An analytical method for the analysis of pumping tests in fractured aquifers

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Abstract

The formula of Cooper-Jacob has been applied to constant-rate pumping tests in fractured aquifers, by considering the fracture and matrix as two separate systems. Some time-drawdown curves which are obtained from the constant-discharge pumping tests display two distinct slopes. The slopes are representative of the fracture and the aquifer matrix systems. The fracture has a high transmissivity and low storativity and the matrix has a low transmissivity and a high storativity. The analytical method considers flow to take place firstly from the fracture to the borehole. The flow from the matrix to the fracture (leakage) will depend on the piezometric gradient and the yield of the matrix is determined from Darcy*s law. The yield of the matrix is then used to calculate its storativity. From the fracture flow equations, the fracture flow velocity and also the distance to the boundary are determined. A pumping test was generated with a finite difference numerical model. Boundaries and a fracture were included in the model with hydraulic parameters. The drawdown with time was analysed with the method and the results compared favourably with the parameters assigned to the model. The method is in the form of a computer (Fortran) program called FTA (Fracture Test Analysis) and it can be used to analyse pumping tests in fractured aquifers. It also yields the distance to the boundary, which influences the sustainability of the aquifer. By determining more reliable aquifer parameters from pumping tests, improved recommendations can be made concerning sustainable pumping rates for fractured aquifers.

Table of notations

S	=	Storage coefficient
S_f	=	Storage coefficient of the fracture
S_m	=	Storage coefficient of the matrix
ϕ	=	Piezometric pressure
sw	=	Drawdown in pumping borehole
∇.	=	Gradient operator
sw_f	=	Drawdown in fracture
μ	=	Viscosity of a fluid
sw_m	=	Drawdown in matrix
g	=	Acceleration of gravity
Tm'	=	Apparent matrix transmissivity
Tf	=	Apparent fracture transmissivity
T	=	Transmissivity
T_f	=	Transmissivity of the fracture
T_m	=	Transmissivity of the matrix
xf	=	Fracture half-length
b	=	Fracture aperture
x_f	=	Fracture half-length
Q	=	Discharge of pumping borehole
Qf	=	Yield of the fracture
Qm	=	Yield of the matrix
vf	=	Fracture flow velocity

Introduction

The hydraulic behaviour of fractured aquifers in South Africa, like the Karoo and other aquifers, differs from the ideal well-known primary aquifers for which most of the analytical analysis techniques have been developed. One particular problem in the fractured aquifers in South Africa is the unsustainable long-term yield which is partly due to incorrect pumping test analysis. It was only during the 1970s that research was focused on the hydraulics of fractured reservoirs in the oil industry (Gringarten and Ramey, 1974).

The main geological formations in South Africa, and thus the aquifers, consist of very old, fractured rocks. Some of these aquifers, like the Karoo aquifers, have a very unique behaviour (Vivier, 1996; Van der Voort, 1996) and the standard techniques like Theis and Cooper-Jacob, fail to analyse these aquifers accurately as far as the determination of the storativity is concerned (Botha, 1993). A common feature is that these aquifers generally have low permeabilities and some large fractures. High- yielding boreholes and waterstrikes can only be obtained by drilling on fractures (like faults and dykes). The frequency and occurrence of these fractures are usually low and sometimes the fractures are isolated. During this investigation, the Cooper-Jacob formula was customised to evaluate single-fracture (fractured zone) aquifers.

The analytical method, FTA, (which is in the form of a Fortran program), is based on the principle that the fracture and aquifer matrix are considered as two separate systems which are interlinked to obtain the combined flow.

Overview of existing models

The conceptual model used, is in accordance with the model of Gringarten (1974) of a single vertical fracture. The model that Gringarten used does, however, not yield the storage coefficient directly; it can be obtained by curve fitting. In his model, Gringarten considers the flow from the matrix to the fracture to be linear during early pumping times and for later pumping times, it becomes radial.

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