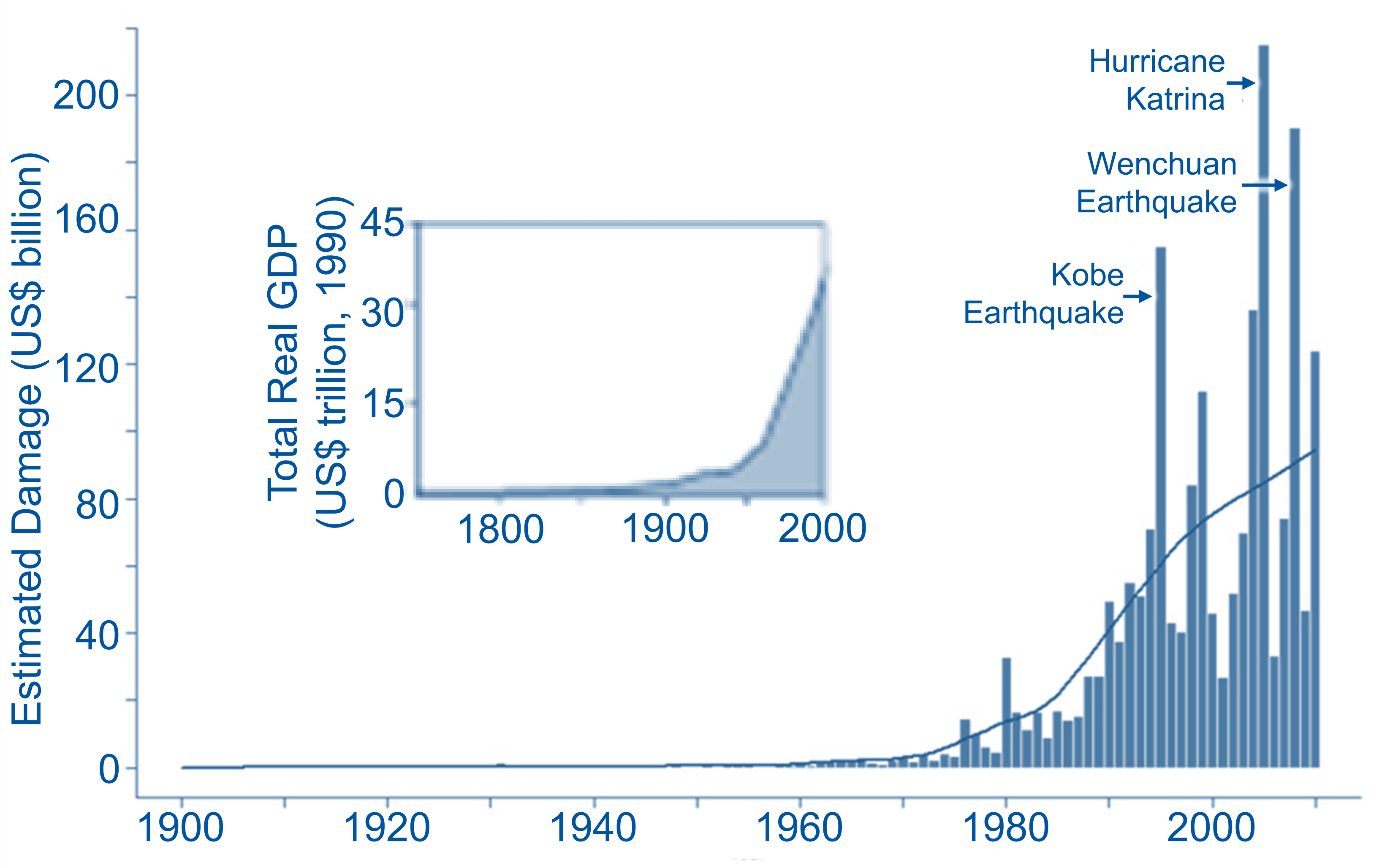
- increased impervious areas in cities
- more assets in flood prone areas
- higher vulnerability



Jha et al. (2012)

More GDP – More Natural Disasters

Estimated Damage (US$ billion) caused by Natural Disasters 1900 - 2010



Steffen et al. (2004)
Guha-Sapir, D., Below, R., Hoyois, Ph. (2016)

Flood Protection Measures 1/3
- Rural Measures-

Overview

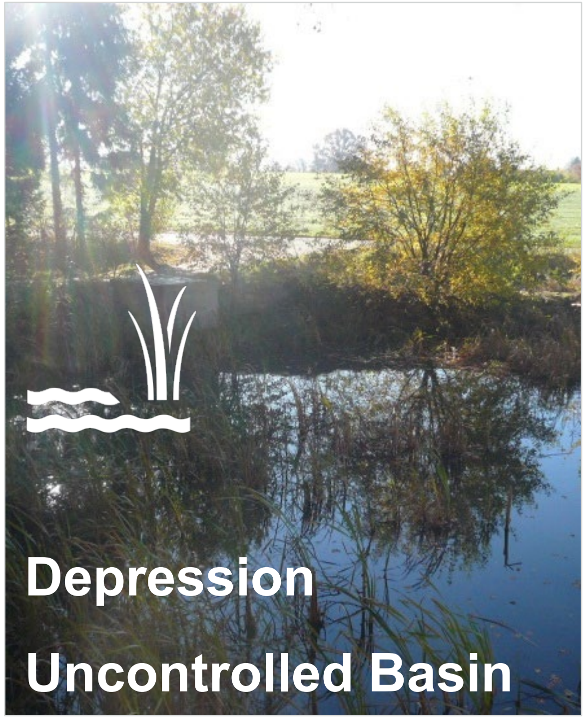
Runoff Generation — Runoff Concentration — Routing

Agriculture

Forestry

areal distributed

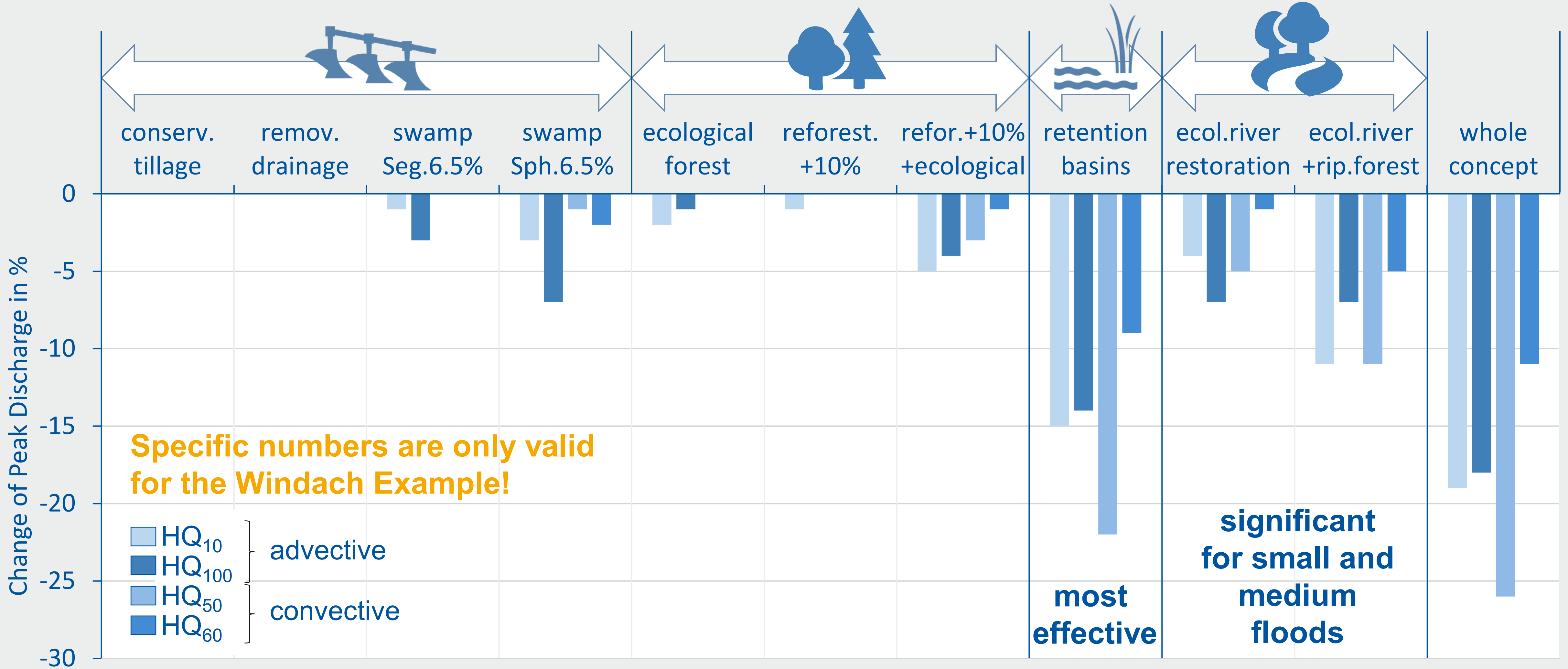
Retention



Ecol. River Rest.

point and linear measures

Effectiveness of Decentral Flood Protection



Summary

Chances

Small and medium flood events

If central measures not possible

No regret measures

BUT

Limits

Generally minor effect in large catchments

Not effective for low probability floods

Soil has more influence than land use

Synergy Effects:

Reducing washout of pesticides

Reducing export of nutrients

Tackling erosion

Mitigation of droughts

Supporting groundwater recharge

Barrier for protection goods

Interconnecting ecosystems

Supporting biodiversity

Enhancing local recreation

Support beauty of landscape

EU-WFD

...

Flood Protection Measures 2/3
- Urban Measures -

Flood Protection Strategies

Concepts:

- Green City Concept
- Blue City Concept
- Blue-Green City Concept

City of Rotterdam (2012)

The Green City

Local Conditions:

- Permeable, not-contaminated soil
- Space available
- Groundwater level far from surface

Strategy:

- New green areas for infiltration
- Decrease of impermeable areas
- Green Roofs
- Green Streets

Examples: Portland, New York, Chicago, London, Melbourne, Sydney

The Blue City

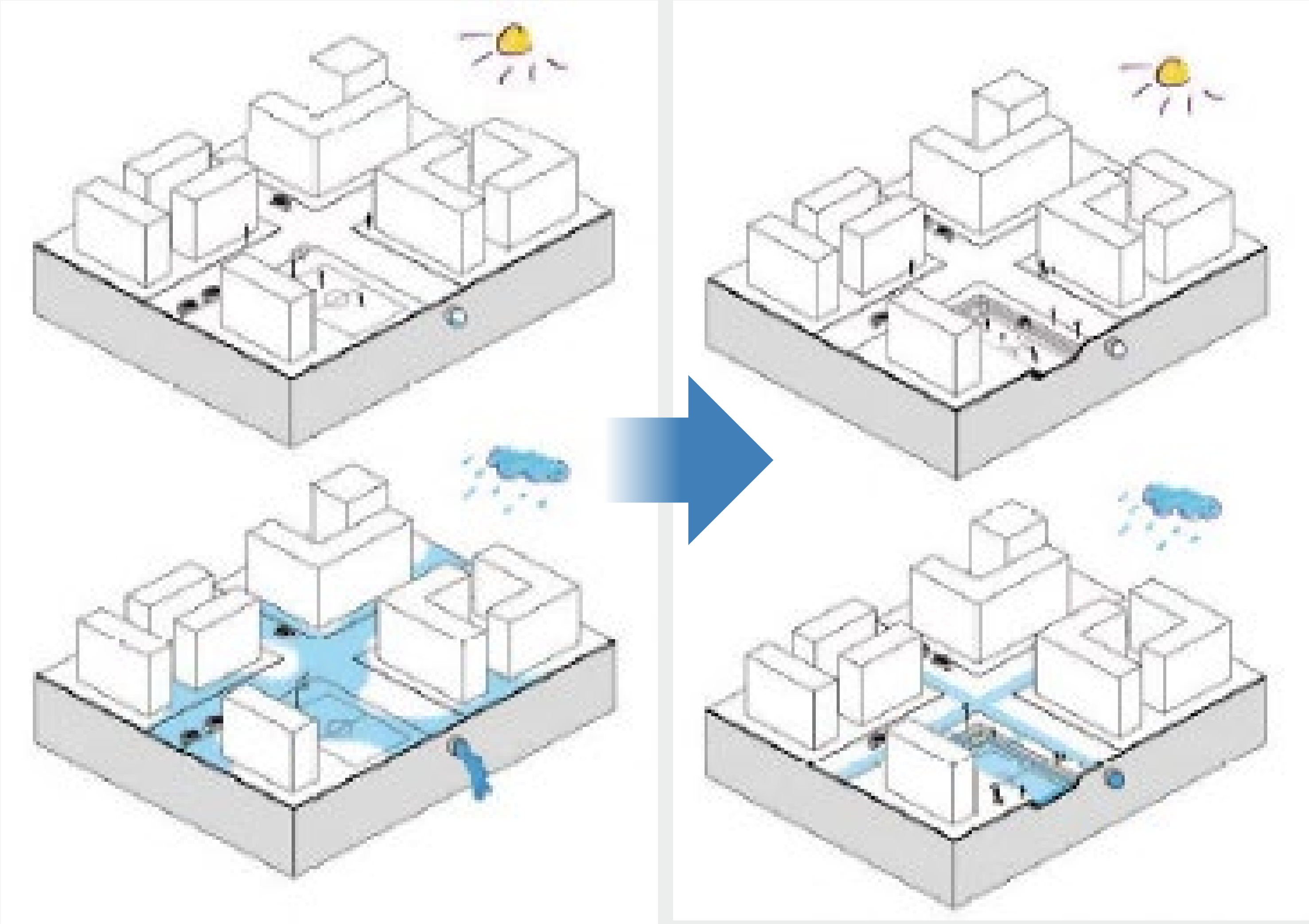
Local Conditions:

- Low permeability of soil
- Lack of space
- High groundwater level

Strategy:

- Integration of water into the city
- Multifunctional usage of areas
- Green and Blue Roofs

Examples: Rotterdam, Amsterdam, Copenhagen



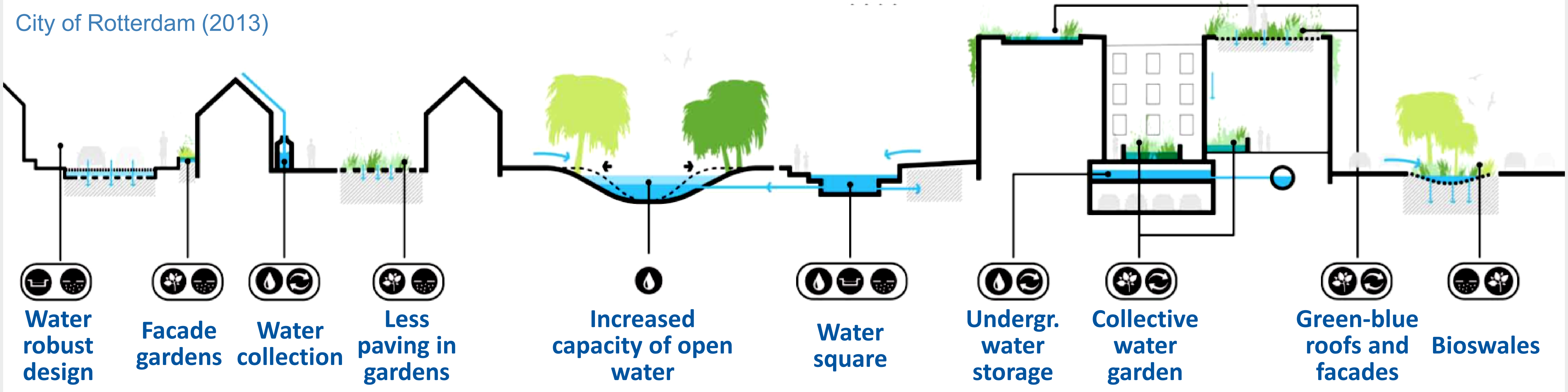
Kruse (2015)

The Blue City – Example: Rotterdam

A City Adapting to Climate Change

- Increased water retention
- Delayed infiltration to open and ground water
- Enhanced recycling of water / flood harvesting
- Temporary and permanent water storages

City of Rotterdam (2013)



The Blue-Green City

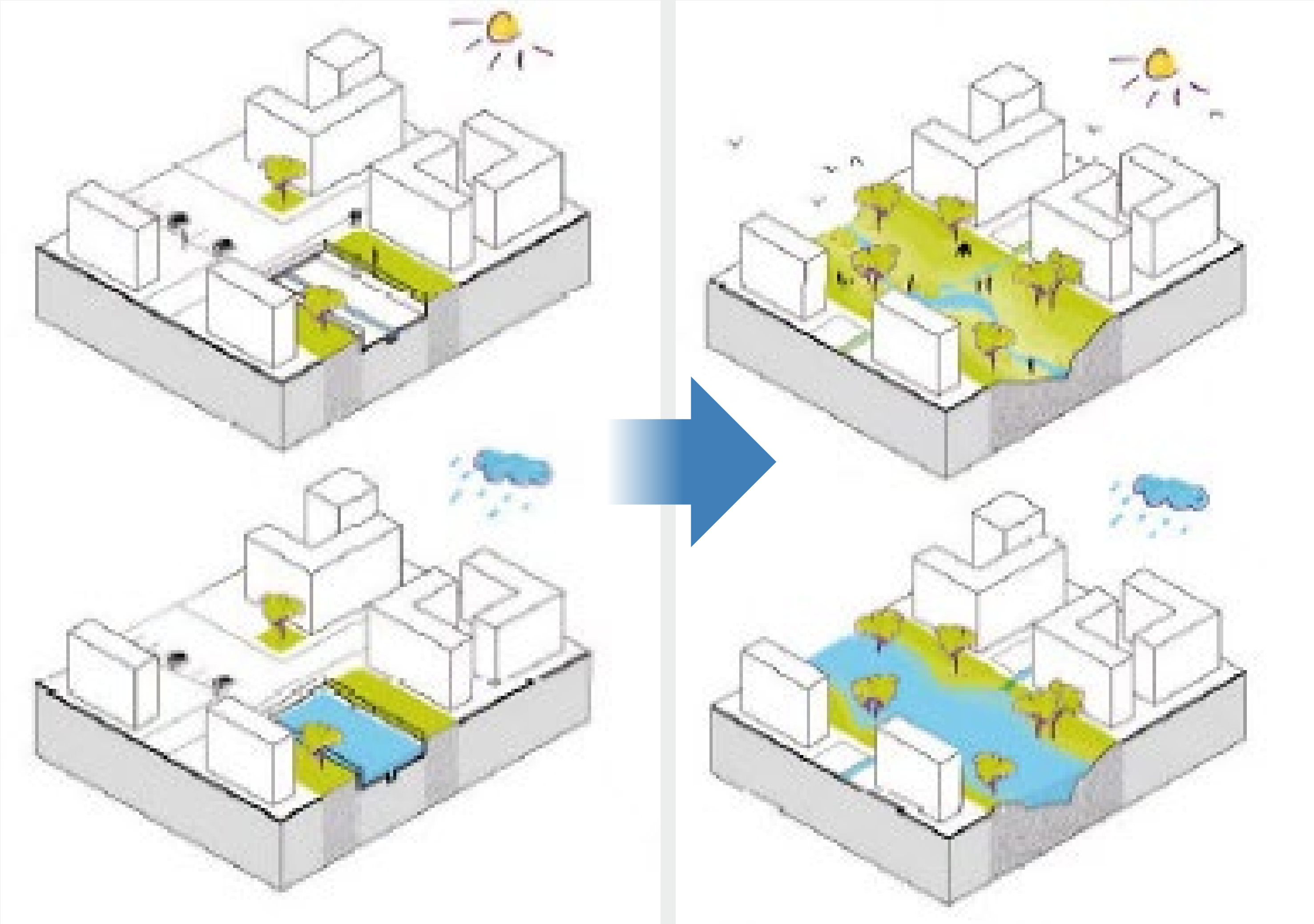
Local Conditions:

- Affected by river floods
- Space availability along the river
- Low permeability of the soil

Strategy:

- Integration of river sections into parks
- Ecological restoration of canalized river section
- Reservoirs, ponds, wetlands

Examples: Singapore, Houston, Malmö, Seoul, Glasgow, Munich



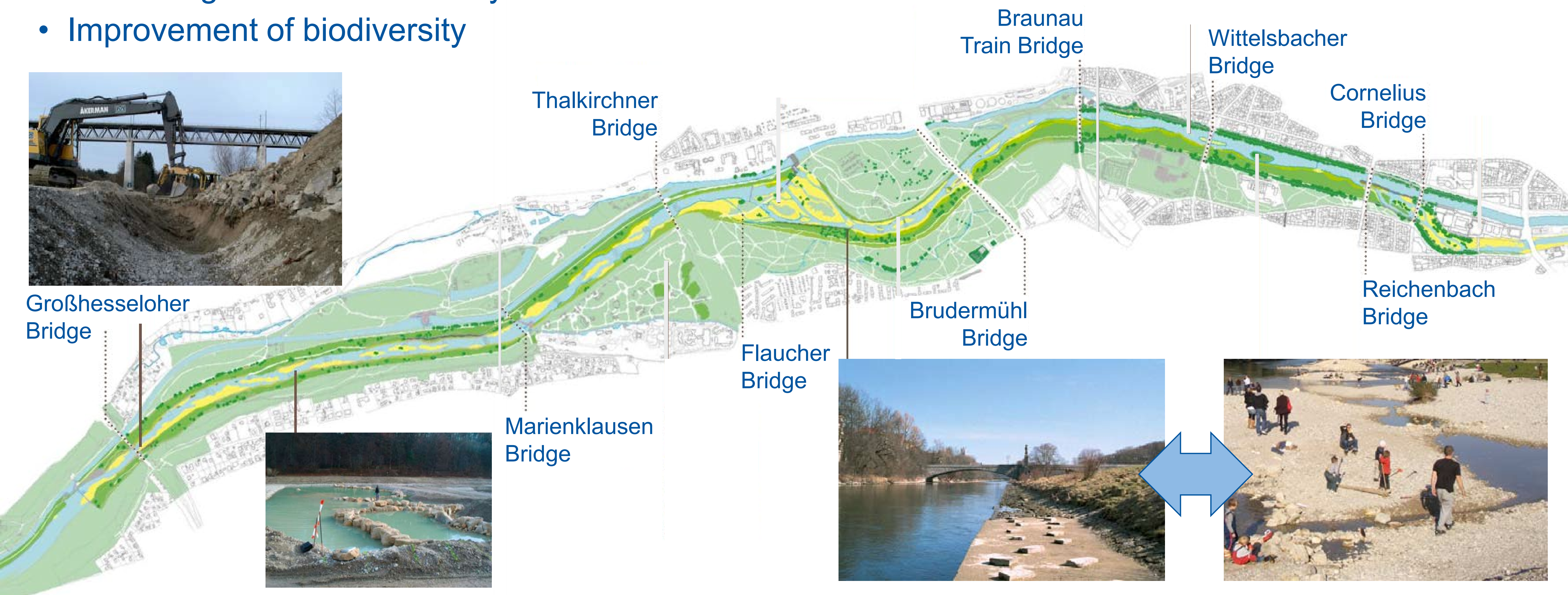
Kruse (2015)

