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Geostatistical Inversion Under Transient Flow Conditions in Heterogeneous Porous Media

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The assessment of hydraulic aquifer parameters is important for the evaluation of anthropogenic impacts on groundwater resources. The distribution of these parameters determines flow paths and solute travel times and is therefore critical for the successful design and deployment of remediation schemes at contaminated sites.

While traditional conceptual models divide the subsurface into a few zones with uniform coefficients, in the geostatistical characterization the hydraulic parameters are considered correlated random space variables, accounting for the spatial variability encountered on practically all scales.

Among the existing geostatistical inversion methods is the quasi-linear geostatistical approach, which is a Gauss-Newton method with geostatistical regularization that exists in several variants regarding efficiency of computations, the stabilization of the iterative scheme, and the type of data that can be inverted. Highest efficiency has been achieved with problems in which flow is at steady state and transport can be described by steady-state equations (e.g. temporal moment generating equations) as well.

The restriction to steady-state problems may be problematic in applications in which boundary conditions cannot be controlled that well. We thus extend the methods to instationary flow. This enables us to take fluctuating boundary conditions caused by e.g. nearby rivers or precipitation into account. Both transient measurements (time series) and discrete measurements at different points in space and time are compatible with this approach. The sensitivities of the resulting objective function regarding the hydraulic parameters can be computed efficiently and jointly by solving an adjoint problem based on the measurement locations and propagating backwards in time.

We integrate the geostatistical inversion methods into the software framework "Distributed and Unified Numerics Environment" (DUNE), developed by the parallel computing group at University of Heidelberg and others. Using high-performance-computing techniques the computations can be fully parallelized, making high-resolution two-dimensional or even fully three-dimensional representations of hydraulic parameter fields feasible. As a proof of concept the methods are applied to pregenerated random parameter fields by computing the data an experiment would yield and using these values as input, resulting in an approximation of the original parameter field.