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Stochastic Modeling of Macrodispersion in Variably Saturated, Spatially Heterogeneous Formations

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The macrodispersion tensor, D, plays an important role in solute transport on the field scale. A key problem is how to relate D to the properties of the spatially heterogeneous formation. Under unsaturated flow conditions, the problem is further complicated inasmuch as the relevant flow parameters, the hydraulic conductivity and the water capacity, which depend on the formation properties, depend also on flow-controlled attributes in a highly nonlinear fashion. Consequently, under variably saturated conditions, quantification of D requires several simplifying assumptions regarding the constitutive relationships for unsaturated flow, the flow regime, and the spatial structure of the formation heterogeneity.

The present talk focuses on the quantification of D in a variably saturated, spatially heterogeneous formation, accomplished by using a two-stage approach. The approach combines a stochastic, continuum description of a steady-state unsaturated flow, based on small-perturbation, first-order approximation of Darcy's law and the continuity equation for unsaturated flow, with a general Lagrangian description of the motion of an indivisible particle of a passive solute that is carried by the steady-state flow. The resultant, time-dependent D depends on the covariances of the water saturation and the components of the water flux vector, and their cross-covariances, which, in turn, depend on the (cross-)covariances of the relevant formation properties and the pressure head.

The effect of few characteristics of the spatially heterogeneous, variably saturated flow system, on D is analyzed and discussed. Main findings reveal that under variably saturated flow conditions, the travel distance required for the principal components of D to approach their asymptotic values may be exceedingly large, particularly in relatively wet formations with significant stratification and with coarse-textured soil material associated with small capillary forces. Hence, in many practical situations of vadose-zone transport, the typical travel distance, may be small compared with the travel distance required for D to reach its asymptotic, Fickian behavior.