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A new model for transport to well in highly heterogeneous aquifer

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Predicting the behavior of a contaminant moving in a heterogeneous aquifer is a challenging task, due to a wide range of sources of uncertainty. In particular, transport is mainly controlled by the variability of the hydraulic conductivity field K, which is customary modeled as a Random Space Function (RSF). Convergent flow fields are widely used in engineered application, such as tracer tests and aquifer remediation, because of both economical and technical reasons. However the non-uniformity of converging flow sharpens the complexity of model, enhancing the computational efforts. Up to now, transport models in 3-D convergent flows rely on analytical formulations, valid only for small heterogeneity, and numerical solutions, which are usually error prone and computationally expensive.

This work is aimed at developing an analytical solution for transport in convergent flows for any degree of heterogeneity. The solution is based on the Multi Indicator Model–Self Consistent Approximation (MIMSCA), which has been used in the past for uniform mean flow and it is applied to convergent flow here, for the first time. The aquifer is confined with a constant thickness D, and the porous medium is conceptualized as an ensemble of cubical inclusions submerged into a homogeneous matrix of effective conductivity. By assuming that flow is locally uniform, the travel time to the well is equal to the linear superposition of the time spend by the particles in each block. Hence, by following a travel time approach, this model provides the Breakthrough Curve (BTC) at the well for an instantaneous injection. Although the tremendous simplifications introduced, this model reproduces both a laboratory experiment and numerical simulations for variances up to 8.
Two different injection modes are considered: a uniform and a flux-proportional injection, representing, for instance, residual DNAPL and leakage from a passive well, respectively. Though the proposed model, the BTC at the well is dependent of few parameters, such as the injection mode and the statistical structure of the aquifer (geometric mean, variance and integral scale of the hydraulic conductivity field). In other words, we emphasize that there is no parameter fitting in this procedure. Results show the influence of injection mode on the BTC shape, especially for high heterogeneity. In particular, a uniform injection produces asymmetric BTCs with long and large tails. In addition, by quantifying the confidence interval of an ensemble of BTC realizations, ergodicity of the travel times is assessed as a function of the number of vertical integral scales. It is shown that ergodic BTC may not develop for the typical thickness natural aquifers (about 10-100 vertical integral scales), even for mild heterogeneous aquifers.