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Equifinality and structure control on bromide and pesticide leaching at tile drained hillslopes: a model study based on a comprehensive field data set

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Rapid flow in connected preferential flow paths is crucial for fast transport of water and solutes through soils, especially at tile drained field sites. The present study tests whether an explicit treatment of worm burrows is feasible for simulating water flow, bromide and pesticide transport in structured heterogeneous soils. The essence is to represent worm burrows as morphologically connected paths of low flow resistance and low retention capacity in the spatially highly resolved model domain. The underlying extensive database to test this approach was collected during an irrigation experiment, which investigated transport of bromide and the herbicide Isoproturon at a 1000 m2 large tile drained field site. The database includes a) initial soil moisture measured in the upper 30 cm at 25 locations, b) irrigation and discharge data, c) hydraulic properties of the soil matrix measured from several undisturbed soil cores as well as d) data on the area density of anecic earthworm burrows, their depth distribution and on the maximum water flow in worm
burrows from macroporous soil samples.

In a first step we investigated whether the inherent uncertainty in key data causes equifinality i.e. whether there are several spatial model setups that reproduce tile drain event discharge in an acceptable manner. We found a considerable equifinality in the spatial setup of the model, when key parameters such as the area density of worm burrows, the maximum volumetric water flows inside these macropores and the conductivity of the tile drains were varied within the ranges of either our measurement errors or measurements reported in the literature. In total 67 out of 432 model runs were acceptable with a Nash-Sutcliffe efficiency larger than 0.75. Among those the thirteen best yielded a Nash-Sutcliffe coefficient of more than 0.9, which
means that more than 90% of the tile drain discharge variability is explained by the model. Also, the flow volumes were in good accordance and peak timing errors where less than or equal to 20 min.

In the second step we investigated thus whether this "equifinality" in spatial model setups may be reduced when including the bromide tracer data into the model falsification process. We simulated transport of bromide for the 13 spatial model setups, which performed best with
respect to reproduce tile drain event discharge, without any further calibration. All model setups allowed a very good prediction of the temporal dynamics of cumulated bromide leaching into the tile drain, while only four of them matched the accumulated water balance
and accumulated bromide loss into the tile drain within the error range. The number of behavioural model architectures could thus be reduced to four.

Thirdly, we selected one of those four setups for simulating transport of Isoproturon, which was applied the day before the irrigation experiment, and tested different parameter combinations to characterise adsorption according to the footprint data base. Simulations could, however, only reproduce the observed leaching behaviour, when we allowed for retardation coefficients that were very close to one. This finding is consistent with observations of Zehe and Flühler (2001) who observed effective retardation coefficients close to one during
their experiment.

We conclude:
a) A realistic representation of dominating structures and their topology is of key importance for predicting preferential water and mass flows at tile drained hillslopes. This requires detailed knowledge about the topology of preferential flows paths - which is simple in the
present case of anecic worm burrows.
b) Those hillslope architectures that perform best with respect to the integral discharge response are also suitable

for predicting dynamics of accumulated bromide leaching, partly without a bias.
c) A simulation of pesticide transport is, without having detailed local data on the adsorption characteristics in different subsurface compartments, largely an unsatisfying issue of trial-and-error, even when using data from the Footprint data base.

Nevertheless, in our case four behavioural hillslope architecture structures remain. Probably we have to accept that a possible cause of equifinality is that part of the indeterminacy may be essentially system inherent, in the sense that several types of architectures of subsurface flow pathways may yield the same integral response in discharge and mass flows.

References

Zehe, E. and Flühler, H. (2001): Preferential transport of Isoproturon at a plot scale and a field scale tile-drained site. Journal of Hydrology, 247 (1-2), 100 - 115.