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Can pore-scale methods overcome limitations of traditional hydraulic property measurement techniques?

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Conventional methods of determining transport properties on core samples using information from hydraulic conductivity, water retention curves, electrical properties, or formation factor have substantial shortcomings:
(1) they represent quasi-1D flow;
(2) possess no a priori information on sample's representativity in terms of its internal heterogeneity;
(3) measurements may seriously alter sample properties, e.g. sample saturation and through-flow can mobilize fine material potentially causing pore blockage; also, saturation in the laboratory may cause swelling or mineral dissolution of some materials hence affecting the measured hydraulic properties, while full saturation may never occur under field conditions;
(4) they require standard shape and size for coring material, thus representing serious limitations for fragile, consolidated, or cemented samples;
(5) often represent quasi-static processes, while flow under field conditions is highly dynamic;
(6) some fitting parameters are invoked to represent pore-connectivity or "tortuosity" and used in cross-property relationships without real physical meaning (e.g., linkage between water retention curve and unsaturated hydraulic conductivity.
Based on experimental data from a broad range of porous materials we show how these shortcomings can be overcame via pore-scale modeling using structural and surface property information. In particular we use following datasets: 1) deep vadose zones for arid environment (central Australia), 2) shallow-to-deep aquifers (Central Russian Upland), 3) agricultural soils known for their preferential flow (Central Russian Upland), and 4) extremely stony forest soils (Russian Far East).
Several approaches exist for acquisition of structural information, with the most information-rich being X-ray microtomography. Alternatively, 2D thin-sections may be used with higher spatial resolution but with limited information on connectivity; reconstruction methods (sequential and stochastic) can help resolve the latter limitation.
Finally, we illustrate how our pore-scale methods fit in a broader upscaling approach and improve large-scale modeling; current limitations and future challenges are also discussed.