The relevance of preferential flow in catchment scale simulations

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Motivation and objectives

- The occurrence of preferential flow in the subsurface has often been shown in field experiments. However, preferential flow is rarely included in models simulating the hydrological response at the catchment scale.

- Does the incorporation of preferential flow in a catchment-scale model improve the simulation of the hydrologic response?
  - → Calibrate a 3D physics-based dual permeability model directly at the catchment scale
  - → Compare with a reference model setup without preferential flow (single permeability scenario)

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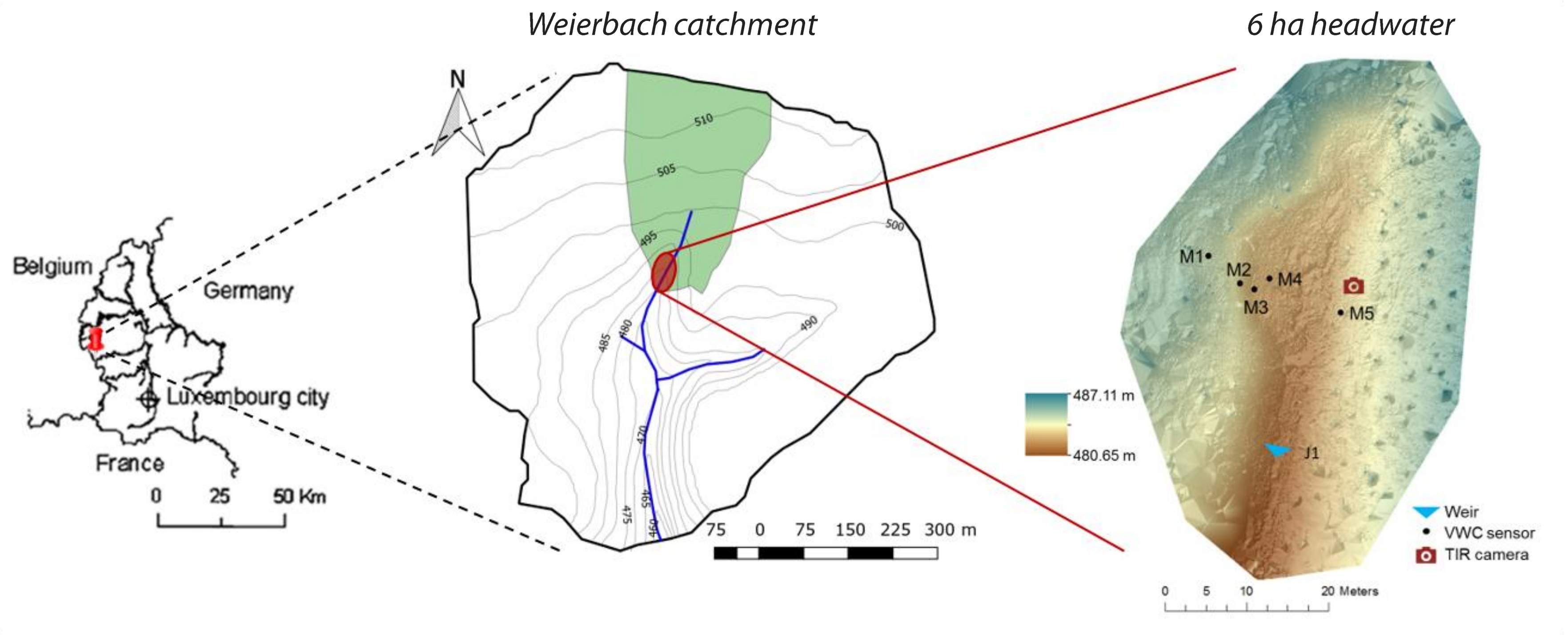
Methods – study site

- Weierbach catchment in Luxembourg
  - → 42 ha sub-catchment within the Attert basin
  - → geology: slate, phyllites, schist and quartzite
  - → soils: cambisol, ranker and lithosol
  - → temperate climate, mean annual P: 900 mm
  - → forest cover: beech, sessile oak, Norway spruce



- Model simulations were carried out in a 6 ha headwater of the catchment

- Period for
  - → calibration: Dec 2013 – Apr 2014 (100 days)
  - → validation: Dec 2012 – Apr 2013 (100 days)

- Hydrological data for calibration and validation:
  - → discharge at weir
  - → soil moisture (VWC) time series in 10 cm depth, at five locations*
  - → high-resolution map of surface saturation in the riparian zone via thermal infrared (TIR) camera*

