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A Review of Darcy's Law: Limitations and Alternatives for Predicting Solute Transport

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Darcy's Law that was derived originally empirically 160 years ago, has been used successfully in calculating the (Darcy) flux in porous media throughout the world. However, field and laboratory experiments have demonstrated that the Darcy flux employed in the convective disperse equation could only successfully predict solute transport under two conditions: (1) uniformly or densely packed porous media; and (2) field soils under relatively dry condition. Employing the Darcy flux for solute transport in porous media with preferential flow pathways was problematic. In this paper we examine the theoretical background behind these field and laboratory observations and then provide an alternative to predict solute movement. By examining the characteristics of the momentum conservation principles on which Darcy's law is based, we show under what conditions Darcy flux can predict solute transport in porous media of various complexity. We find that, based on several case studies with capillary pores, Darcy's Law inherently merges momentum and in that way erases information on pore-scale velocities. For that reason the Darcy flux cannot predict flow in media with preferential flow conduits where individual pore velocities are essential in predicting the shape of the breakthrough curve and especially "the early arrival" of solutes. To overcome the limitations of the assumption in Darcy's law, we use Jury's conceptualization and employ the measured chemical breakthrough curve as input to characterize the impact of individual preferential flow pathways on chemical transport. Specifically, we discuss how best to take advantage of Jury's conceptualization to extract the pore-scale flow velocity to accurately predict chemical transport through soils with preferential flow pathways.