Jul 12th, 9:10 AM - 9:30 AM

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*International Environmental Modelling and Software Society (iEMSs)*
*8th International Congress on Environmental Modelling and Software*
*Toulouse, France, Sabine Sauvage, José-Miguel Sánchez-Pérez, Andrea Rizzoli (Eds.)*
*http://www.iemss.org/society/index.php/iemss-2016-proceedings*

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# On the use of finite-difference model to evaluate the impact of underground water overexploitation

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**Abstract:** The potentiometric surface in the Annaba basin, which covers an area of 264 km$^2$, has declined significantly since 1995. A transient multilayer model has been developed to synthesise the hydrologic data. The groundwater flow was modelled using the finite difference method with a horizontal dimension of 500 x 500 m for the cells. The model consists of two layers, the first corresponding to the alluvial phreatic aquifer and the second to the deep confined aquifer, and is calibrated against the steady state groundwater heads recorded before 1996. Under steady-state conditions, the correspondence between simulated and observed water levels is generally good (average difference of 0.4 m). For the deep aquifer, the simulated time-series hydrographs closely much the recorded hydrographs for most of the observation wells. For the alluvial aquifer, the recorded hydrographs cover only a short time period, but they are reproduced. The model indicates that groundwater pumping induced a decrease in natural discharge, a downward leakage in most of the basin and a continual water-level decline. The model has also been applied to the analysis of recharge impact. Simulating the behaviour of the system over the period 1991-2009 without pumping indicated small changes in hydraulic head. These results show that the groundwater reservoir has a low recharge, but excellent hydraulic properties; A solute-transport model was used to study aquifer contamination from salty intrusion in coastal sectors; it was extended to the year 2030 by simulating an optimistic hypothesis that maintains present pumping until 2030.

**Keywords**: Unconfined aquifer, Confined aquifer, Steady-state flow, Transient, Solute-transport model.

## 1 INTRODUCTION

The Annaba coastal aquifer is the only natural source of water supply in the Annaba region. Water is presently accessed through pumping of more than 100 wells, with a total estimated annual production in 2001 of about 20 million cubic meters (Hani *et al.*, 2003, Djabri *et al.*, 2010). Current rates of aquifer abstraction are dramatic, and deterioration of groundwater quality is documented in many parts of the Annaba region.
In this study, we tried using hydrodynamic model to know the present state of the resource and evaluate the anthropic effects on the environment.

## 2 MATERIAL AND METHODS

### 2.1 Study area

The studied area is situated in the extreme North Eastern of Algeria. It limited to the north by the Mediterranean Sea, to the west by the metamorphic Edough complex. It is limited to the South by the Fetzara Lake and the Numidian chain of Cheffia mounts (Fig. 1). The aquiferous formation is composed of Mio-Pliocene and Quaternary sediments of Ben-Ahmed and Ben-M'hidi trench.

The filling sediments of these two grabens is heterogeneous, they comprise an alternation of sandy clays, sands and gravels where two main aquifers of unequal importance are distinguish:

- the superficial aquifer which extends over the whole plain of Annaba and flows through the superficial silts,
- the gravel aquifer which covers the entire area of study and shows good hydraulic characteristics.

These two horizons are separated by an intermediate level of semi-permeable and/or impermeable layer. They constitute a single complex aquifer (Hani et *al.*, 2003; Djabri *et al.*, 2010; Bougherira *et al.*, 2014).

In this study, we are interested in hydrodynamic behaviour and hydrodispersive of the Ben-Ahmed graben (Fig. 1).