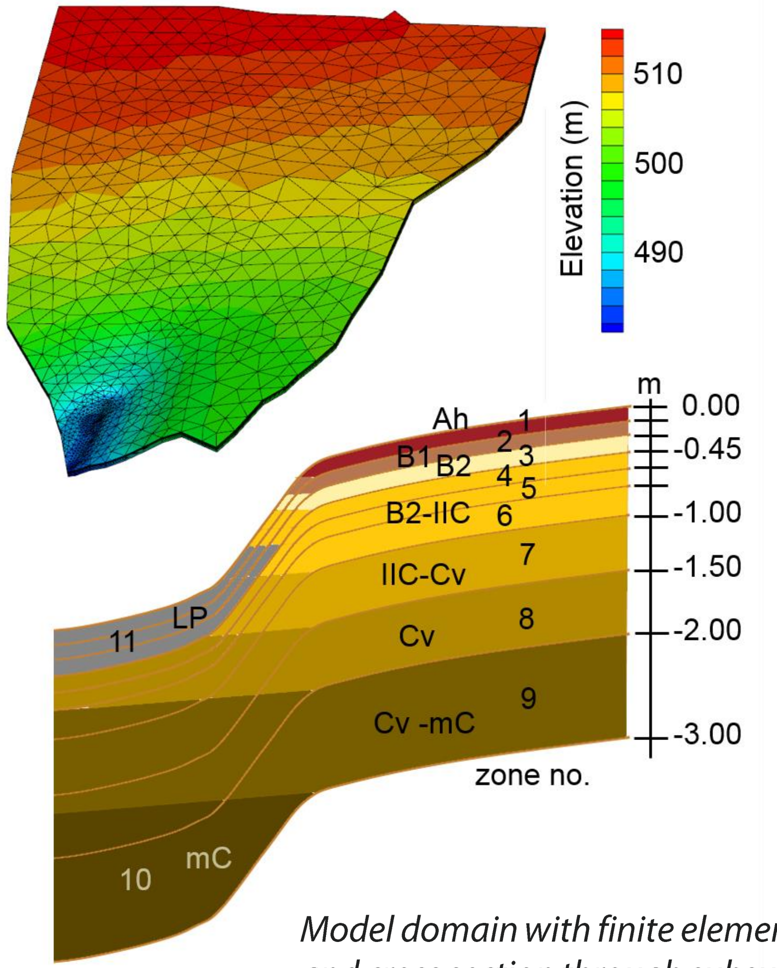
*In this presentation, only comparison with discharge data is shown.

Methods - model

- Integrated surface-subsurface hydrologic model HydroGeoSphere (HGS)
  - → Richards equation for variably saturated subsurface flow (3D)
  - → diffusive wave approximation for surface flow (2D)
  - → preferential flow implemented via dual permeability approach (macropore domain and matrix domain)

- Coupling of HGS with the optimization algorithm DiffeRential Evolution Adaptive Metropolis (DREAM)

- Soil hydraulic parameters in the initial model setup were defined based largely on field evidence (van Genuchten-Mualem soil hydraulic model)



Model domain with finite element grid (top) and cross section through subsurface with 11 soil layers (bottom). Soil hydraulic parameters were fitted for layers 1-10.

Methods – calibration scenarios

- Five soil hydraulic parameters were calibrated that had been shown before to be most influential for the simulation of discharge:
  - → sat. hydraulic conductivity *Ks* and porosity *n* of matrix domain
  - → sat. hydraulic conductivity Ks_{dp} and porosity n_{dp} of macropore domain
  - → volumetric proportion of macropore domain *dp*

- Parameters of the matrix domain and the macropore domain were calibrated with a fixed parameter ratio between soil layers instead of calibrating every layer separately ("hyperparameters"). These ratios reflected observed depth profiles of soil hydraulic properties at our study site.

