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Effective hydraulic conductivity of stony soils: an improved model based on generalized effective medium theory

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A new model is presented which predicts the effective hydraulic conductivity of stony soils. It is based on the generalized effective medium (GEM) theory in a three-dimensional medium consisting of a homogeneous background soil and ellipsoidal inclusions. The formulation accounts for the hydraulic conductivities of background soil and stones, volumetric stone content, and the shape and orientation of the stones. One advantage of the new model over existing approaches is that it considers the hydraulic conductivity of the stones and is therefore applicable to soils containing permeable inclusions. Furthermore, effective hydraulic conductivity can be calculated for mixtures which consist of more than two constituents with contrasting hydraulic conductivities and for mixtures which contain tightly packed and even intersecting stones. As a consequence, soils with high stone content (>50 % v/v) and soils close to the percolation threshold can be treated. In the case of non-porous, spherically-shaped stones, the model reduces to the Maxwell model which has been used in vadose zone hydrology before. We illustrate the behavior of the model for different binary mixtures and compare its results with those of numerical simulations in three spatial dimensions. Model results lie well within the Hashin-Shtrikman bounds over the whole range of volumetric stone content. The generality and simplicity of the model make it attractive for practical applications in vadose zone flow and transport studies.