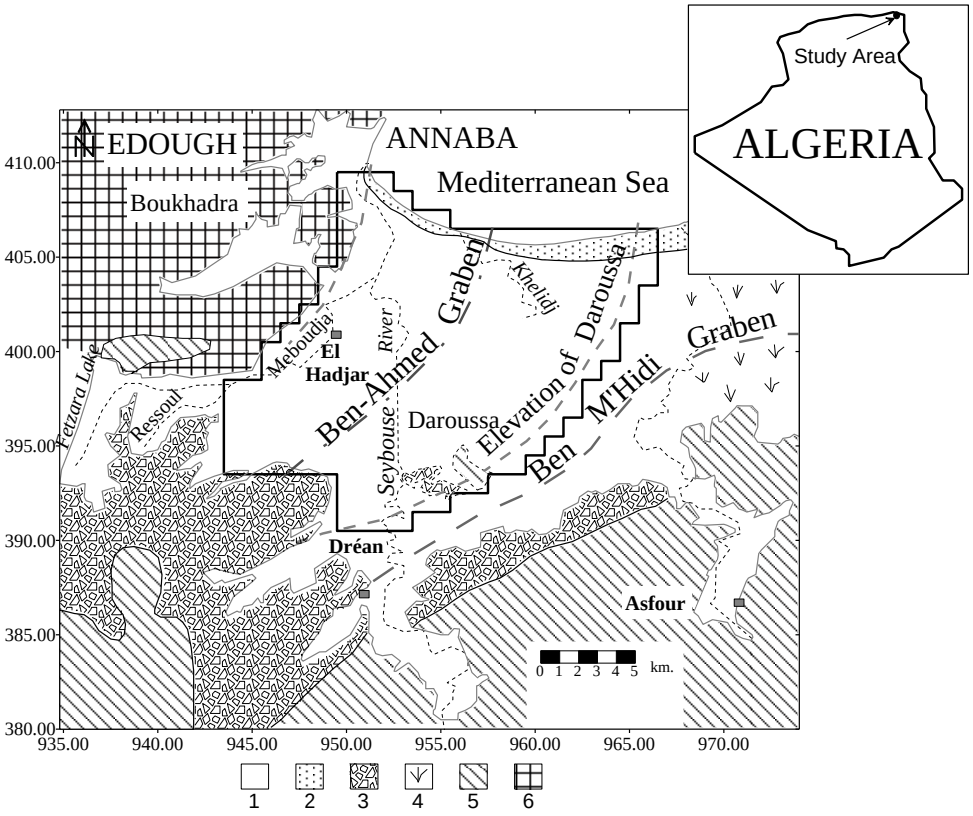


**Figure 1.** Location map of study area. 1: Undifferentiated Quaternary, 2: Sandstone of dune, 3: Ancient alluvium, 4: Marshes, 5: Numidian sandstone or clay, 6: Metamorphic formation

### 2.2 Methods

Many semi-annual surveys of the piezometric level and geochemical analysis have been monitored from 2012 to 2015. The analyses are carried out on a network of 60 wells in the lower Seybouse basin. Some sampled wells are used by the neighbouring population for daily drinking, irrigation and animal alimentation.

The temperature (T), electrical conductivity (EC) and pH were measured in situ using a multiparameter WTW set (Multiline P3 PH/LF SET), an Oxymeter (WTW) with an oxygen probe (CellOx 325) for the measurement of dissolved oxygen. The concentration of chloride ($Cl^-$), sulfate ($SO_4^{2-}$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), carbonates ($HCO_3^-$), were determined using the volumetric

method (AFNOR, 1987). Nitrate ($NO^{3-}$) and ammonium ($NH_4^+$) were analysed by colorimetry method using spectrophotometer (Spectronic 20 D).

In the present study, groundwater monitoring has been taken up for effective assessment through understanding of hydrogeology, geology and water-chemistry of the watershed. The collected basic data is used for the preparation of the groundwater flow and mass transport model for quantitative assessment of impact of anthropical influence on contaminant migration in the watershed.

## 3. RESULTS AND DISCUSSION

### 3.1 Results

Earlier studies in this area have shown the following observations (Hani *et al.*, 2003):

- The decrease of water levels, due the intensive use of groundwater near the coast, creates piezometric depressions and the extension of zero level towards the south. Such situation is accentuated by the weakness of inputs (fig. 2).