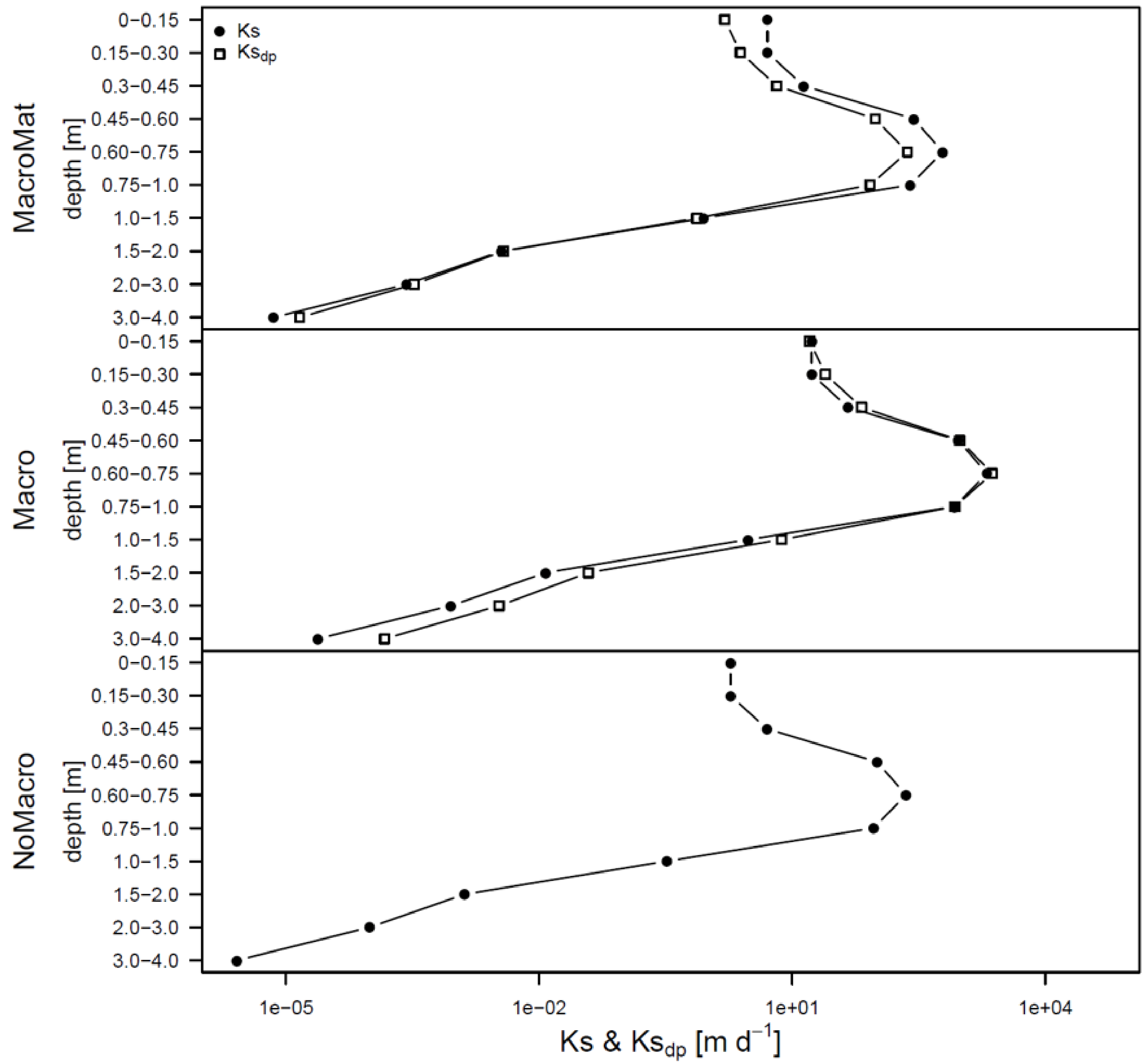
Calibration scenarios

Number of hyperparameters to be fitted	Hyperparameters to be fitted	Name of scenario
5	Ks, n, Ks_{dp}, n_{dp}, dp	MacroMat
3	Ks_{dp}, n_{dp}, dp	Macro
2 (single domain)	Ks, n	NoMacro

Results – identified soil hydraulic parameters

- Saturated hydraulic conductivities of the macropore domain (Ks_{dp}) were calibrated such that they became very similar to matrix saturated hydraulic conductivities (Ks) → effect of macropores was effectively removed!