The Blue-Green City – Example: Munich

City of Munich (2011)

Ecological Restoration – Giving Rivers Space

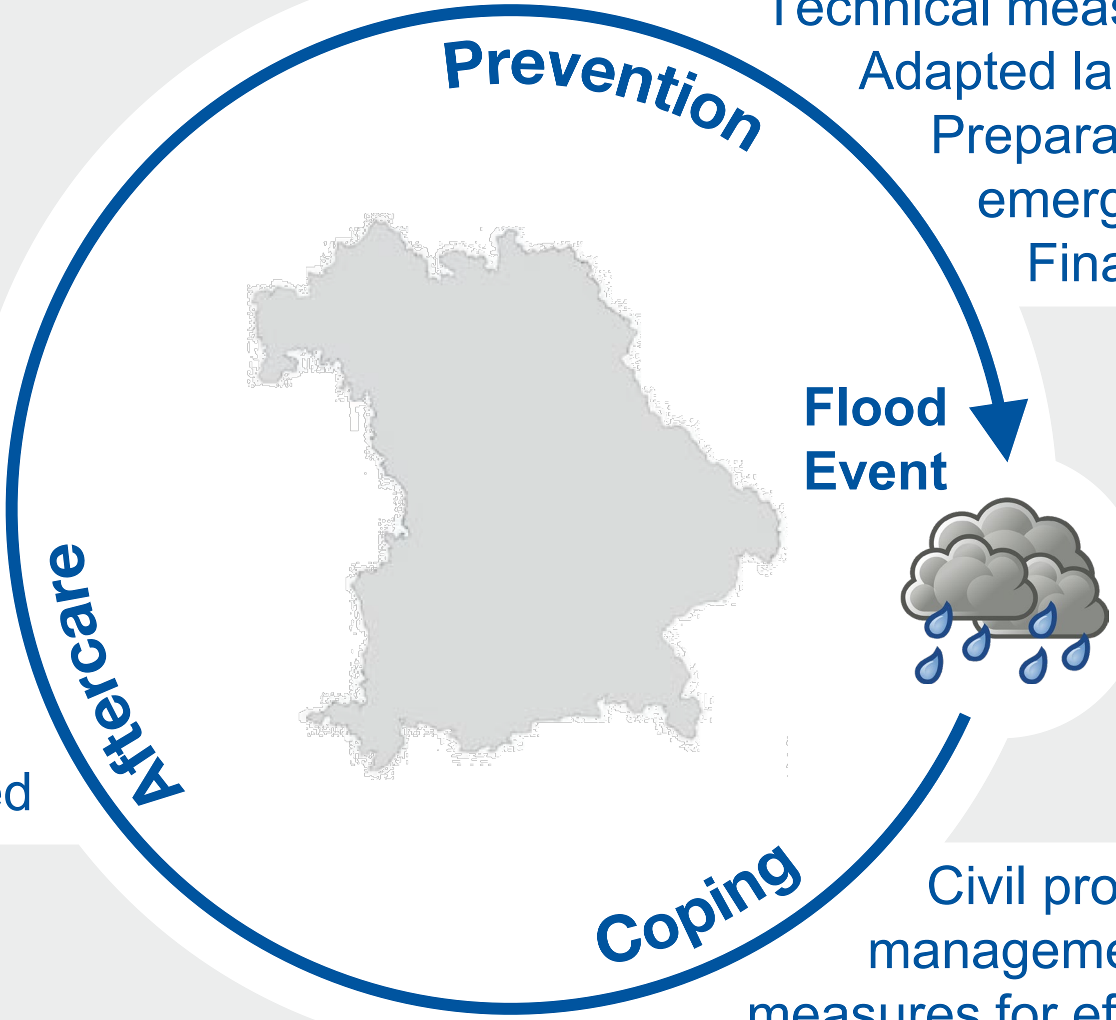
- Increasing habitat connectivity
- Improvement of biodiversity



Flood Protection Measures 3/3
- Protection Strategies -

Flood Risk Management Cycle

Technical measures, Retention areas,
Adapted land zoning / Building codes,
Preparation of civil protection and emergency management,
Financial precautions, Information

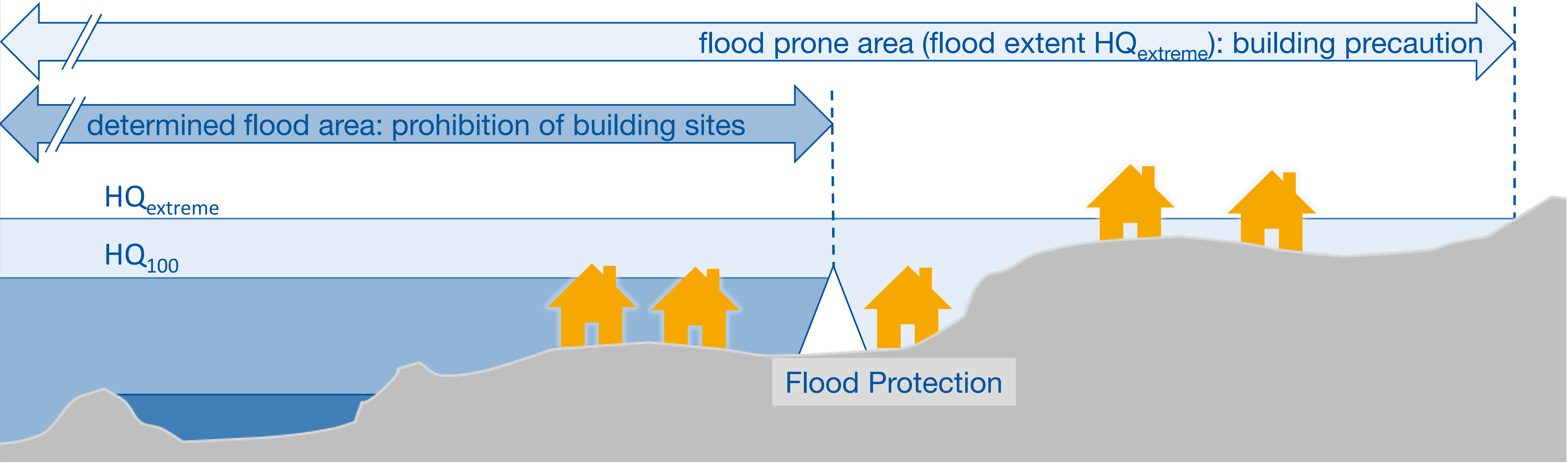


Reconstruction
Documentation
Evaluation
Lessons learned

Civil protection and Emergency management, Disaster relief measures for effected population

Adapted Land Zoning

Keeping flood-prone areas free and determine the way of land use.
Implementation in urban land-use planning by the government.



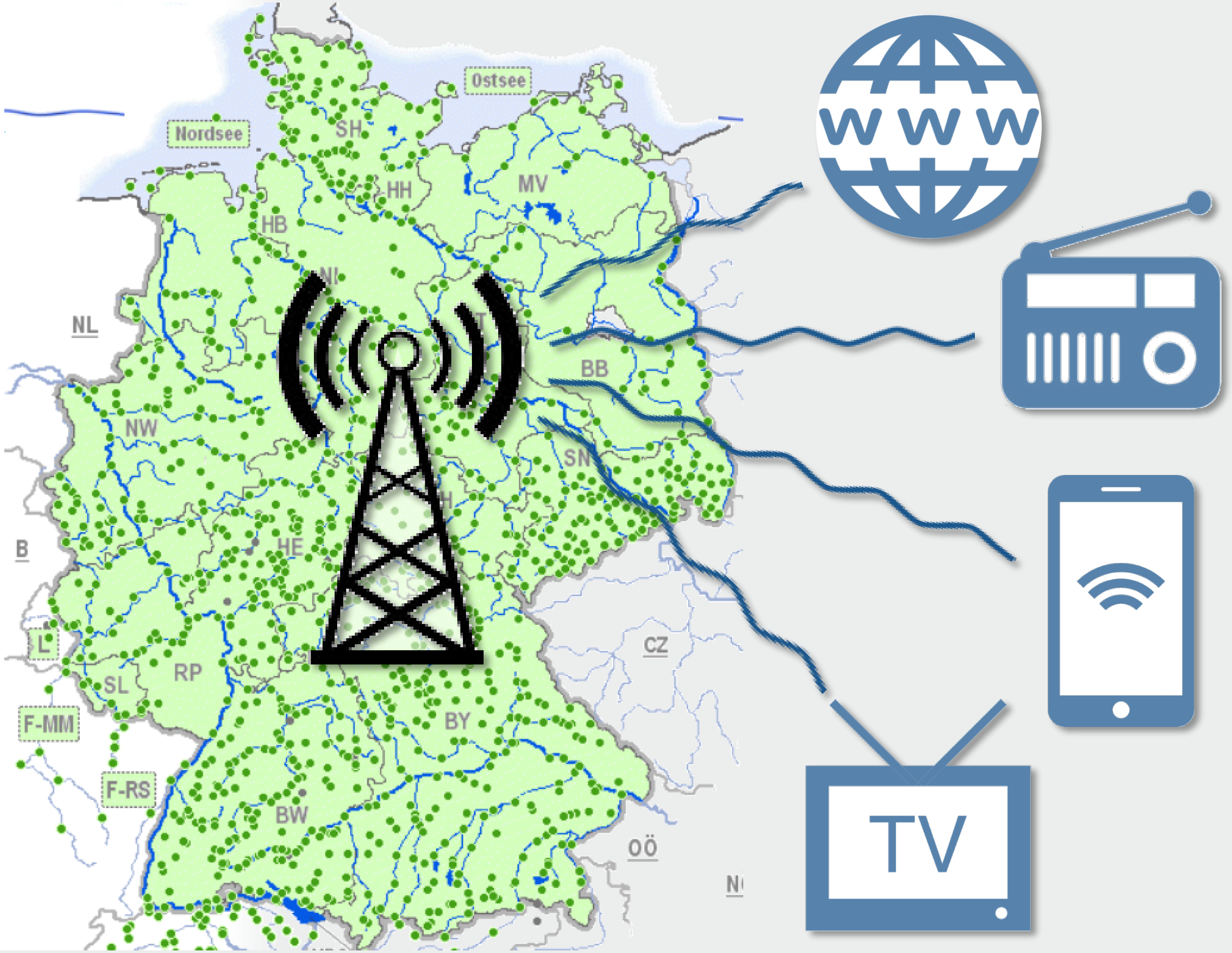
Information

Goals:

- Increase awareness about flood risk
- Provide information basis for decisions concerning flood protection measures

Important Aspects:

- Operational flood forecast
- Flood risk warning
- Dissemination of information by media
- Awareness in protected areas



Emergency Management

Right behavior before, during and after a flood event, e.g.:

- Preparedness
- Evacuation plans
- Emergency Planning and Coordination
- Timely implementation of temporary flood protection measures

Financial Precaution

Own Reserves

Flood Insurance

State Reserves

Technical Measures – Barriers

Stationary Measures

- Don’t require any lead time or preparation
- Change appearance of landscape
- Need space

BMUB (2015)

Temporary Measures

- Require lead time and preparation
- Often foundation needed (type dependent)
- Space can be shared

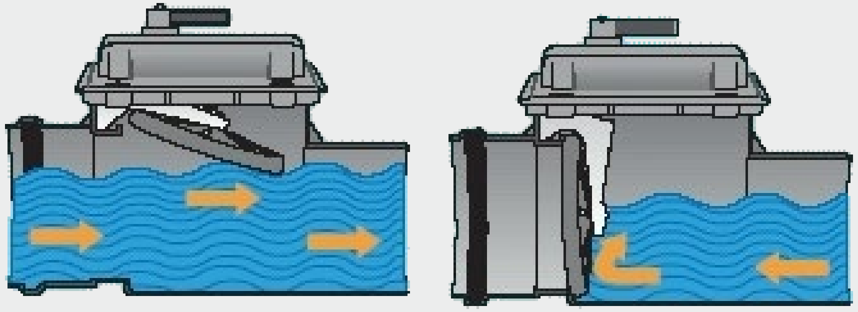
BMUB (2015)

Technical Measures – Sewer System

Types of Sewer Systems:

Combined: waste and storm water in one pipe

Separated: waste and storm water in separate pipes



Potential Risks:

Overflow: precipitation intensity exceeds drainage capacity (flash floods)

Backflow: increasing river water level impounds and pushes back sewer water (river floods)

BWB (2016)

Retention Areas

1. Infiltration

Desealing
- Improves permeability
- Increases Evapotranspiration
- Purification

2. Retention

Green Roofs
- Decentralized retention
- Increases evapotranspiration
- Improves insulation

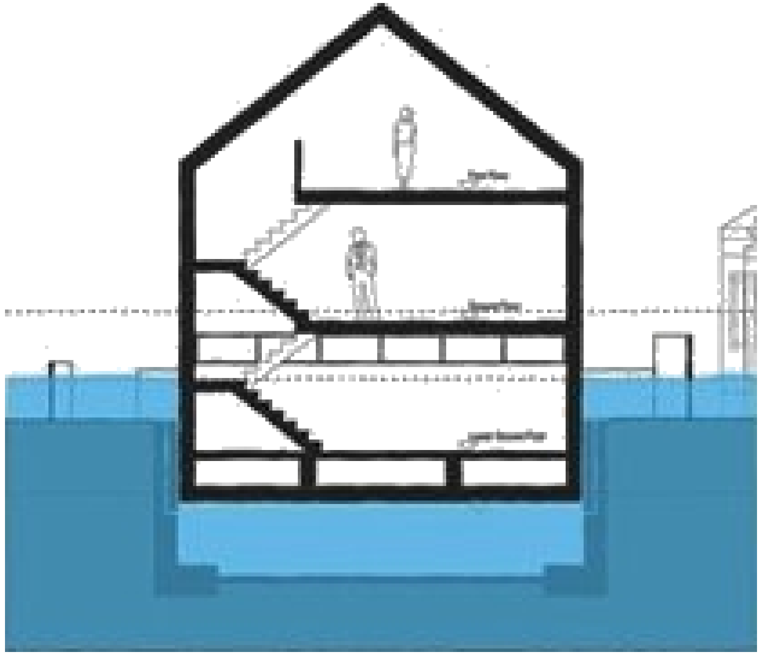
3. Retarded Runoff

Sewerage Storage
- Centralized retention
- No spilling of untreated water

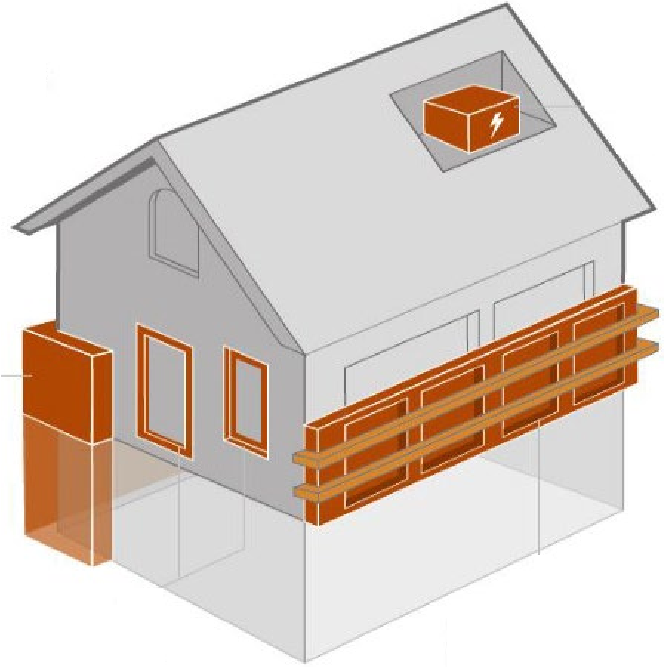
Hamburg (2016), München (2015)

Building Codes

Flood-adapted design and construction measures **implemented by homeowners to decrease the damage** potential of flood events



Avoidance



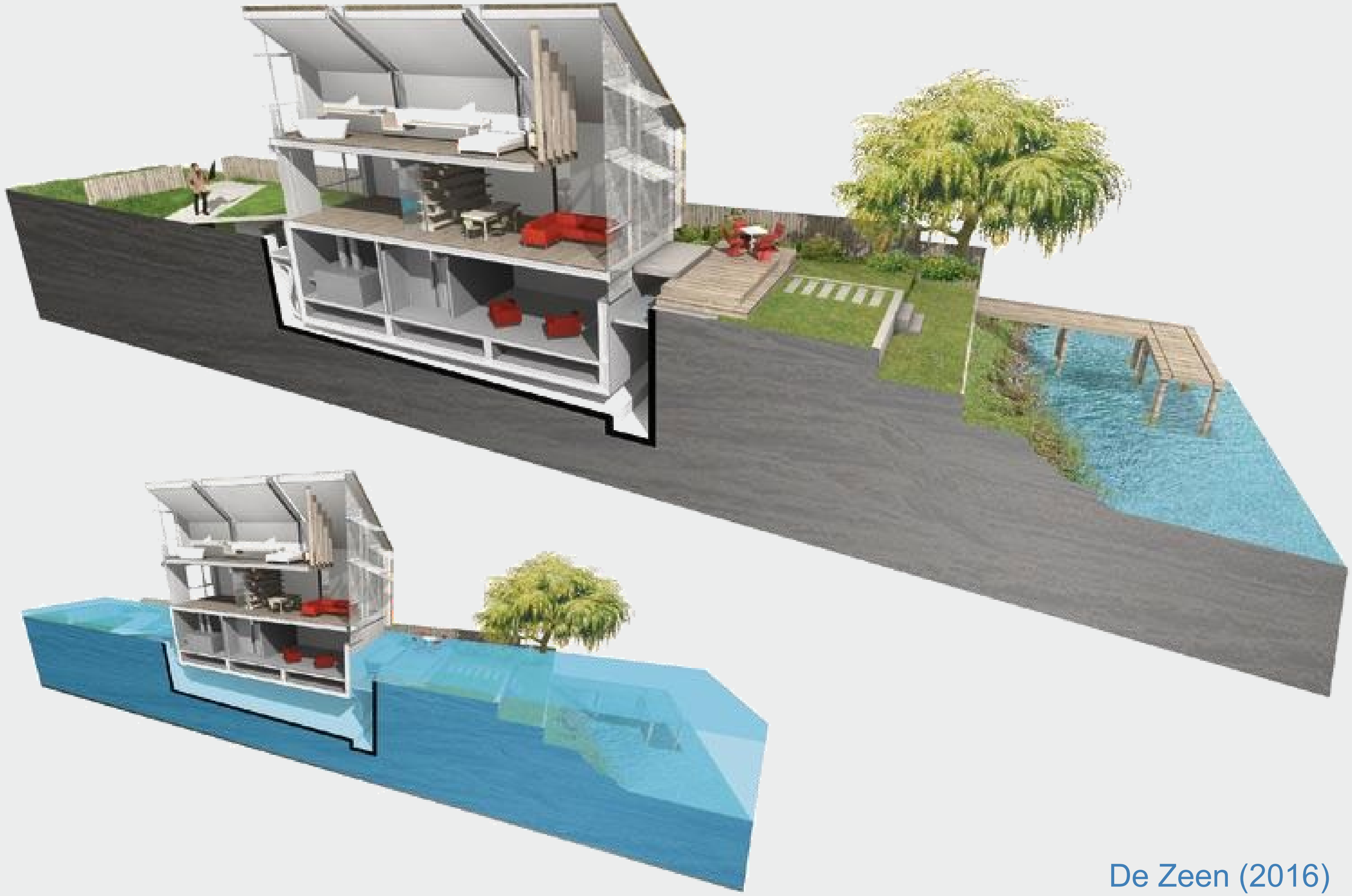
Resistance

Alleviation

De Zeen (2016)

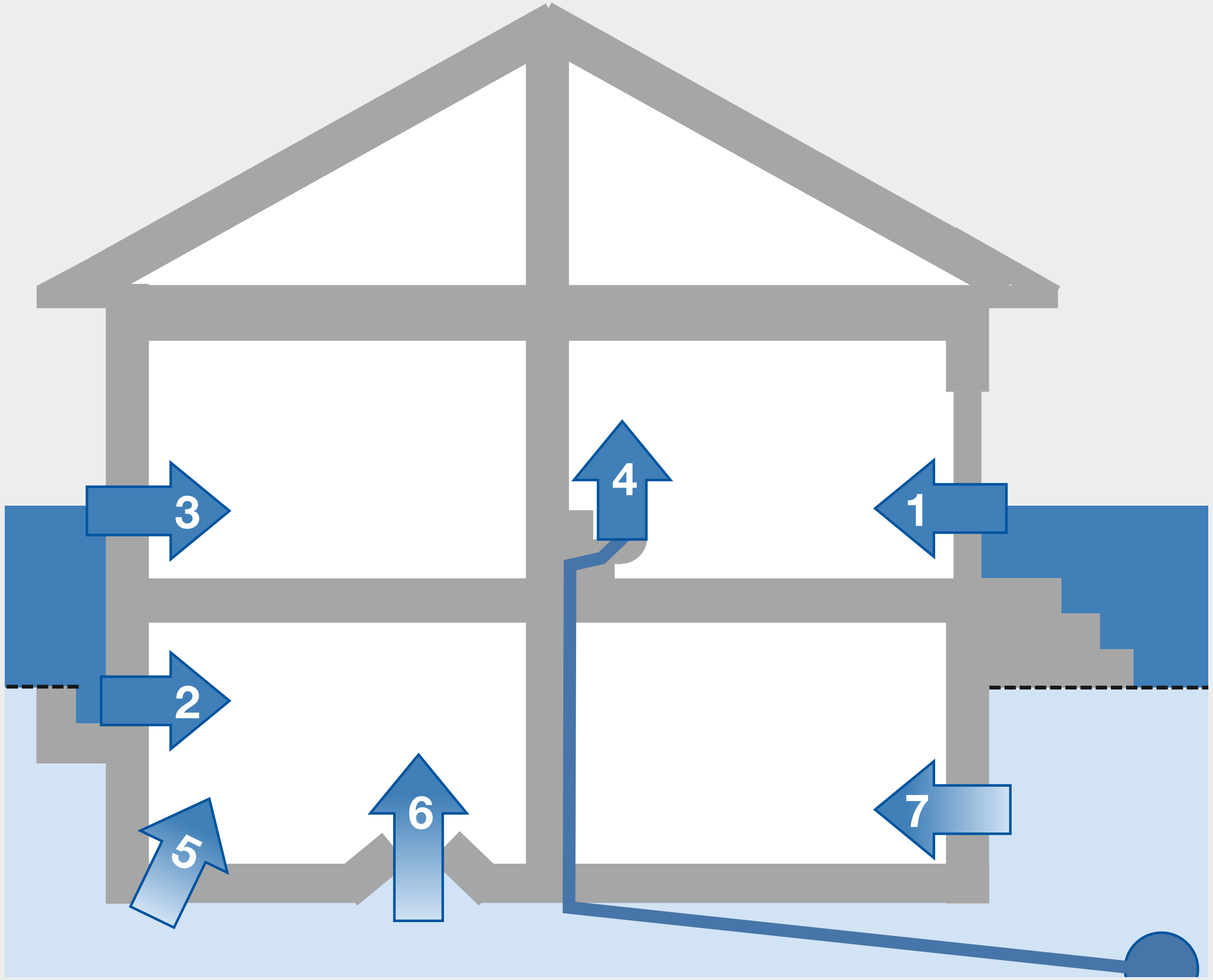
Building Codes – Avoidance

- Construction outside of the flooding zone
- Building without basement
- Building on stilts or piles
- “Swimming houses“



