Characterization of scenarios of salt intrusion in coastal aquifers with salt flats

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ABSTRACT

The 2-D scenery formed by salt bodies covering part of the surface of coastal aquifers is simulated by the network method. The problem is formulated in dimensionless form using the three dimensionless groups of the Henry problem plus two new groups: the permeability ratio and the fraction of aquifer length occupied by the salt body. The qualitatively influence of each group in the steady state patterns seems to be in according to the physical coupled processes that take place in the problem: regional flow advection and salt transport.

INTRODUCTION

Coastal aquifers in arid or semiarid regions are partially covered at their surface by highly saline bodies –coming from active or abandoned salt works– that determine the steady state groundwater flow and isoconcentration patterns. The rainfall sweeps away salt towards subsoil where it is gradually retained once the rain stops. When permanent regional underwater flows reach these saline areas, salt is dragged towards the aquifer discharge boundary where it finds the saline intrusion coming from the seaside. Examples of these scenarios can be found in Mediterranean coast at the southeast of Spain, province of Alicante (Agua Amarga, Santa Pola and Torrevieja aquifers). The extension of the mixing region varies depending of many factors and, eventually, can reach the whole aquifer domain when saline bodies are near the sea.

The problem, even in the non-dispersive but diffusive case, is governed by a great number of parameters –geometrical and hydrogeological– for non-homogeneous and anisotropic aquifers. The scenery can be assumed as a Henry problem that contains a salt body occupying a limited –left– region of the aquifer surface. In order to make the solution independent of the salt body concentration, this is assumed the same of the seawater. Therefore, we have assumed that the problem is governed by the Henry dimensionless parameters (Henry, 1964) plus other two: the first related to the anisotropic permeability, the permeability ratio, and the second related to the fraction of the surface that is occupied by the salt body. The simulation is carried out by the network method (González-Fernández, 2002 and Soto *et al.*, 2007).

Nomenclature

c, c_s concentration of salt in saltwater and seawater (kg/kg)
g gravitational acceleration (m/s)
H depth of the aquifer (m)
p pressure (Pa)
Q volumetric freshwater inflow rate (m^2/s)
v_{amb} regional ambient velocity (m/s)
ε porosity (dimensionless)
ρ_s, ρ_o saltwater and freshwater densities ($kg\ m^{-3}$)
D salt dispersion coefficient (m^2/s)
L length of the aquifer (m)
L_0 length of the salt flat (m)
k aquifer permeability (m^2)
q specific discharge $=\varepsilon v$ (m/s)
v groundwater velocity (m/s)
x,y,t spatial coordinates (m) and time (s)
μ dynamic viscosity of saltwater ($kgm^{-1}s^{-1}$)

