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Estimating hydraulic conductivity profiles using borehole resistivity logs

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Abstract

Measurements of aquifer resistivity are intuitively attractive for estimating aquifer hydraulic conductivity because of the fundamental relation between hydraulic conductivity and electrical conductivity; both of these properties depend on porosity, grain size and packing configuration ([1], [2]). In this study porosity and hydraulic conductivity profiles are estimated in three boreholes in Glafkos aquifer, located near the city of Patras in Western Greece. For this purpose, resistivity measurements, the law of Archie [1], the Kozeny-Carman model [2] and numerical simulations of pumping tests performed in the boreholes, have been used. It is shown that resistivity logs and pumping tests constitute a useful data set for the estimation of hydraulic conductivity profiles. The reliability of the results has been discussed. The relationships between porosity and hydraulic conductivity resulting for each of the three investigated boreholes have been compared to each other as well as with literature data. The comparison confirms that the value of the hydraulic conductivity for a given value of the porosity varies significantly.

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Keywords: hydraulic conductivity profiles; resistivity logs; pumping tests, numerical simulations.

1. Introduction

The coastal aquifer of Glafkos River (Fig. 1a) is a very important groundwater reservoir for the water supply of the city of Patras. The aquifer covers an area of about 25km^2. Due to its importance, a network of seven observation wells shown in Fig. 1b has been constructed in the last years. The depth of the

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boreholes varies from 80 m to 120 m and their diameter is 12 in. Groundwater level data collected during the period from 2008 to 2012 have been used for the calibration of a groundwater model used for the investigation of management issues (Ziogas, [3]). In order to refine the estimation of the hydraulic properties of the aquifer, data collected during the construction of the boreholes, are used. In this study we focus on the analysis of the data collected in the boreholes G1, G4 and G5 (Fig. 1b). The analysis of the remaining wells is still in progress. The data collected in each of the aforementioned boreholes are: (a) a cuttings log, (b) a gamma ray (GR) log, (c) a spontaneous potential (SP) log, (d) two electrical resistivity logs, i.e. one short normal and one long normal (see below), and (e) water level measurements in the borehole during a pumping test of short duration (three to four hours). The logs (b), (c) and (d), which have been measured before the installation of the casing, have a vertical resolution 0.20 m.

The cuttings logs show that the aquifer consists of mixtures of coarse and fine gravel, sand and clay. The GR-logs show that the values of the radiation are smaller than 35 API units. According to [4] (see page 30 therein) such values correspond to clean formations, i.e. to formations with negligible clay content. Concerning the SP-logs, they add little to the investigation, because, due to the lack of clay layers in the formation, the clay base line cannot be established. Thus, concerning the structure of the formation at the location of the boreholes G1, G4 and G5, the logs (a), (b) and (c) provide only qualitative information.

Concerning the two types of the resistivity measurements, the difference between the short normal and the long normal log consists in the spacing of the electrodes of the measuring device. In the short normal device, which is characterized here as 16NR, the separation distance of the electrodes is 16 in (or 406 mm) whereas in the long normal, which is characterized here as 64NR, the separation distance of the electrodes is 64 in (or 1630 mm). The spacing of the electrodes determines the depth of the current penetration into the formation for a given borehole diameter ([4], [6]). Which of the aforementioned resistivity measurements are appropriate for the estimation of the hydraulic conductivity profiles, can be decided by considering the conditions, under which the law of Archie [1] that is used for the analysis of the resistivity measurements, is valid.

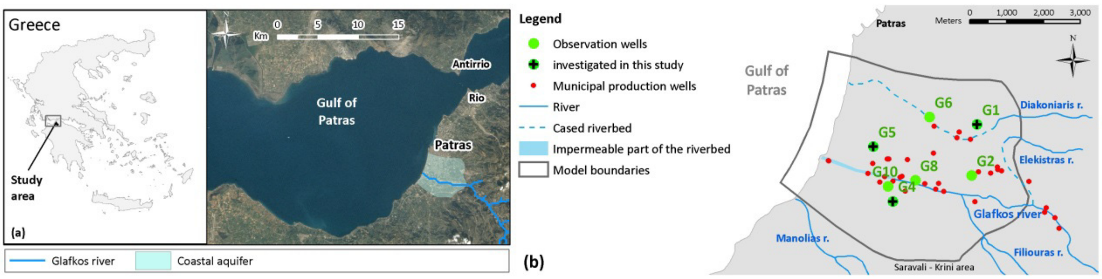

Fig. 1. The aquifer of Glafkos River: (a) location of the aquifer; (b) the constructed network of observation wells

2. The proposed method

The first step in in the estimation of the hydraulic conductivity profile is to estimate the porosity profile. This estimation is based on Archie's law [1], which correlates the formation factor with the porosity. The formation factor F_a is defined as the ratio of the resistivity of the porous material R_o saturated with an electrolyte, to the bulk resistivity of the electrolyte R_w: