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Preferential flow as a consequence of soil structure - measurements, models, predictability

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The widespread phenomena of preferential flow in soil is the consequence of the soils' structure at a given water flux and water content. This is true for all the various types of preferential flow including macropore flow, flow through soils with heterogeneous hydraulic properties or instable wetting fronts in coarse textured and/or poorly wettable materials. During the last decades, measurement techniques, especially dye tracing, have been developed and were extensively applied to characterize preferential flow phenomena. It is now clear that preferential flow is rather the rule than the exception. However predictive modelling remains to be a challenge. A key problem is how to adequately represent the structure of the material.

The most common approach is the formulation of implicit models where the flow domain is separated into virtual parts of different mobility as a convolute of the subscale heterogeneity. The required model parameters, however, have to be adjusted to experimental observations and are in principle only valid for the specific experimental conditions used for calibration. An alternative approach, which is highlighted in this contribution, is to use direct structural information. Such information might originate from two different sources: i) direct measurements using techniques for non-invasive inspection which are more and more available, e.g, X-ray tomography, NMR, geophysical tools or ii) the understanding of structure forming processes in soil which may allow for modelling structural properties including their dynamics.

Once the relevant structures are measured or modelled, a fundamental challenge is how to quantify these structures in order to link them to models of flow and transport. This step poses a formidable problem in soil physics. It is required because we are not in the position to solve the microscopic equations of fluid dynamics (Navier-Stokes)

at the pore scale considering the typical scale of flow from the soil surface towards groundwater.

In this contribution such a morphological path is discussed along with various examples including i) network models for flow and transport in heterogeneous porous media based on Monkowski functions, ii) quantification of macropore continuity to estimate the transition from preferential flow to a convective-dispersive regime. iii) estimation of critical thresholds of infiltration rates to induce non-equilibrium conditions and preferential flow. It turns out that spatial correlation and connectivity are the most critical structural properties both at the pore scale and at the continuum scale. The combination of the actual technical potentials for non-invasive imaging, the understanding of structure formation in soil and the available quantitative tools to quantify complex structures makes up a promising avenue to improve predictive modelling of preferential flow.