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Experimental and modeling study of unsaturated solute flow in soils: from classical to discrete approaches

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Most dye staining experiments in natural soils result in highly heterogeneous flow patterns which are usually explained with presence of preferential flow paths or different kinds of flow instabilities. It is quite logic that soil structure is one of the main factors affecting infiltrations regimes, however the degree of flow stochasticity is not studied enough. In this contribution a substantial amount of large scale (2-4 m lateral excavations) field experiment data is considered (including forested hillslopes and agricultural fields) with special attention to sprinkling of two different staining substances with different dyeing mechanisms (common dye is visible both in adsorbed and in solution states; fluorescent dye – only in solution). The latter method allows an estimation of the flow stability (stochasticity). Most staining field experiments are supported by undisturbed sample collections (laboratory measurements for hydraulic conductivity, water retention curves, X-ray microtomography scans, grain size distributions, etc.).

Preliminary results strongly support the evidence of stability of flow under similar precipitation and moisture conditions. Infiltration also correlated with soil structure and microproperties. Numerical modeling using classical approach (single-porosity coupled Richard's and advection-dispersion equations, random hydraulic properties based on log-normal experimentally obtained distribution) fails to describe experimentally obtained staining patterns. Multi-porosity models may provide better tools to account for different soil heterogeneities, but their parameters can not be obtained experimentally. Small scale solutions using pore-network or lattice-Botzmann methods based on microtomography scans are accurate, but computationally expensive (volumes around tens of cm3). Based on field observations a simple cellular automata approach to model staining patterns is developed and tested on experimental data. Our results are much better then those obtained using classical, stochastic or diffuse-limited aggregation solutions. One of the main drawbacks of the proposed model is the lack of temporal resolution. Some discussion on possible future improvements is provided. Significant betterments can be achieved by implementation of structural-hydraulic spatial stochastic optimization (e.g., simulated annealing, etc.). Finally, a framework for hydrological modeling using pore structure data (X-ray scans and NMR relaxation curves) on soil structure, including multi-porosity model parameters, is given.