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A time-domain random walk approach to solute transport in highly heterogeneous aquifers: Theory and application

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It is well understood that advective transport in aquifers is controlled by the hydrodynamics of flow which mainly depends on the heterogeneous structure. Predictive modelling of advective transport in aquifers of high heterogeneity in three dimensions however is still a considerable challenge. Hydrodynamics of flow can in principle be resolved numerically for any degree of heterogeneity, but such resolution is not always reliable and by no means routine. We therefore seek semi-analytical tools for predictive modelling of advective transport in highly heterogeneous aquifers that honour the hydrodynamics. In this work, we study advective transport in three-dimensional aquifers of arbitrary variability and point distribution of the hydraulic conductivity K. The transport will be analysed in the time domain, as a random walk. The time-domain random walk (TDRW) methodology is conceptually simple, and efficient for implementation; it provides an intuitive framework for the extension of scale, from single segments to an arbitrary number of segments. First, we set out the conceptual framework for TDRW modelling of advective transport and then derive transition densities as dependent on the K-statistics and the hydrodynamics. The theoretical results are implemented using the MADE-1 tracer data set. We study hypothetical transport at the MADE site with a significant extension of scale, and illustrate the role of hydrodynamics on non-gaussian features of tracer breakthrough with increasing scale. We also show the relationship between TDRW and the continuous-time random walk (CTRW) approach emphasising the important conceptual role of backward flow.