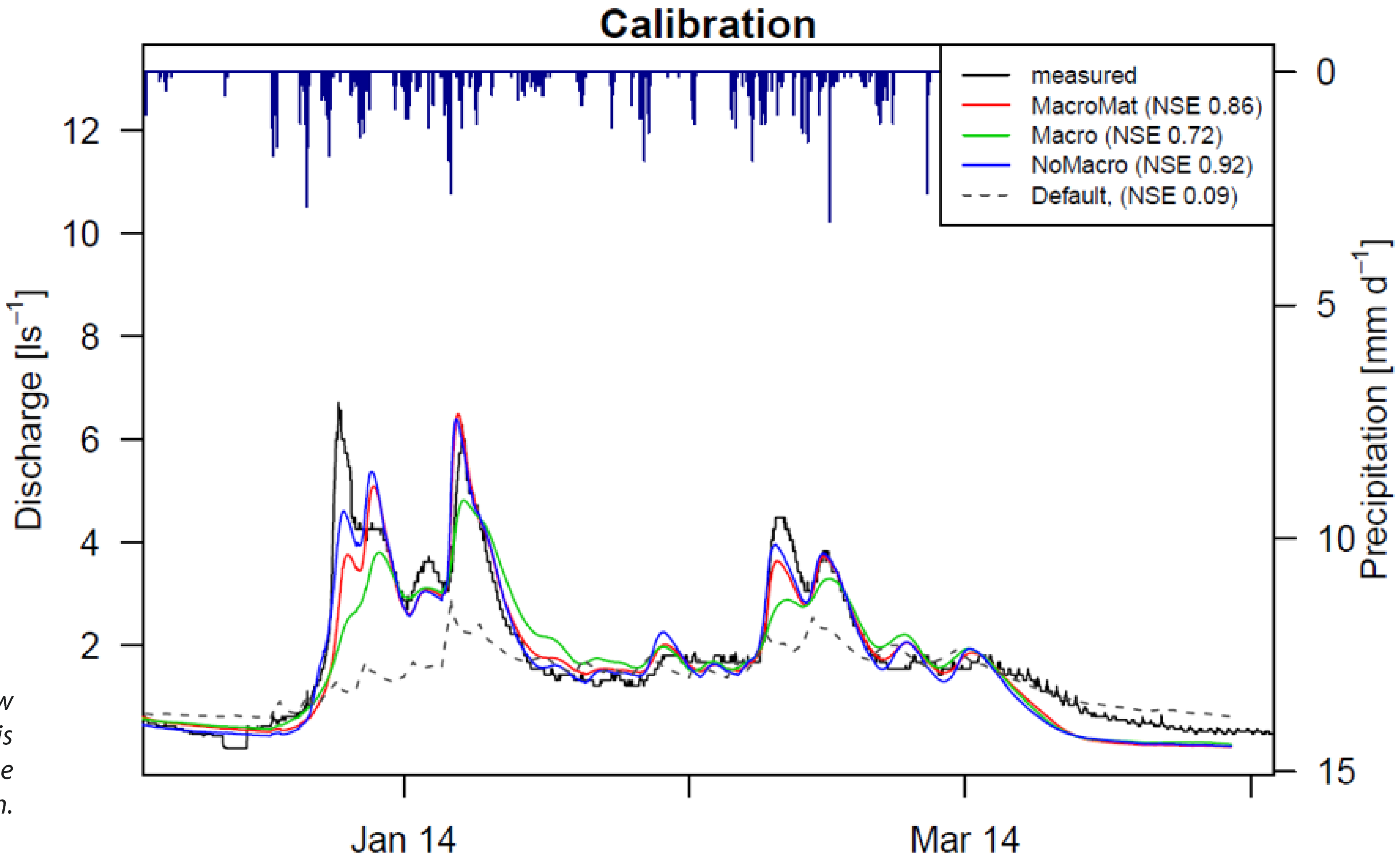
Scenario	No. of iterations for convergence of DREAM	Run times (days)
MacroMat	1780	73
Macro	420	16
NoMacro	1220	42



Profiles of calibrated saturated hydraulic conductivities for matrix domain and macropore domain of the best performing model run per scenario

Results - calibration

- The identified parameter sets for all calibration scenarios were able to simulate observed discharge time series satisfactorily