De Zeen (2016)

Building Codes – Resistance



BMUB (2015)

Resistance: Shielding against Floods

Surface Water Invasion:

1. through doors and windows
2. from light wells and cellar wells
3. through permeability in walls

Sewage Water Invasion:

4. backwater

Ground Water Invasion:

5. by sealing measures
6. undercurrents of groundwater flows
7. water penetration through walls

Building Codes – Alleviation

General:

- Relocation of sensitive furniture and applications to the upper floors
- Water resistant building materials

Measures for Buildings:

- Brick & Mortar Sealing
- Power Socket Height
- Drainage Points
- Outer layer with waterproof building materials
- Ventilated facade to support drying of isolation

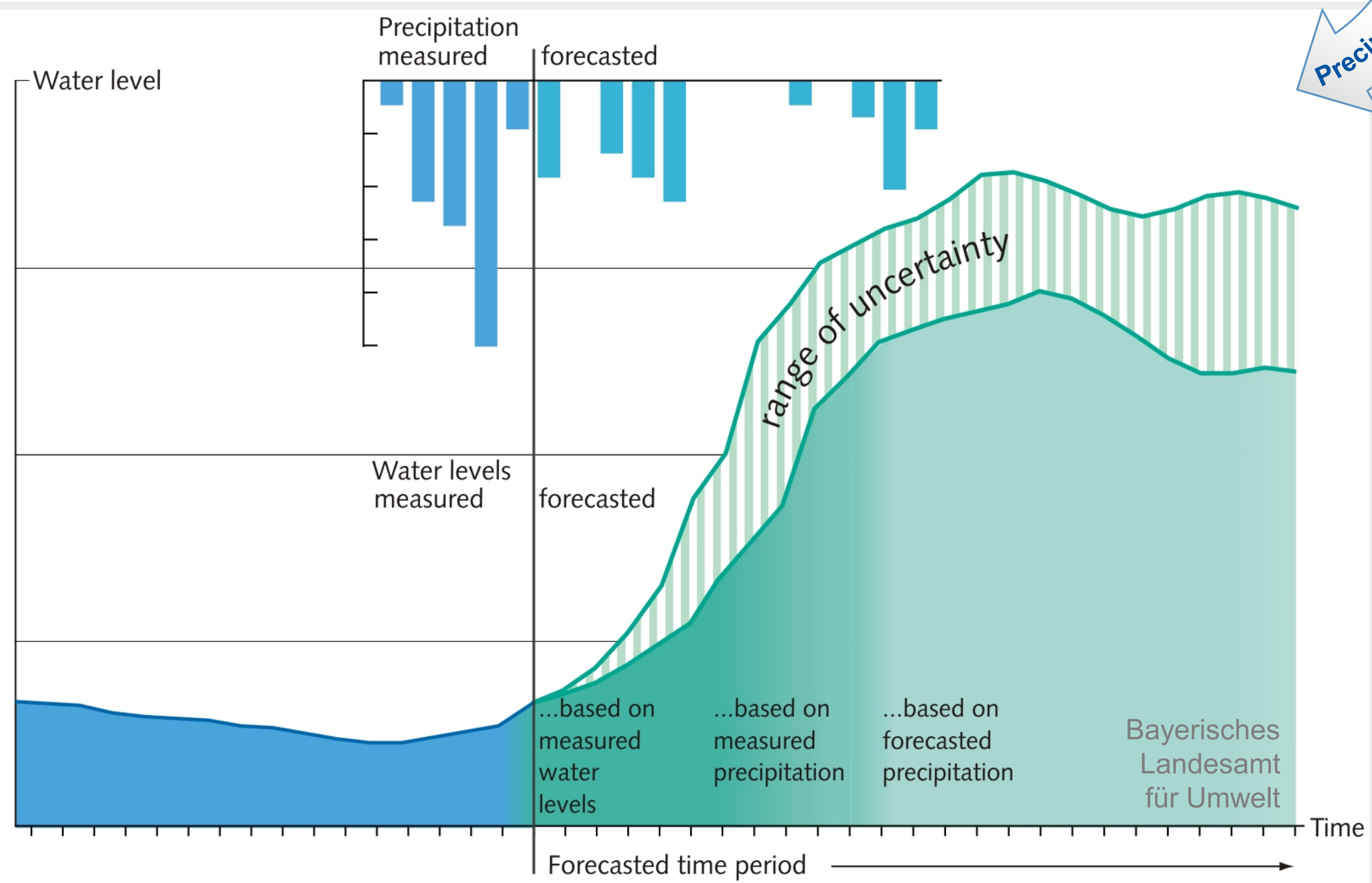
increasing water resistance ↓

Anhydrite and Gypsum
Isolating Materials (Glass wool, etc.)
Wood
Cement-bound Building Materials
Homogeneous Building Materials
Metal, Glass and New Bricks

BWB (2016)

Flood Chain Uncertainties

Uncertainties in the Flood Forecasting Process



Online Available Information

How can we know the inundated area?

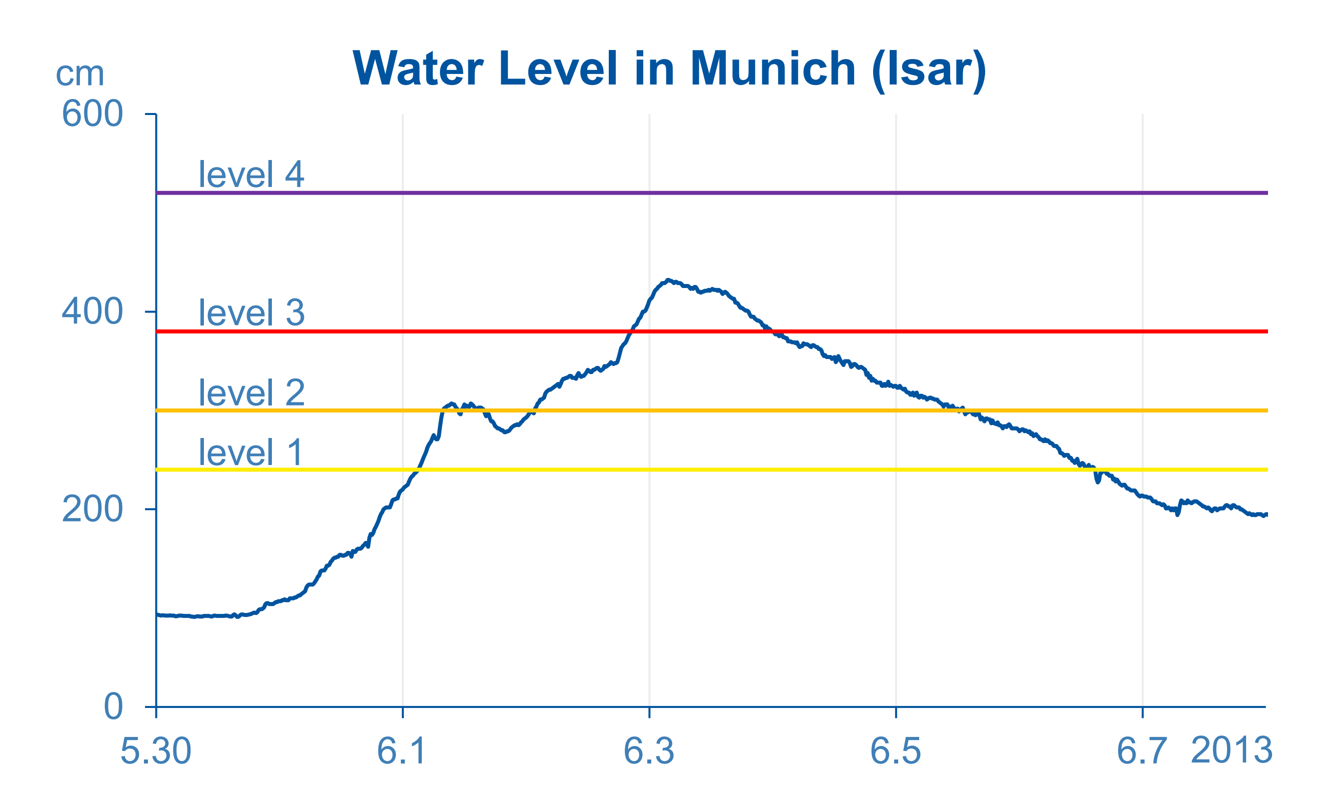
INFORMATION
HND
www.hnd.bayern.de

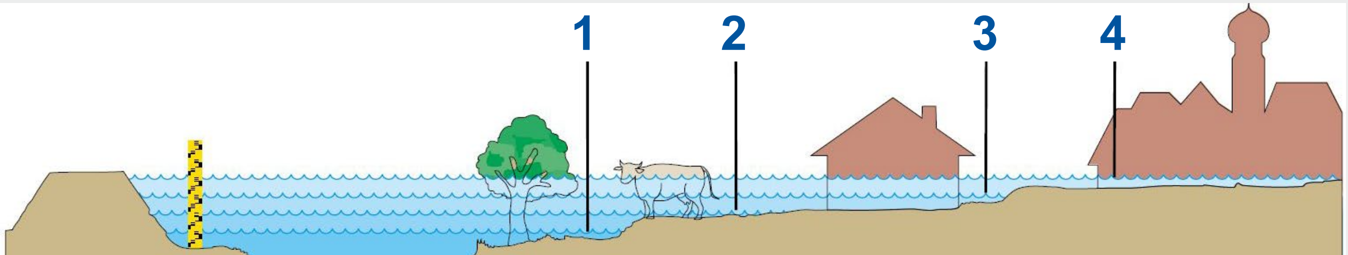
DOWNLOAD
BayLfU
www.gkd.bayern.de

Gauge

Munich / Isar

- water level
- discharge
- discharge table
- reference data
- location map
- inundation area
- statistics
- catchment data
- run time

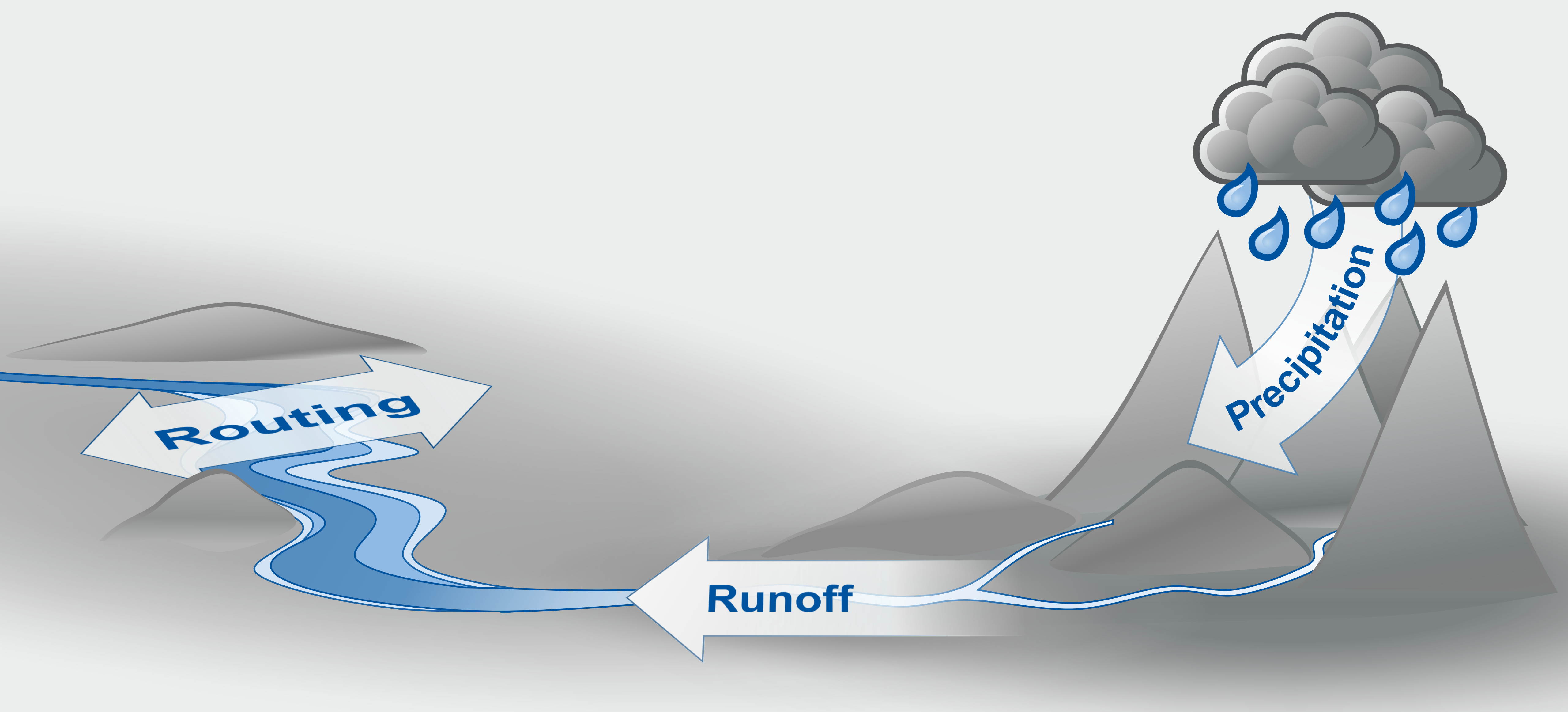




Bayerisches Landesamt für Umwelt (2010)

Flood Chain Uncertainties 1/3
- Precipitation -

The Flood Chain: Precipitation – Runoff – Flood Routing

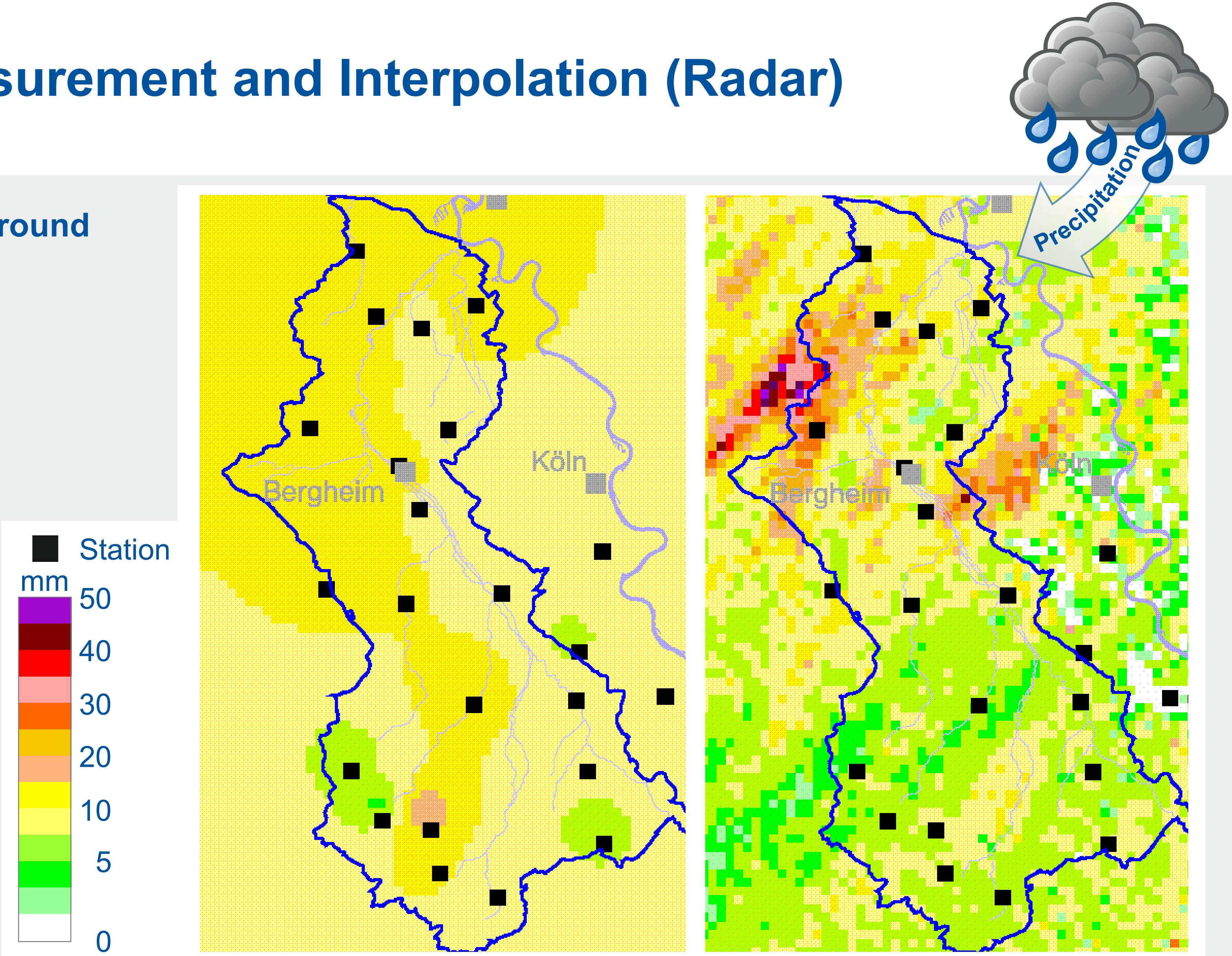


Measurement and Interpolation (Radar)

Comparison of Interpolated Ground Measurement and Radar Data

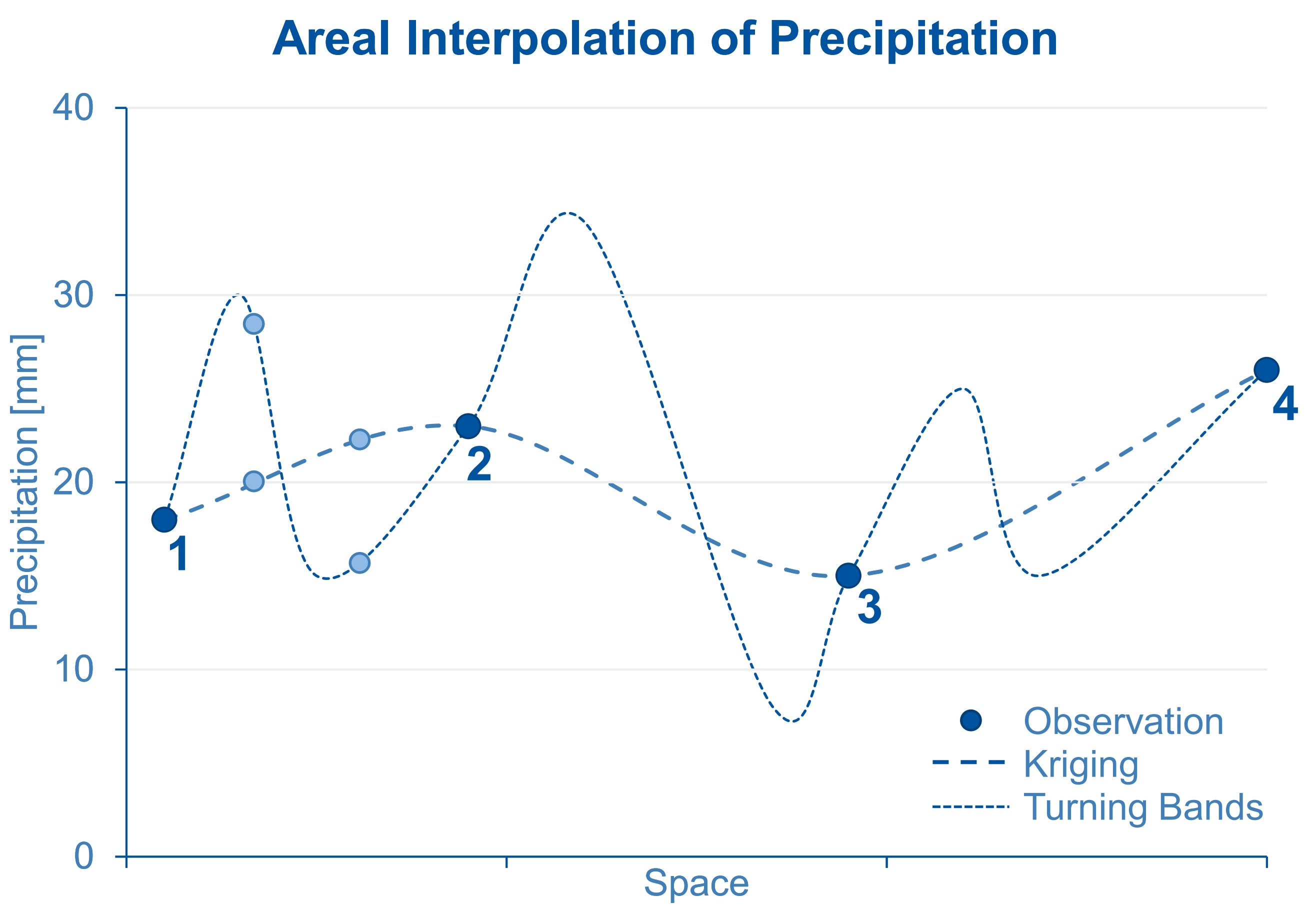
Precipitation from Interpolated Point Measurements (left) and Radar Records (right)

