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Transport toward a well in highly heterogeneous aquifer

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Solute transport toward a well is a challenging subject in subsurface hydrology since the complexity of the mathematical model is tremendously increased by the non-uniformity of the mean flow and heterogeneity of the formation. Up to date, analytical solutions for such flow configurations are limited to low heterogeneous conditions. On the other hand, numerical simulations in 3D highly heterogeneous formations are computationally expensive and plagued by numerical errors. In this work we propose an analytical solution for the Breakthrough Curve (BTC) at the well for an instantaneous linear injection across the aquifer's thickness for any degree of heterogeneity of the porous medium.

Our solution makes use of the Multi Indicator Model–Self Consistent Approximation (MIMSCA), by which the aquifer is conceptualized as an ensemble of blocks of constant hydraulic conductivity K randomly drawn from a lognormal distribution. In order to apply MIMSCA, we assume the flow as locally uniform, given that K is uniform within the block. With this approximation, the travel time to the well is equal to the superposition of the time spent by the solute particle within each block. We emphasize that, despite the approximations introduced, the model is able to reproduce the laboratory experiment of [1] without the need to fit any transport parameters.

In this work, we present results for two different injection modes: a resident injection (e.g., residual DNAPL) and a flux proportional injection (e.g., leakage from a passive well). The proposed methodology allows to quantify the BTC at the well as a function 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). Results illustrate that the release condition has a strong impact on the shape of the BTC. Furthermore, the difference between different injection modes increases with the heterogeneity of the K-field. The importance of the both injection mode and heterogeneity degree are also elucidated on the early and late solute arrival times at the well. Finally, we show how travel times become ergodic only for very thick aquifers, even in case of mild heterogeneity. We emphasize that the present framework has a practical validity, giving an affordable, although approximated, first estimation of mass arrival at an extraction well.

<u>References</u>

[1] Fernàndez-Garcia, D., T. H. Illangasekare, and H. Rajaram (2004), Conservative and sorptive forced-gradient and uniform flow tracer tests in a three-dimensional laboratory test aquifer, Water Resour. Res., 40, W10103, doi:10.1029/2004WR003112.