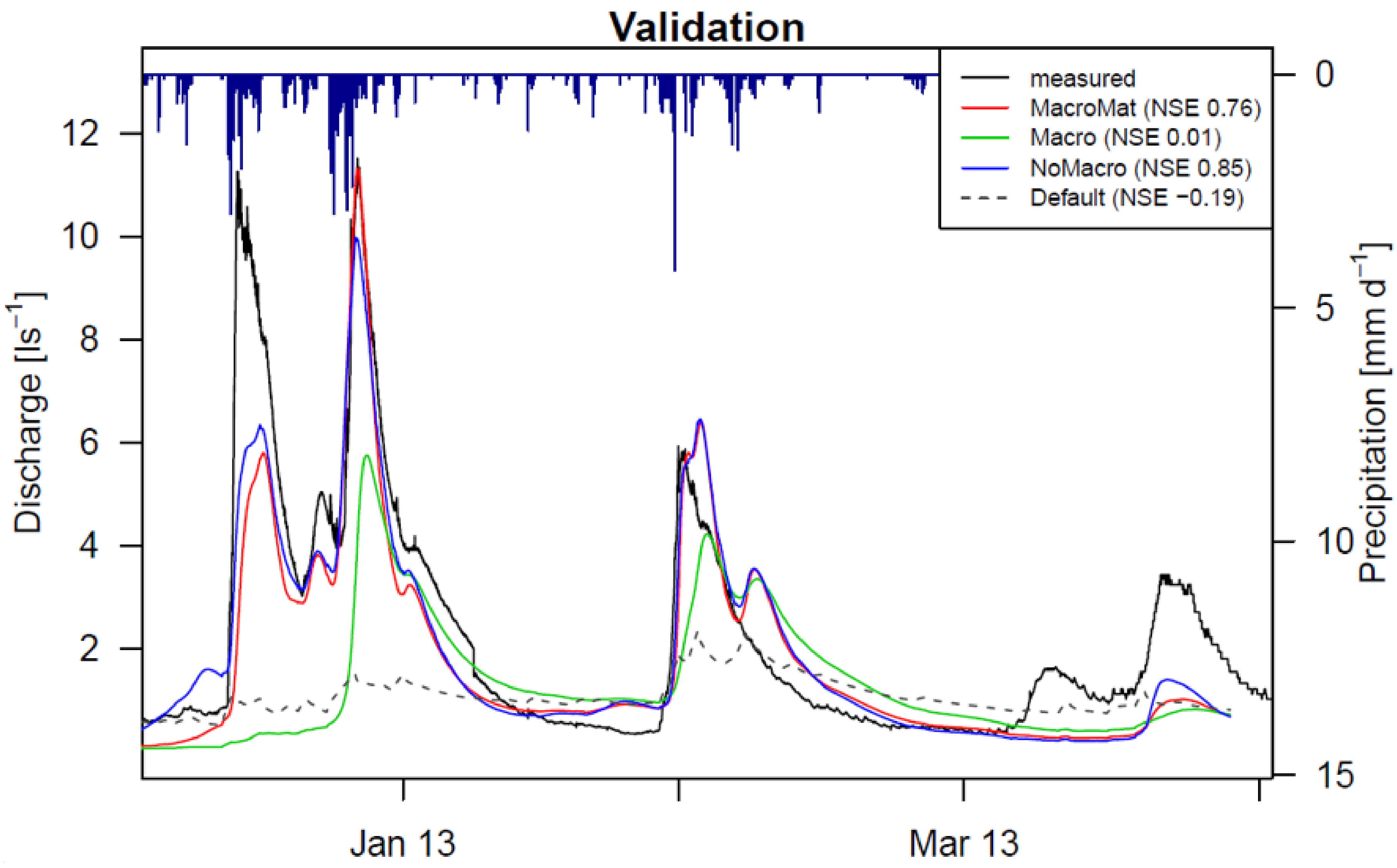


Hydrographs of measured (black) and modelled streamflow during the calibration. The Nash-Sutcliffe efficiency statistic is shown in parentheses. The dashed line shows the discharge simulated with the initial parameter set before optimization.

Results - validation

- The dual-permeability parameter set of the scenario *MacroMat* identified during calibration was able to simulate observed discharge time series satisfactorily for the validation period but did not outperform the calibrated single-domain reference model scenario *NoMacro*.

- The scenario *Macro* now clearly failed to reproduce observed discharge → calibration of only the macropore parameters, without calibrating also the matrix domain parameters at the same time, was not a successful strategy.



Hydrographs of measured (black) and modelled streamflow for the validation period. The Nash-Sutcliffe efficiency statistic is shown in parentheses. The dashed line shows the discharge simulated with the initial parameter set before optimization.

Conclusions

- We successfully used the optimization algorithm DREAM to calibrate a 3D physics-based dual-permeability model at the catchment scale.
- Our findings suggest that the incorporation of vertical preferential flow as represented by the dual-permeability approach was not relevant for reproducing the hydrometric response reasonably well in the studied catchment.
- The heterogeneity of soil hydraulic properties and lateral preferential flow already implemented by having soil layers with contrasting saturated hydraulic conductivities seemed to be sufficient to reproduce the hydrometric response reasonably well in the studied catchment.

For more details, please refer to:
Hopp, L., Glaser, B., Klaus, J., and Schramm, T. (2020). The relevance of preferential flow in catchment scale simulations: Calibrating a 3D dual-permeability model using DREAM. *Hydrological Processes*, 34:1237–1254. https://doi.org/10.1002/hyp.13672.

Thanks for your attention!