PHYSICAL AND MATHEMATICAL MODEL

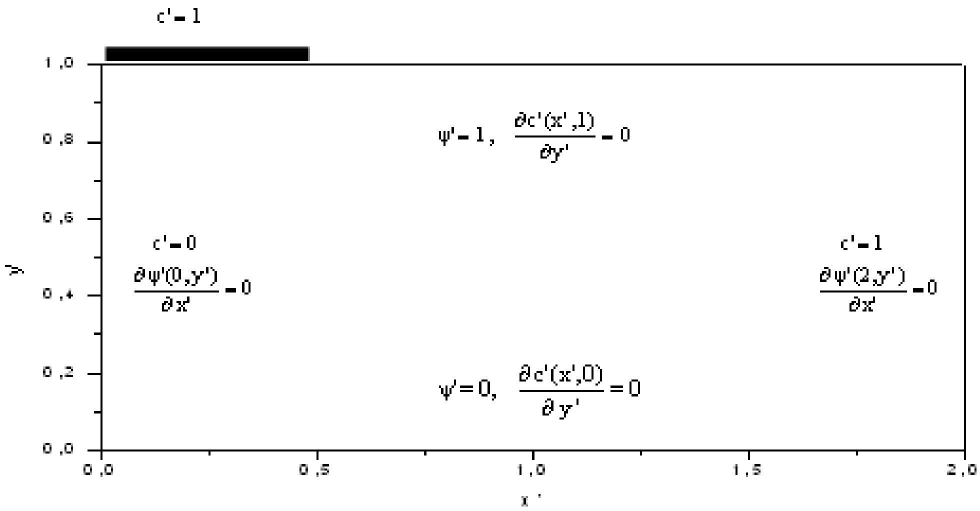

Figure 1. Physical model of the Henry problem

Figure 1 shows the 2-D physical model. The governing equations, Darcy and conservation water and salt fluxes, are:

$$(\mu/k)\mathbf{q} + \nabla p - (\Delta\rho)\mathbf{g} = 0 \qquad (1)$$
$$\nabla \mathbf{q} = 0, \qquad (2)$$
$$\partial\rho/\partial t - \mathbf{v}\cdot\nabla\rho = \nabla\cdot(\mathbf{D}\,\nabla\rho) \qquad (3)$$

with $q=v\varepsilon$. The dimensionless parameters resulting from this picture (note that D is isotropic and that the same concentration was chosen for the seaside and salt body horizontal boundaries) are:

$$a=(\mu Q/k_y gH)(\rho_s-\rho_o)^{-1}=\varepsilon\mu v_{amb}/(k_y g\Delta\rho),\ b=\varepsilon D/Q=D/(v_{amb}H),\ \xi=L/H,\ r_k = k_x/k_y \text{ and } \beta=l_o/L$$

The parameter a controls the pressure distribution which, in turn, defines the inland extent of the seawater intrusion (Sanz and Voss, 2006 and Voss and Souza, 1897). Note that the permeability that defines a is the vertical component, k_y, as make other authors (Abarca, 2006). This is justified by the fact that k_y is related to the vertical characteristic velocity of Darcy´s law, $k_y g\Delta\rho/\varepsilon\mu$, which balances with the regional velocity v_{amb} in the parameter a.

SIMULATION RESULTS

Some simulations that show the effects of the above parameters are represented in Figure 2a-e. The parameter values (SI) for the reference pattern, case 1, are L=2 m, H=1 m, l_o=0.5 m, μ=1E-3 kg/(ms), Q=6.6e-5, $k=k_x=k_y$=1.02e-9 m^2, g=9.81 m/s^2, ε=0.35, v_{amb}=1.88E-4, $\Delta\rho$=25 kg/m^3 and D=6.6E-6 m/s^2. The grid size is 20×10 cells.

Table 1. Simulated cases (units in SI)

Case	k_x	D	l_o	v_{amb}
1	1.02e-9	6.6E-6	0.5	1.88E-4
2	2.04e-9	6.6E-6	0.5	1.88E-4
3	1.02e-9	13.2E-6	0.5	1.88E-4
4	1.02e-9	6.6E-6	1	1.88E-4
5	1.02e-9	6.6E-6	0.5	3.76E-4

