Comparative analysis of groundwater modeling software to describe the interaction between surface water and groundwater during floods

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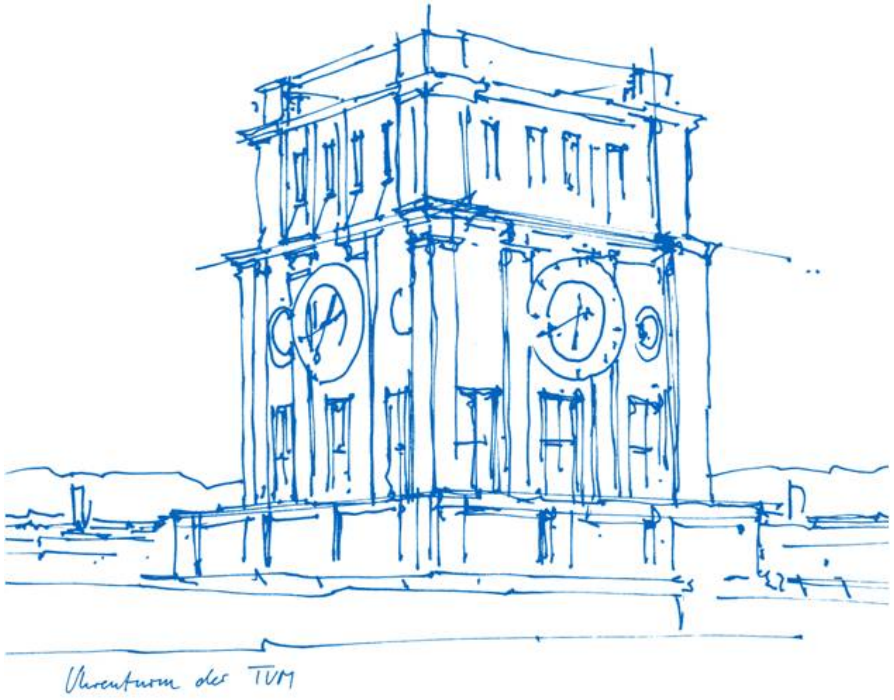
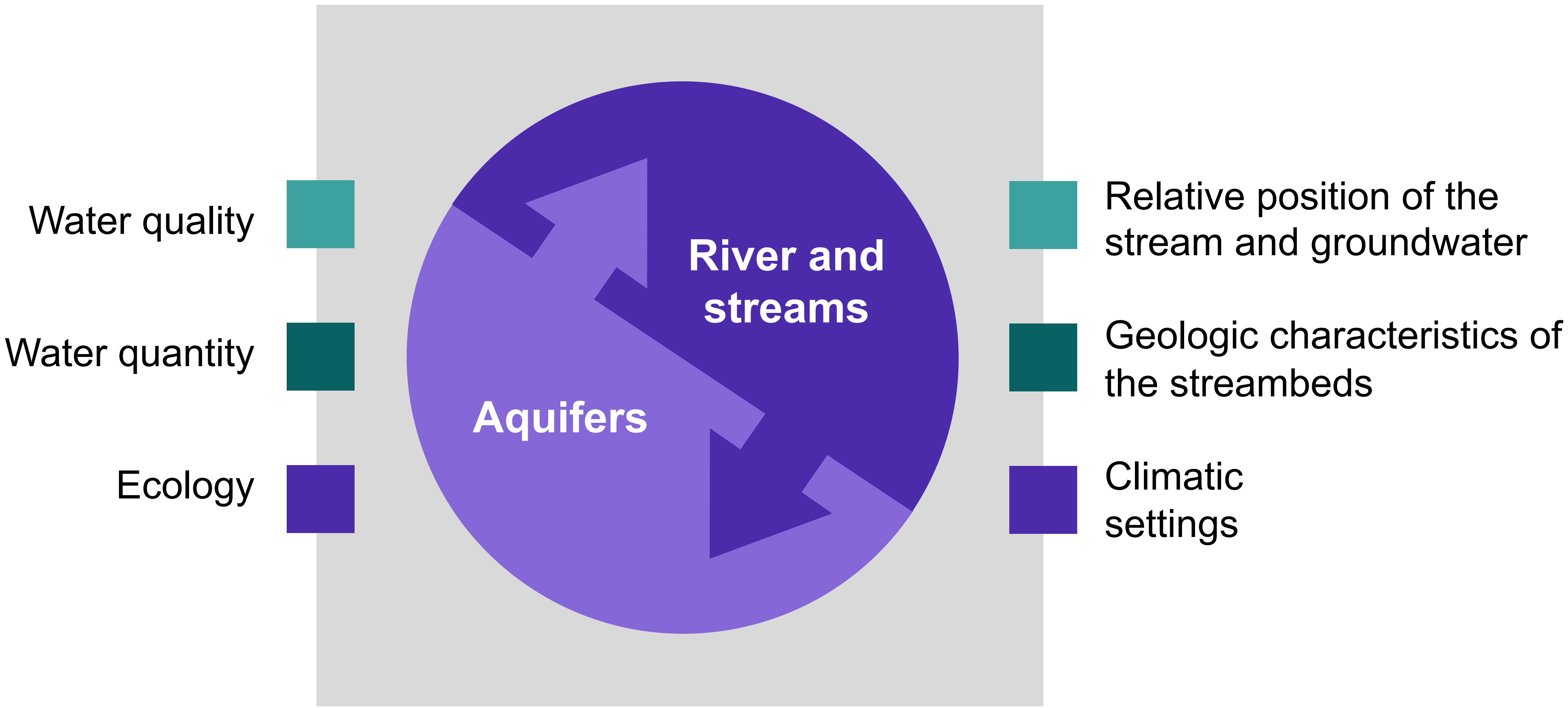
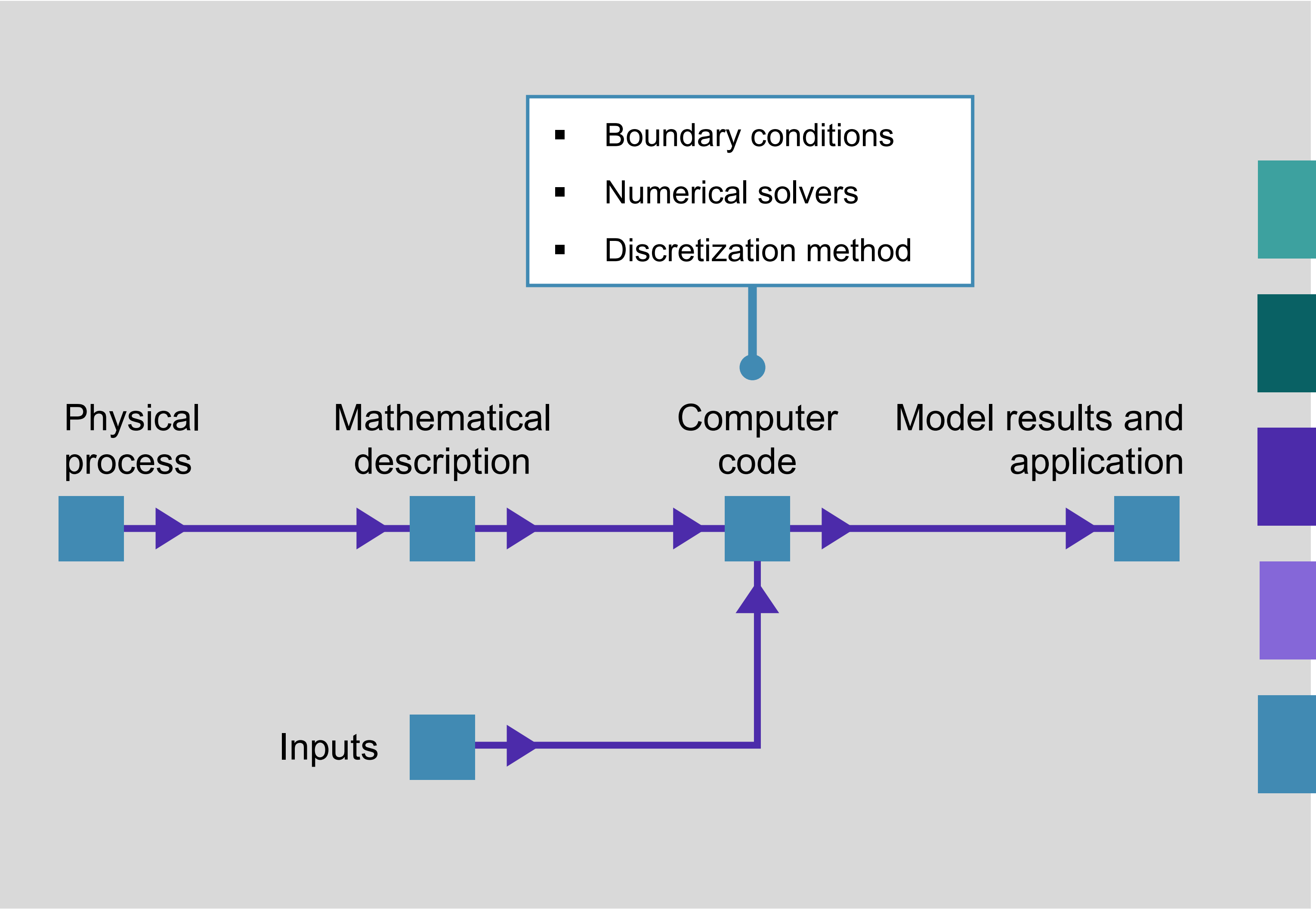


Surface water (SW) and groundwater (GW)



Numerical flow modeling and uncertainty



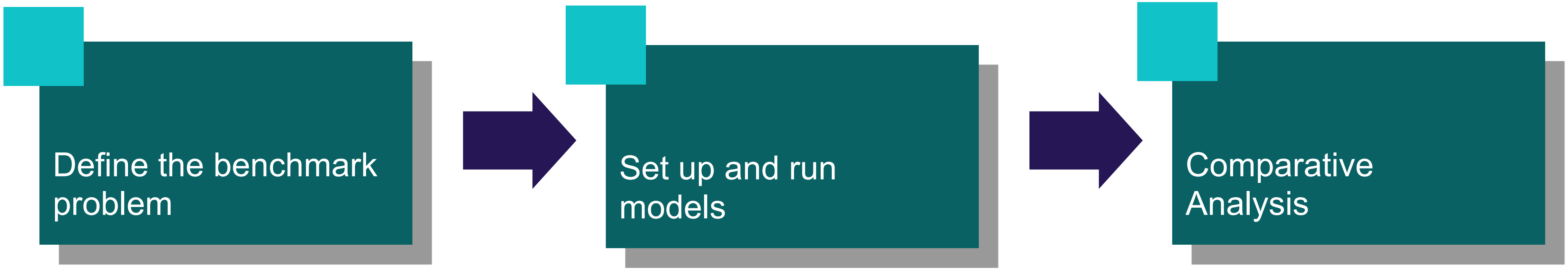
- Not only parametric uncertainty but also in the conceptualization of the underlying physics
- Models does not incorporate the full complexity of SW-GW interactions
- Validity is tested comparing the results to relatively simple analytical solutions
- It has not been deeply studied for extreme conditions such as floods
- Several misconceptions, specially, at the practitioners' level

