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Improving dual-porosity-medium approaches to account for karstic flow in a fractured limestone: Application to the automatic inversion of hydraulic interference tests (Hydrogeological Experimental Site, HES — Poitiers — France)

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Summary A reassessment-improvement of a previous work by the authors is proposed on the inversion of hydraulic interference testing by means of dual-porosity-medium approaches. The tests have been performed over a fractured limestone aquifer (Poitiers, France) showing a preferential and rapid flow path along open karstic drains. All drawdown curves are merged together both in amplitude and time irrespective of their location relative to the single pumped well and classical dual-porosity-medium approaches are unable to mimic this behavior. A pressure wave propagation by advection is added to the classical diffusion equations of dual-porosity-medium in order to stress the medium almost evenly whatever the distance from the pumped well. The problem is set up to keep the continuous dual-porosity-medium framework with only two state variables, i.e. the heads in fractures and matrix. Even though the wave velocity is not well-conditioned because the ratio of the volume of drains to the total volume of the medium is unknown, automatic inversion remains feasible. The dual-porosity-medium (without the drains) can be homogeneous or fractal, having in the latter case hydraulic parameters ruled by scaling power laws. In both cases, it is shown that adding an advection term allows to invert accurately all experimental drawdown curves. Statistical fluctuations of the sought hydraulic parameters are quite small and do not show any trend with respect to the distance. Thus, modifying a dual-porosity-medium approach by adding an advection term allows for the

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homogenization of a reservoir that combines the general drainage of a fracture-matrix system and a rapid drainage through karstic conduits.

Introduction

The University of Poitiers had a Hydrogeological Experimental Site (HES) built nearby the Campus for the sole purpose of providing facilities to develop long-term monitoring and experiments for a better understanding of flow and transfers in fractured rocks. The site is set up over a confined Jurassic fractured limestone of about 100 m in thickness beneath 20 m of Tertiary clays. The building phase started in 2002 and up to now, about 35 wells have been bored over the whole thickness of the reservoir. Among the teaching, research and engineering activities (sub-surface geophysics, geochemistry monitoring, in situ decontamination, vadose-zone hydrology, groundwater) carried out on the site and shared between several teams from France and Europe, a small group in Poitiers has been interested in addressing the hydraulic properties of the fractured reservoir by means of interference tests (Delay et al., 2004; Bernard et al., 2006; Delay et al., 2007; Kaczmaryk and Delay, 2007). The 35 wells were drilled during two campaigns, each being followed by a series of large-scale interference pumping tests. In the following, the data obtained during the pumping campaigns held in 2004 and 2005 are designated C2004 and C2005, respectively. The principle of interference testing is quite simple: a well is pumped at a constant flow rate and the head-pressure depletion is monitored in time at one or several distant wells, far enough from the pumped one to avoid non linear problems, casing effects, non-Darcian flow, etc. Even if the volume of rock experienced and the way hydraulic properties are averaged can be questioned (Sanchez-Vila et al., 1999; Neuman and Di Federico, 2003), the test is still of valuable interest. It may for instance condition new continuous and/or homogenized approaches to fractured rocks advocated by a non negligible part of the Community (e.g. Neuman, 2005).

Several methods for interpreting C2004 and C2005 data have been handled: the homogeneous single medium approach (i.e. the Cooper Jacob solution, 1946), the homogeneous single medium approach with non-integer flow dimension (i.e. the Barker model, 1988), the single-fractal medium approach (e.g. Chang and Yortsos, 1990; Acuna et al., 1995; Bernard et al., 2006), and finally the dual-porosity-medium approach (e.g. Gringarten, 1984, 1987; Gerke and Van Genuchten, 1993; Delay et al., 2007; Kaczmaryk and Delay, 2007). In short, the main result is that the aquifer's behavior is different between C2004 and C2005. The C2004 data show that the reservoir responds to convergent radial flow as expected from a fractured rock (example in Fig. 1). The drawdown curves are well individualized and separated in time and amplitude according to the distance between the observed and pumped wells. An inflection in the drawdown curves is often observed at intermediate pumping times, which is commonly interpreted as the signature of a dual-porosity-medium behavior. This inflection corresponds to the transition between the end of the fracture network draining and the general water feeding of the system by the porous matrix. Note, however, that fractal media may also show inflected curves due to changes in the flow dimension (e.g. Acuna and Yortsos, 1995). In the end, C2004 data are interpretable with both single-fractal and dual-porosity-medium models.

On the other hand, the C2005 data show drawdown curves merged together in time and amplitude irrespective of the distance between the monitored and pumped wells and whatever the pumped well (example in Fig. 1). The medium behaves as if it was rapidly and almost evenly stressed by the pressure depletion due to pumping. This almost even stress whatever the distance explains the smaller range of drawdown amplitudes spanned by C2005 curves (see Fig. 1, the same pumping rate yields 4 m of maximal amplitude for C2005 curves instead of 7 m for C2004). Compared with classical responses, the drawdowns are smaller than expected at short distances from the pumped well. Note that inflections in the C2005 drawdown curves at intermediate times disappear but the curves remain convex over large periods (the drawdown increases more rapidly than linearly with the natural logarithm of time, (ln t)). This shape is also observed in fracture-matrix dual media where

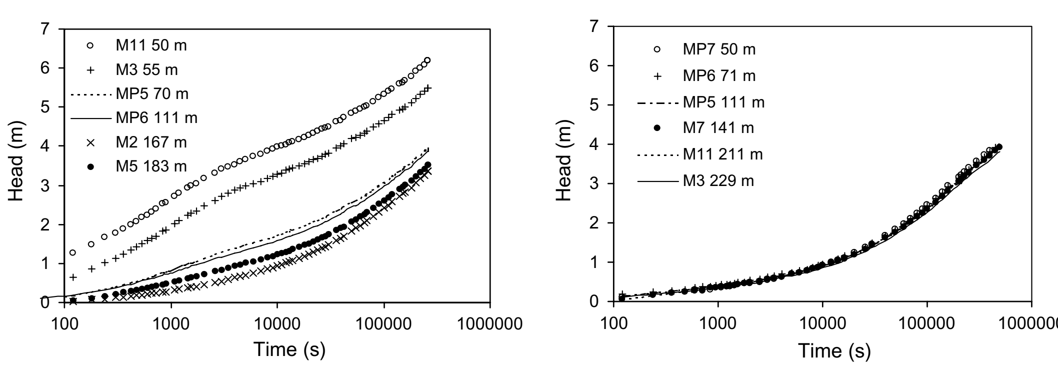

Figure 1 Example of experimental drawdown curves from an interference test pumping in well M6 (C2004 data set) and in well M16 (C2005 data set).