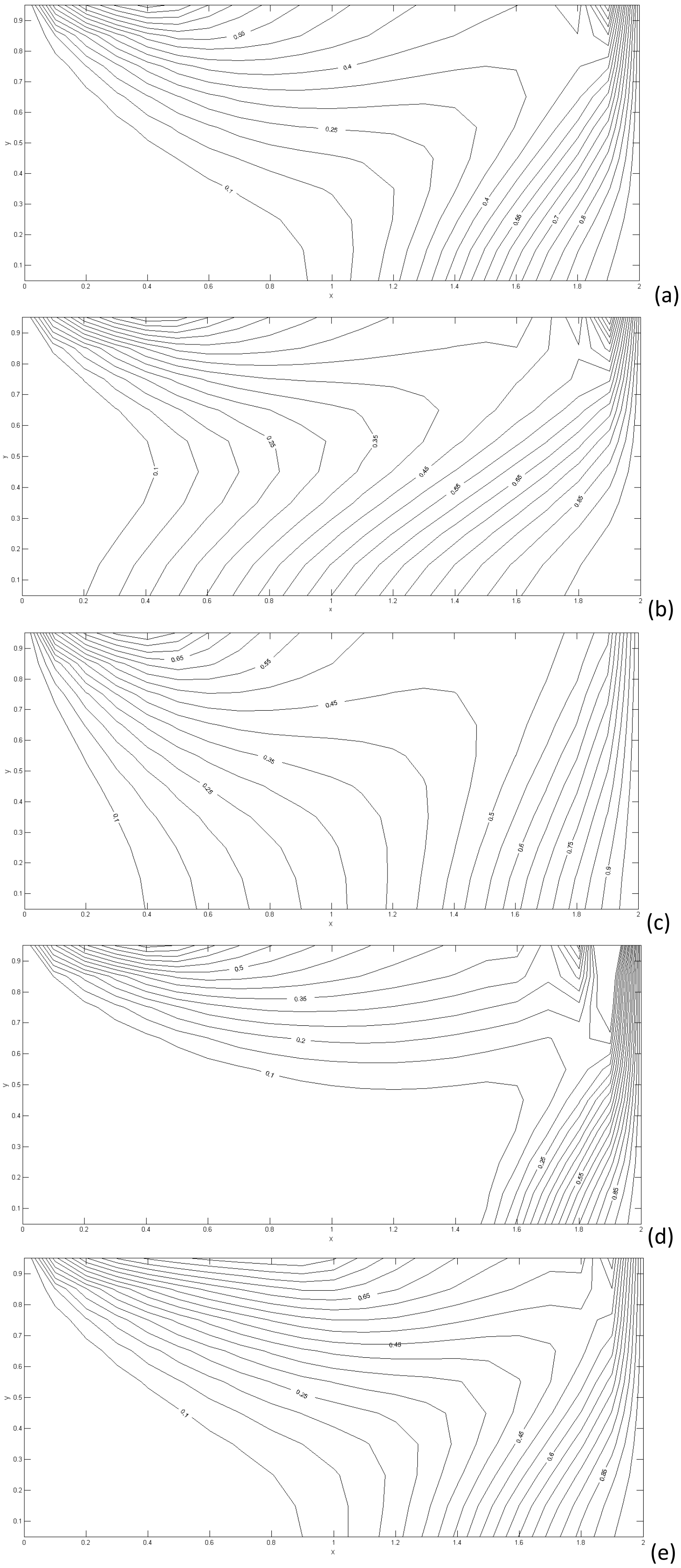

Figure 2. Steady state isoconcentration patterns, c´. (a): case 1 –reference–, (b): case 2, (c): case 3, (d): case 4 and (e): case 5

Simulates cases are summarized in Table 1. The influence of parameters k_x, D, l_o and v_{amb} are shown in Figures 2b-e, using the case 1 as reference. Note that D, k_x and l_o changes only one of the dimensionless parameters b, r_k and β, respectively (cases 1-3), while v_{amb} changes two parameters, a and b (case 4).

It is appreciate that, assuming a, b, r_k and β to be the suitable, well defined, parameters for this problem, the effect of each one on the patterns is clearly different for the chosen range. On the one hand, k_x extends horizontally the patterns in the upper and lower regions of the aquifer, an effect someone similar to D in the upper region. On the other hand an increase in l_o, as expected, squeezes the salt intrusion isolines towards the right boundary. Finally, v_{amb} pushes the isolines under the salt body towards the surface while produces small changes in those of salt intrusion.

CONCLUSIONS

2-D scenarios defined by coastal anisotropic aquifers partially cover by salt bodies at the surface, in the inland boundary, have been introduced by simulations based on the network method. Assumed that the dimensionless numbers that control the steady state patterns are the three of the Henry problem plus two more, one related to the fraction of the surface occupied by the salt body and one related to the anisotropic permeability, patterns were determined for different values of each one of this parameters by changing a suitable geometrical or physical characteristics. Qualitative results seem to be in according with the effects caused by each dimensionless parameters.

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