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Evaluation of a dual-permeability model for subsurface flow and solute transport against tracer data along a forested hillslope

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Preferential flow has a decisive influence on subsurface water movement and solute transport in boreal forest hillslopes. We performed a parallel and coupled simulation of lateral subsurface stormflow and solute transport in the soil matrix and preferential flow domain of a forested hillslope section in Kangaslampi, Finland, using a highly complex, physically-based dual-permeability model. The objective was to evaluate the model against spatially distributed tracer data that were available from a chloride irrigation experiment.

The mean slope at the site was 15 %, and the mean thickness of the stony, sandy till profile above a low-permeable bedrock was about 80 cm. The soil was first irrigated with chlorinated water for 80 min and then with tracer-free water for 130 min using a line-type irrigation source that was located upslope from a field of observation wells. Water table levels and chloride concentrations along the slope were recorded during the irrigations and for 220 min afterwards. 2-D tracer plumes were interpolated from the chloride concentration measurements. The model was calibrated against the chloride plumes of the tracer irrigation period; the remaining plumes as well as all water table data were used for the model validation. Calibrated model parameters included those parameters that the model was most sensitive to, i.e. the saturated hydraulic conductivity and the porosity fraction of the preferential flow domain, and the water transfer parameter between the soil pore domains.

The observed stormflow event was characterised by the transmissivity feedback phenomenon and controlled by preferential flow mechanisms, in particular by lateral by-pass flow. The model was able to mimic the observed tracer transport during tracer irrigation, as well as the water table levels during the entire observation period, but overestimated the dilution velocity of the tracer plume in the highly conductive soil horizons near the soil surface directly after changing the irrigation to tracer-free water. This implied that parameter values that only changed with depth did not account for the unknown, exact 3-D spatial variability of highly heterogeneous till. In addition, we may have over-simplified the calculation of solute exchange between the pore domains by restricting the exchange to only advective exchange and by using a same value for the calibrated transfer parameter at all depths in soil.

Our study emphasized the importance of spatial tracer data for the evaluation of a complex, distributed two pore domain model of subsurface flow and solute transport. Fixing the values of most model parameters and calibrating the model against the tracer data made it possible to find a rather unambiguous set of parameter values, and to assess the structural compatibility of the model within the framework of the parameterization. According to our simulations, a more detailed parameterization of the model, as well as different definitions for the solute exchange between the two soil pore domains need to be investigated in future studies.