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Pumping test in a layered aquifer: Numerical analysis of self-potential signals

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A B S T R A C T

We used numerical modeling to study self-potential (SP) signals associated with a pumping test in a layered aquifer containing the main aquifer, a thin aquitard, and a shallow aquifer. The results revealed an unusual behavior of SP signals, which were not linearly correlated with the hydraulic head distributions. We explained this behavior by a vertical downward groundwater flow, from the shallow aquifer to the main aquifer, in the course of the pumping test. However, when plotted as a function of time, the SP signals and hydraulic heads displayed coherent behavior. In both distributions, three stages of the pumping test were determined: at early times, only the main aquifer and the aquitard responded to the pumping; at intermediate times, the downward flow from the shallow aquifer occurred; and at late times, the layered aquifer responded to the pumping as a whole. The SP signals reacted to the sequence of these stages much faster than the hydraulic head distributions. In principle, this might allow reducing the duration of the pumping tests without losing valuable information.

1. Introduction

In the last decades, there has been an increased interest in application of self-potential (SP) method to investigation of groundwater flow, especially in cases of pumping and infiltration tests (e.g., Vasconcelos et al., 2014; Jardani et al., 2009; Bolève et al., 2007; Titov et al., 2005; Rizzo et al., 2004).

Some pioneering works in this area have been done by the Russian researchers (e.g., Murashko et al., 1981; Semenov, 1981; Bogoslovsky and Ogilvy, 1973; Gorelik and Nesterenko, 1956), who have shown measurable SP signals in response to pumping tests. Later on Suski et al. (2006), Titov et al. (2005), Rizzo et al. (2004) used quasi-linear relationships between the hydraulic head data and SP signals, which allowed considering SP signals as a proxy of piezometric level.

In recent works, a general approach has been developed to perform hydraulic conductivity tomography using the joint inversion of SP signals and groundwater head data. The hydraulic conductivity distribution within a synthetic heterogeneous aquifer was defined through the use of adjoint-state method (Ozaki et al., 2014; Soueid Ahmed et al., 2014). In a very recent paper, Chidichimo et al. (2015) assessed the saturated hydraulic conductivity in a conditions of large (field comparable scale) laboratory setup using a coupled model based on the modified Richards equation coupled with the Poisson equation providing the SP signals. The inversion was performed on the basis of the Spars Nonlinear Optimizer (Gill et al., 2005).

Although this very general approach had been addressed in previous works, experimental or numerical relationships between the hydraulic head data and SP signals are still of interest because they determine sensitivity of SP signals to the hydraulic head variation. As mentioned above, these relationships are frequently considered quasi-linear, which was confirmed by experimental and numerical data (see also Jardani et al., 2009). The linear relationship results in an SP signal distribution whose shape represents a “mirror image” of the water table (e.g., Darnet et al., 2003). Also, in steady state conditions, the electrical potential decreases as the inverse of the distance from the pumping well (Straface et al., 2011; Rizzo et al., 2004). The above-mentioned features of SP signals are typical of pumping tests in isolated aquifers. Two semi-analytical solutions for SP signals associated with pumping tests in isolated aquifers have been developed: the SP responses to pumping tests in confined (Malama et al., 2009a) and unconfined (Malama et al., 2009b) aquifers. These models also confirm a quasi-linear relationship between the drawdowns and the SP signals.

Vasconcelos et al. (2014) studied SP signals produced by pairs of injecting and pumping wells in an isolated aquifer using a tank experiment and numerical modeling. They compared electrical potentials for the cases of (1) SP produced by pumping and injection and (2) electrical potential produced by electrical sources (positive and negative) located at the same points that had been used for pumping. They showed that, in homogenous medium, these potentials have the same bipolar