Date: 07/07/2004

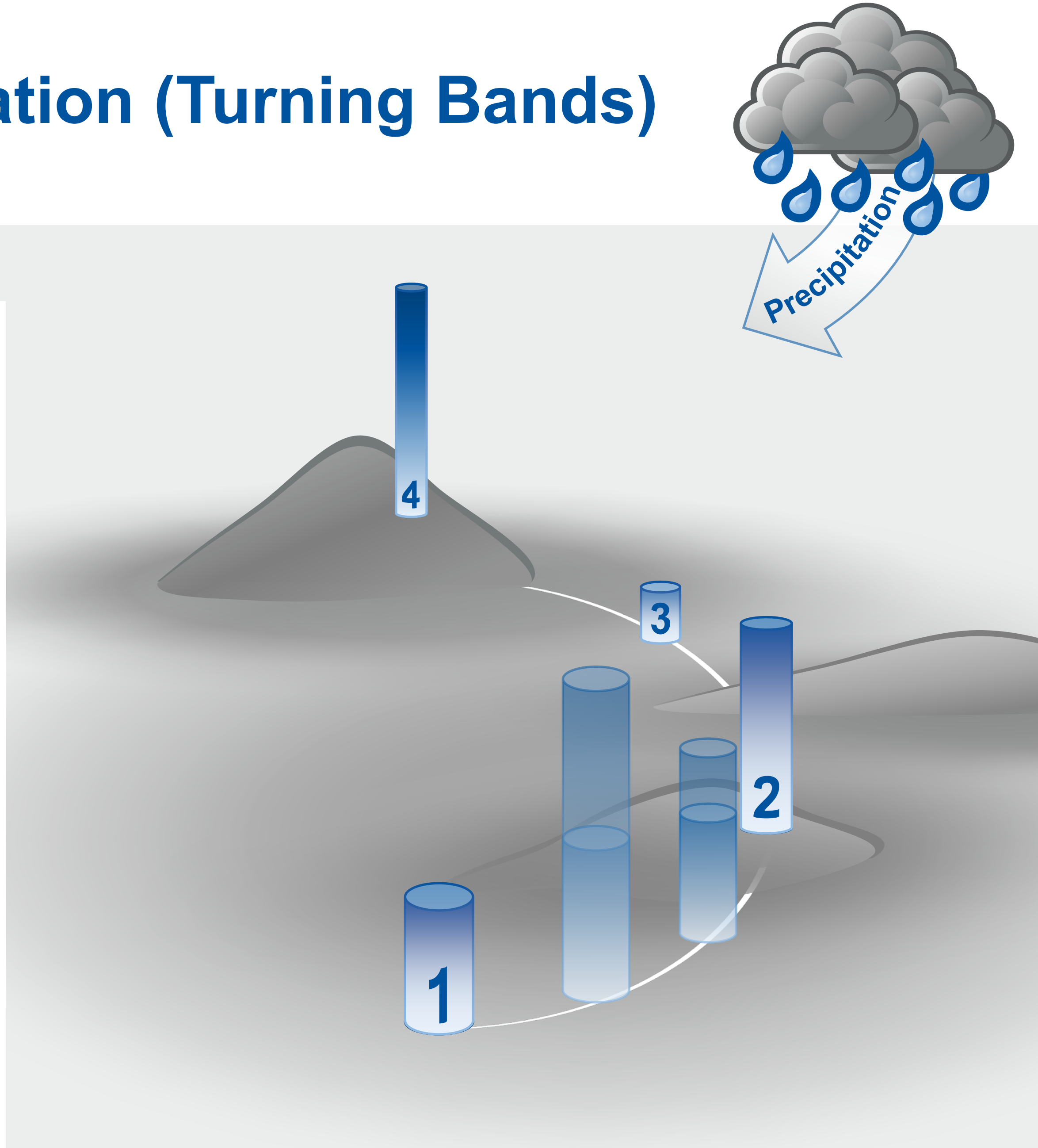


geodata: Deutscher Wetterdienst (DWD)

Measurement and Interpolation (Turning Bands)



Bliefernicht et al, 2008



Example White Main

catchment size: 360 km²
grid cells: 1 x 1 km²
flood event: 5/27 - 6/1/2006

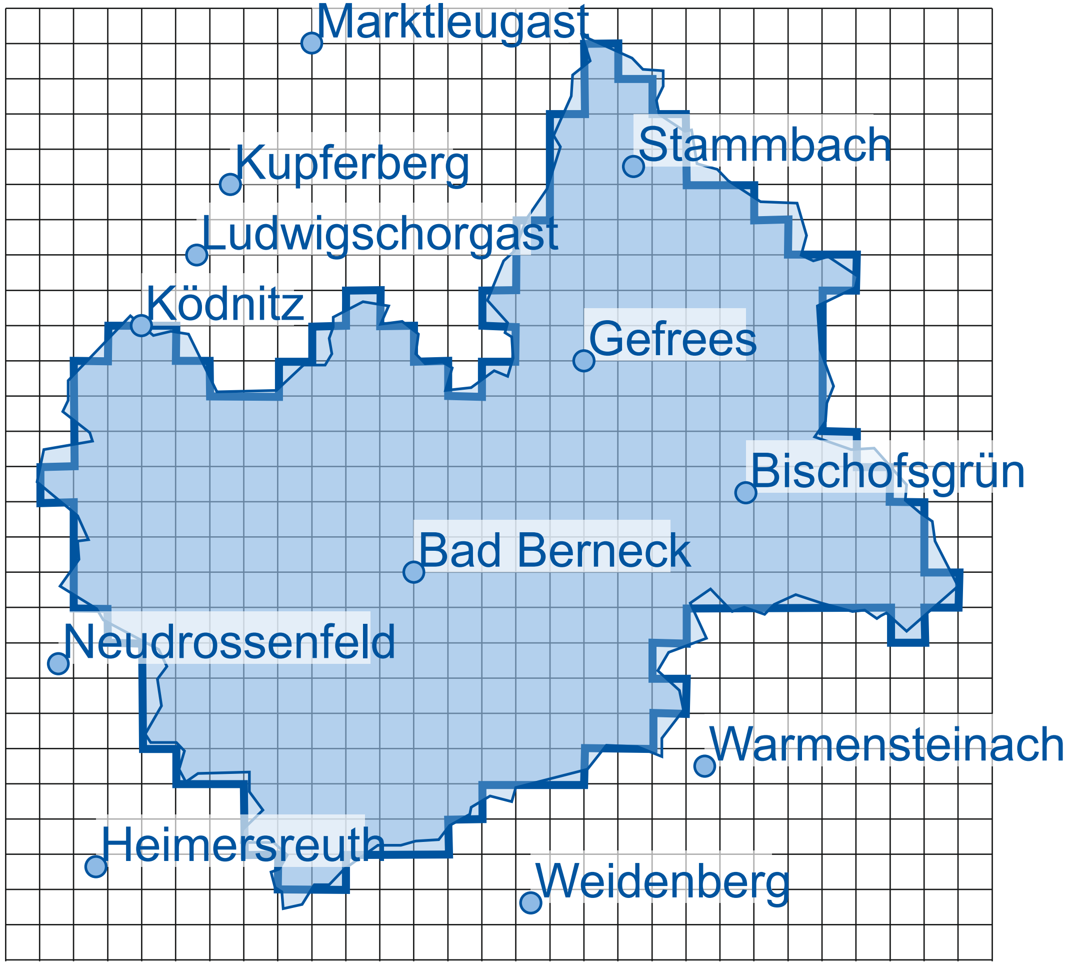
Basis: Geodata - Bavarian Surveying Administration Munich

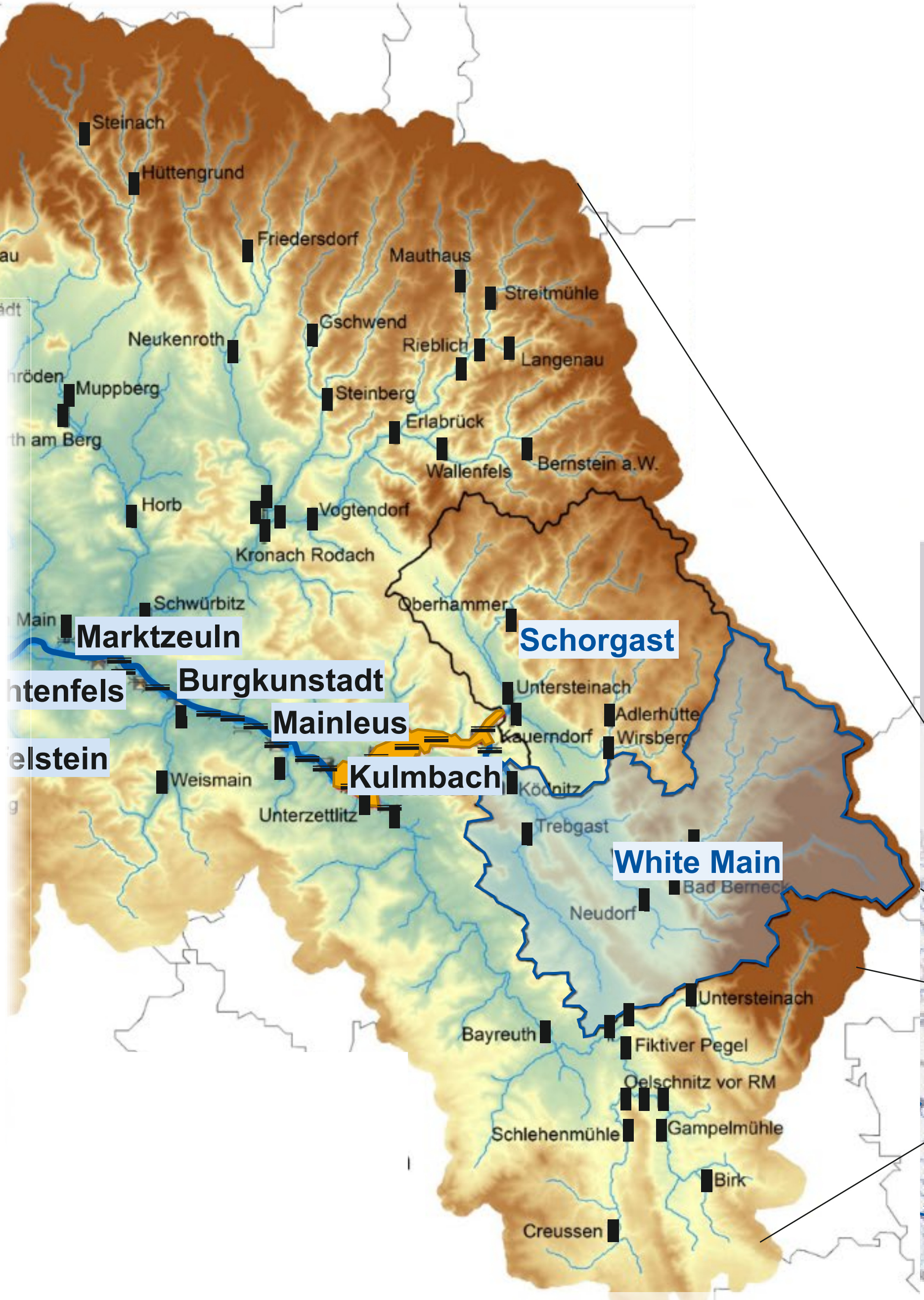
Example White Main

catchment size: 360 km²

grid cells: 1 x 1 km²

flood event: 5/27 - 6/1/2006



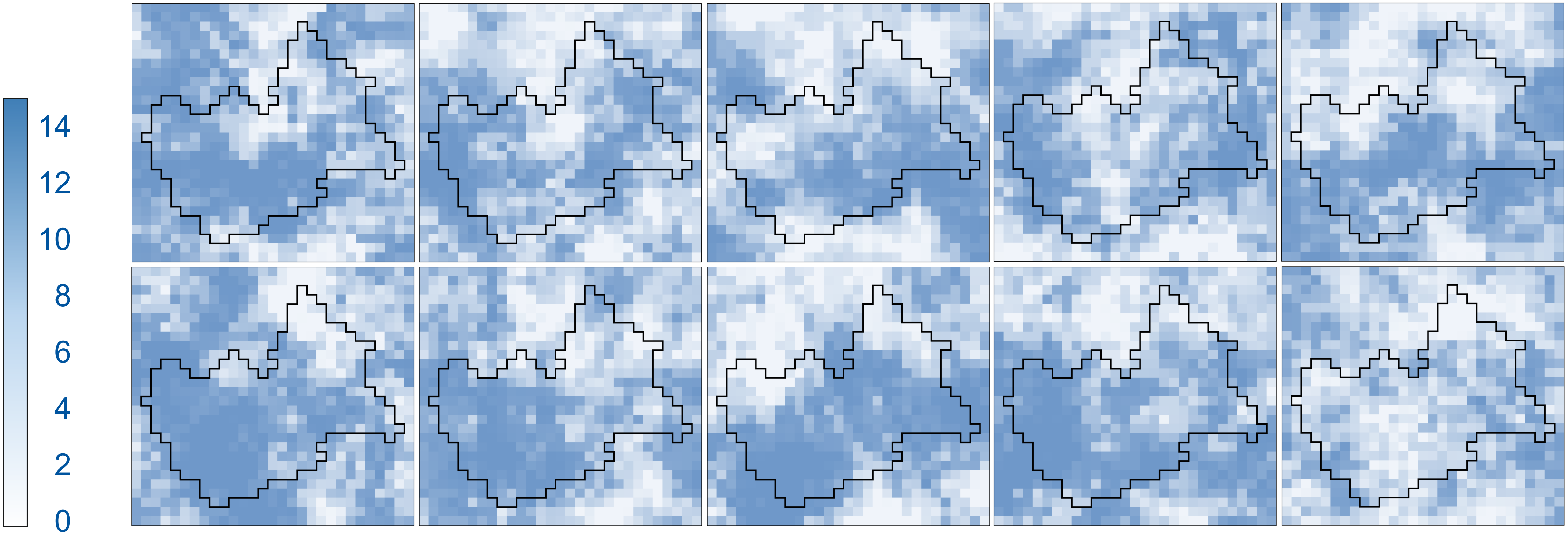


Basis: Geodata - Bavarian Surveying Administration Munich

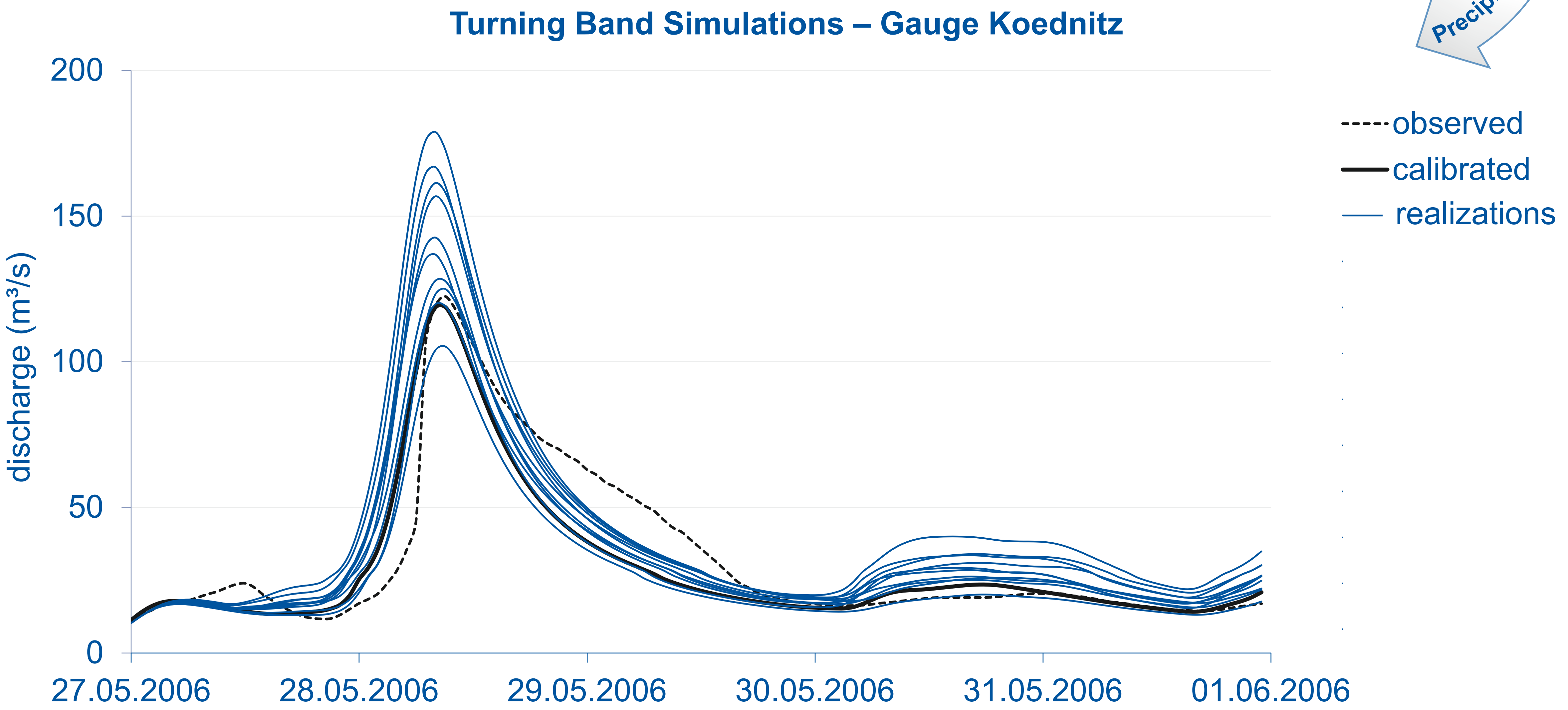
Spatial Distribution (Turning Bands)

10 Realizations for Turning Band with 8 Stations

Precipitation [mm]
Time: 05/28/2006, 3:00 am

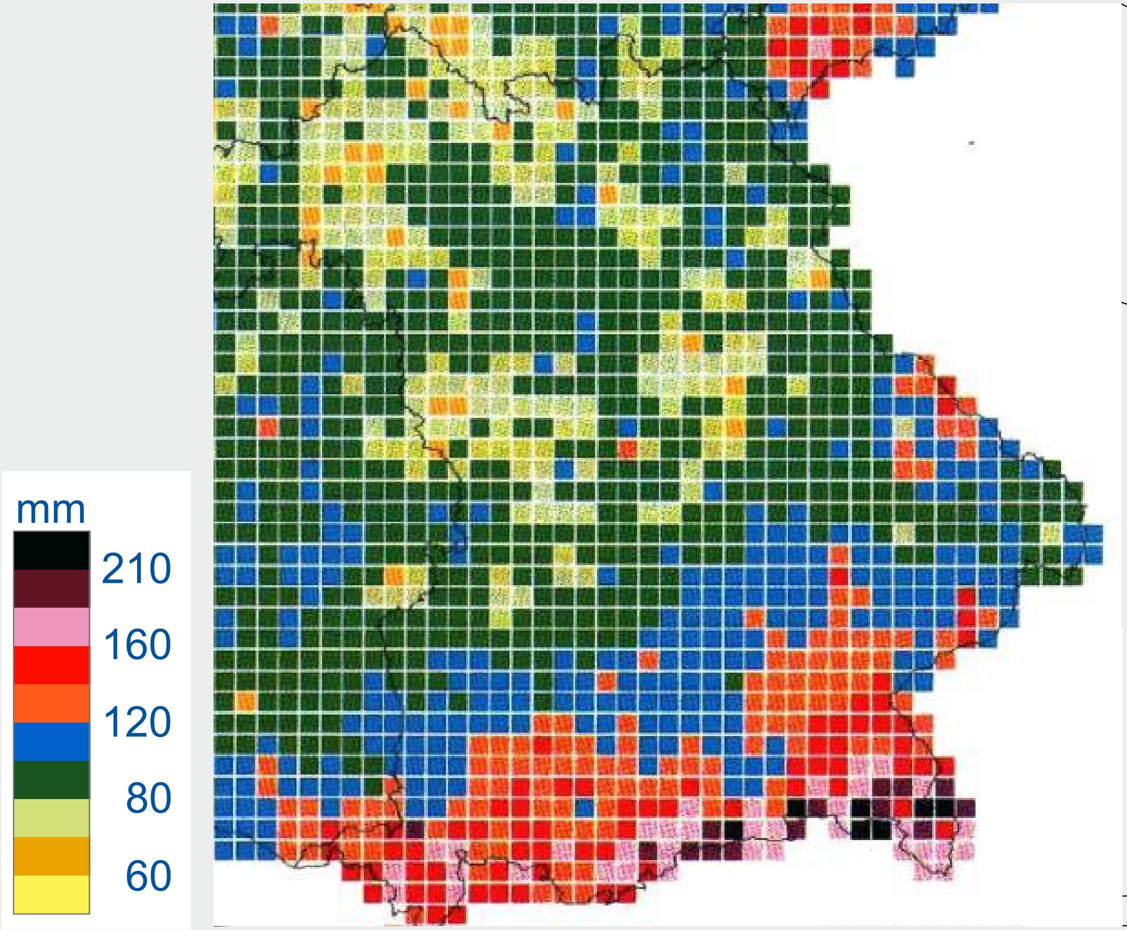


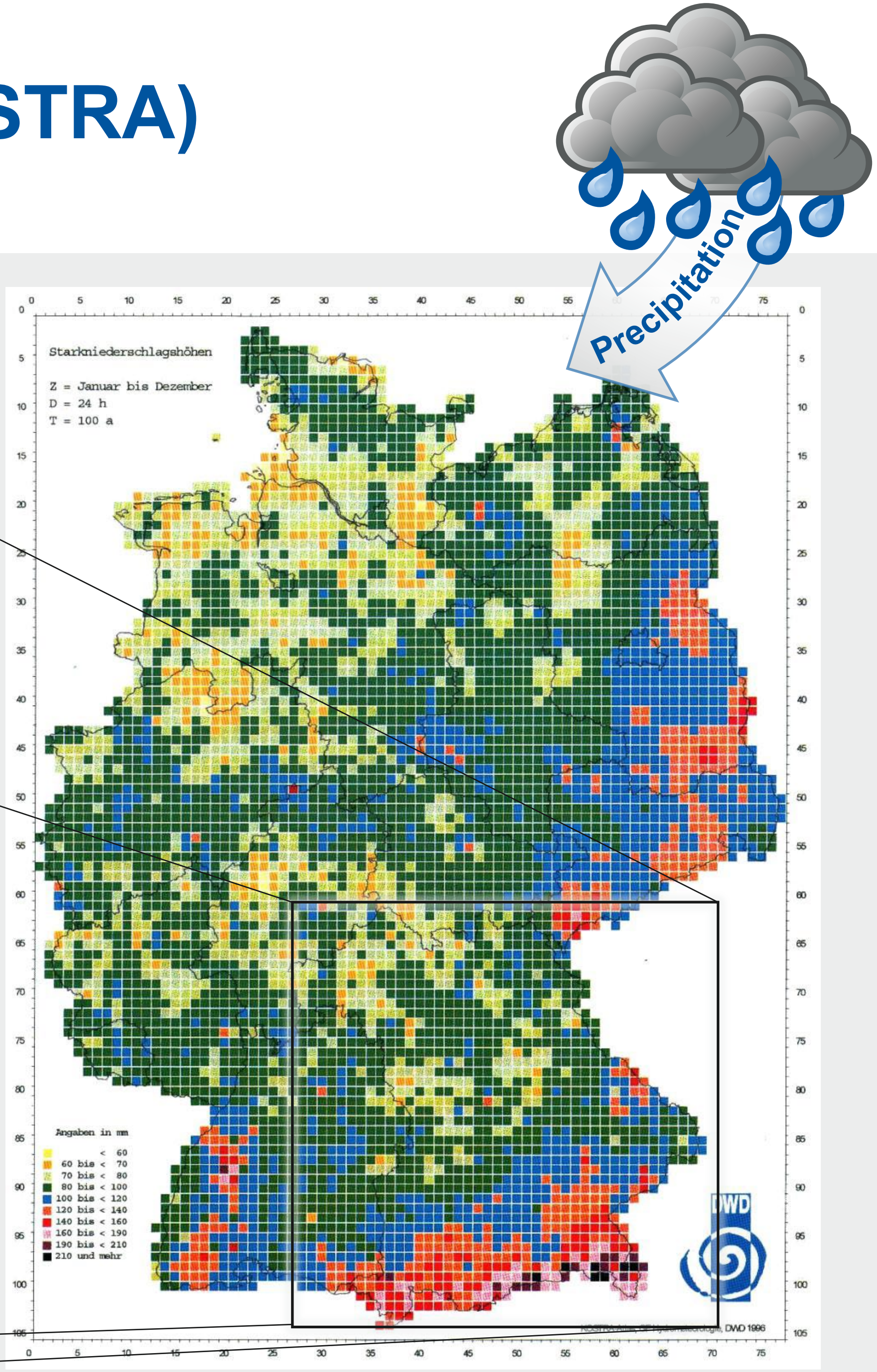
Resulting Flood Waves (Rainfall Runoff Model LARSIM)