Our main goal: compare epistemic uncertainty

1. To identify and compare the **applicability**, **performance**, and **results** of widely used hydrogeological simulation tools for modeling, applying a **sophisticated benchmark problem**
2. To understand the significance of the **conceptualization of the physical processes** for simulating the SW-GW interaction
3. To provide a framework for researchers and practitioners to assess the choice of **simplicity-complexity** in the conceptual and numerical flow modeling of SW-GW

Materials and methods

Methodological approach



Groundwater modeling software

MODFLOW-2005

MIKE SHE

PARFLOW

Groundwater modeling software

MODFLOW-2005

- Modular code for solving the **groundwater flow** equation
- Source code is **free public domain software**
- Microsoft Windows or Unix-like operating systems
- Standard code for aquifer simulation
- USGS (United States)

MIKE SHE

- Integrated hydrological model for **surface water flow**, **groundwater flow**, recharge and evapotranspiration
- **Proprietary software**
- Microsoft Windows
- DHI (Denmark)

Characteristics

MODFLOW-2005

NUMERICAL METHODS

- **Finite Difference**
  - Saturated subsurface flows (3D groundwater flow equation)

MIKE SHE

NUMERICAL METHODS

- **Finite Difference**
  - Overland processes (2D Saint-Venant equation)
  - Saturated subsurface flows (3D groundwater flow equation)
- Analytical solutions
  - Interception, evapotranspiration and snow melt

Characteristics

MODFLOW-2005

SOLVERS

- Preconditioned Conjugate Gradient (PCG)
- Geometric Multigrid (GMG)
- Newton Solver (NWT)

MIKE SHE

SOLVERS

- Preconditioned Conjugate Gradient (PCG)
- Successive Over-Relaxation (SOR)

Characteristics

MODFLOW-2005

RIVER REPRESENTATION

- River Package
  - To simulate head-dependent flux boundaries (Cauchy boundary conditions)
  - Parameters: elevation, stage, and **conductance**

MIKE SHE

RIVER REPRESENTATION

- Coupled with MIKE 11
  - Hydraulic modelling system
  - Based on the complete dynamic wave formulation of the Saint Venant equations
  - Parameters: elevation, stage, inflows, stream cross section, **leakage coefficient**

The flood event and the benchmark problem

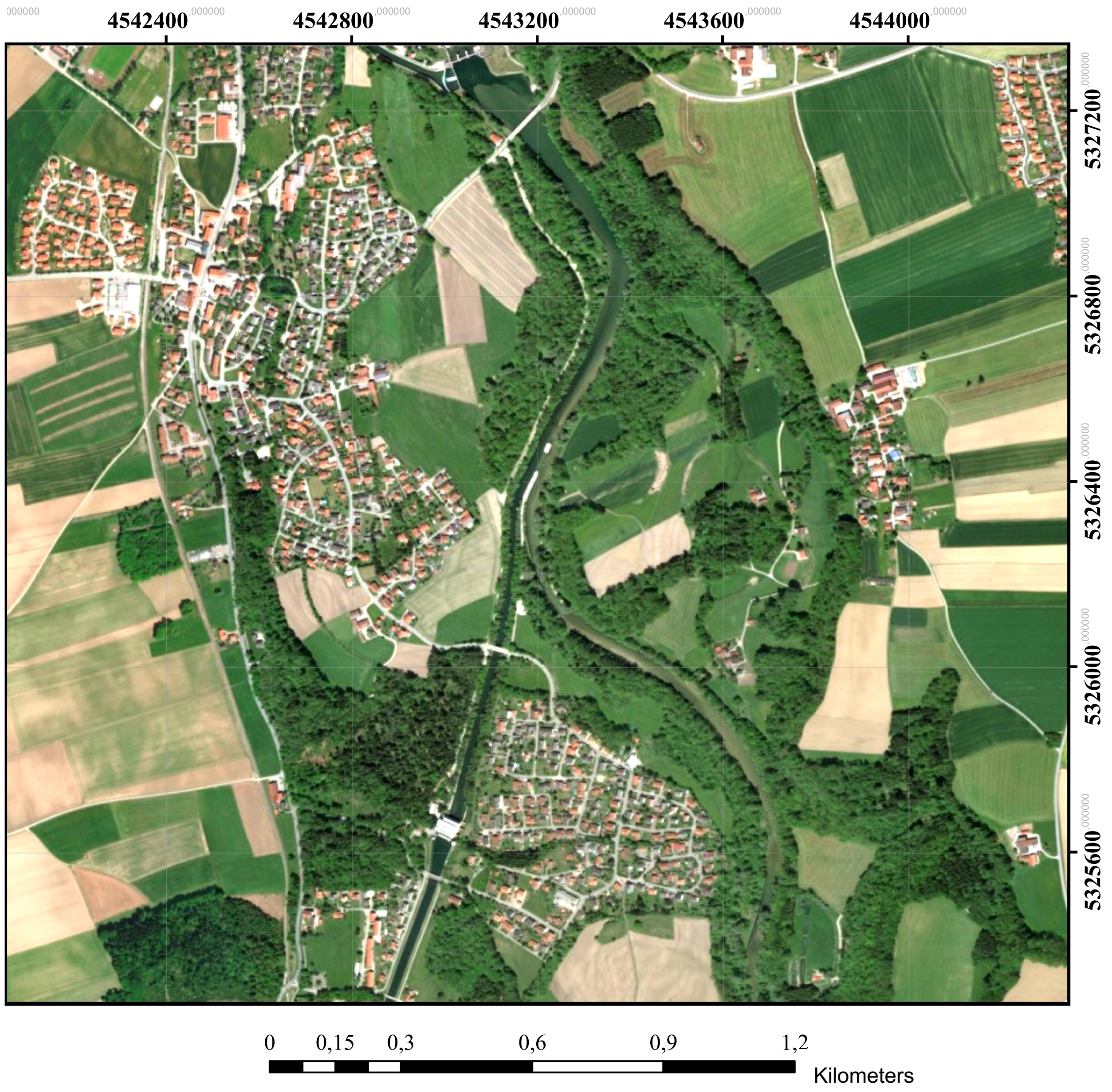
Benchmark problem

Flood event (30/may/2013 – 02/jul/2013)

