

Proposed guidelines for the execution, evaluation and interpretation of pumping tests in fractured-rock formations

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Abstract

The main purpose of this paper is to give practical guidelines to every-day groundwater practitioners on how pumping tests should be performed and analysed to obtain proper estimates for questions like: what is the assured yield of the borehole; at what depth must the pump be installed; at what rate could the borehole be operated and for how many hours per day and what are the T- and S-values, etc.?

Introduction

More than ninety per cent of the aquifers in South Africa are fractured aquifers. The conventional type curve analysis procedures (e.g. Theis method of 1935) developed for homogeneous media contain assumptions that are not applicable to field conditions in fractured rocks. Fracture-dominated media cover a wide range of geological materials which, in turn, have a wide variety of infrastructural properties.

For the majority of geohydrological problems, the transmissivity and storativity (together with recharge) are the most important parameters to be determined for the long-term prediction of the behaviour of an aquifer. In practice, the most common methods applied to determine these parameters are from pumping or slug tests. Other methods used to estimate these parameters include:

- rock sampling and laboratory measurements
- analysis of natural variations of water levels (water balance)
- inverse modelling
- correlation with other parameters, e.g. electrical resistance or grain size
- use of environmental tracers
- packer and double packer tests.

During a three-year project to study the exploitation potential of Karoo aquifers, the authors found that the S-values obtained from pumping tests are an order too low, if compared to the S-estimates obtained by means of a groundwater balance and a two-dimensional flow model (Kirchner et al., 1991).

Recently, Bredenkamp and co-workers (Bredenkamp, 1992 and Bredenkamp et al., 1994) demonstrated that the calculated storativities (S-values) in fractured-rock aquifers are a function of the distance between the abstraction and observation boreholes (the larger the distance, the smaller the estimated S-value). Until now, more than 15 fractured-rock aquifers in South Africa show this rather interesting response. A possible explanation for this behaviour will be given in this paper.

In an unreviewed paper, Lachassagne et al. (1989), focused on the determination of the hydraulic conductivity by means of

short-duration (less than 72 h) and long-duration pumping tests. They showed that in the case of the short-duration pumping tests, the local transmissivity values are highly variable in heterogeneous media, while for the long duration test an effective mean transmissivity can be calculated.

Matheron (1967) demonstrated that if the flow is macroscopically uniform (approximately parallel flow lines), the average hydraulic conductivity always ranges between the harmonic and the arithmetic mean of the local hydraulic conductivity values. If, in addition, the probability density function of the K-values is log-normal and unvarying by rotation in two dimensions, the average K-value is exactly equal to the geometric mean.

It may be difficult to determine the S-values of secondary aquifers from pumping tests. In a laboratory experiment, La Moreaux et al. (1984) showed that it can take up to six months for a carbonate rock to drain completely, so that the storativity increases with time. Seimons (1990) pointed out that the calculated storativities from short-duration pumping tests in the Marble aquifer, near Otjiwarongo, Namibia, yield underestimated S-values compared to the results obtained from long-duration pumping tests of the aquifer.

De Marsily (1986) demonstrated that in a well-sorted sand 40% of the drainage occurred after the first few hours, but that drainage continued for a period of up to 2.5 years.

Barker and Black (1983) showed that for the application of slug tests in fissured aquifers, the calculated T-values will always be overestimated, while the S-values derived can be in error by a factor ranging from 10^{-6} to 10^5 .

Walthall and Ingram (1984) found that it was necessary to use multiple piezometers to obtain sensible S-values in a fissured sandstone aquifer.

Jacobson (1978) reported that all models for fractured aquifers lead to drawdowns that can also be found under other conditions than those assumed. In many cases boundaries, differing hydraulic conductivity distributions, leaky aquifers, faults and stratification can all lead to drawdowns that may resemble the curves found for the given models of fractured formations. The drawdowns produced by both the delayed gravity response and heterogeneous non-fractured aquifers are the same as some observed in fractured formations. He concluded that additional information from core samples and drilling logs from an aquifer is needed to help decide which model will best describe the aquifer.

Kruseman and De Ridder (1991) showed that the drawdown curve in a single fracture is similar to the well-known Theis curve

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