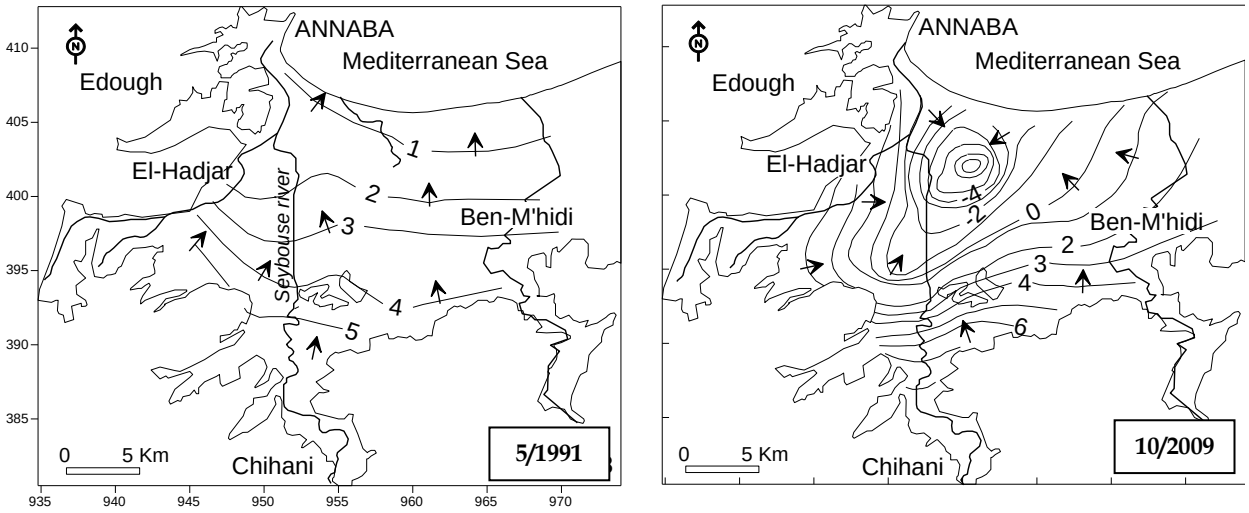


**Figure 2.** Variation of piezometric levels between 1991 and 2009

- The dip of the gravel strata is mainly towards the sea:
The geometrical characteristics (thickness and dip changes) of gravel layer show that aquifer would emerge to the sea on a few kilometres (about 4-5 km) from the coast (Hani, *et al.*, 2006; Lamouroux and Hani, 2006; Djabri *et al.*, 2010).

The steady decrease of hydrochemical features from the sea to the continent on about 15 km (Fig. 3). So, the graphs show a significant fall of the values for the whole of chlorides, sodium and electric conductivity. In the sector near the sea, the chloride values vary from 800 to less than 200 mg/l and the sodium values fall of 400 to less than 100 mg/l. Finally, EC decreases from 3500 to 1500 µS/cm. Towards the South, the values of these elements increase again to very higher values. The increase of strontium values, in this part, can translate the influence of evaporitic formations on the physico-chemical contents of water (Debièche *et al.*, 2003; Hani, *et al.*, 2006; Lamouroux and Hani, 2006; Djabri *et al.*, 2010). Such parameter variations seem to indicate a competition between sea and salt deposits influence.