Temporal Distribution (KOSTRA)

KOSTRA – design rainfall for 100 year recurrence interval

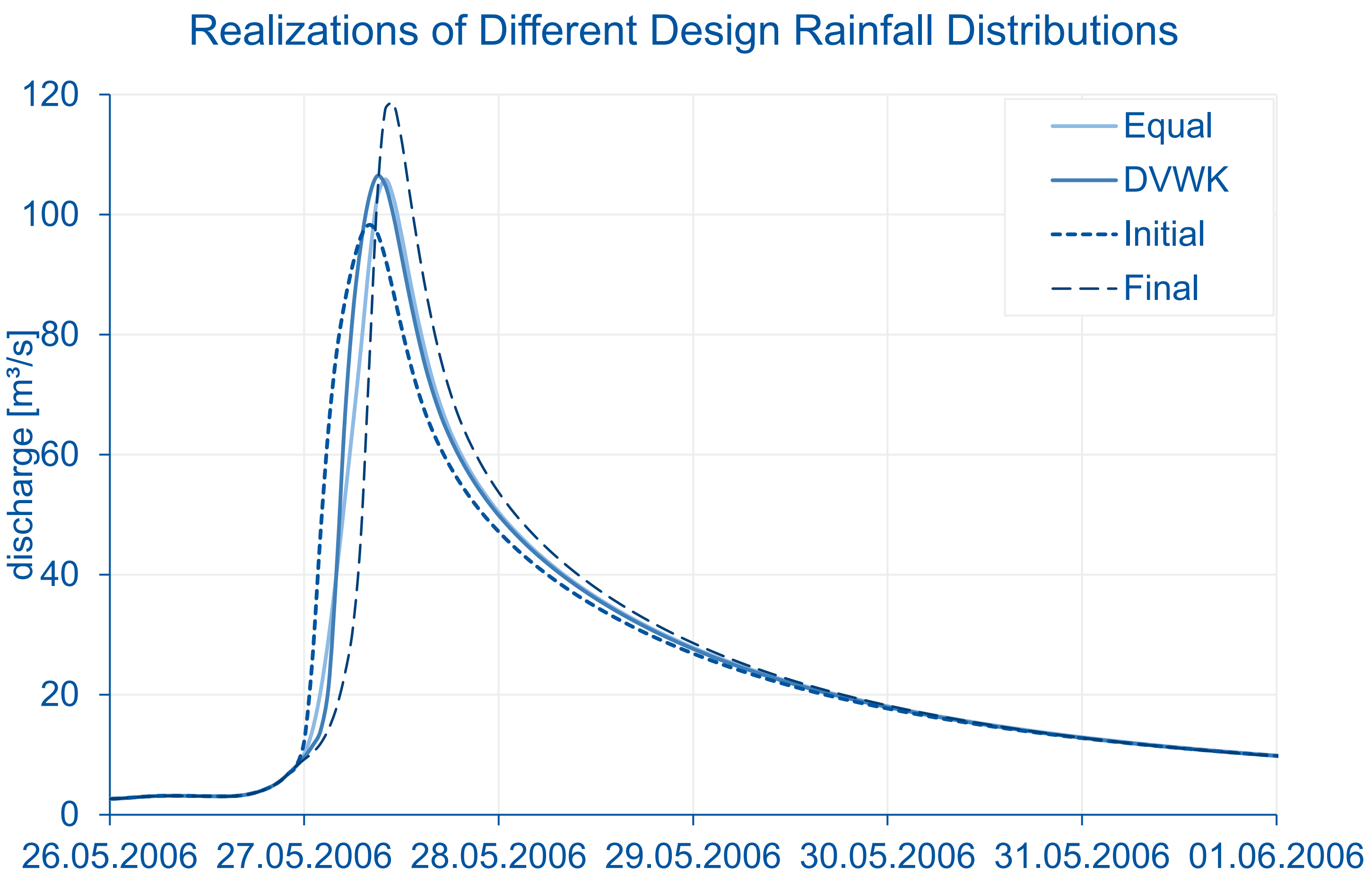


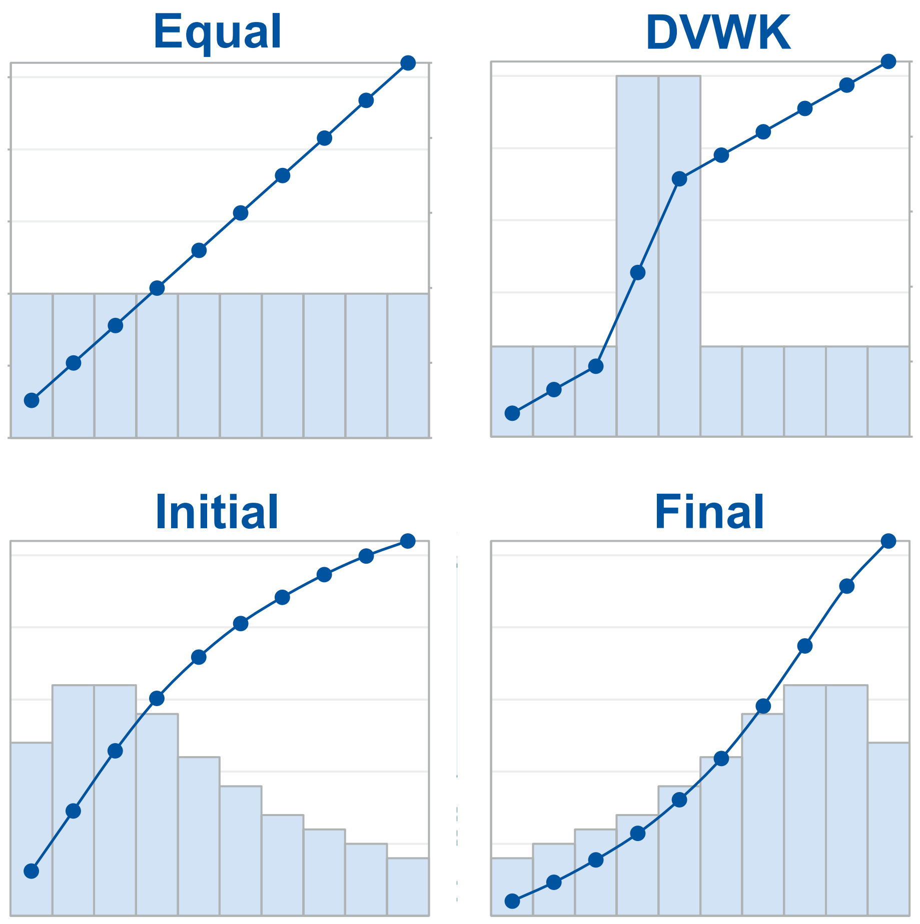


Deutscher Wetterdienst (DWD)

Temporal Distribution (KOSTRA)

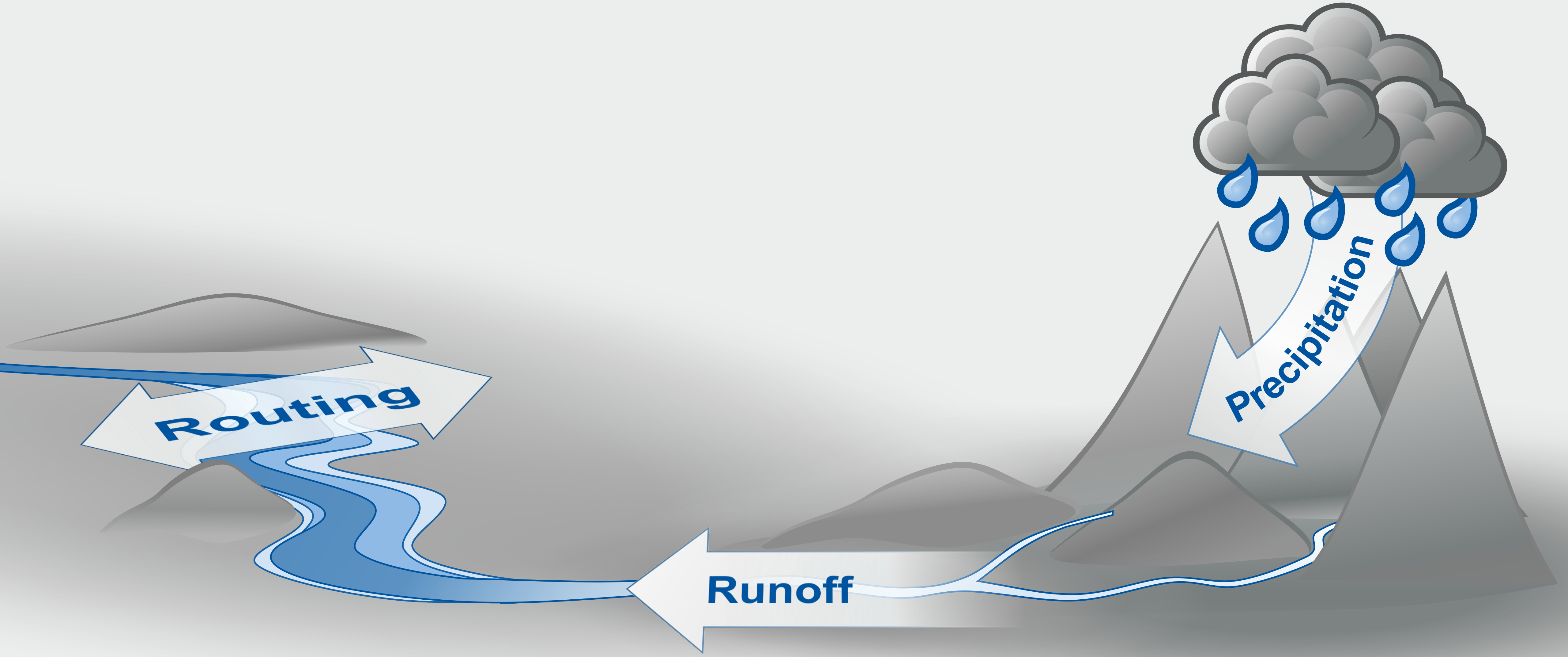
KOSTRA – design rainfall for 100 year recurrence interval





Flood Chain Uncertainties 2/3
- Runoff -

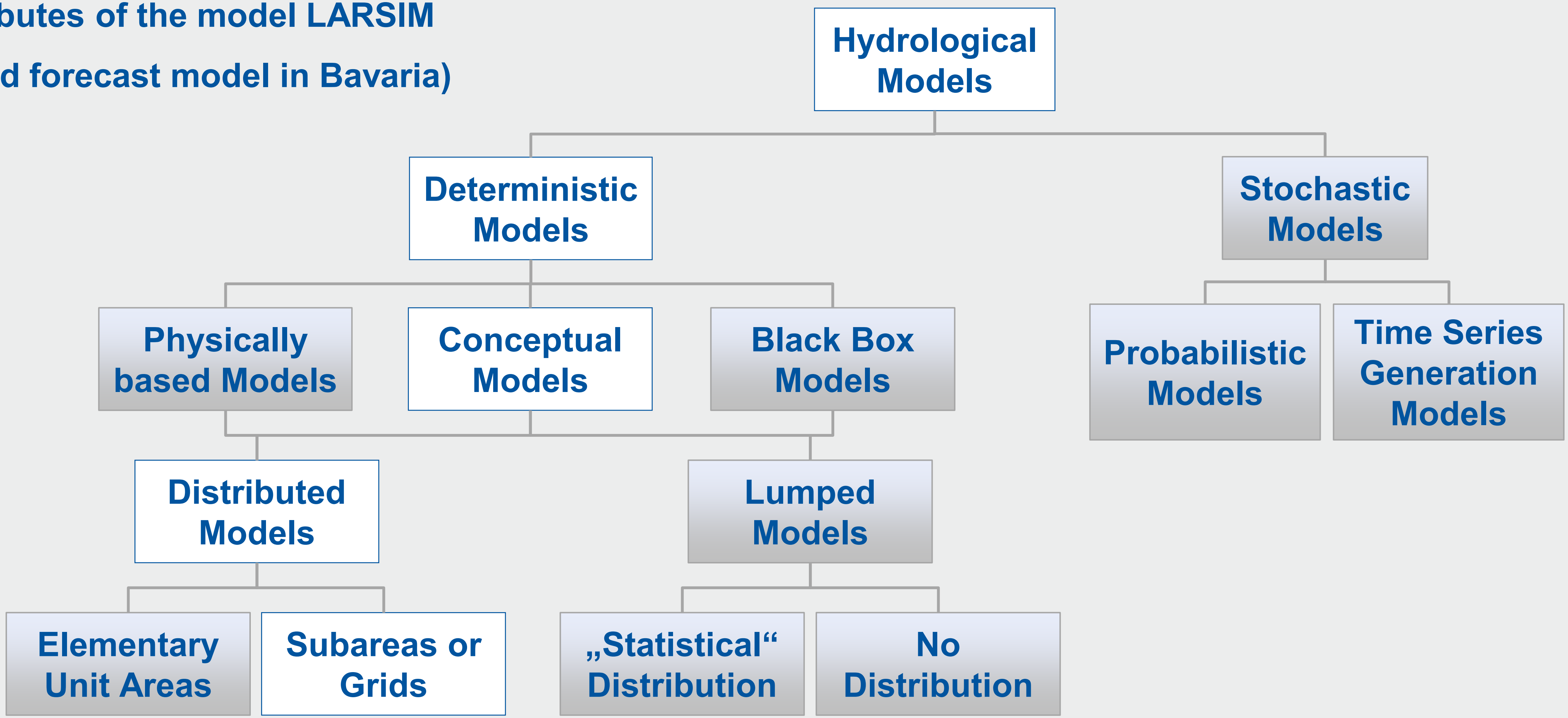
The Flood Chain: Precipitation – Runoff – Flood Routing



Classification of Rainfall-Runoff-Models

Attributes of the model LARSIM

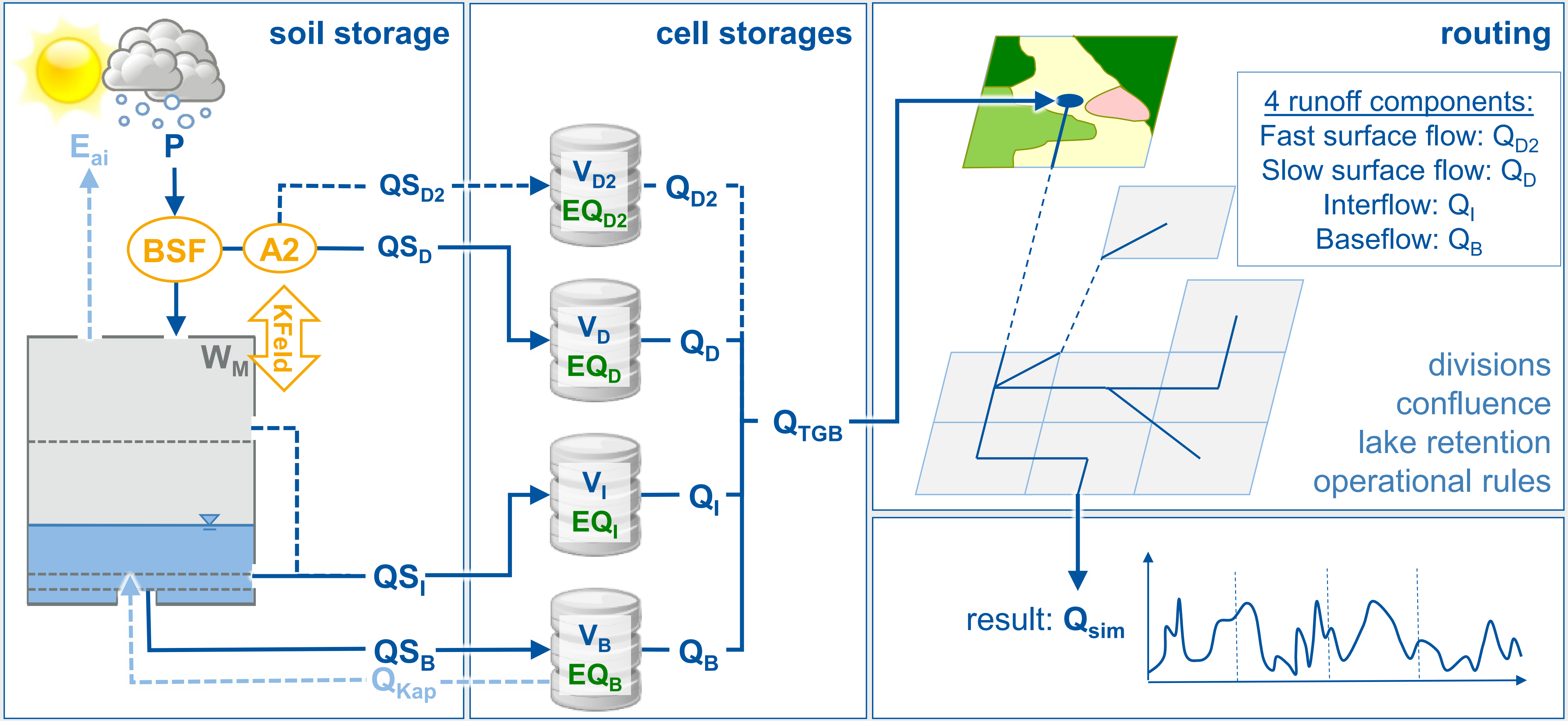
(flood forecast model in Bavaria)



Becker (1995)

Structure of the Rainfall-Runoff-Model LARSIM

Runoff

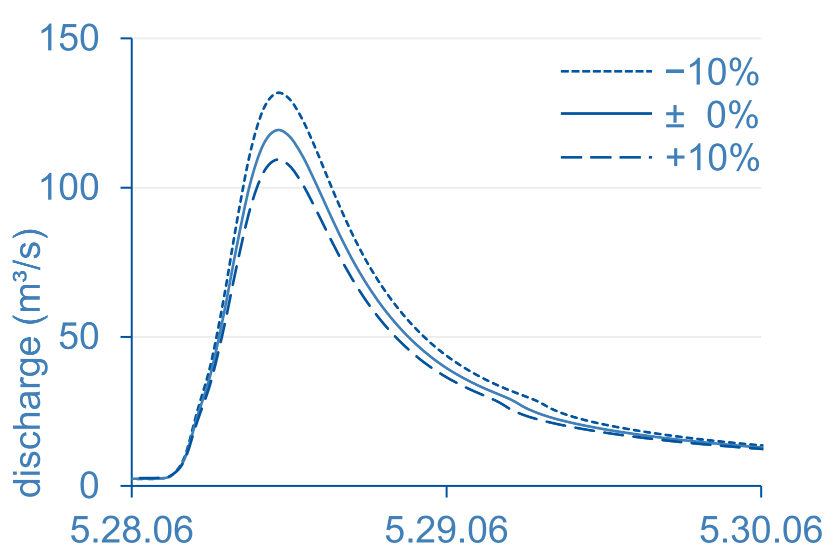


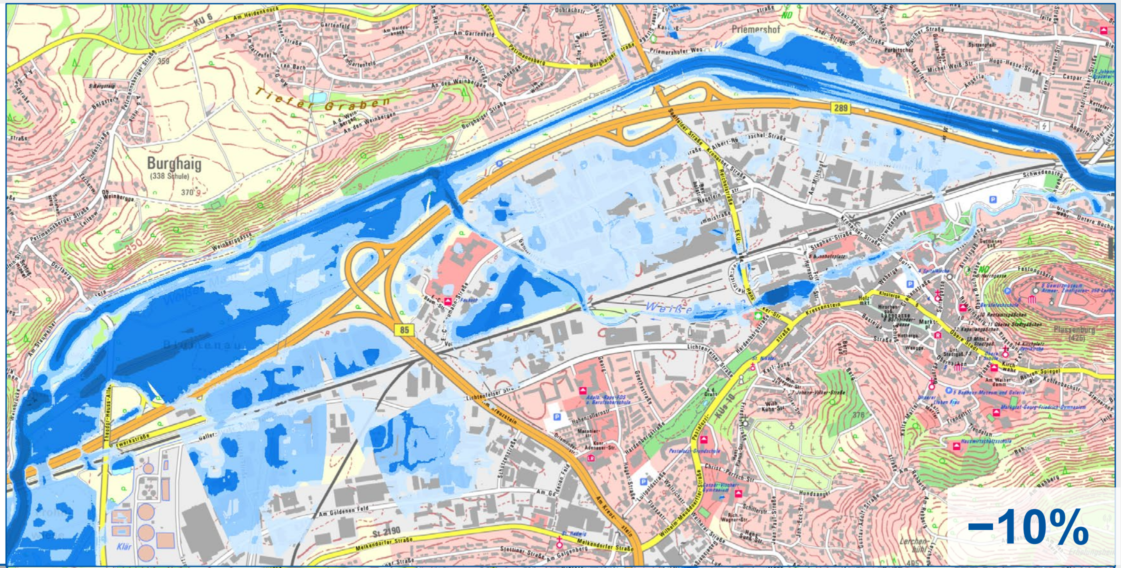
Uncertainties of Soil Parameter *KFeld* in LARSIM

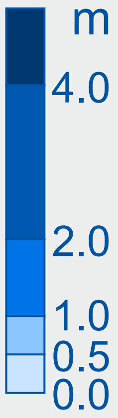
Runoff

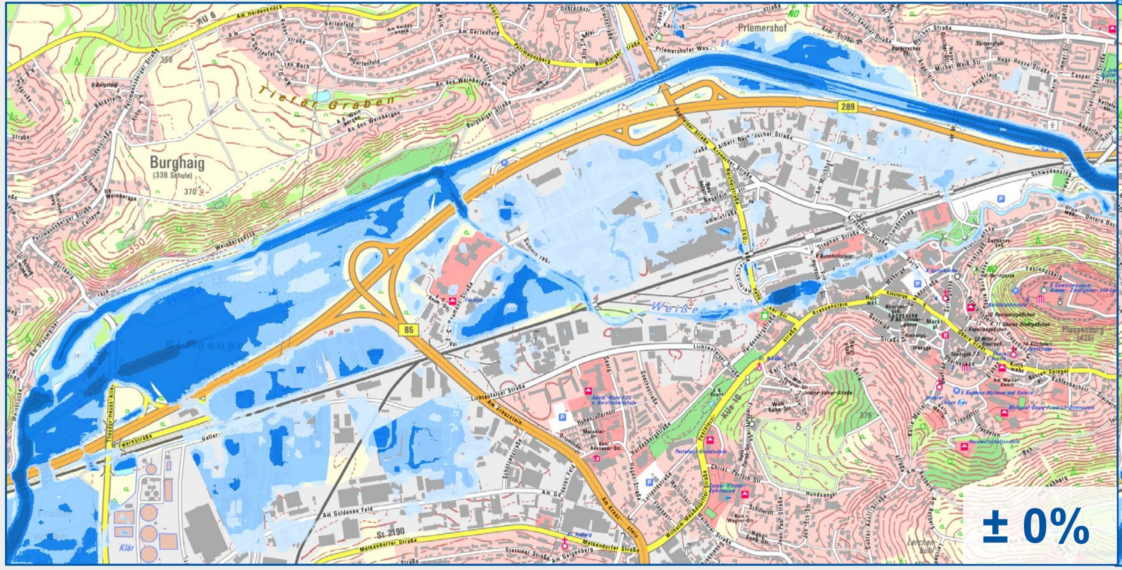
Variation of soil parameter **Kfeld** (storage volume of upper soil): ± 10%

