

Influence of non-linear flow on the pumping tests in karstified and fractured aquifers

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When evaluating pumping test data in karstified or fractured aquifers remarkable deviations from the theoretically estimated curves can be observed. The assumptions of the commonly used evaluation methods (Theis, Cooper-Jacob, Papadopulus-Cooper) usually do not fit to properties in hard rock aquifers, where often non-linear, heterogeneous and non-isotropic conditions can appear. The analysis of the effect of these conditions helps to better evaluate the pumping test data and to avoid the mistakes caused by the use of traditional methods. In this study the influence of non-linear flow was analysed based on field data and computer-generated time series. Using Non-Linear Flow Process for MODFLOW (Mayaud, C., Walker, P., Hergarten, S. and Birk, S., 2015, Nonlinear Flow Process: A New Package to Compute Nonlinear Flow in MODFLOW. *Groundwater*, 53: 645–650) allowed the simulation of non-linear flow in aquifers based on the Forchheimer equation. The analysis showed that the detection of non-linear flow can be subserved by separate evaluation of drawdown and recovery time series or by using additional observation wells. Recovery data and data from observation wells far enough from the pumped well are not disturbed by nonlinearity; the comparison with drawdown data of observation wells and the pumped well therefore can show whether or not non-linear flow appears. In particular, proper results of aquifer parameters can be obtained from recovery data. If only drawdown data from the pumped well are available it is helpful to replace the losses caused by non-linear flow by non-linear well losses (see also Mathias, S. A., and L. C. Todman, 2010, Step-drawdown tests and the Forchheimer equation, *Water Resour. Res.*, 46, W07514). The applicability of the Jacob's step-drawdown-test evaluation in Forchheimer-flow cases is demonstrated by comparison with the numerical non-linear flow model. Inaccurate parameter estimates resulting from neglecting non-linear flow demonstrate the significance of taking nonlinearity into account when data from karstified or fractured aquifers are evaluated.