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The effect of hydraulic conductivity structure on transport towards a well

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Natural aquifers are characterized by heterogeneity in hydraulic properties which are impossible to characterize exhaustively, thereby making flow and transport simulations plagued by uncertainty. A way to deal with incomplete knowledge of hydraulic property variations is by employing a stochastic model of spatial variability. The classic approach assumes the hydraulic logconductivity $Y = \ln(K)$ as a second-order stationary Gaussian Random Space Function (RSF) with constant mean and variance and a given covariance function. This model, known in the literature as MultiGaussian model, is adopted in a number of analytical solutions of flow and transport, based on the First-Order Approximation in the variance of Y. Although widely used, this model has been criticized because unable to represent the spatial patterns observed in outcrops and expert representations of geological reality. More complex models, involving moments higher than the second one, have been envisaged, with the purpose to better represent geological connectivity. In the present work, we systematically analyze the impact of hydraulic conductivity structure on transport towards a pumping (extracting) well. We consider a fully penetrating well pumping a three-dimensional heterogeneous aquifer of random logconductivity $Y = \ln(K)$. Flow is solved numerically by using MODFLOW and transport toward the pumping well is simulated by particle tracking.

We considered four different conductivity fields: a standard MultiGaussian field and two additional conductivity fields derived from it, showing respectively more connected high conductivity values (connected field) and more connected low conductivity values (disconnected field). The fourth field is made of blocks of random homogenous conductivity. These RSFs share the same two-point statistics (i.e. mean, variance and integral scales), but differ in the higher-order K-correlations and represent rather extreme cases in term of connectivity patterns. We computed numerically the BreakThrough Curve (BTC) at the extraction well as a function of a few structural parameters: the logconductivity variance, the longitudinal integral scale, the ratio of statistical anisotropy, the local-scale dispersivity, for a few distances of the injection point from the pumping well. In doing that, the differences emerging from the BTCs are only due to the effect of moments larger than the second one and the spatial structures that they generate. The numerical simulations are compared with two analytical solutions available in the literature, i.e. the Fist Order Approximation and the Multi-Indicator Model - Self Consistent Approximation. The main results confirm that the bulk of BTC is insensitive to the hydraulic conductivity structure, with observable differences being limited to early arrivals and tail of the BTC. We conclude that the simple MultiGaussian model can be safely used in most applications, when the bulk of the BTC is the main concern. These are good news, given the daunting difficulties in characterizing such structures. Moreover, the MultiGaussian model offers a rich library of analytical solutions of transport, which can be conveniently used as a reliable screening tool in most applications.