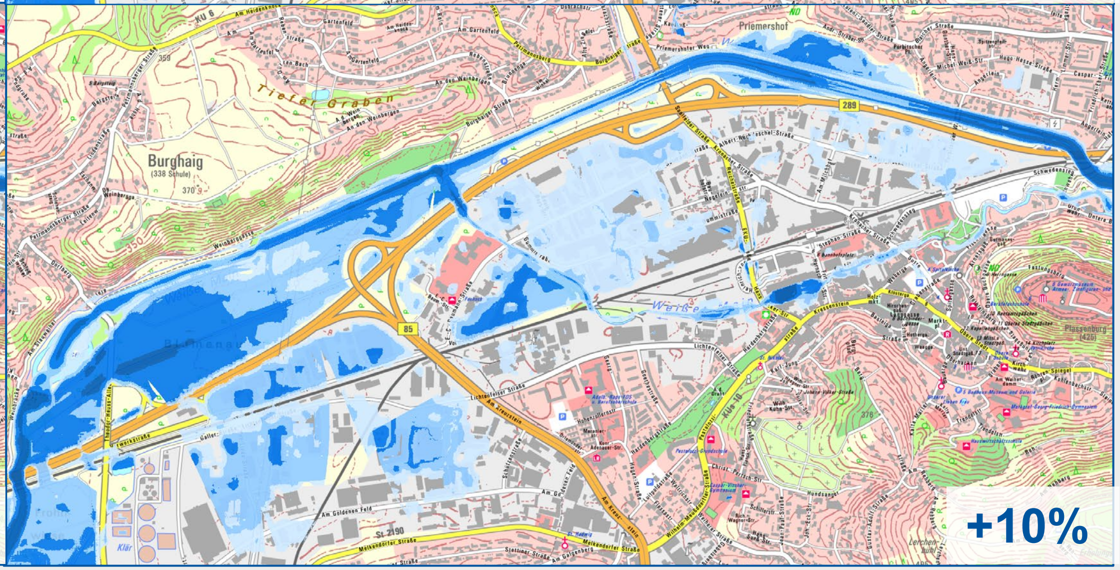
Basis: Geodata - Bavarian Surveying Administration Munich



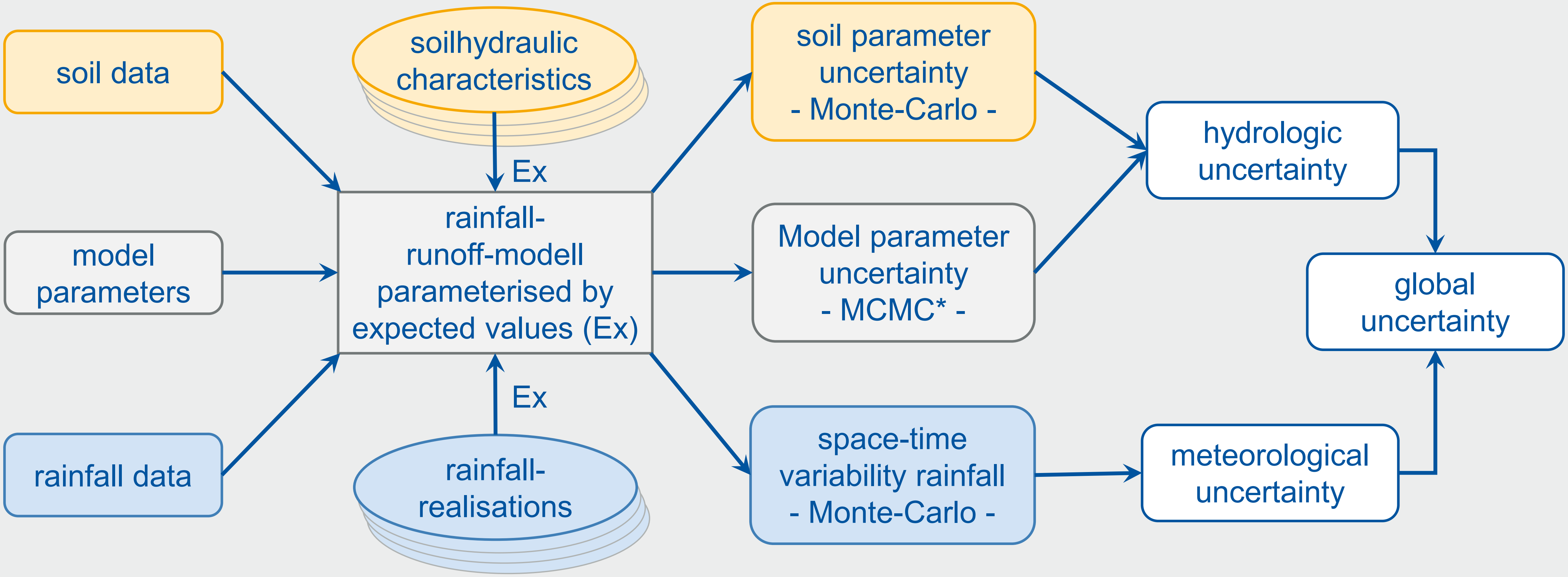








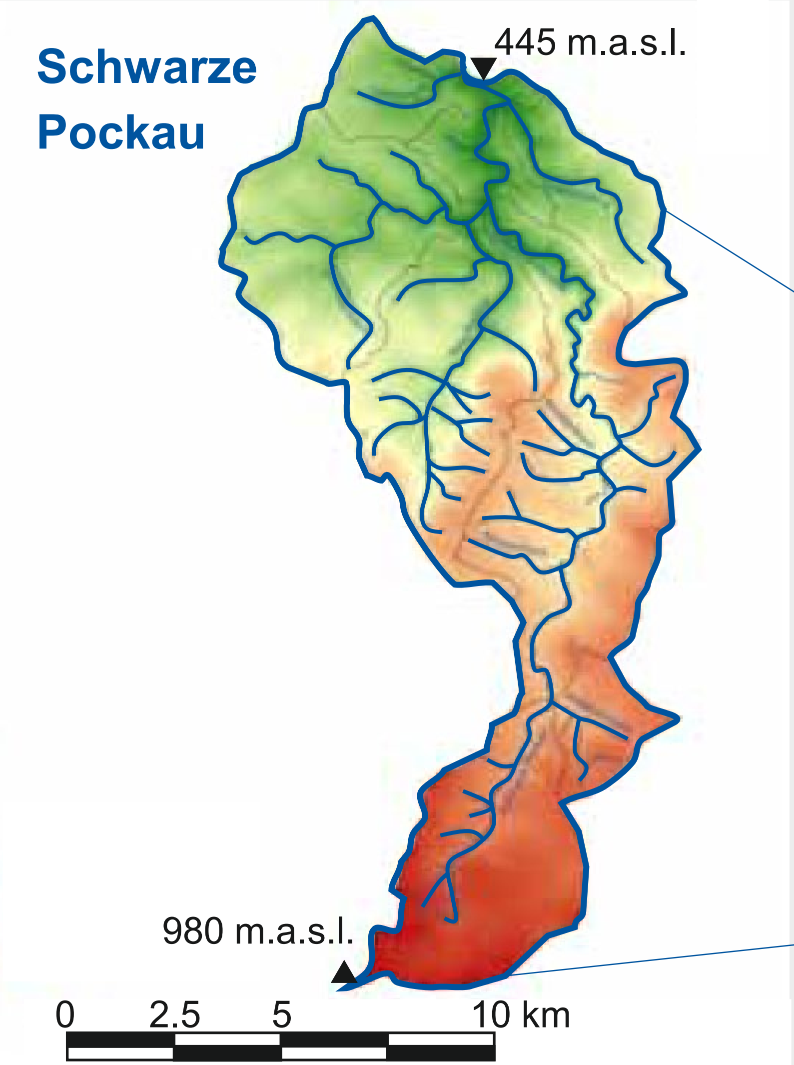
Uncertainties in Rainfall-Runoff-Modelling

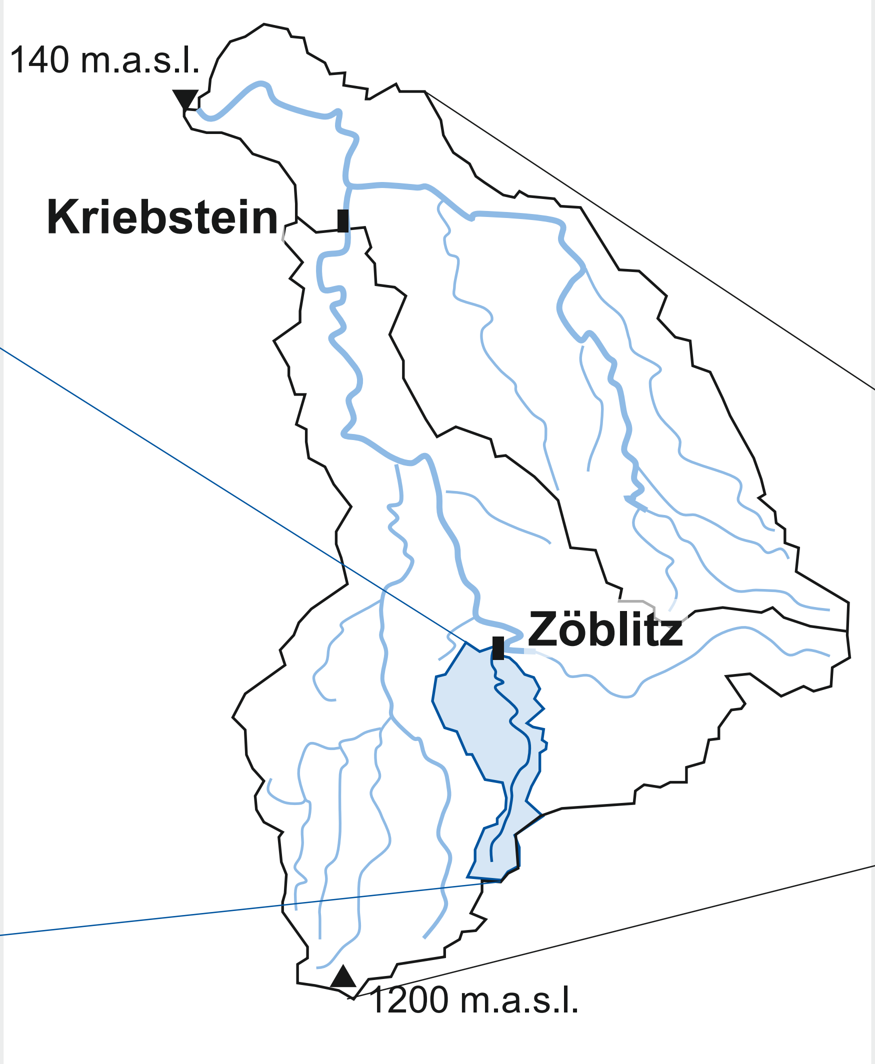


Numerical solution: *Markov-Chain-Monte-Carlo (MCMC) method

Grundmann J., 2010

Uncertainties in Rainfall-Runoff-Modelling





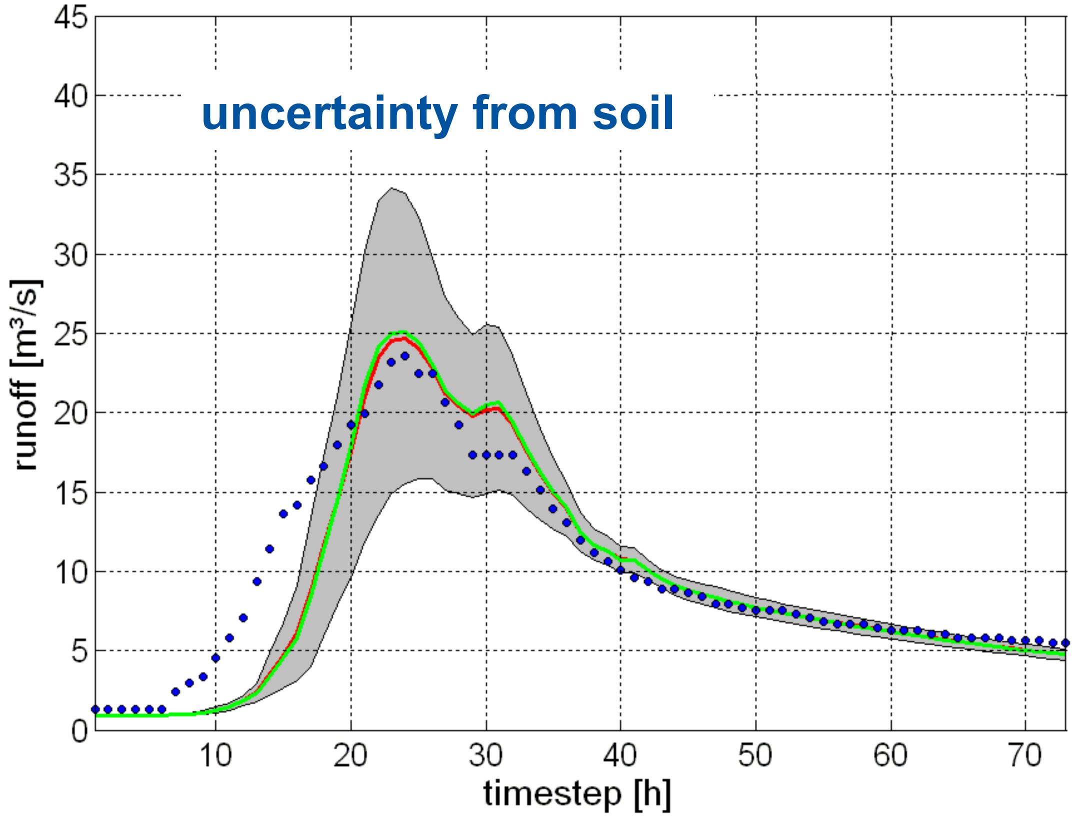
catchment size: 130 km²

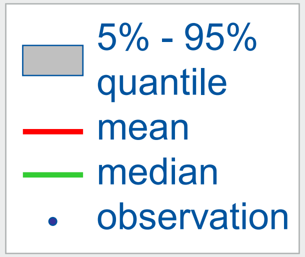
flood event: 09/1995

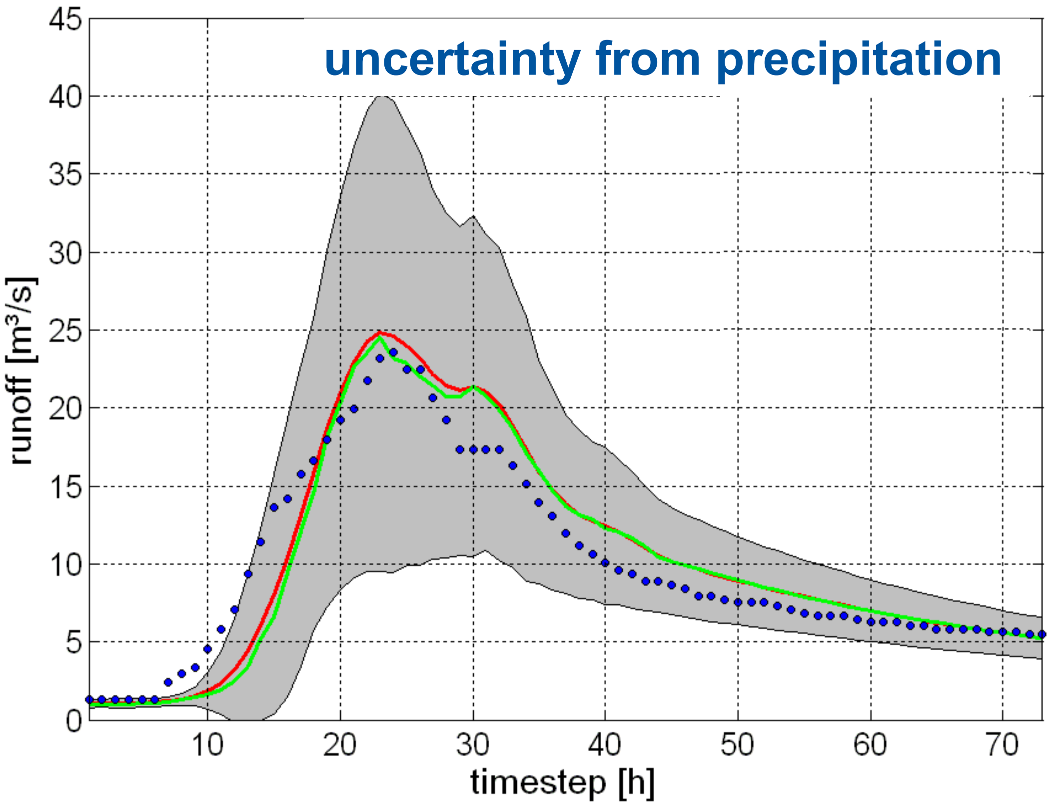
Grundmann J., 2010

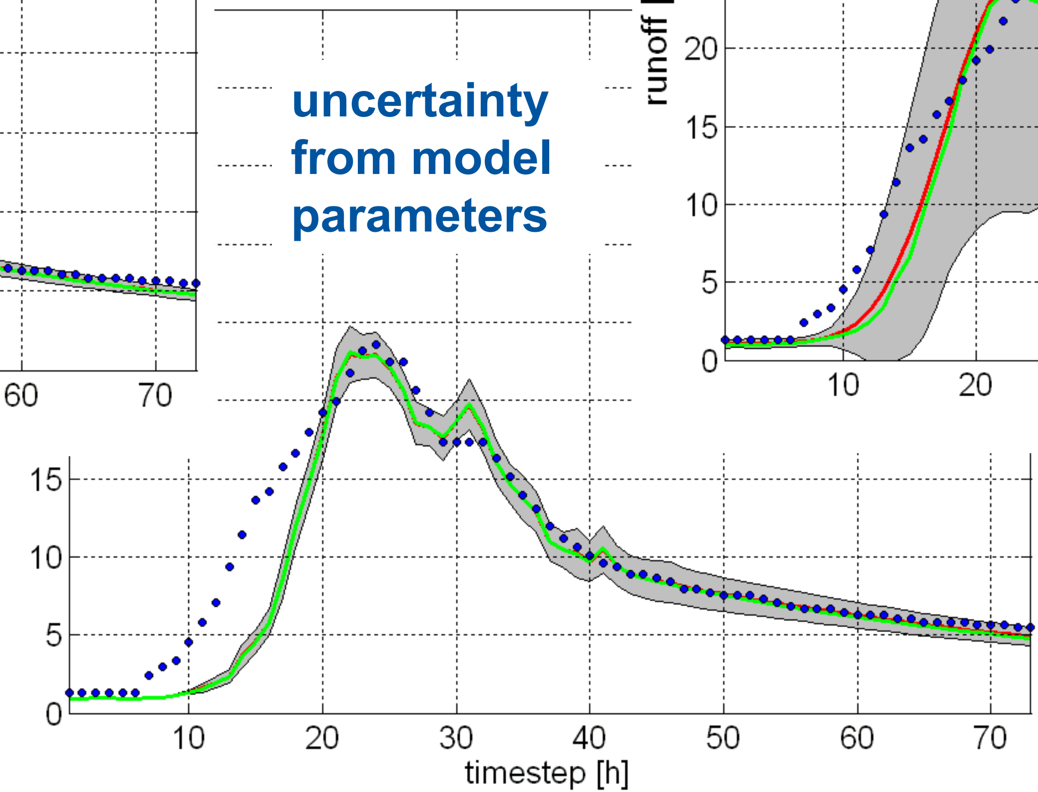
Uncertainties in Rainfall-Runoff-Modelling