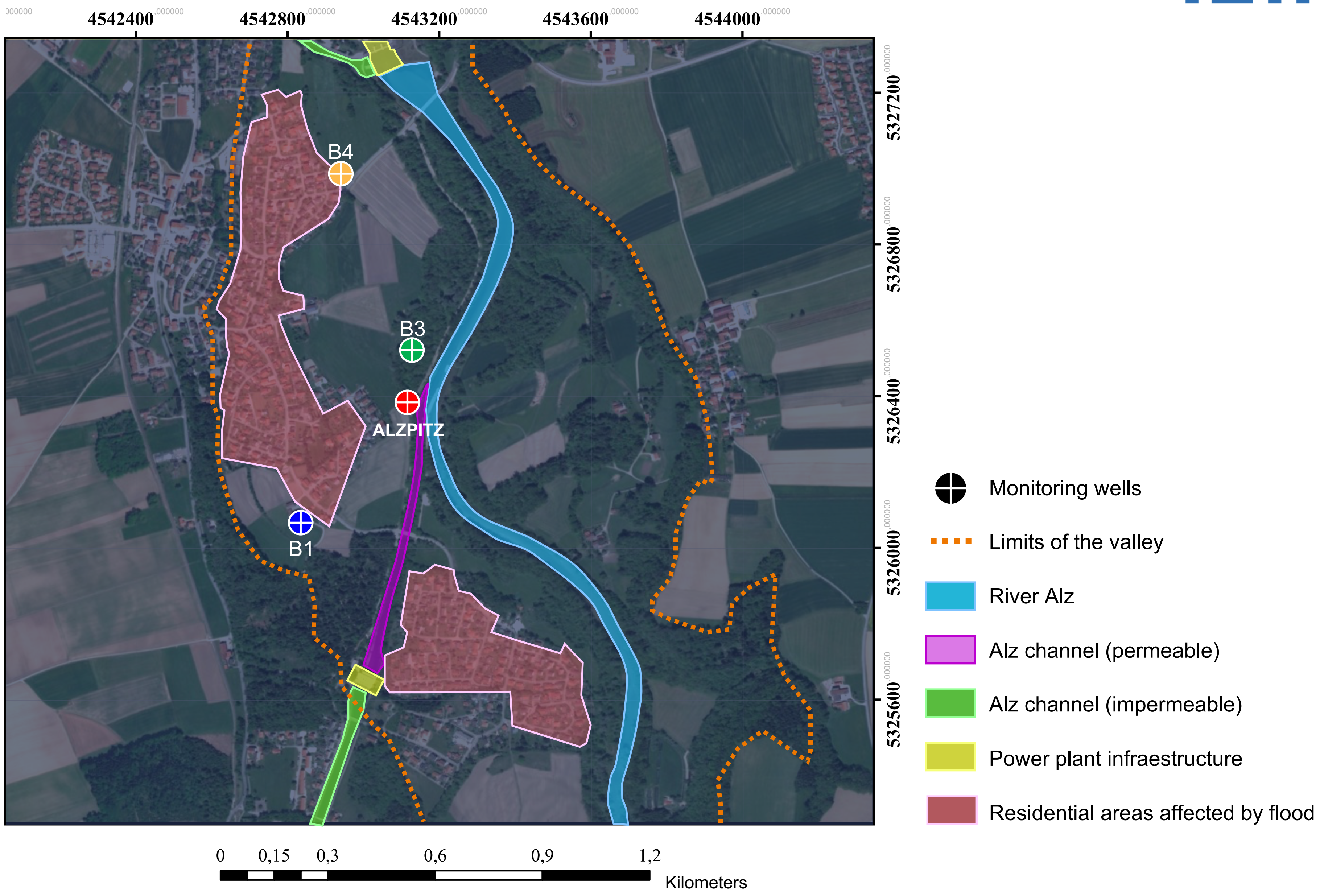
Grundner, 2013

Grundner, 2013

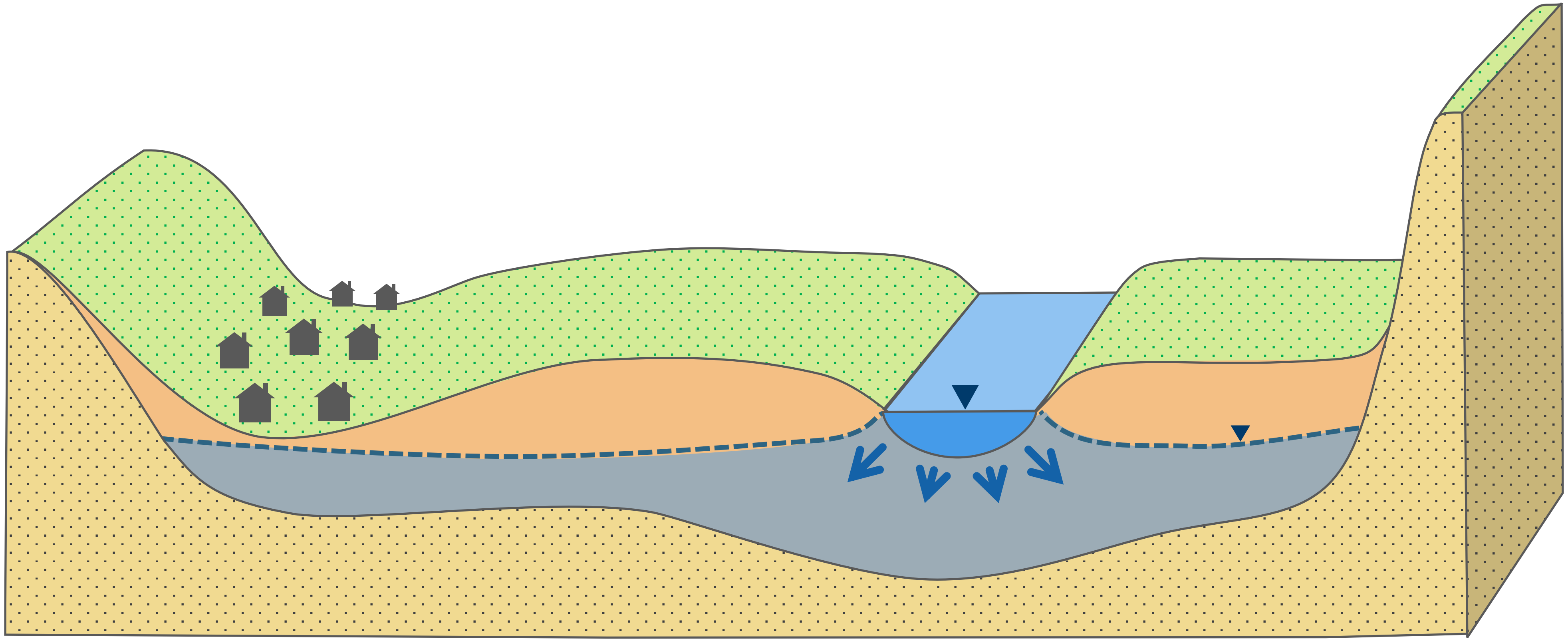
Benchmark model



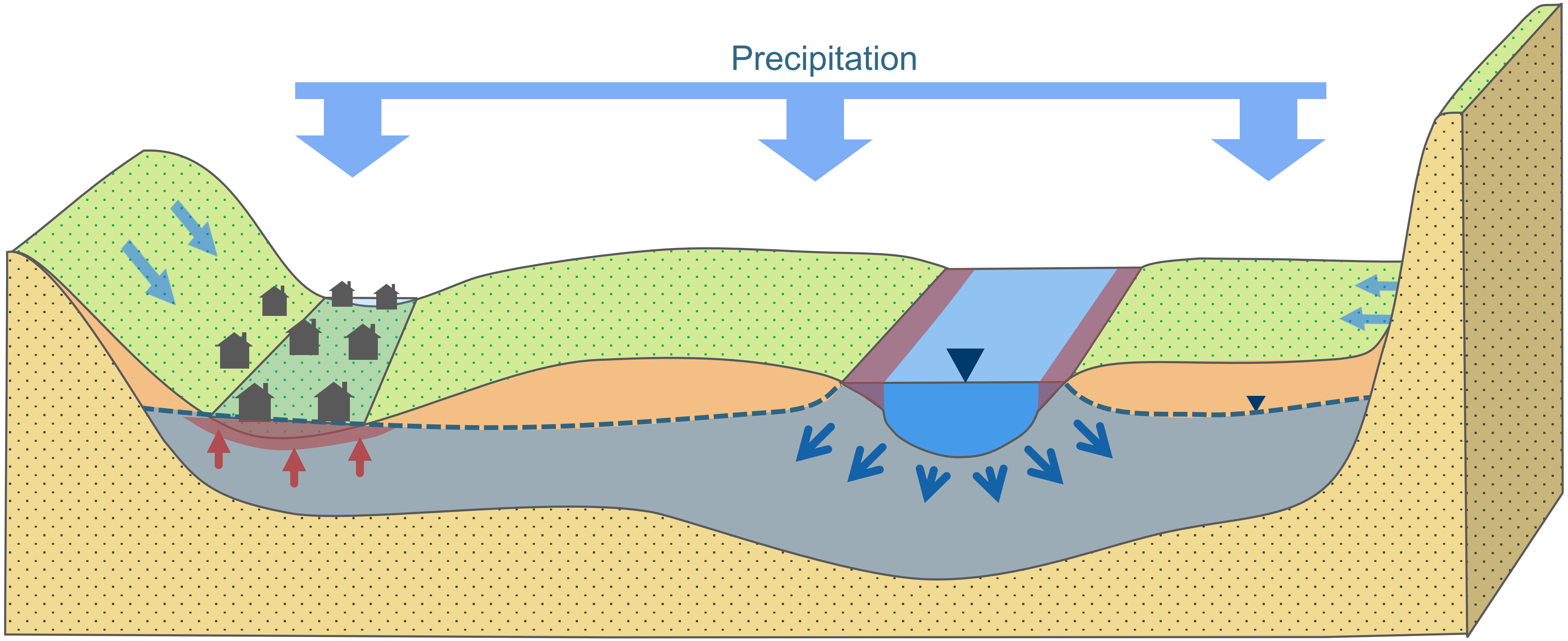
Benchmark model



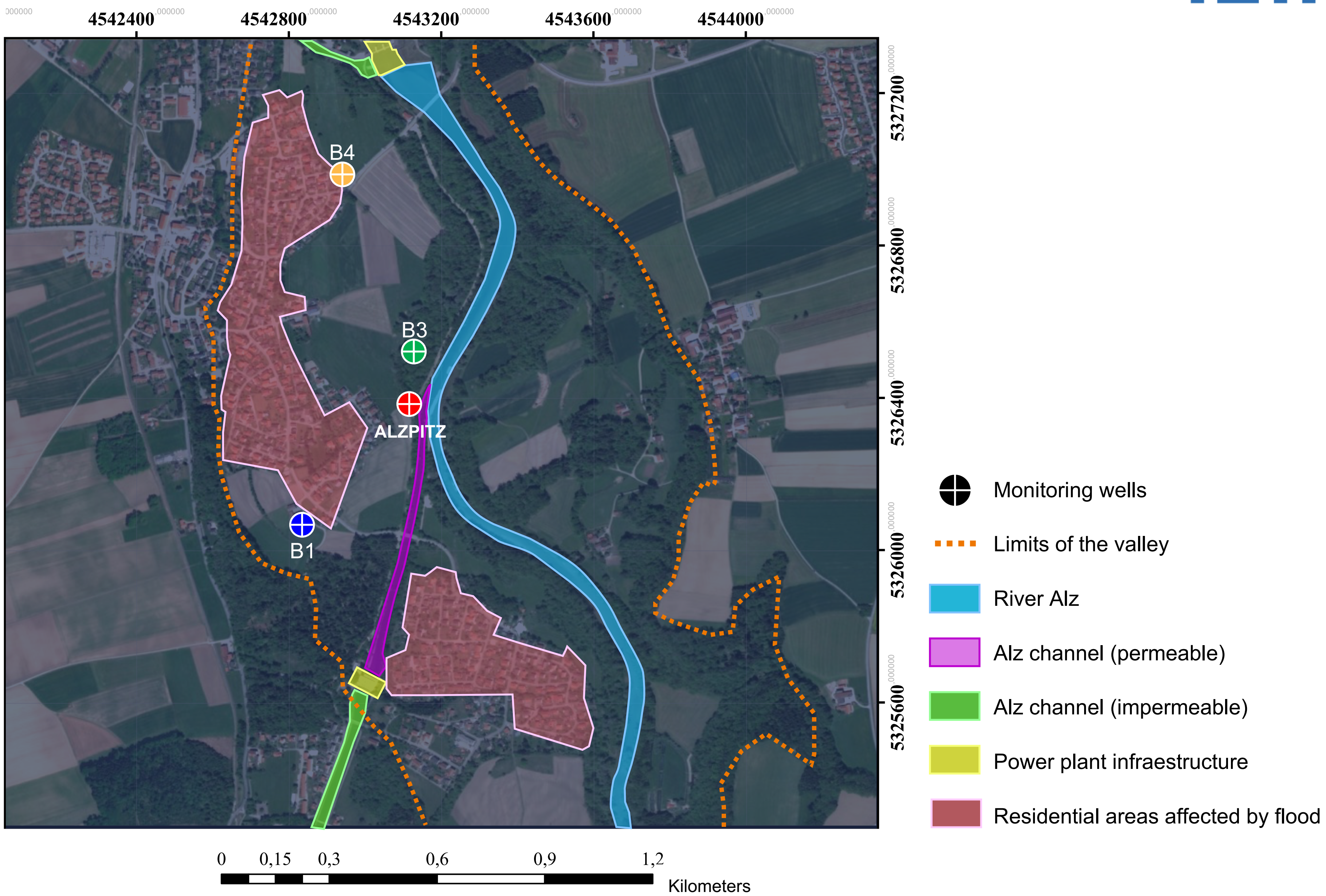
Shallow unconsolidated sedimentary aquifer



