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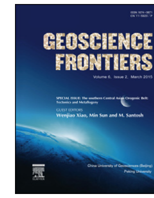

Research paper

Evaluation of alternative conceptual models for groundwater modelling

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A R T I C L E I N F O

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A B S T R A C T

This study evaluates the alternative conceptual models for groundwater modelling. A true model was created with a synthetic alluvial fan-plain hydrogeological framework. Various alternative conceptual models were evaluated for groundwater flow simulations. The first alternative model is a single aquifer layer model; the second alternative model is a 3-layer aquifer model; and the third model is a 5-layer model consisting of 3 aquifers separated by 2 aquitards. All models could fit very well to the observations with optimized values of hydraulic conductivities. However, the single aquifer layer model can only compute water balance components with good accuracy. The 3-layer aquifer model can be used for water balance computation and groundwater head simulation with small errors. The 5-layer model is capable of simulating water budget, groundwater head distribution and travel times with high accuracy. Multi-model analysis found only the 3rd alternative model superior.

1. Introduction

Conceptual model is defined as a simplified version of real world system (Anderson and Woessner, 1991). Conceptual models are formulated by including major physical processes operating on simplified hydrogeological formations within the generalized boundary conditions. However, hydrogeological systems are complex, rendering them prone to multiple interpretation and conceptualizations (Poeter and Anderson, 2005). Uncertainties in groundwater conceptual models come from various sources (Hill and Tiedeman, 2007). For example, uncertainty in estimated parameter values, boundary conditions, assumed model structure and hydrological stresses. Recent research indicates that the largest prediction uncertainty may come from the conceptualization of hydrogeological system (Bredehoeft, 2005; Hojberg and Refsgaard, 2005; Rojas et al., 2010). Ignoring the conceptual model uncertainty may result in biased predictions and/or underestimation of predictive uncertainty.

Since the real world groundwater systems are very complex because of spatial variation of geology and involving of different types of flow process, there is a need for simplification of real world systems. Over-simplification may result in a model with lack of information and under-simplification may result in a costly model. Both generate unrealistic predictions. It is therefore important that all features relevant to the real system must be included in the conceptual model and irrelevant ones be excluded. There are usually insufficient data to completely characterize the groundwater system. It is difficult to select a single appropriate conceptual model for the system (Bredehoeft, 2005). Then, alternative conceptual models can be developed based on different set of simplified assumptions (Hojberg and Refsgaard, 2005; Poeter and Anderson, 2005) and evaluate them to select most appropriate model for the system (Poeter and Anderson, 2005).

A number of statistical criteria have been used to evaluate alternative conceptual models (Poeter and Anderson, 2005). These include Kashyap Information Criterion (KIC), Bayesian Information Criterion (BIC), Corrected Akaike Information Criterion (AICc), and the Sum of Weighted Squared Residuals criteria (SWSR). Statistical discrimination criteria are calculated based on conceptual model predictive uncertainties. Generally, more than one model provides a similar acceptable fit to the observations: thus model discrimination should be made from multiple models. Multi-model analysis method (MMA) (Poeter and Hill, 2007) is one of computer code developed for identifying alternative models for the groundwater system using KIC, BIC, AICc, SWSR criteria.

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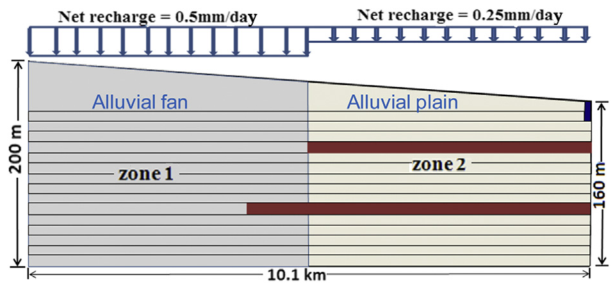

Figure 1. Cross-section of a synthetic alluvial fan-plain aquifer and model layers for the true model, red colour layers are clayey silt.

In this paper, a synthetic alluvial fan-plain aquifer system was created to test alternative conceptual models for simulating groundwater flow and travel time. Multi-model analysis method was used to identify the best alternative model. The results show that for computing water budget, a single layer model is sufficient. However, for simulating groundwater travel time, a conceptual model consisting of multiple aquifer-aquitard model layers must be used. The results provide guideline for choosing appropriate complexity of the conceptual model for different modelling purposes.

