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Connectivity in modelling subsurface stormflow and tracer transport in a forested hillslope

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Preferential flow characterizes subsurface water movement in forested hillslopes. Connectivity of preferential flowpaths in soil, as well as connections between the preferential flowpaths and the soil matrix, control the flow patterns in hillslopes. We simulated subsurface stormflow and tracer transport within a forested hillslope section in Eastern Finland with a modifiable and detailed, physically-based 3-D dual-permeability model. The objective was to investigate the role of flowpath connectivity in capturing the observed migration velocity and concentration status of a tracer plume during the different stages of an irrigation experiment. Hypotheses to explain the observed transport behaviour were formulated based on observed spatial variations in the soil properties. The hypotheses were then tested by running corresponding model versions against spatial high-frequency data from the irrigation experiment.

The 3-D distribution of preferential flowpaths, and the connections and disconnections between them, had the most crucial role in capturing the observed transport event with the model. Lateral by-pass flow in the preferential flow network and the transmissivity feedback phenomenon dominated the tracer transport. However, disconnections in lateral preferential flow restrained the transport, making the transport route devious instead of being directly lateral. These disconnections were caused by spots of cemented soil material. Stones had an opposite effect on the flow route formation compared to the cemented spots because preferential flowpaths were present on stone surfaces. Preferential flowpaths related to stones were linked with other types of preferential flowpaths in soil, facilitating the connectivity of preferential flowpaths within the entire hillslope.

To take into account the discontinuity in lateral preferential flow and the tortuosity of the dominant flow routes in the model, an explicit representation of the 3-D distribution of saturated hydraulic conductivity in the preferential flow network was required. In addition, with-depth changing porosity values of both pore domains of soil, i.e. the preferential flowpaths and the soil matrix, as well as explicit descriptions of local water losses into the underlying bedrock, were found important for successful simulations. Other investigated model features, including complexity in the values of the rest of the model parameters and in the calculation routines used in describing the flow connections between the preferential flowpaths and the soil matrix, were not found beneficial for the model outcome.