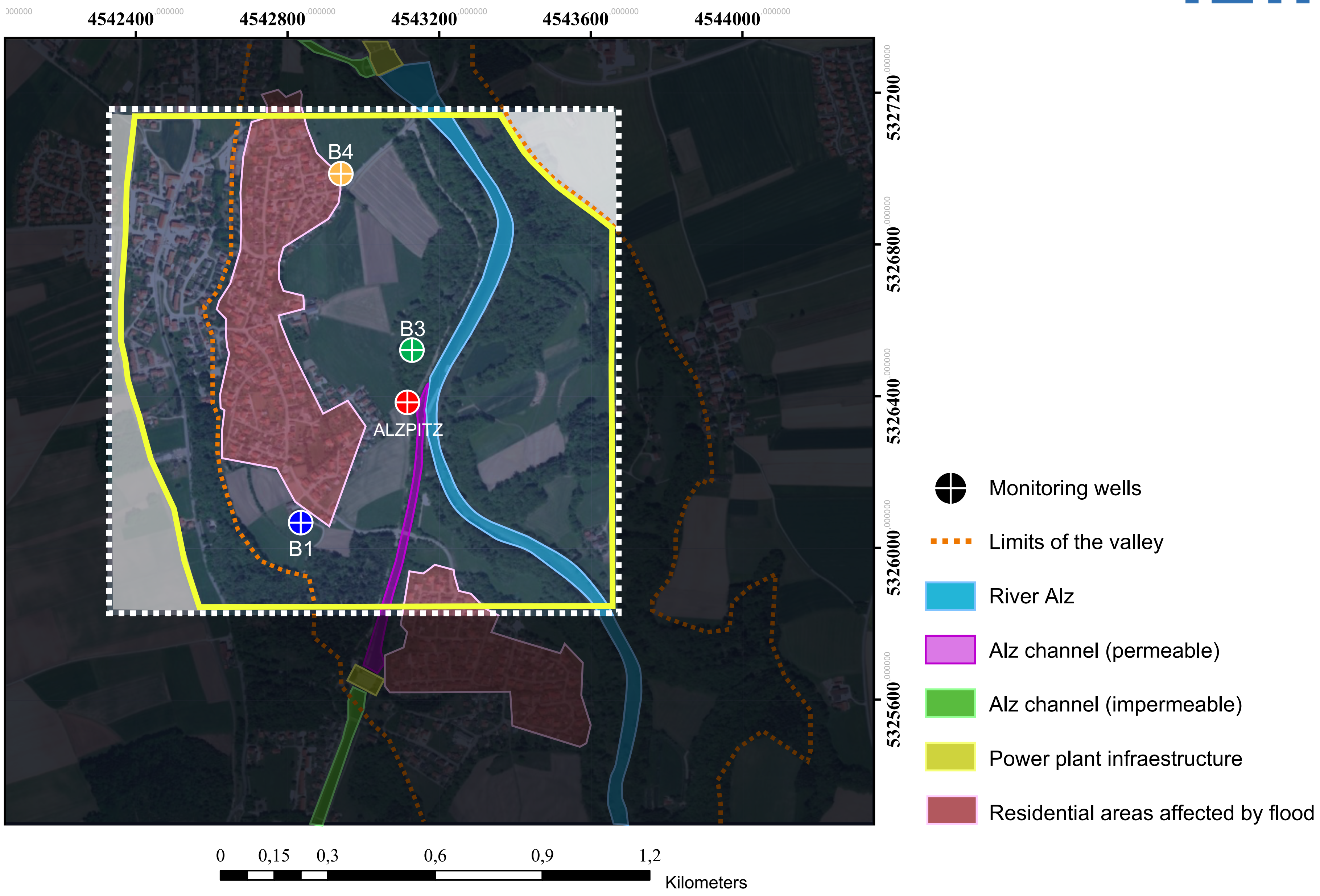
Groundwater flooding



Benchmark model



Benchmark model



Model setting

Simulation period:
15.05.2013 – 15.07.2013
75 days

Boundary conditions:
Time-variant specified-head
River
Recharge

Grid:
260 × 260 ($5m^2$)
Number of layers:
1 layer (2 dimensional)
5 layers (3 dimensional)

Input parameters:
Horizontal hydraulic conductivity
Vertical hydraulic conductivity
Specific storage
Specific yield

Flow type simulation:
Transient
Number of stress periods:
300 stress periods (6 hours)

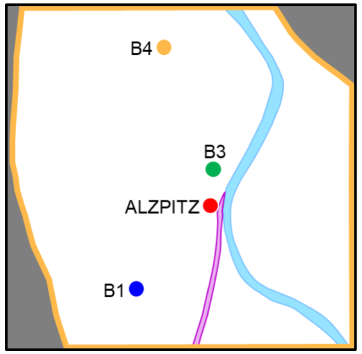
Results and discussion

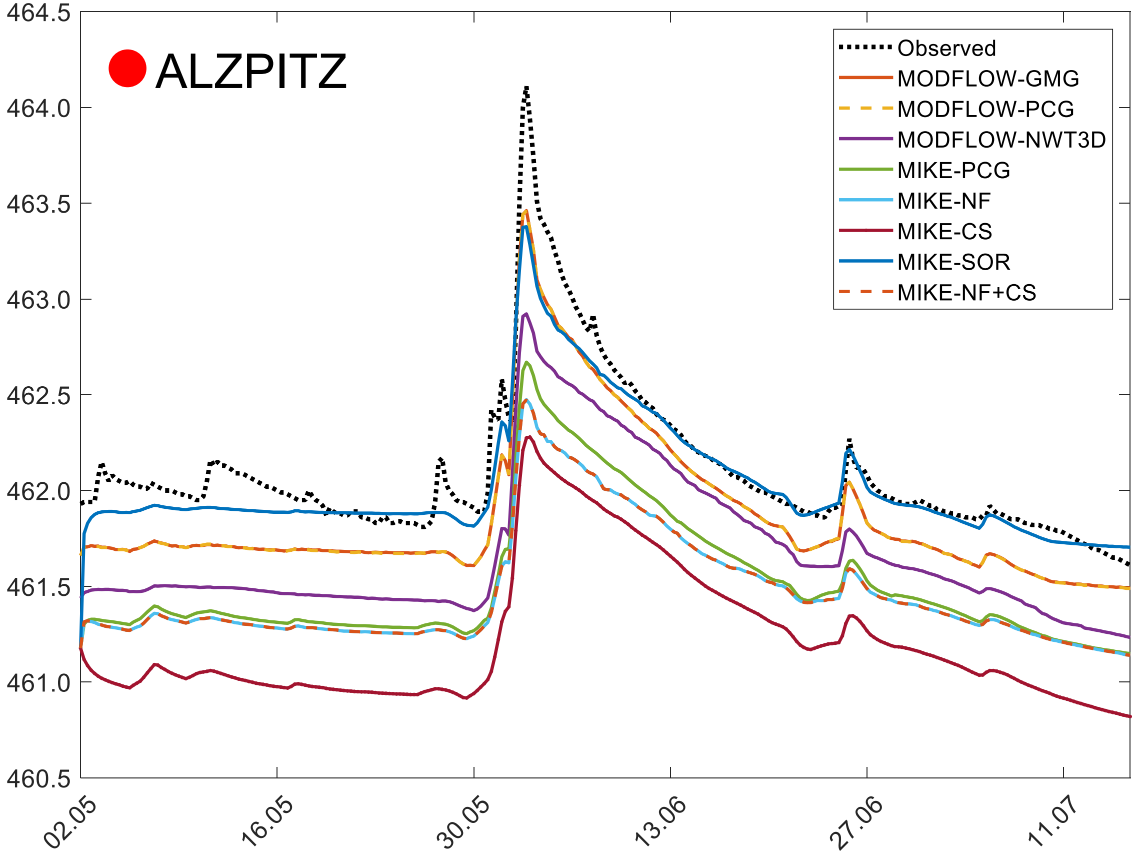
Summary of comparison

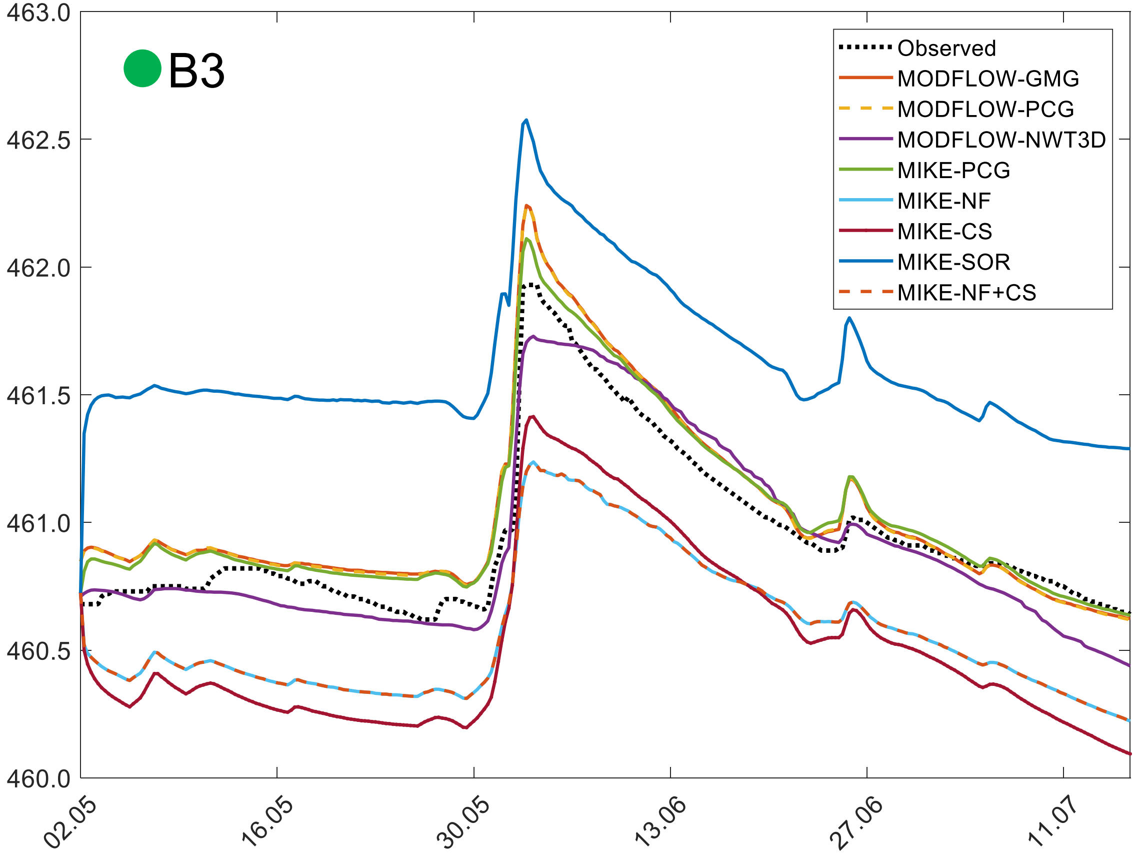
Software	Solver	Name	Conditions	RMSE
MODFLOW-2005	Preconditioned Conjugate Gradient (PCG)	MODFLOW-PCG	2D model	0.1746
	Geometric Multigrid (GMG)	MODFLOW-GMG	2D model	0.1748
	Newton Solver (NWT)	MODFLOW-NWT3D	3D model Vertical discretization of 5 layers	0.2500
MIKE SHE	Preconditioned Conjugate Gradient (PCG)	MIKE-PCG	2D model Bed topography using grid data	0.3214
	Preconditioned Conjugate Gradient (PCG)	MIKE-NF	2D model No flooding area	0.3981
	Preconditioned Conjugate Gradient (PCG)	MIKE-CS	2D model Bed topography using cross sections	0.5121
	Preconditioned Conjugate Gradient (PCG)	MIKE-NFCS	2D model No flooding area Bed topography using cross sections	0.3981
	Successive Over-Relaxation (SOR)	MIKE-SOR	2D model Bed topography using grid data	0.4235

