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A hydraulic tomography approach coupling travel time inversion with steady shape analysis based on aquifer analogue study in coarsely clastic fluvial glacial deposit

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Rarely is it possible to draw a significant conclusion about the geometry and the properties of geological structures of the underground using the information which is typically obtained from boreholes, since soil exploration is only representative of the position where the soil sample is taken from. Conventional aquifer investigation methods like pumping tests can provide hydraulic properties of a larger area; however, they lead to integral information. This information is insufficient to develop groundwater models, especially contaminant transport models, which require information about the spatial distribution of the hydraulic properties of the subsurface.

Hydraulic tomography is an innovative method which has the potential to spatially resolve three dimensional structures of natural aquifer bodies. The method employs hydraulic short term tests performed between two or more wells, whereby the pumped intervals (sources) and the observation points (receivers) are separated by double packer systems. In order to optimize the computationally intensive tomographic inversion of transient hydraulic data we have decided to couple two inversion approaches (a) hydraulic travel time inversion and (b) steady shape inversion.

(a) Hydraulic travel time inversion is based on the solution of the travel time integral, which describes the relationship between travel time of maximum signal variation of a transient hydraulic signal and the diffusivity between source and receiver. The travel time inversion is computationally extremely effective and robust, however, it is limited to the determination of diffusivity. In order to overcome this shortcoming we use the estimated diffusivity distribution as starting model for the steady shape inversion with the goal to separate the estimated diffusivity distribution into its components, hydraulic conductivity and specific storage.

(b) The steady shape inversion utilizes the fact that at steady shape conditions, drawdown varies with time but the hydraulic gradient does not. By this trick, transient data can be analyzed with the computational efficiency of a steady state model, which proceeds hundreds of times faster than transient models.

Finally, a specific storage distribution can be calculated from the diffusivity and hydraulic conductivity reconstructions derived from travel time and steady shape inversion.

The groundwork of this study is the aquifer-analogue study from BAYER (1999), in which six parallel profiles of a natural sedimentary body with a size of 16m x 10m x 7m were mapped in high resolution with respect to structural and hydraulic parameters. Based on these results and using geostatistical interpolation methods, MAJI (2005) designed a three dimensional hydraulic model with a resolution of 5cm x 5cm x 5cm. This hydraulic model was used to simulate a large number of short term pumping tests in a tomographical array.

The high resolution parameter reconstructions gained from the inversion of simulated pumping test data demonstrate that the proposed inversion scheme allows reconstructing the individual architectural elements and their hydraulic properties with a higher resolution compared to conventional hydraulic and geological investigation methods.

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Maji, R. (2005) Conditional Stochastic Modelling of DNAPL Migration and Dissolution in a High-resolution Aquifer Analog, Ph.D. thesis at the University of Waterloo, 187 pp.