Hydrol. Earth Syst. Sci. Discuss., 10, C7785–C7788, 2014
www.hydrol-earth-syst-sci-discuss.net/10/C7785/2014/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Stochastic inversion of sequential hydraulic tests for transient and highly permeable unconfined aquifer systems" *by* C.-F. Ni et al.

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Received and published: 7 February 2014

We thank anonymous referee #1 for the detailed comments on our manuscript. The points raised in the comments are crucial to our manuscript, especially for the simulation issues. We will follow the suggestions to revise the text to clearly present our simulation results. The following is the summary of our responses to the comments from anonymous referee #1.

Responses to the specific comments:

1)Thanks for the suggestion. In the revised manuscript we will present the hydraulic

tomography as "a concept" not "a method." This will make the description of hydraulic tomography smoothly.

2)It is true that the derivation of equation (5) requires further manipulation of the resulting equations and some additional assumptions to obtain the final form of equation (5). The derivations of equations (10) and (11) are based on the small perturbation assumption to derive the state sensitivity for ln K and ln Sy. Previous investigations had shown similar derivation processes for equations (5), (10), and (11). The main difference in this study is that the governing equation is a nonlinear one because the unconfined aquifer system is considered for the model. The derivation processes are similar but the equations are slightly different. There are additional terms to reflect the nonlinearity of the governing equation. To make the derivation clear, we will added the required equations and the associated descriptions for the derivation of equations (5), (10), and (11).

3)The nonlinearity of the governing equations and adjoint state equations require numerical iterations to solve for the equations such as equations (5) and (6). The solutions of equations (5) and (6) are the basis to obtain sensitivities of head at different times and locations to ln K and ln Sy, i.e., the equations (10) and (11). In this study the objective of numerical iterations is for the accuracy of solutions to equations (5) and (6). We will present the objective and the detailed iteration processes in the session of optimization algorithm in the revised text.

4)The objective of the synthetic example is to test the developed mode that can reproduce well the predefined K and Sy distributions. It is challenging if the number of cells is increased to several orders of magnitudes greater than that of the synthetic example. This computational issued had been recognized by many previous investigations. Additional references will be added in the text to address this issue. We had discussed the computational issue with two additional expanded domains (see figures 12-15).

In this study the adjoint state method share the assumption same as other small pertur-

bation approaches. The assumption is valid only for a small ln K variance. We expect that the approximations used in this study will fail with large ln K variances. We will address this issue in the methodology section in the revised manuscript. Thanks for the comments.

5)The objective of the field-scale experiment is for our model implementation. For entire aquifer that extends over kilometers, the stress applied to a well may not strong enough to produce head responses far away from the injection well. Different types of stresses such as rainfall events or river stage fluctuations near the aquifer can be the potential stimuli for large-scale problems.

The observations that are not used for the inversion are the wells that we inject the water. We will make it clear in the text. It is possible to used head observations at injection wells for inversion. For synthetic example, this is fine because the head observations are generated by a numerical flow model. In a realistic problem, the well installation processes may introduce well bore effect and such effect can be either positive or negative to the flow rate near an injection/pumping well. The reason that we excluded the head observations at an injection well is to eliminate such effect.

It is very important to have conditioning points in the simulation domain to make the inversion stable. We did have slug test results for two of the 4 inch wells. The average K value based on two slug tests is 50.2 m/day. This value is the initial mean K value for our field-scale inversion. We will add the description of how we put initial values in the model and the associated discussion in the revised text.

6)The objective of the field experiment is to test our inverse model for a field-scale problem. We did have two slug test results for 4 inch wells. These two K data can be served as the basis for comparing inversed K field. We will add the discussion in the section 6.3 parameter estimation.

Responses to some other comments:

1)The definition of high resolution in this study is not for small cell sizes in the model. We emphasis here the concept and the numerical model that can resolve the variations of K and Sy in the simulation area. Unlike conventional single or multiple well hydraulic tests that provide single K or Sy value between wells, the concept of hydraulic tomography integrates multiple stress events and the identifications of K and Sy variations between wells become possible.

2)The head variance will be zero at constant head boundaries because the head values are deterministically defined at boundaries. The hydraulic conductivity variance will be very small because of the fixed head values. We will rephrase the sentences in the text. Thanks for the comment.

3)The initial values for the case study simulation will be addressed in the section 6.3 parameter estimations. Small changes of initial values such as the means, variances, and correlation lengths will give same simulation results. The computation times can be different because of the model convergence criteria. For extremely changes of initial values, the results are significantly different. In the case study, we did have reference values for the initial input values. The initial mean K and Sy values are from slug tests and the statistical parameters are from average well distances.

4)Before the day we start the injection test, try tests were conducted to evaluate suitable injection rates for injection wells and head responses for observation wells. Additionally, the injection and recovery times for each injection were also recorded for references. The information will be added in the revised text. For the boundary condition issue, we cannot obtain precise boundary values from field experiment. This was why we made all the injection tests in one day and evaluated the boundary effect for different domain sizes.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 14949, 2013.