Simulation results

Hydraulic heads [m a.s.l.] - Time

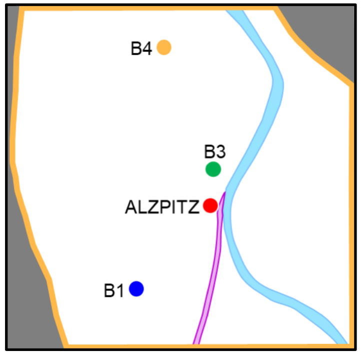


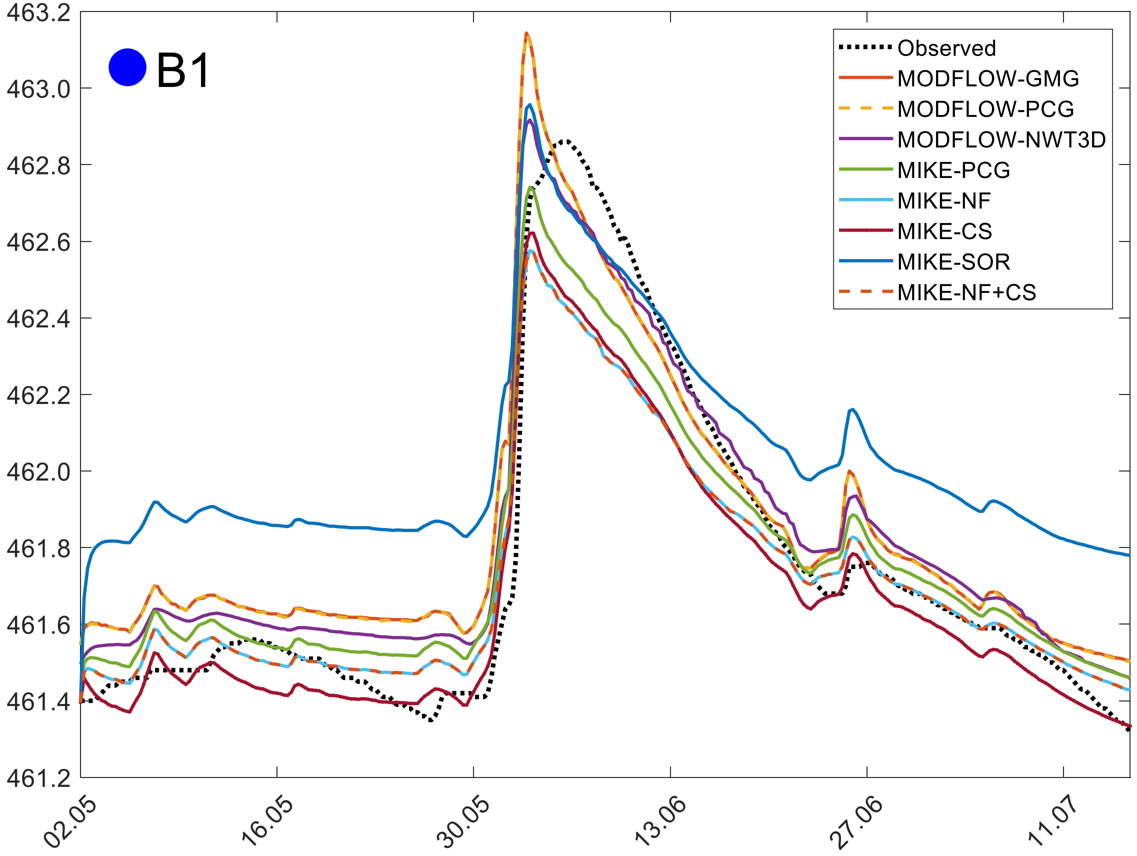


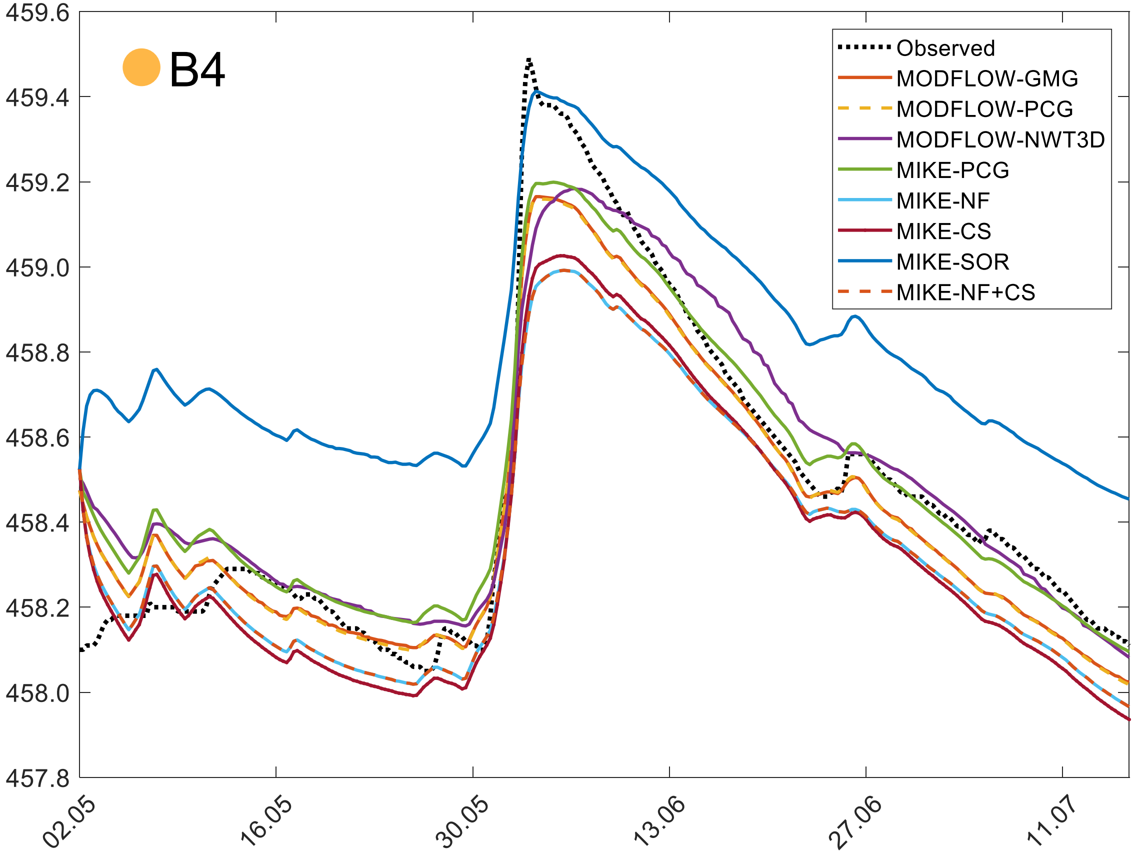


Simulation results

Hydraulic heads [m a.s.l.] - Time

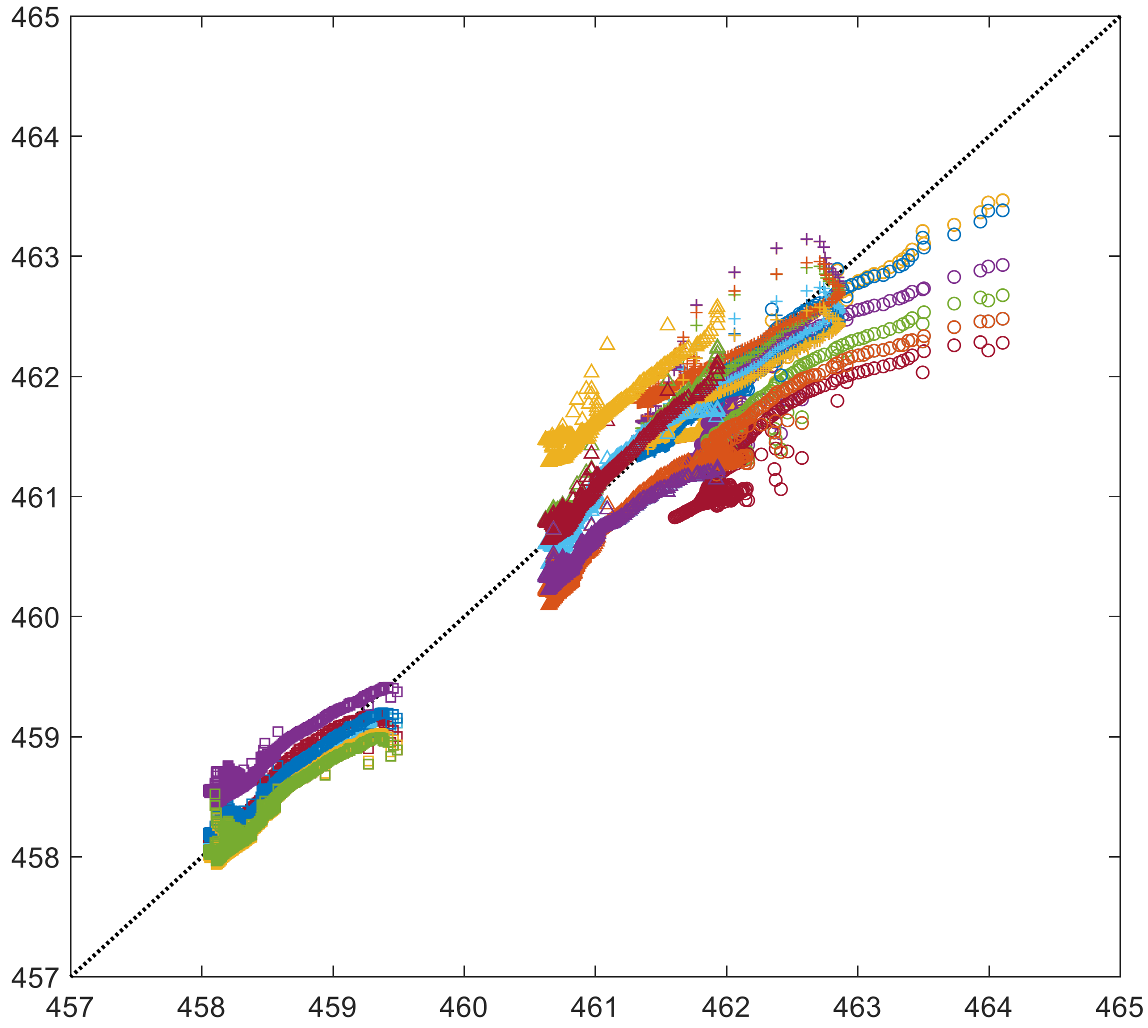






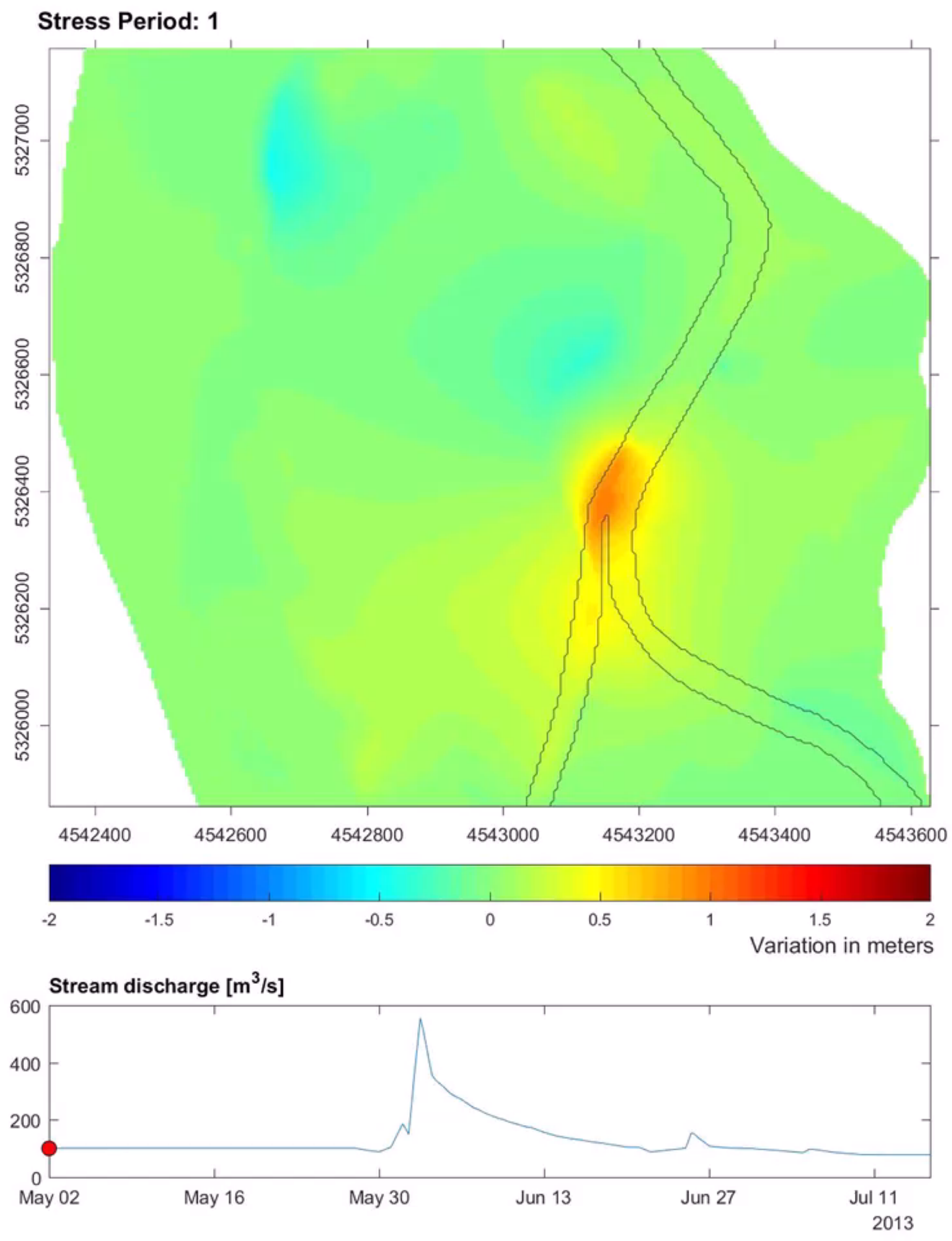
Simulation results

Observed hydraulic heads [m a.s.l.] – Modeled hydraulic heads [m a.s.l.]



