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# Seawater intrusion modeling in heterogeneous costal aquifers with recharge and surface flow coupling via diffusive wave, Boussinesq and sharp interface equations.

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## Introduction

In some coastal aquifers one may have streams or rivers going into the sea. In this case modelling saltwater intrusion requires taking into consideration the surface and subsurface flow interactions. Here we develop 2D plane model aimed to represent the process under sharp interface conditions between the fresh /saltwater zones. The model is implemented in a finite volume numerical code BIGFLOW (Ababou and Bagtzoglou, 1993) and tested in simple configurations domains.

## Surface flow model

The surface water body flow is modelled using the diffusive kinematic wave. This model is obtained from the N-S system by two steps: First by vertical integration to get the 2D St-Venant system and second by neglecting the inertial terms in the St-Venant system. In the resulting model there is a direct relation between the velocity and the hydraulic head thus the St-Venant system is reduced to a single PDE. The main parameter is the Manning-Strickler friction coefficient or the Chezy coefficient.

## Subsurface flow model

As for the subsurface flow it is represented by the 2D vertically integrated Boussinesq flow equation considering an underlying saltwater zone. In natural environments a certain transition zone exists between the freshwater zone and the saltwater zone. The process is generally modelled using a density dependent solute transport model (Ackerer *et al.* 1999, Diersch and Kolditz 2002). The other approach is to consider the freshwater and the saltwater as two immiscible fluids separated by a so called 'sharp interface'. The resulting nonlinear PDE system can be solved by interface tracking or by a continuous approach. In the last approach one gets an equivalent two-phase flow system with pseudo-capillary pressure (Huyakorn *et al.* 1996, Holm and Langtangen 1999). Now if the saltwater zone is considered as immobile, the Badon Ghijben-Herzberg condition is obtained. This condition gives a direct relation between the freshwater hydraulic head, the freshwater/saltwater density contrast and the position of the saltwater zone considering hydrostatic conditions in the saltwater. Thus the system of PDE is reduced to one PDE with the freshwater hydraulic head as unknown.

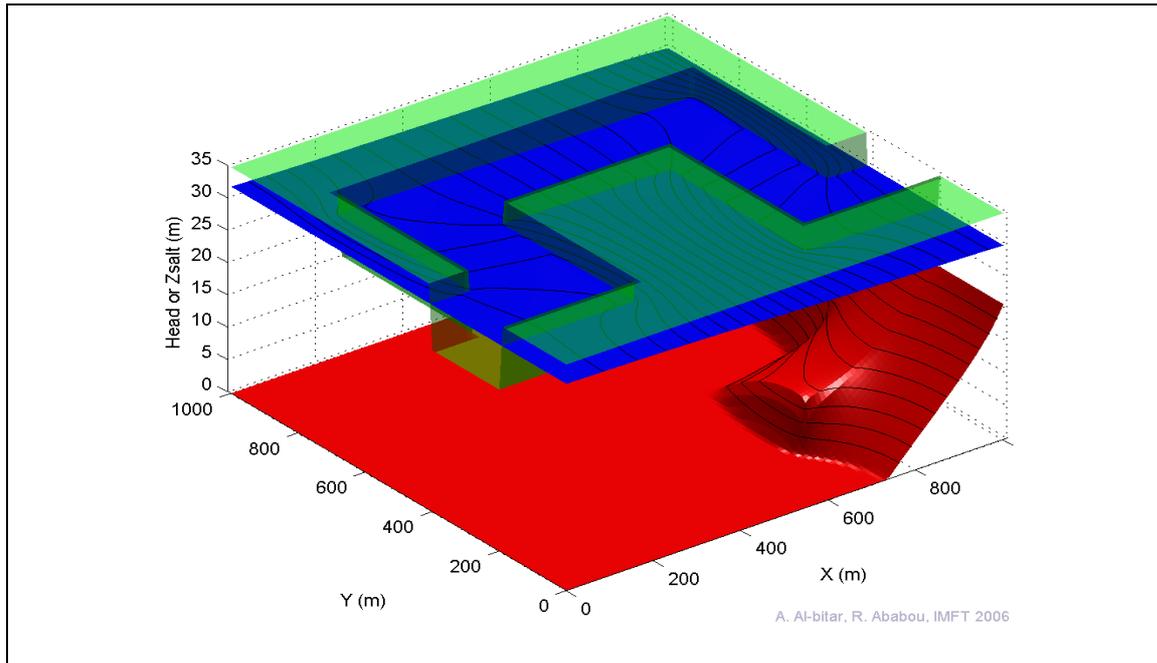
The major inconveniences of the solute transport models are the computational loads (Johannsen *et al.* 2002) and the difficult evaluation of the dispersion coefficients, more specifically of the macrodispersion. Another factor is that in most cases the width of the transition zone, at regional scale, is small compared to the uncertainty of the interface position due to the heterogeneity of the conductivity field. Dagan and Zeitoun (1998) investigated the effect of stratification under Boussinesq approximations. Albitar and Ababou (2005) investigated the effect of plane heterogeneity under Boussinesq approximation. The sharp interface models major weakness is the less physical representation of the processes on small scales and thus the inability to incorporate chemical processes.

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## Single generic equation coupling

To enable a single equation representation of the coupled system, the kinematic wave PDE is written as a diffusive process in the form of the Darcy flow equation with a non-linear coefficient. Then we consider one continuous fresh water body in permanent equilibrium with a saltwater body, the system is then reduced to a single diffusive equation with an equivalent conductivity coefficient for the river-aquifer system. The hydraulic head which is the only unknown coincides with the water level in the river or in the aquifer indifferently. This model has been implemented using the generic single equation code BIGFLOW. Simulations were done on simple test cases, such as the simplified meander configuration shown in Fig. 1.



**Fig 1** Numerical results in a simplified meandering channel. Light green color : topographic map; darker blue color : water level (hydraulic head), and dark red color : saltwater/freshwater interface.

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