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Unsaturated Flow Modeling with Source-Responsive Film Flow in the Preferential Domain

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Various dual-domain approaches have been developed for representing unsaturated flow when some of the flow is in preferential pathways. Overall model performance is highly sensitive to the physical basis and mathematical form of the model applied to the preferential domain. The formulation for this domain this presents a further challenge in that the short time scale and large spatial scale of preferential flow contrast markedly with those of diffuse flow. Often, the preferential domain is characterized formally by the Darcy-Buckingham-Richards (DBR) unsaturated-flow theory, as used for diffuse flow, but this approach may fit poorly because preferential flow is not an equilibrium-maintaining diffusive process. An alternative conceptualization with certain advantages is preferential flow in films along macropore walls.

A quantitative model for the preferential domain based on this concept assumes the average film thickness to be constant and characterizes the medium with an effective macropore facial area per unit volume. The model also incorporates a source-responsive hypothesis, that the occurrence and cessation of preferential flow is governed not by the local moisture state but by the temporal and spatial character of the water input to the macroscopic medium (e.g. infiltration). Tested with field measurements of space- and time-dependent soil water content during preferential flow, for example during a ponded infiltration experiment in a virgin soil of silt-loam texture and well developed structure, this model represents fast-changing conditions at one-meter and larger scales better than the DBR model. Where both preferential and diffuse flow are significant, an interactive combination of film-flow and DBR approaches can improve prediction of unsaturated-zone fluxes in response to hydraulic inputs and the evolving distribution of soil moisture.