2. Generation of synthetic alternative conceptual models

Alluvial fan-plain aquifer is widely distributed and usually consists of multiple hydrogeological layers (Zhou et al., 2012). Hydrogeological layers can be conceptualized into a single aquifer up to multiple layers of aquifers separated by aquitards. Thus, alternative conceptual models are plausible. A true model and three alternative conceptual models were created for the analysis of alternative conceptual models for groundwater modelling in this study. These alternative models are differed only in the number of model layers; boundary conditions and hydrological stresses are kept the same.

The synthetic alluvial fan-pain aquifer consists of an alluvial fan of gravels and pebbles and an alluvial plain of sand layers separated by two clayey silt layers (Fig. 1). The hydraulic conductivity is specified as 100 m/d for the alluvial fan; to be 20 and 0.1 m/d for the aquifer and aquitard in the alluvial plain, respectively. Net groundwater recharge is uniformly distributed in two areas: 0.5 mm/d in the alluvial fan and 0.25 mm/d in the alluvial plain. The boundary on the west is assumed in contact with the impermeable rocks as no-flow boundary. The east boundary is a perennial river defined as a head-dependent flow boundary. Boundaries in the north and south are specified no-flow boundaries since groundwater flow is assumed parallel to these boundaries under natural flow.

The true model was constructed to generate benchmark data sets for comparing alternative conceptual models. The true model consists of 16 model layers (Fig. 1). The thickness of the model layer 1 varies from 10 m in the east to 50 m in the west. The thickness of the rest layers is 10 m. The model grid consists of 101 columns and 100 rows with a uniform cell size of 100 m. The model covers an area of 10,100 m × 10,000 m. MODFLOW-2000 (Harbaugh et al., 2000) was used to simulate the steady state groundwater head distribution. Groundwater heads computed at locations of observation wells (Fig. 2a) were used as observation values to compare model results of alternative conceptual models. All observation wells are single-layer well in the true model. There are 5 clusters of observation wells; each cluster consists of 5 observation wells. Two shallow wells are located in the layers 4 and 5 (just above the first aquitard) representing hydraulic heads in the shallow aquifer. Two middle wells are located in the layers 10 and 11 (just above the second aquitard) representing hydraulic heads in the middle aquifer. One deep well is located in the layer 16 (just above the bottom of the aquifer) representing hydraulic head in the deep aquifer. Computed hydraulic heads with the true model (16 layer

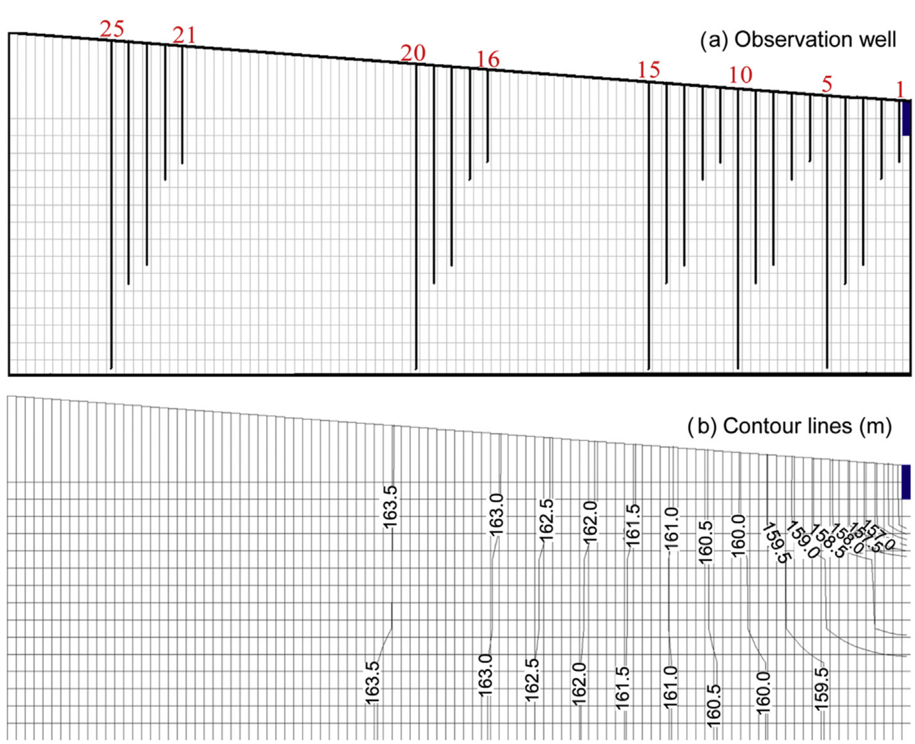

Figure 2. (a) Locations of 5 clusters of observation wells at various depths of the aquifer, observation wells are numbered in sequence from east to west; (b) Contour lines of computed hydraulic heads in the west-east profile with the true model.

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