Doctoral School in Environmental engineering

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Characterization of heterogeneous aquifers: an innovative methodology for inversion of hydraulic tomography data

Abstract

The success of a groundwater inverse model depends critically on some factors: the choice of the data to invert, the accuracy of the forward model for relating flow parameters and measured data, the setting of the estimation criteria and of the model for reproducing spatial variability of flow parameters and finally the effectiveness of the optimization algorithm. In the present thesis hydraulic tomography transient data are inverted trough the use of an innovative methodology which, for the choices of the utilized tools and for some theoretical aspects, represents a development of the existing inverse models.

The methodology is based on the Maximum a Posteriori (MAP) technique, which, in a Bayesian formalism, yields to posterior estimates of flow parameters, given the prior information and the available data. The MAP technique is particularly efficient because produces optimal parameters maps from a combination of measured data fitting and prior information agreement. The spatial variability of flow parameters is reproduced trough a stochastic model characterized by an exponential covariance function, considering its parameters unknown. According to the pilot point approach, the optimal field consists of conditional generation of a random field, generated by using the model of spatial variability, to the actual parameters measurements and to the pilot point values. The joint calibration of the pilot point values and of the stochastic parameters of the model of spatial variability (which generates the unconditional fields), implies an additional complexity for the inverse methodology, which, for the same reasons, increases its capability to interpret the data. The forward model for relating flow parameters and measured transient head data is the accurate numerical solution obtained solving the groundwater flow equation with the finite element method. The optimal solution is derived by minimizing the MAP fitness function trough the use of Particle Swarm Optimization technique, an evolutionary stochastic algorithm which has demonstrated its effectiveness for electromagnetic inverse problems.

Several researchers have proved the effectiveness of the hydraulic tomography technique, in comparison with the traditional pumping tests, for the characterization

of heterogeneous aquifers at the scale of relevance for transport investigations. Hydraulic tomography for the characterization of the inter-well field derives from the crosshole geophysical tomography: the field is perturbed by a series of pressure pulses at different depths and the pressure responses are monitored. However, its real effectiveness is still unclear, because of limitations in the capability to adequately interpret hydraulic tomograms. The potential of hydraulic tomography for inferring the model of spatial variability of the hydraulic parameters is investigated trough the implemented inverse methodology.

First the inverse methodology is applied for the inversion of cross-well hydraulic tomography data in a synthetic two dimensional hypothetical aquifer, for the characterization of the hydraulic conductivity spatial variability. The results obtained from the two dimensional case are validated with three dimensional synthetic examples.

For a detailed characterization of Transmissivity and Storativity spatial variability, in a two dimensional aquifer, the hydraulic tomography test is performed trough the use of several wells, scattered distributed in the investigated area. The inversion of hydraulic tomography data is performed both for two dimensional synthetic aquifers and for a real fractured rock aquifer sited in the Experimental site of Altona.

The inference methodology, applied to cross-well hydraulic tomography data, allows for mapping the main features of heterogeneous permeability fields and provides reliable estimates of the parameters of the geostatistical model of spatial variability with minimal needs of prior information, showing that the distance between the two wells has an important effect on the accuracy of the inferred parameters. From the optimal permeability maps results that the hydraulic tomography is particularly sensitive to the high conductivity channels which influence transport behaviour.

The inverse methodology applied for the characterization of Transmissivity (T) and Storativity (S) produces reliable optimal maps with a different level of accuracy in according to the modes of pump test operation. In particular a constant pumping rate test allows a better interpretation of T spatial variability and a pulse pumping rate test describes better the S spatial variability.