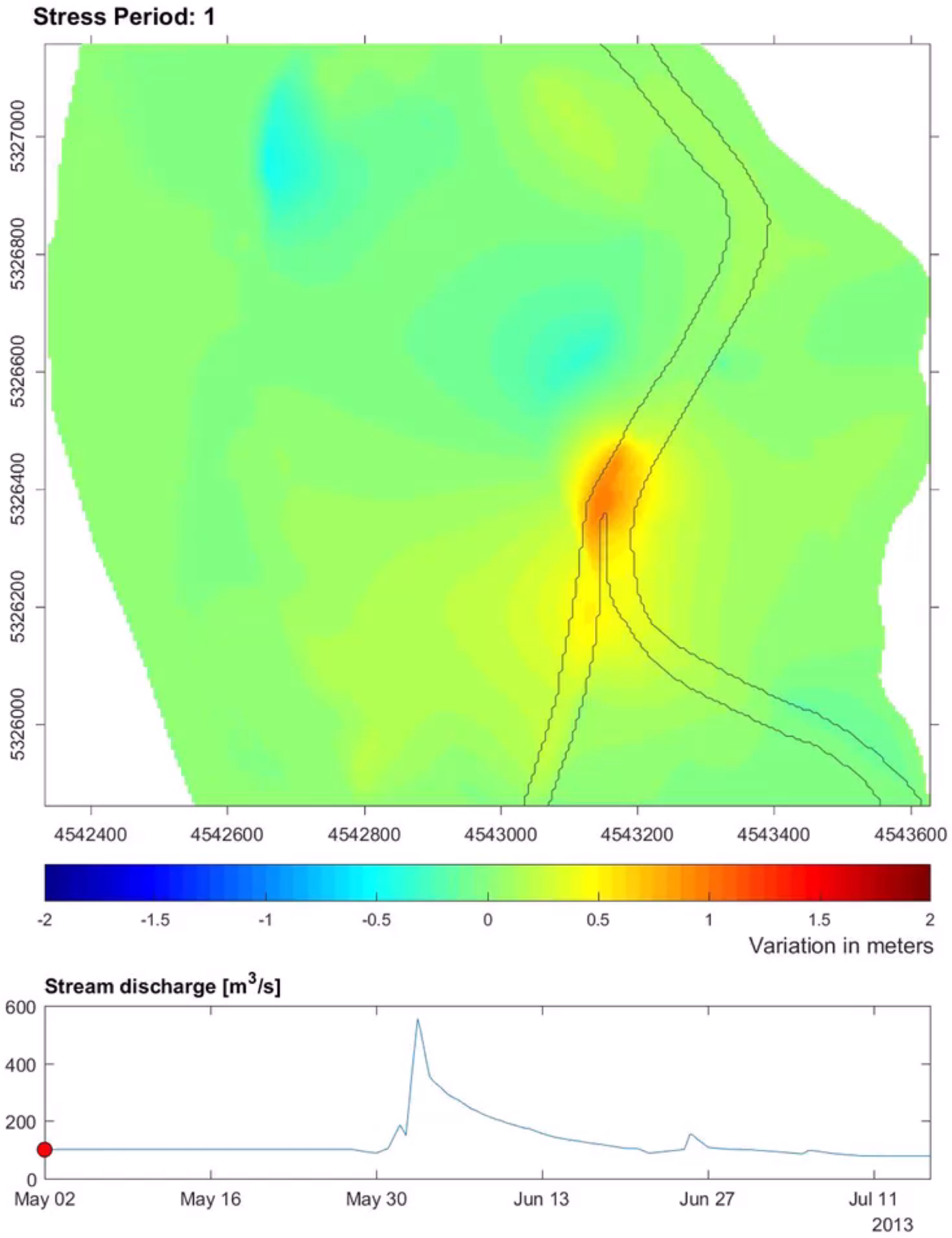
Hydraulic head differences

MODFLOW-PCG
MIKE-PCG

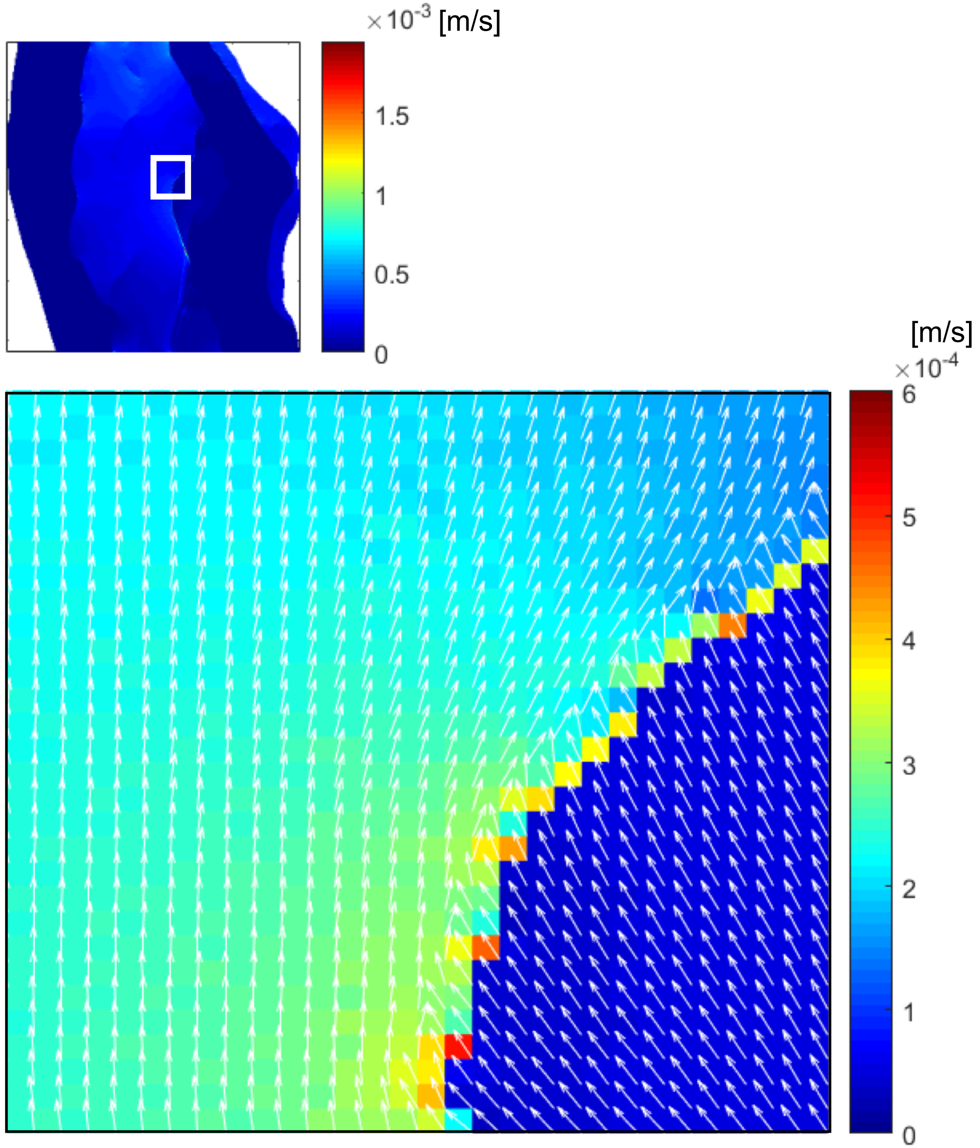


Hydraulic head differences

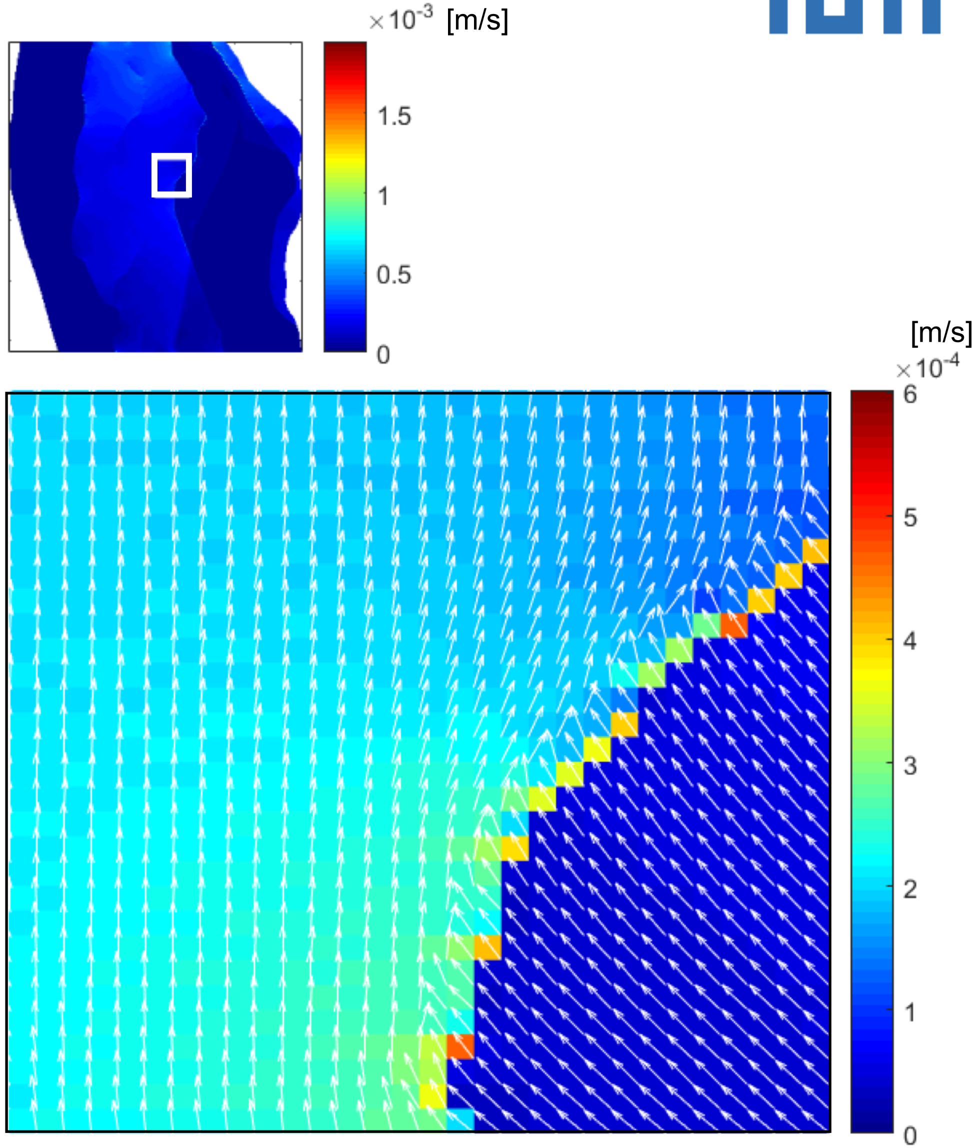
MODFLOW-PCG
MIKE-NF



MODFLOW-PCG



MIKE-PCG

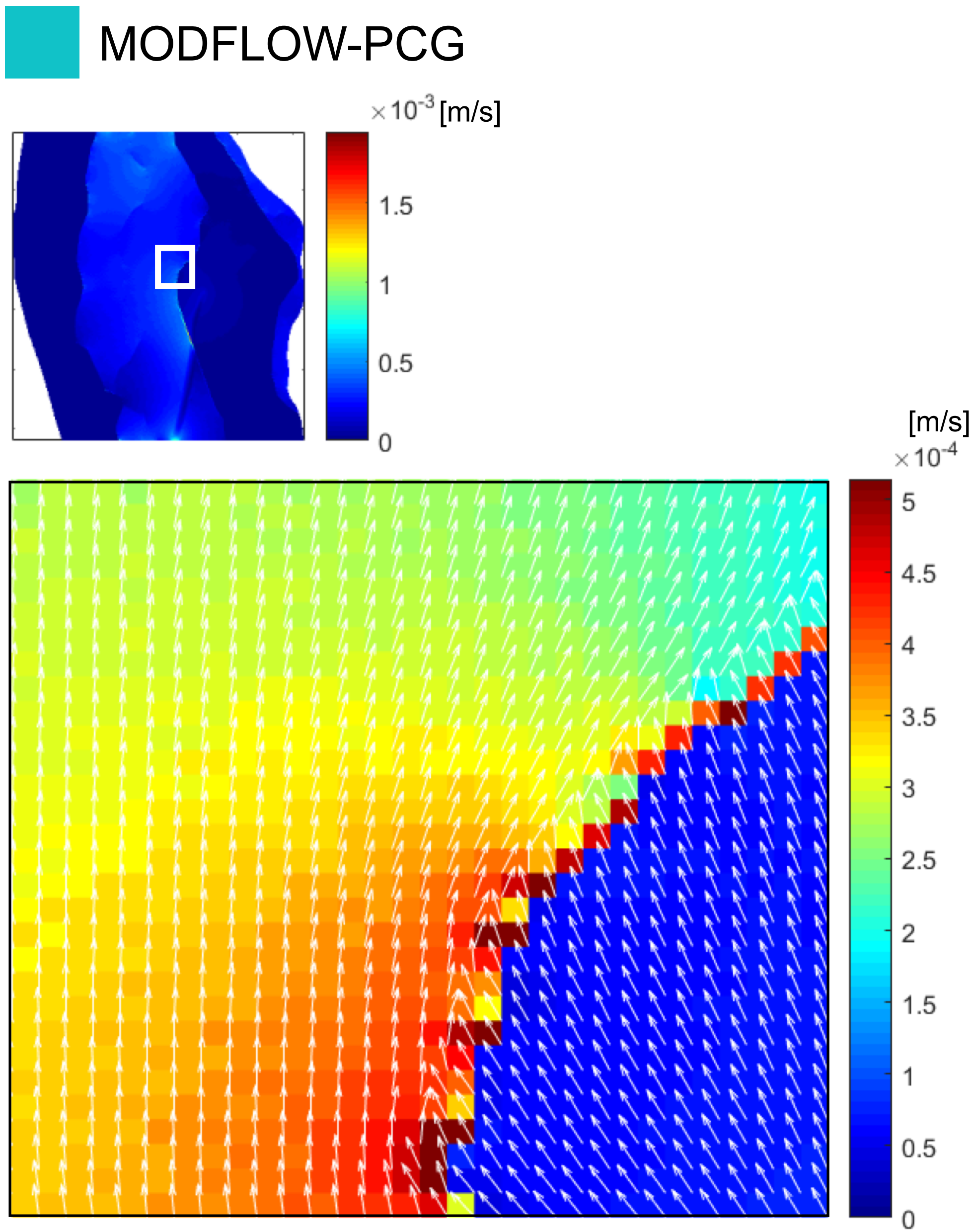


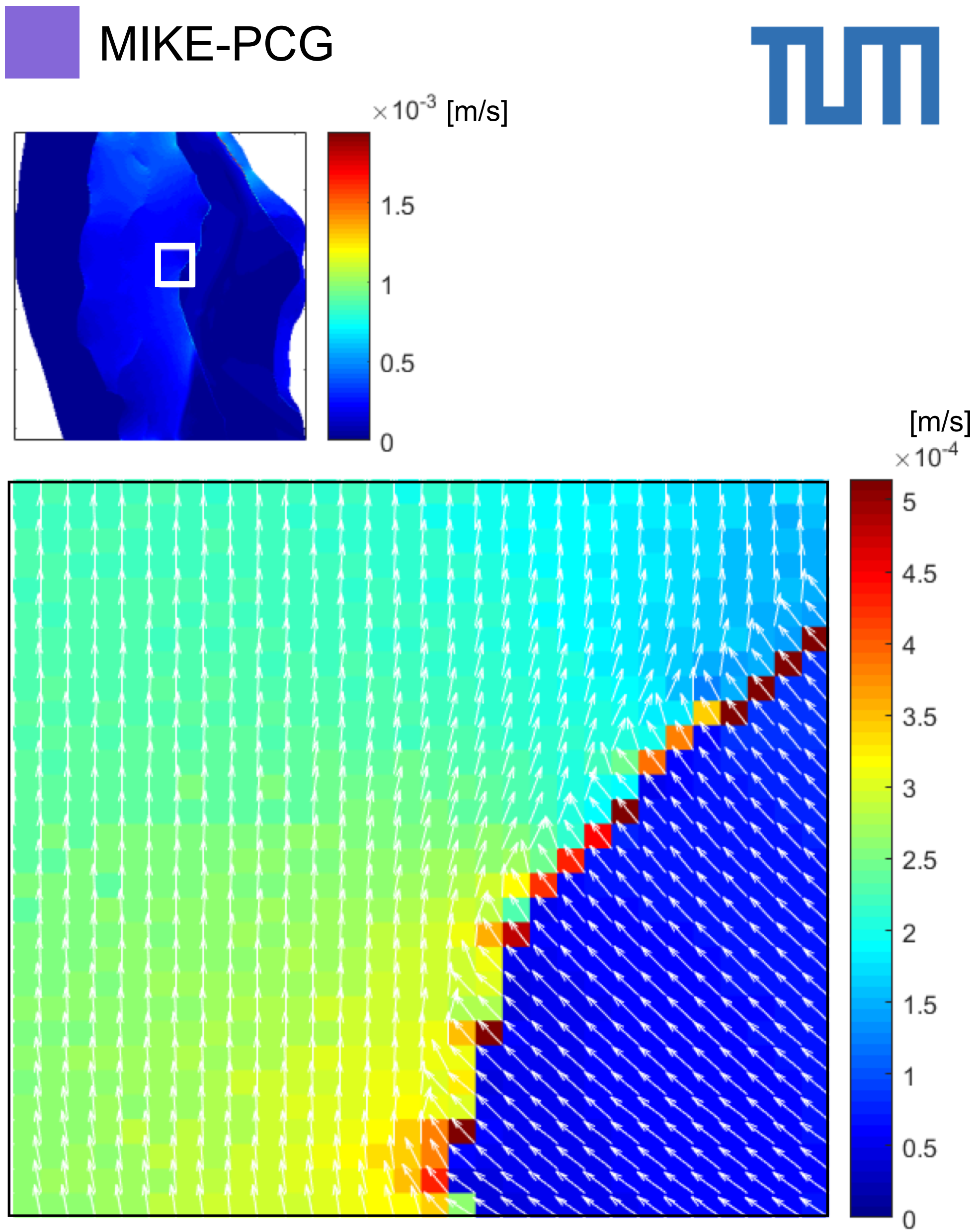
Flow fields

Stress Period 20
Peak of the flood

Flow fields

Stress Period 127
Peak of the flood

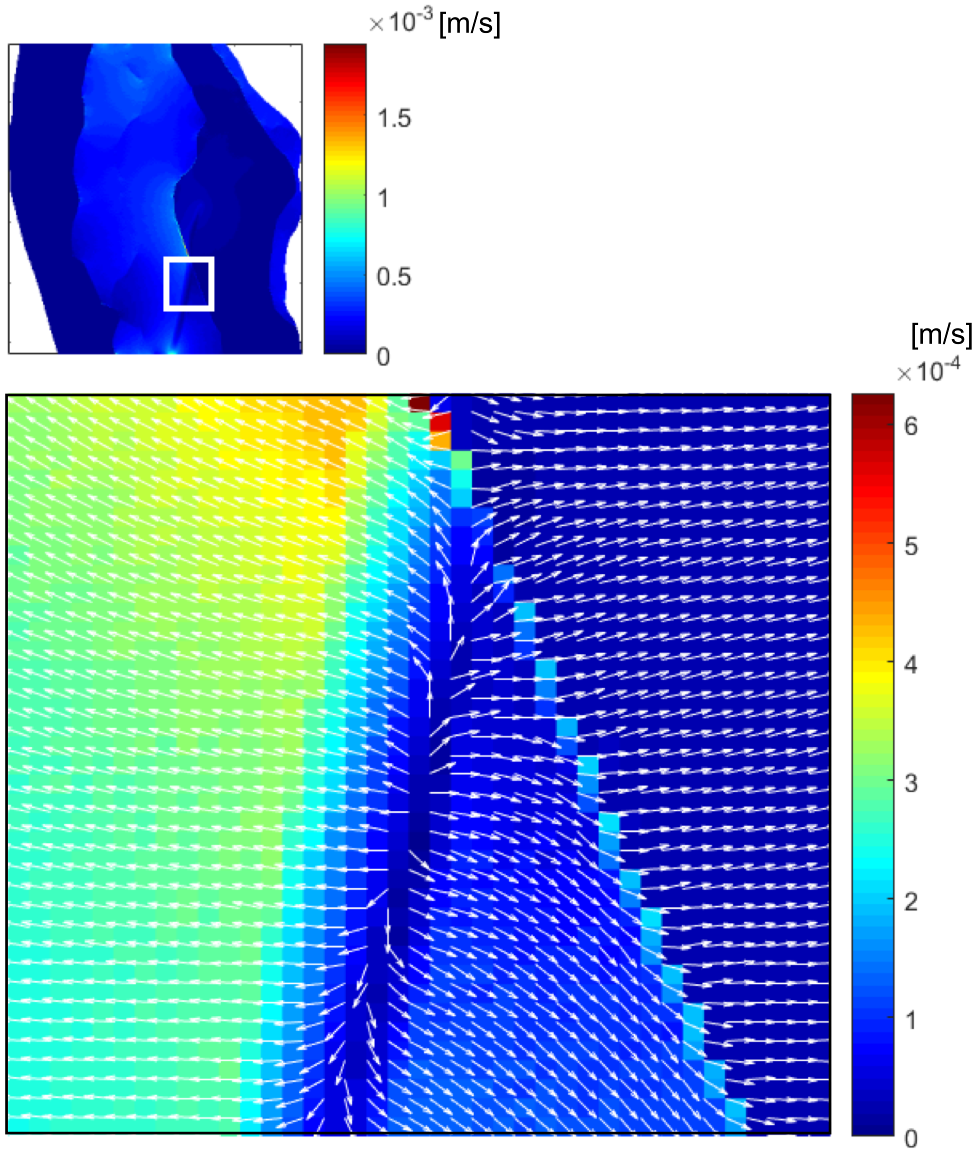




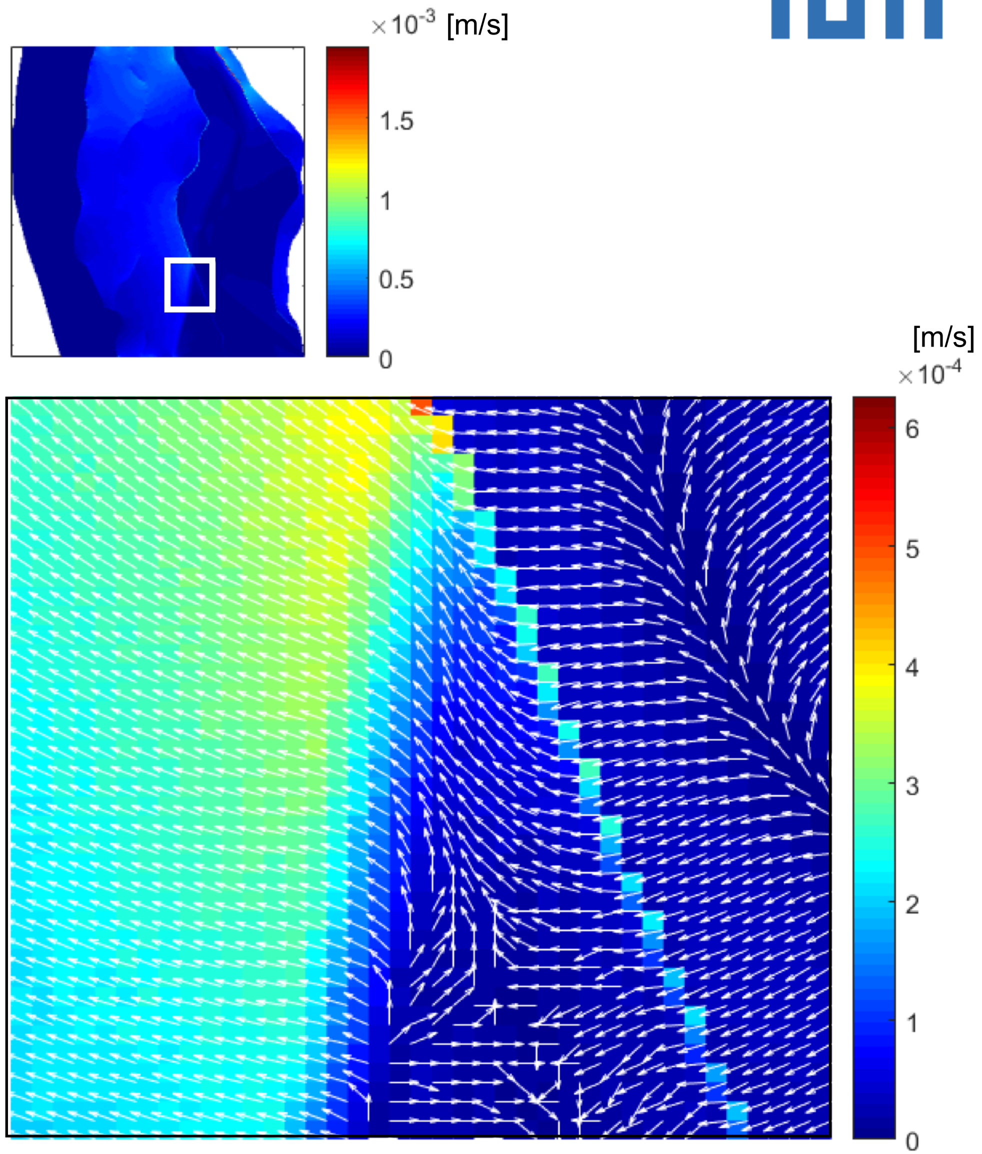
Flow fields

Stress Period 127
Peak of the flood

MODFLOW-PCG



MIKE-PCG



Some conclusions…

Conclusions

- The models perform similarly on the simulated case, but none of them catches the responses of the aquifer in the zone immediately close to the streams
- The model intercomparison give us a baseline for understanding the impact of numerical couplings, model physics and parameterizations
- It is necessary to extend the tools for comparison and the applied methodology in order to understand the incomes that are necessary to improve the solutions of complex SW-GW models during extreme events

Outlook

- Extend and adapt the model to more software with different approaches to simulate SW-GW interactions
- Evaluate the uncertainty related to river boundary conditions during flood events
- Extend our evaluation to understand the movement of solutes in the groundwater during groundwater flooding

Thank you for your attention!

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