Runoff







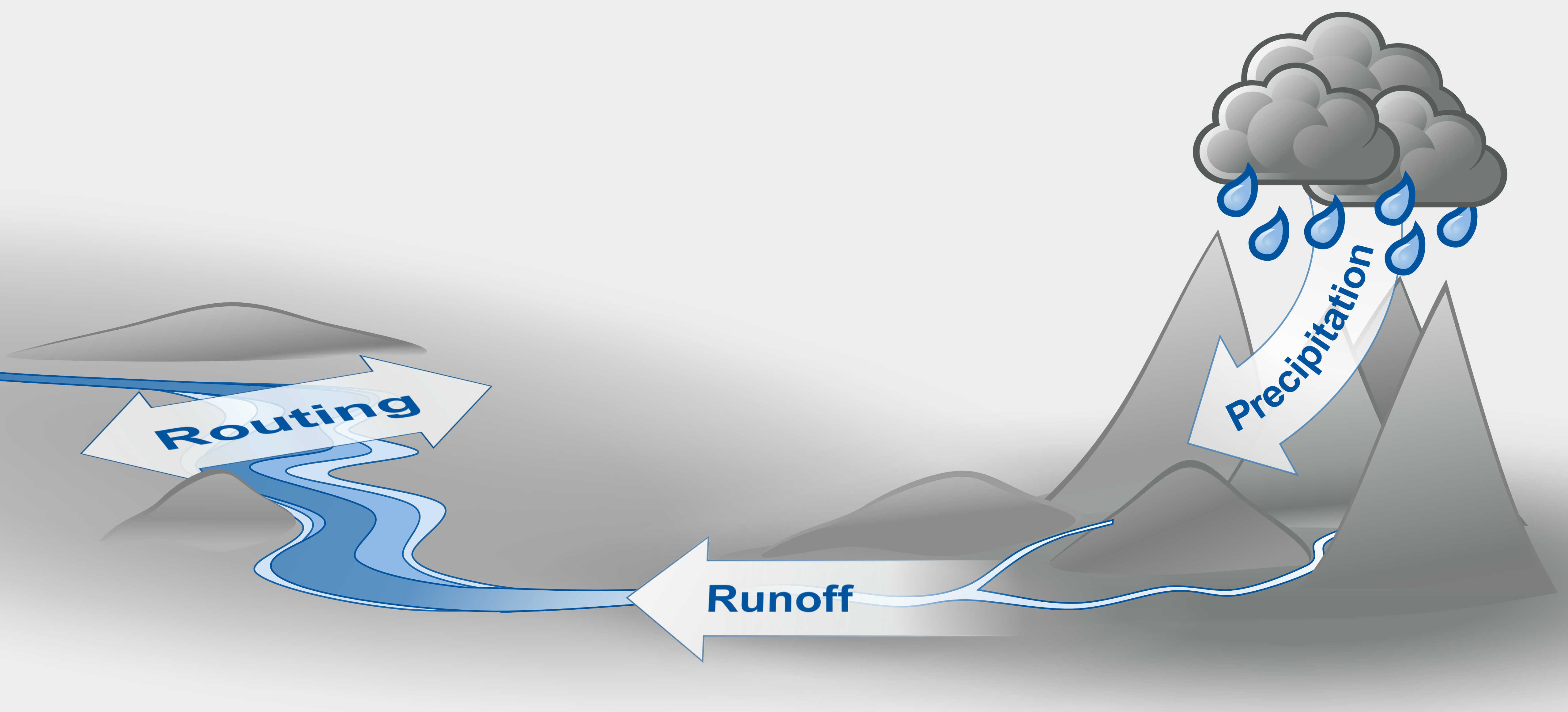


Schwarze Pockau
catchment size: 130 km²
flood event: 09/1995

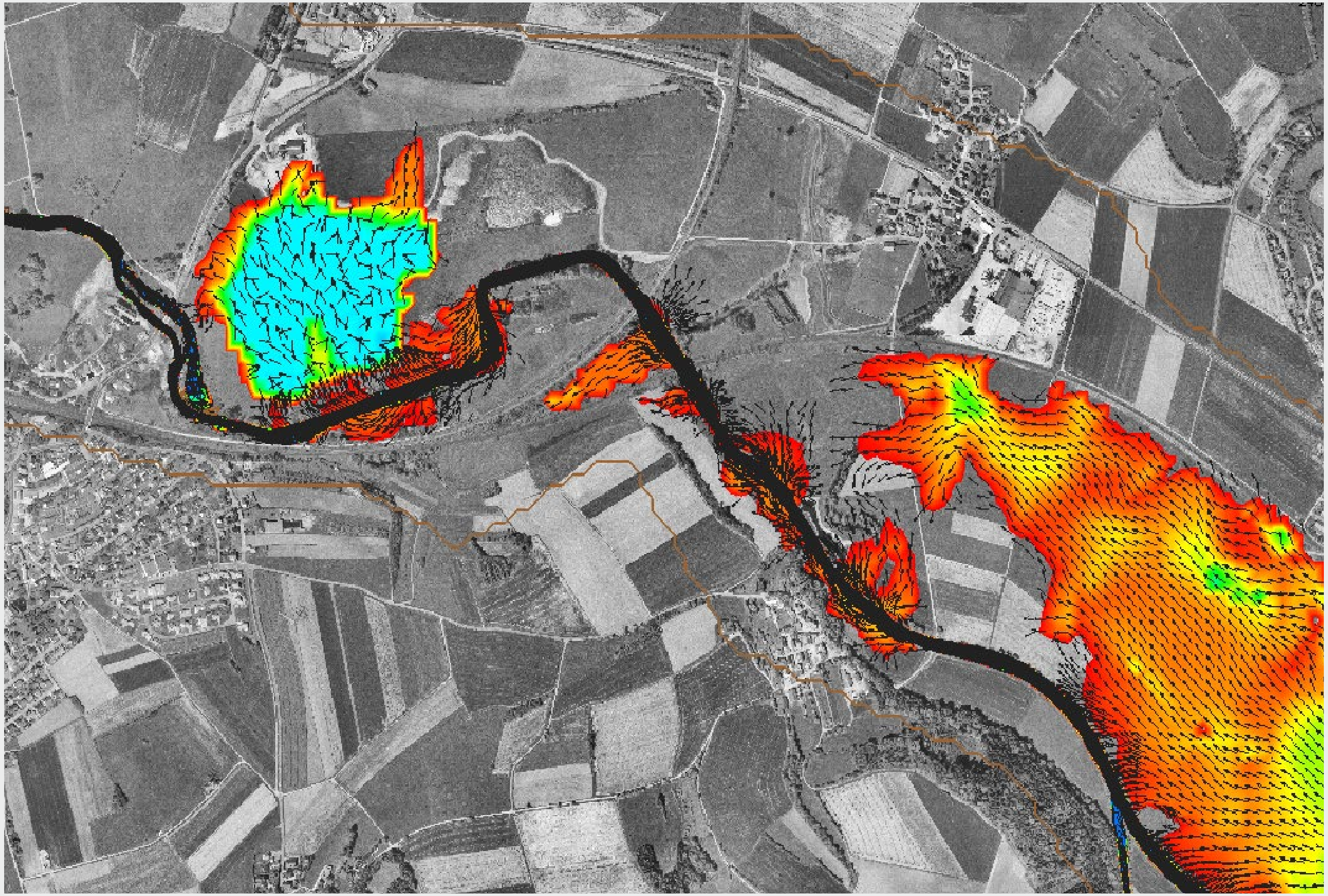
Grundmann J., 2010

Flood Chain Uncertainties 3/3
- Routing -

The Flood Chain: Precipitation – Runoff – Flood Routing

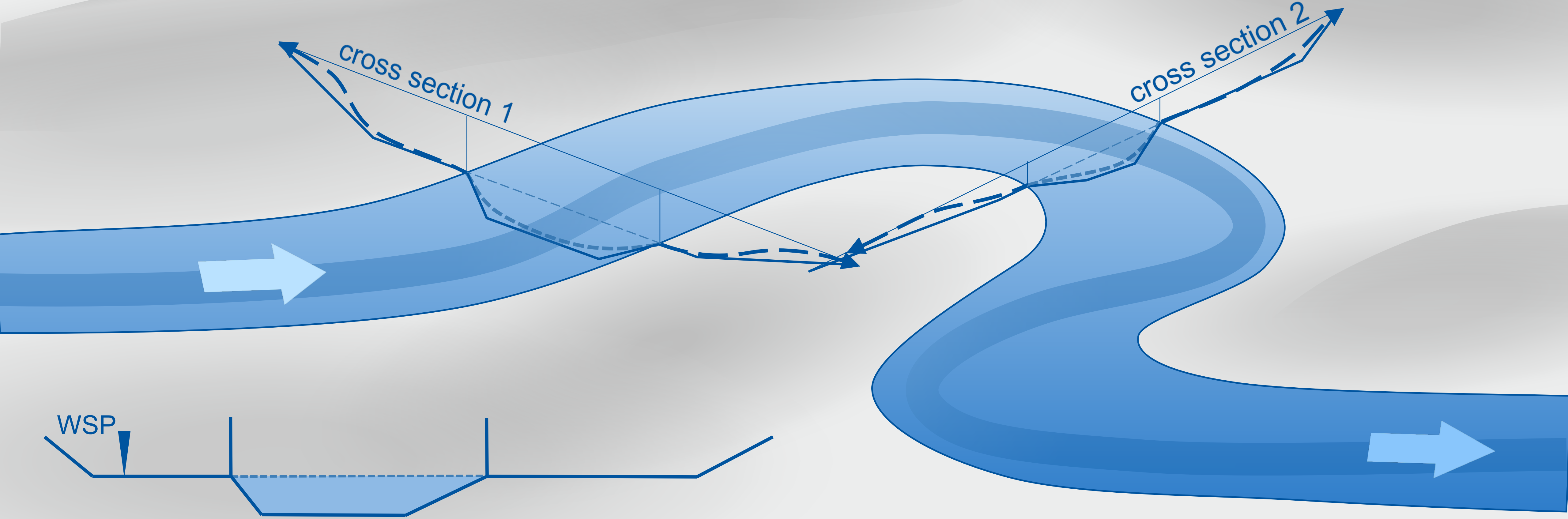


Hydrodynamic Modelling: 1D or 2D?



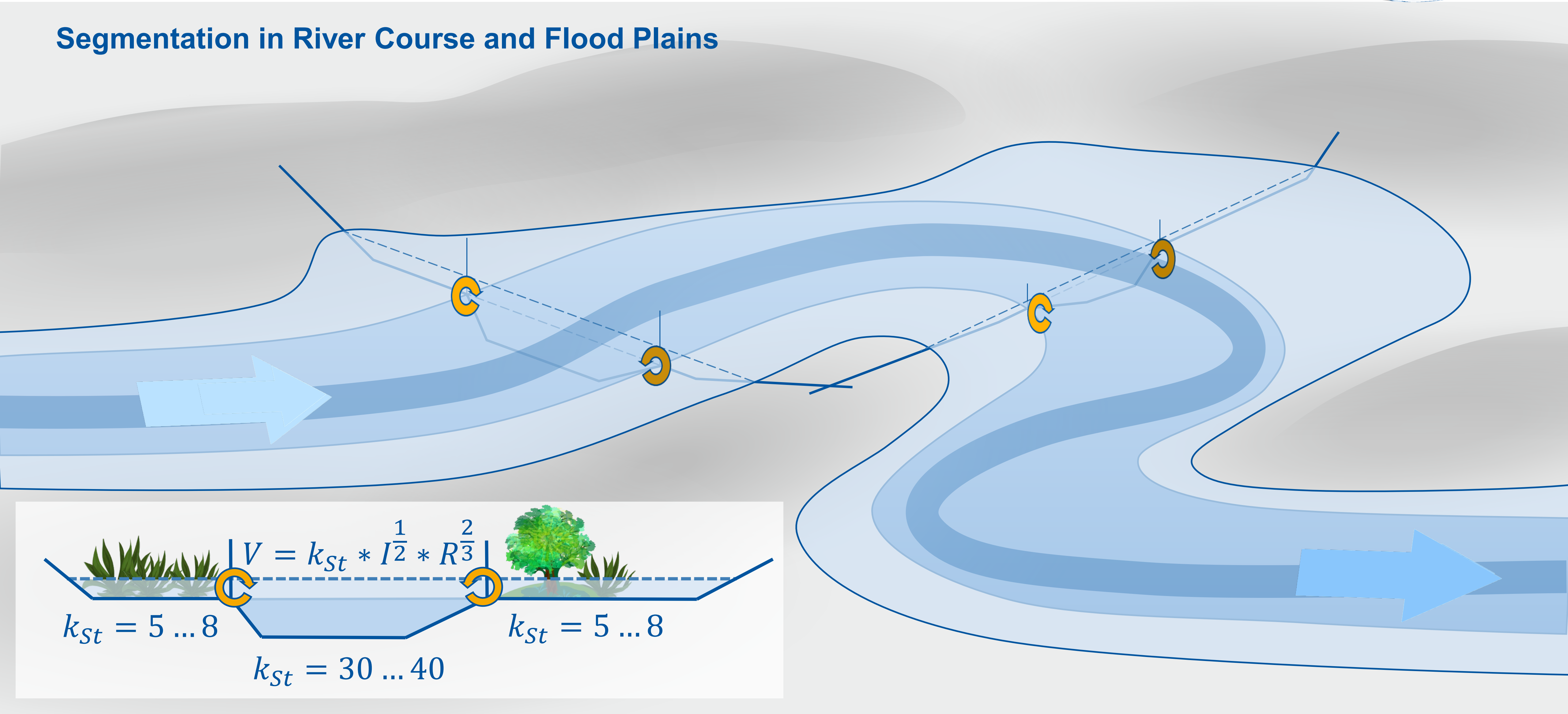
1D Hydrodynamic Modelling

River Cross Sections



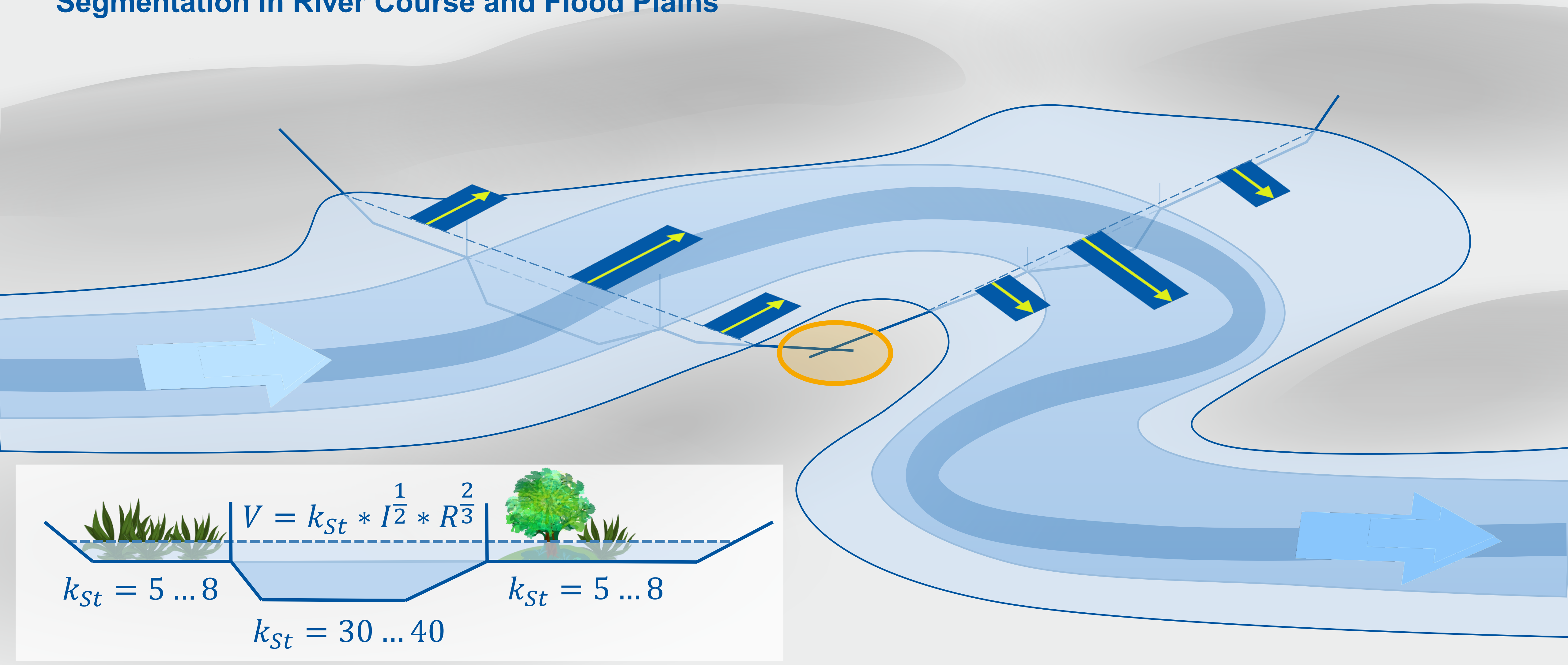
1D Hydrodynamic Modelling

Segmentation in River Course and Flood Plains



1D Hydrodynamic Modelling

Segmentation in River Course and Flood Plains



1D Hydrodynamic Modelling

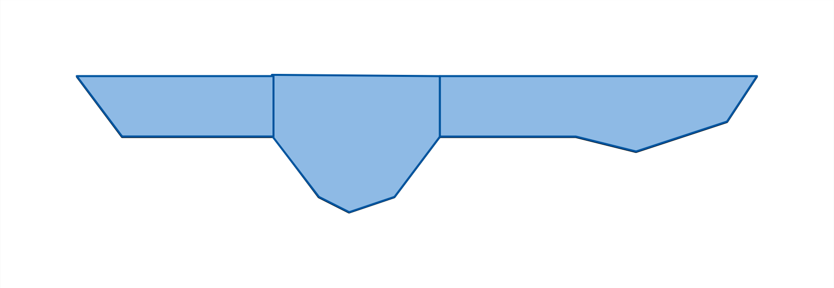
Basis: Geodata - Bavarian Surveying Administration Munich

Pros:

- short computation time
- very good modelling of the 1D water routing (flow in the river bed)

Cons:

- flow in flood plains is difficult to simulate
- no turbulent shear stresses
- handling of overlapping cross sections



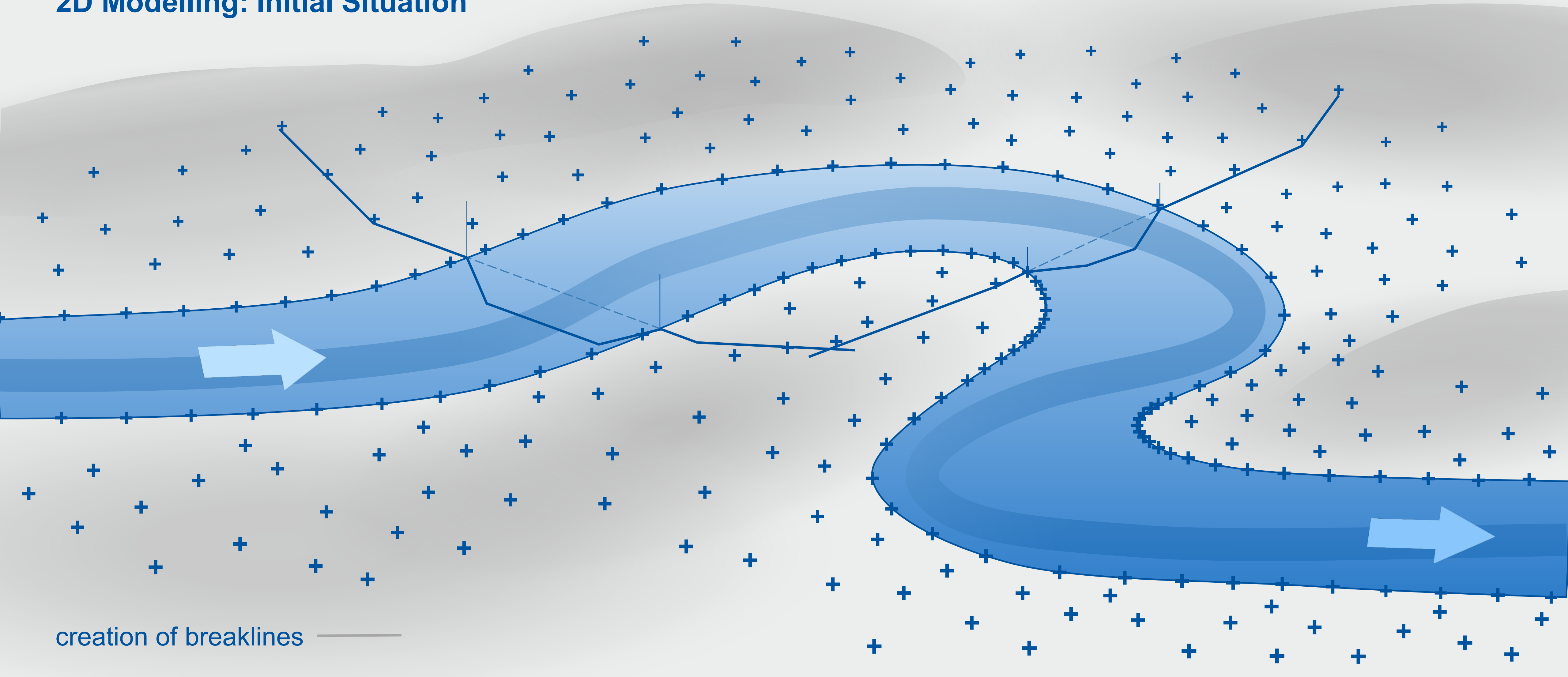
1D Hydrodynamic Modelling

Setup

1. Segmentation in cross sections (compact / structured)
2. Creation of the river system including structures
3. Reproduction of short cut flows and flow around structures by secondary branches
4. Implementation of breaklines (i.e. roadway embankments)
5. Segmentation of the river system in sections with different roughnesses
6. Calibration
7. Validation

