Comparative Inverse Modeling with Combination of Multiphysics Codes and Parameter Estimation Snap-on Tools

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Incorporation of different types of data such as piezometric head, solute or other tracer concentration, and age inferred from environmental isotopic data can improve parameter estimation and reduce non-uniqueness of inverse modeling-based calibration of groundwater models. We are interested to investigate the importance of the groundwater age observation in the inverse modeling and the extent of information it can provide to the inverse process in order to reduce its inherent non-uniqueness in a real world aquifer.

Most groundwater flow models have been calibrated using only hydraulic head measurements as complementary data to whatever geologic information is available. Model insensitivity and non-uniqueness often occur when head measurements are used alone. In many groundwater flow models, simulated heads are not highly sensitive to minor differences in the transmissive properties of the medium. This non-uniqueness in calibrated parameters brings into question the robustness of assigned values and the spatial distributions of hydraulic parameters. Of particular concern is the dependability of such a calibrated model under a new and different set of boundary conditions. Such insensitivity and non-uniqueness can be reduced by use of additional information gained from field observations of other types, for instance, flow rate at head-dependent boundaries, temperature, electrical resistivity, and tracer solute concentration. Incorporation of different types of data such as age, environmental isotopic data, temperature and other sources of information may dramatically improve the stability of inversion and the robustness as well as the reliability of the model. As noted by Anderman et al. (1996), advective-dispersive transport observations reflect groundwater velocities and patterns over a long period of time and provide more complete information about the groundwater flow system than flow measurements taken at a discrete point in time.

In our preliminary idealized study we applied modeling of both flow and transport in an idealized 2-D problem in the forward sense to solve simultaneously the steady-state piezometric head and mean age distributions, the output of which is used as input to an indirect inversion scheme to calibrate some of the parameters involved. The goal of this study was to understand how addition of observation data density and type (e.g., head, flow rate, age) can improve the inverse solution and potentially reduce its inherent non-uniqueness. Based on the results of our study, the addition of groundwater age data was found to reduce the level of non-uniqueness as defined by the mean square error between the estimated hydraulic conductivity field and the true field (taken here as a measure of non-uniqueness) in our parameter estimation. The implication is that for inverse calibration of hydraulic condition age, that reflects advective-dispersive transport, may serve as a more powerful data type than head, which reflects local conditions through the diffusion operator. Nevertheless, the non-uniqueness persists because the heterogeneity of the domain allows different flow-fields to generate similar mean ages at the observation locations. This reflects that the global nature of age does not guarantee uniqueness, as long as data are absent from locations where observations are needed to distinguish paths that give rise subsequently to similar ages at downstream locations, even when ages depart upstream. One potential way to address remaining non-uniqueness is to collect age data at observation locations at multiple points along the flow paths. For instance, with addition of some samples at the bottom of a two-dimensional (section view) aquifer, the calibration resulted in unique solutions in our idealized study. These simple results reflect that distributed sampling location and combined use of different calibration targets (such as head and age) help to partially overcome the intrinsic non-uniqueness of the inverse problem.

In another part of our study we simulated the entire distribution of groundwater age under both transient and steady-state conditions in another idealized setting. Unlike the “tracer concentration measurement” which yields a single-valued estimation of age of water at a particular location, a water sample represents a mixture of different ages as a result of waters travelling in different flow-paths. Even the use of higher moments besides the mean of groundwater age may not adequately describe the important age densities represented in a given sample because the shape of underlying distribution is generally unknown. This may lead to possible misinterpretations of natural travel time and consequent errors in estimating the values of hydraulic parameters that are related to travel time. To investigate the impact of aquitard-aquifer mass transfer on groundwater age, we seek to examine the form of the distribution of groundwater age in such an idealized setting and how it changes with time. We used a synthetic system that consists of two layers of aquifers adjacent to an aquitard following Bethke and Johnson (2002) and simulated both the entire distribution of groundwater age and the mean groundwater age in both transient and steady-state conditions. The results showed that for even idealized heterogeneous aquifers, the distribution of groundwater age does not reach steady-state for relatively long times after perturbations in boundary fluxes. This result brings into question the validity of the steady-state assumption when applied to groundwater age in natural subsurface materials. It also highlights that age distributions can be expected to change gradually with trending changes in driving fluxes (e.g., climate change) and are not currently, or for the foreseeable future, at steady state.

As the next step of our study we choose a regional alluvial aquifer system in the San Joaquin Valley, surrounding the Modesto city area dominated by irrigated agriculture to investigate the importance of the groundwater age observation in the inverse modeling and the extent of information it can provide to the inverse process in order to reduce its inherent non-uniqueness in a real world aquifer. The boundaries of the regional groundwater system are the Merced River at the south, the Sierra Foothills at the east, the San Joaquin River at the west, and the Stanislaus River at the North. The San Joaquin Valley aquifer has been modeled by USGS (Phillips et al., 2007) and the model was provided to us. Our goal is to collect piezometric head, concentration, and environmental isotopic data so that we can evaluate the relative value of combined head, concentration and groundwater age data (as opposed to only head data) in the quality of the inversion and estimated parameters for this regional groundwater flow model. As was shown in our preliminary idealized study it is necessary to have age dating observations of both deep and shallow aquifers so that we can capture all the information provided by the advective-dispersive transport in the system. Thus another goal of our study is to evaluate the relative importance of the observation locations in the parameter estimation quality, this would help us to determine where additional observation should be added. Also, as typically several types of age dating data are available in this basin, another goal of the study is to evaluate relative importance of the different environmental isotopic data at different depths of the aquifers in parameter estimation quality.

To summarize, our preliminary idealized studies showed that incorporation of different types of data such as piezometric head and age data can improve parameter estimation and reduce non-uniqueness of inverse modeling, and that steady-state assumptions about the distribution of groundwater age (and therefore also its moments) are not generally applicable. To investigate these aspects in a realistic setting we choose a regional alluvial aquifer system in the San Joaquin Valley, California. We are using the USGS San Joaquin Valley regional model (Phillips et al., 2007) and have done some modifications on the model, including the refinement of the grid at the city of Modesto (local model) using the refinement capability of MODFLOW (MODFLOW_LGR, Mehl and Hill, 2005). We are building a coupled transport model via MODPATH to simulate the groundwater age and configuring the model for inversion using both piezometric head and groundwater age data via UCODE. This will allow us to explore the linkages between the three models: (1) flow model via MODFLOW-LGR, (2) transport model via MODPATH and (3) inverse model via UCODE.

Publications

Ginn, TR; Haeri, H; Massoudieh, A, Foglia, L. Notes on Groundwater Age in Forward and Inverse Modeling, TRANSPORT IN POROUS MEDIA, 2009, 79 (1): 117-134.

Professional Presentations

Haeri H., Foglia L., Ginn TR., Simulation of the Entire Distribution of Groundwater Age, American Geophysical Union (AGU), San Francisco, December 2008.

Haeri H., Foglia L., Ginn TR., Downscaling from Regional to Local Scales in Groundwater Flow Modeling, 27th Biennial Groundwater Conference, 18th Annual Meeting of the Groundwater Resources Association of California, Sacramento, Oct 2009.

Collaborative Efforts

As part of this study, the city of Modesto asked us to characterize the groundwater hydraulics in the vicinity of six selected rockwells installed in the city, and to use this information to plan the locations of observation wells to be installed near the rockwells, one upgradient and one downgradient per each selected rockwell.

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