TWO EXAMPLES OF ROTATING BRACKISH ZONES

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INTRODUCTION

The mathematical formulation of regional seawater intrusion may be simplified significantly by neglecting the resistance to flow in the vertical direction within an aquifer (the Dupuit approximation), by replacing the mass balance equation with the flow balance equation (the Boussinesq approximation), and by neglecting diffusion and dispersion. The principles of this formulation were presented at SWIM16 (Bakker, 2000). Recently, the theory has been extended and generalized and is applicable to both stratified flow, where the groundwater is separated in zones of constant density, and variable density flow, where the groundwater is separated in zones of vertically linearly varying density. This formulation is currently being implemented in a MODFLOW package, of which the first release is planned for the summer of 2002 (check http://www.engr.uga.edu/~mbakker/swi.html).

During SWIM17, several simulations were presented, based on a preliminary implementation of the new formulation. A discussion arose on the validity of a problem of a rotating brackish zone sandwiched between fresh and salt water (Figure 1). This problem and an asymmetric variation of the problem are discussed in this paper.

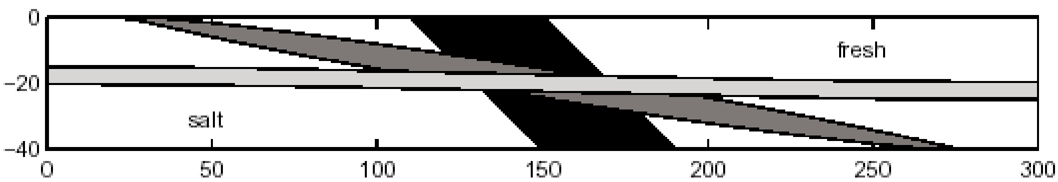

Figure 1 *A rotating brackish zone at times t=0 (black), 2000, and 12000 days (light grey).*

PROBLEM DESCRIPTION

Consider two-dimensional, confined flow in a vertical cross-section. The origin of a Cartesian *x,z* coordinate system is chosen at the upper left-hand corner of the section. The horizontal top of the aquifer is at *z*=0 m and the horizontal bottom at *z*=–40 m. The freshwater hydraulic conductivity of the aquifer is homogeneous and isotropic and equal to *k*=2 m/d. The effective porosity of the aquifer is *n*=0.2, and the aquifer and water are incompressible. A 300 m long section of the aquifer is considered and all boundaries are impermeable. Three types of water are present: fresh, brackish, and salt water, with densities of ρ=1000, ρ=1012.5, and ρ=1025 kg/m^3, respectively. Initially, at time *t*=0, both the interface between the fresh and the brackish water and the interface between the brackish and the salt water are straight and make a 45° angle with the horizontal. The brackish zone is 40 m wide initially; the fresh/brackish interface runs from (*x,z*)=(150,0) to (*x,z*)=(190, –40) and the brackish/salt interface from (*x,z*)=(110,0) to (*x,z*)=(150, –40). The black area in Figure 1 represents the initial position of the brackish zone. The fresh, brackish, and salt water are approximated as immiscible. The position of the brackish zone at times *t*=2000 and 12000 days are shown with decreasing shades of grey.

COMPARISON

The discussion at SWIM17 concerned whether it was realistic that while the brackish zone rotates, it gets thicker in the middle and thinner at the ends; this is visible at time *t*=2000 days, especially in Figure 2. To verify the results, they are compared to results obtained with a stream function model (Plug, 2002), and a combined flow and transport model with density effects called MOCDENS3D (Oude Essink, 1999); both models were presented at SWIM17. The comparison is shown in Figure 2, where the vertical direction is exaggerated to facilitate comparison. Results of the three models are very similar, and it may be concluded that the deformation of the brackish zone is realistic. In addition, it may be concluded that the Dupuit approximation seems to be a good approximation for this problem, even though the initial brackish zone makes a 45^{o} angle with the horizontal; the other two models do not make this approximation.

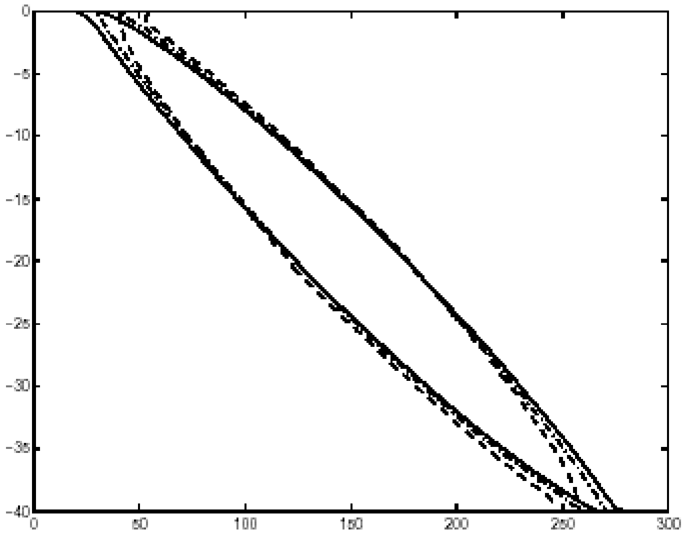

Figure 2 *Comparison at t=2000 days. Dupuit (solid), Stream function (dashed), MOCDENS3D (dashed-dotted); vertical scale exaggerated.*

THE NON-SYMMETRIC CASE

The previous example was symmetric; the density of the brackish water was the average of the densities of the fresh and salt water. Next it is investigated what happens when the density of the brackish water is chosen closer to the density of the fresh water, namely ρ=1005 kg/m^3. Results for this case are shown in Figure 3 for the same times as Figure 1. Since the density of the brackish water is now closer to the density of fresh water, the buoyancy effect is larger and the brackish water tends to flow to the top of the model, creating an interface between fresh and salt water at the right side of the model. Eventually, the brackish zone will deform to a horizontal layer of equal thickness, but this takes much longer than for the symmetric case.

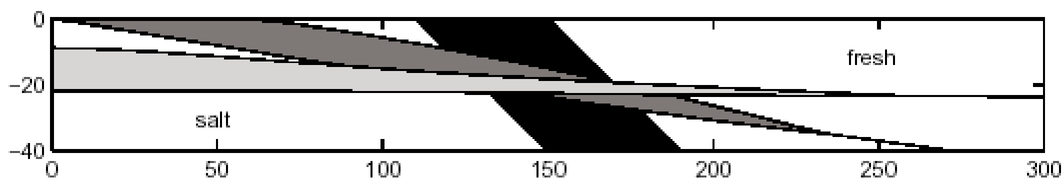

Figure 3 *An asymmetric rotating brackish zone at times t=0 (black), 2000, and 12000 days (light grey).*

ACKNOWLEDGEMENTS

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