2D Hydrodynamic Modelling

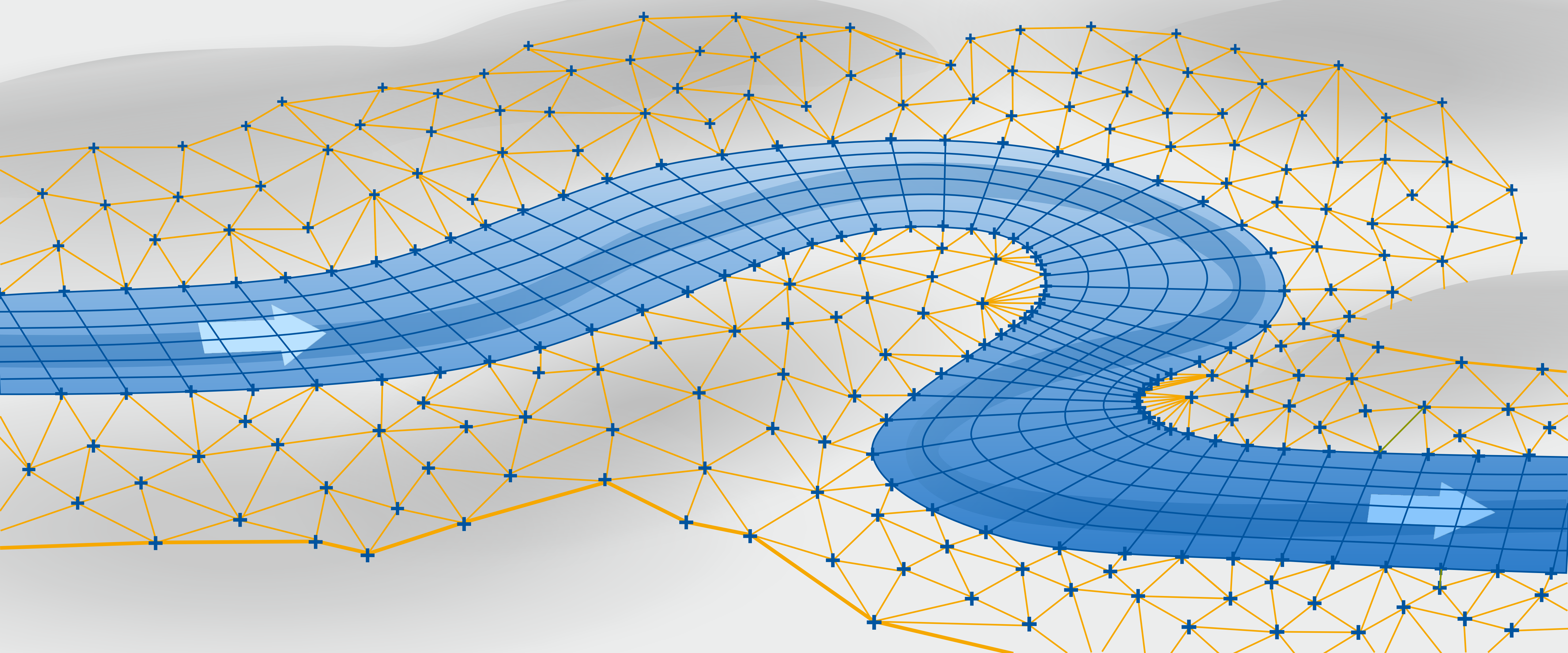
2D Modelling: Initial Situation



creation of breaklines

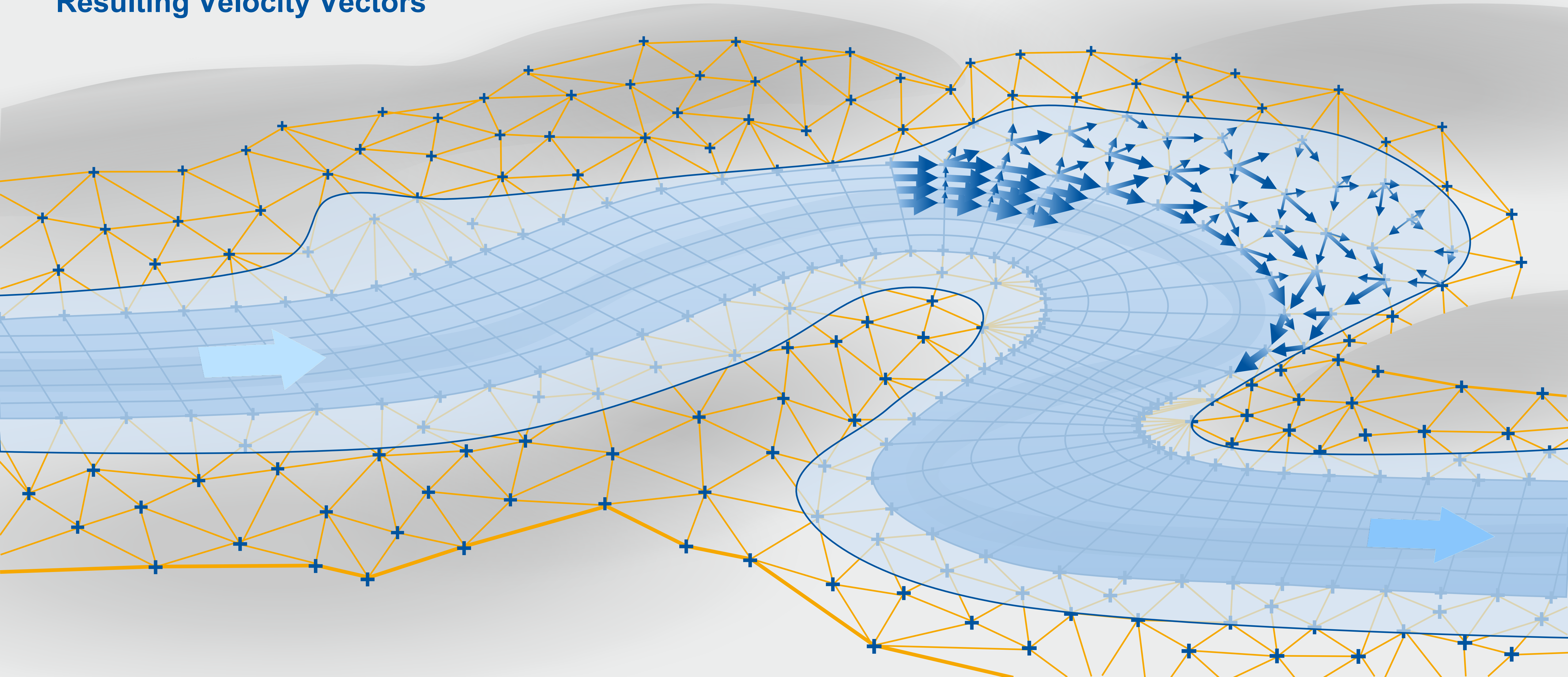
2D Hydrodynamic Modelling

Triangulation

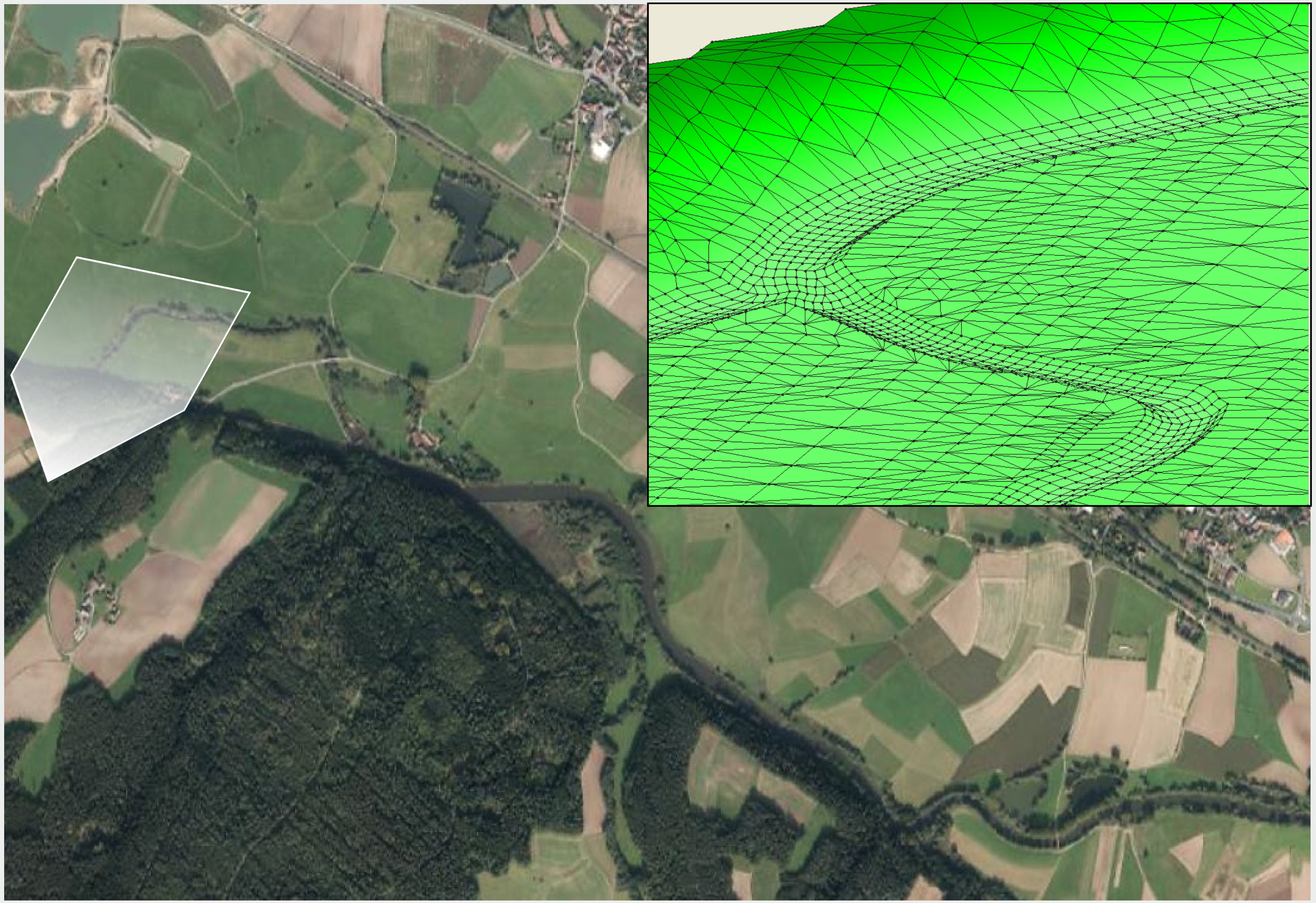


2D Hydrodynamic Modelling

Resulting Velocity Vectors



2D Hydrodynamic Modelling



Basis: Geodata - Bavarian Surveying Administration Munich

Pros:

- Very good reproduction of flow processes in flood plains
- Higher accuracy of runoff simulation
- Convenient for retention calculations

Cons:

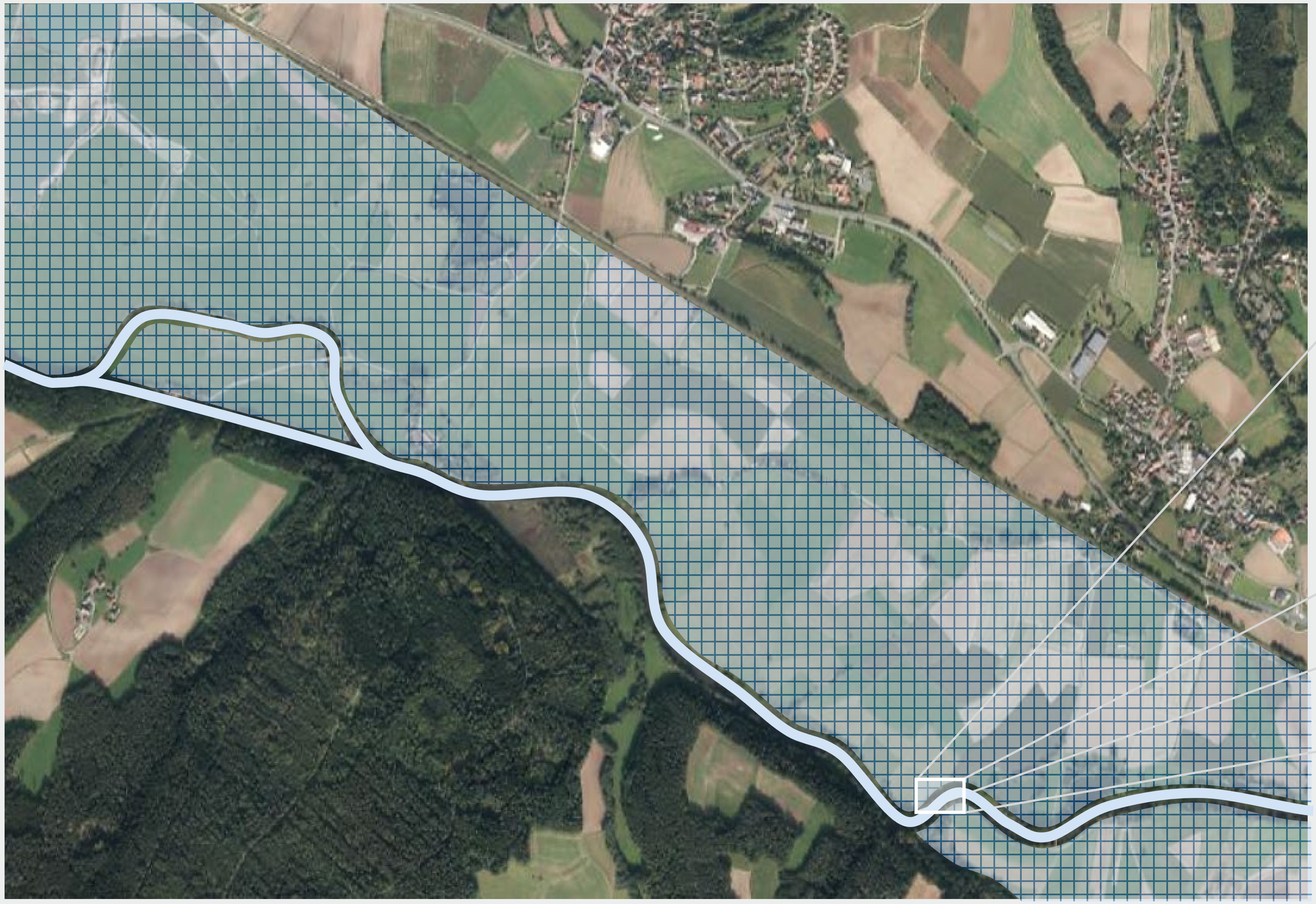
- High computational effort

2D Hydrodynamic Modelling

Setup

1. Creation of the river mesh
2. Creation of the mesh in the floodplains (consideration of breaklines)
3. Merge of river mesh and floodplain mesh
4. Implementation of buildings, bridges and other constructions
5. Segmentation of the river system in sections with different roughnesses
6. Calibration
7. Validation

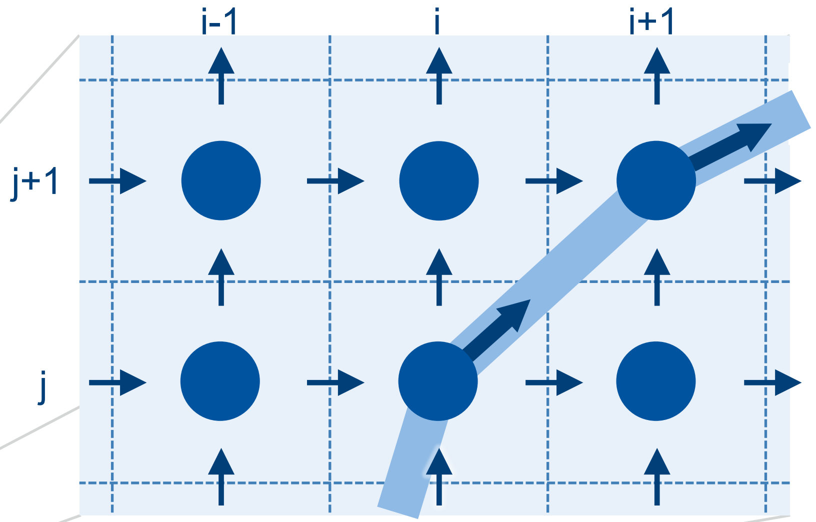
1D/2D Hydrodynamic Modelling

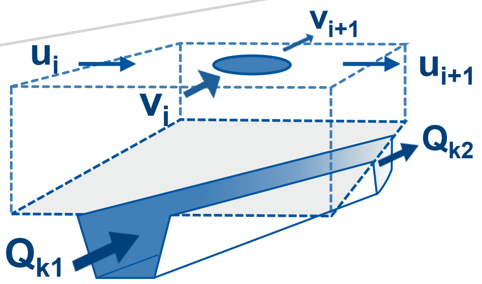


Basis: Geodata - Bavarian Surveying Administration Munich

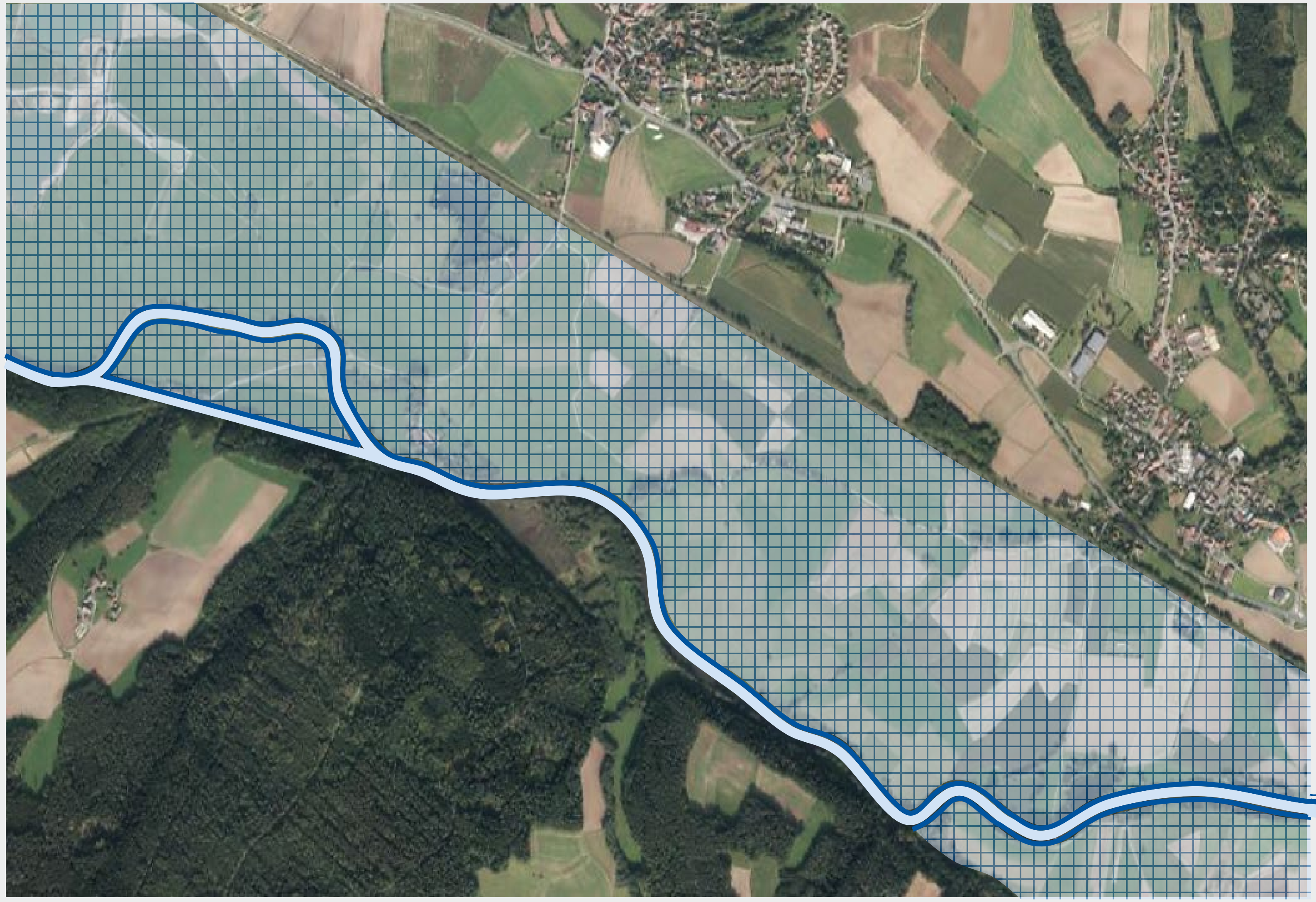
1D/2D Simulation (hybrid)

Advantages of 1D and 2D models but no interaction of momentum!



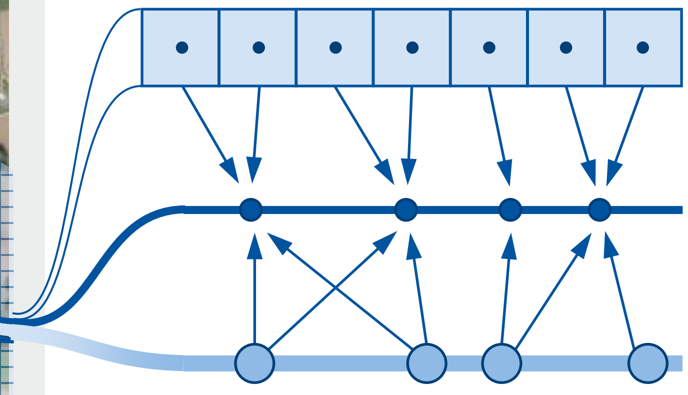


1D/2D Hydrodynamic Modelling



1D/2D Simulation (hybrid)

Advantages of 1D and 2D models but no interaction of momentum!



Basis: Geodata - Bavarian Surveying Administration Munich

Thank you
for your Attention!
Questions?

Sources

Bayerisches Landesamt für Umwelt (BayLfU), 2010: Warnen und Informieren bei Hochwasser – Der Hochwassernachrichtendienst in Bayern. Leaflet, Stieber Druck GmbH, Augsburg.

Bliefernicht, J., Bárdossy, A. and C. Ebert, 2008: Stochastische Simulation stündlicher Niederschlagsfelder für Extremereignisse an der Freiberger Mulde, dem Oberen Main und der Fränkischen Saale. Hydrologie und Wasserbewirtschaftung 52/4 (2008) 168-172.

Mantoglou, A. and Wilson, J.W. 1982: The Turning Bands Methods for Simulation of Random Fields Using Line Generation by a Spectral Method. Water Research 18 (5): 1379.

Sources

Becker, A. (1995): Problems and progress in macroscale hydrological modelling. In: Feddes, R. A. (ed.): Space and time scale variability and interdependencies in hydrological processes. Intern. Hydr. Series, Cambridge University Press, pp 135-144.

Grundmann, Jens (2010): Analyse und Simulation von Unsicherheiten in der flächendifferenzierten Niederschlags-Abfluss-Modellierung, Dresdner Schriften zur Hydrologie, Heft 8

Source

Yörük, Alpaslan (2009): Unsicherheiten bei der hydrodynamischen Modellierung, Mitteilungen / Institut für Wasserwesen der Universität der Bundeswehr München, Heft 99

Sources

Guha-Sapir, D., Below, R., Hoyois, Ph. (2016): EM-DAT: *The CRED/OFDA International Disaster Database*. www.emdat.be, Université Catholique de Louvain, Brussels, Belgium

Jha, A. K., Lamond, J. und Bloch, R. (2012): *Cities and flooding - A Guide to Integrated Urban Flood Risk Management for the 21st Century*. Washington, D.C: World Bank.

Patt, H. und Jüpner, R. (2013): *Hochwasser-Handbuch*. Bde. 2., neu bearb. Aufl. Berlin u.a.: Springer Vieweg.

Steffen, W. et al. (2004): *Global Change and the Earth System – A Planet Under Pressure*. Springer-Verlag Berlin Heidelberg New York.

StMUV (2014): *Bavaria, Land of Water.* Bavarian State Ministry of the Environment and Consumer Protection (StMUV), Munich, download available here: http://www.bestellen.bayern.de/application/applstarter?APPL=STMUG&DIR=stmug&ACTIONxSETVAL(artdtl.htm,APGxNODENR:283761,AARTxNR:stmuv_wasser_003,USERxBODYURL:artdtl.htm,KATALOG:StMUG,AKATxNAME:StMUG,ALLE:x)=X

Sources

Rieger, W. & M. Disse (2013): *Physikalisch basierter Modellansatz zur Beurteilung der Wirksamkeit einzelner und kombinierter dezentraler Hochwasserschutzmaßnahmen (A physically-based model approach to assess the effectiveness of single and combined measures of decentralized flood protection)*. In: Hydrologie und Wasserbewirtschaftung, HW 57.2013, H.1, S. 14 – 25.

Rieger, W. (2012): Prozessorientierte Modellierung dezentraler Hochwasserschutzmaßnahmen. Dissertation, Mitteilungen des Instituts für Wasserwesen der Universität der Bundeswehr München, number 116, ISBN 978-3 8440-1209-5

Sources

City of Munich (2011): *Neues Leben für die Isar!*. https://www.muenchen.de/rathaus/Stadtverwaltung/baureferat/projekte/isar-plan.html

City of Rotterdam (2013): Rotterdam adaptation strategy. http://www.deltacities.com/documents/20121210_RAS_EN_lr_versie_4.pdf.

City of Sydney (2012): *Decentralised Water Master Plan 2012-2030*. http://www.cityofsydney.nsw.gov.au/vision/towards-2030/sustainability/water-management. Sydney: author‘s edition.

City of Chicago (2014): Green Stormwater Infrastructure Strategy.

https://www.cityofchicago.org/content/dam/city/progs/env/ChicagoGreenStormwaterInfrastructureStrategy.pdf

Hoyer, J. (2011): *Water sensitive urban design - Principles and inspiration for sustainable stormwater management in the city of the future*. Berlin: Jovis.

Kruse, E. (2015): *Integriertes Regenwassermanagement für den wassersensiblen Umbau von Städten*. Stuttgart: Fraunhofer IRB Verl.

Sources

BMUB (Bundesministerium für Umwelt; Natur; Bau und Reaktorsicherheit), 2015: Hochwasserschutzfibel - Objektschutz und bauliche Vorsorge.

BWB (Berliner Wasserbetriebe), 2016: Rückstau sicher vermeiden (11/22/2016 11:22 a.m.).

De Zeen, 2016: https://www.dezeen.com/2014/10/15/baca-architects-amphibious-house-floating-floodwater/ (11/23/2016 3:26 p.m.).

DWA (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall) (Hrsg.), 2014: Hochwasserangepasstes Planen und Bauen.

GDV (Gesellschaft Deutscher Versicherer), 2015: Bautenschutz Hochwasser.

München, 2015: https://veranstaltungen.stadt-muenchen.de/mse/wp-content/uploads/hirschgarten.jpg (11/23/2016 3:28 p.m.).

Hamburg, 2016: http//www.hamburg.de/gruendach (10/28/2016 4:18 p.m.).

Jüpner, R., Patt, H. 2013: Hochwasser-Handbuch. Bde. 2., neu bearb. Aufl. Berlin u.a.: Springer Vieweg.

Schmieding, 1995: Rückstauklappe mit Schwimmerhohldeckel, Produktinformation der Fa. Schmieding Armaturen in Jüpner, R., Patt, H. 2013