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Incorporating preferential flow into a 3D model of a forested headwater catchment

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Preferential flow plays an important role for water flow and solute transport. The inclusion of preferential flow, for example with dual porosity or dual permeability approaches, is a common feature in transport simulations at the plot scale. But at hillslope and catchment scales, incorporation of macropore and fracture flow into distributed hydrologic 3D models is rare, often due to limited data availability for model parameterisation.
In this study, we incorporated preferential flow into an existing 3D integrated surface subsurface hydrologic model (HydroGeoSphere) of a headwater region (6 ha) of the forested Weierbach catchment in western Luxembourg. Our model philosophy was a strong link between measured data and the model setup. The model setup we used previously had been parameterised and validated based on various field data. But existing macropores and fractures had not been considered in this initial model setup. The multi-criteria validation revealed a good model performance but also suggested potential for further improvement by incorporating preferential flow as additional process.
In order to pursue the data driven model philosophy for the implementation of preferential flow, we analysed the results of plot scale bromide sprinkling and infiltration experiments carried out in the vicinity of the Weierbach catchment. Three 1 sqm plots were sprinkled for one hour and excavated one day later for bromide depth profile sampling. We simulated these sprinkling experiments at the soil column scale, using the parameterisation of the base headwater model extended by a second permeability domain. Representing the bromide depth profiles was successful without changing this initial parameterisation. Moreover, to explain the variability between the three bromide depth profiles it was sufficient to adapt the dual permeability properties, indicating the spatial heterogeneity of preferential flow.
Subsequently, we incorporated the dual permeability simulation in the larger 3D headwater model under consideration of the constrained range of dual permeability parameters. The simulation results showed how important a catchment wide incorporation of preferential flow is for an accurate representation of the flow processes. Further, our approach demonstrated how experimental investigations at the plot scale can be used to further develop a catchment model and its process representation.