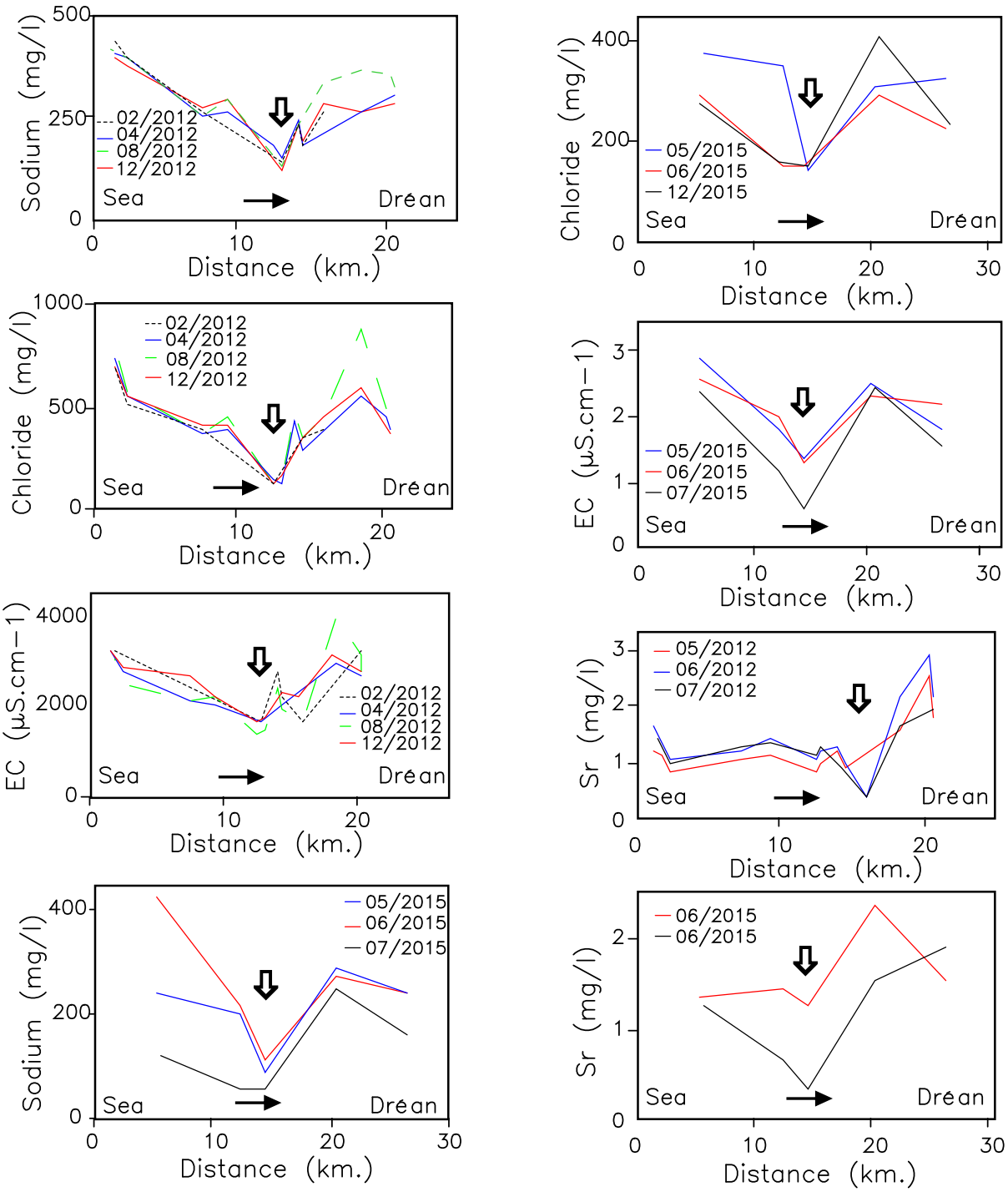


**Figure 3.** Variations of hydrochemical features for different years. Graphs for chlorides, sodium, Strontium and EC from the sea to Dréan, in southern part

### 3.2 Discussion

***Groundwater flow model:***

A transient multilayer model has been developed to synthesise the hydrologic data and study the regional changes in aquifer interactions caused by changes in discharge. The groundwater flow was modelled using the finite difference method with a horizontal dimension of 500 x 500 m for cells (Fig. 4).

The model consists of two layers, the first corresponding to the alluvial phreatic aquifer and the second to the deep confined aquifer, and is calibrated against the steady state groundwater heads

recorded before 1996. Model verification was done by history matching over the period 1991-2009. The figure represents the mesh and boundaries conditions use by Modflow (McDonald M.G. & Harbaugh A.W., 1988; Zheng, 1990; Bougherira *et al.*, 2015) of the two aquifers (Aoun-Sebaiti *et al*,. 2014; Chouchane, 2014):

- the superficial aquifers (SA)
- and the gravel aquifer (GA)

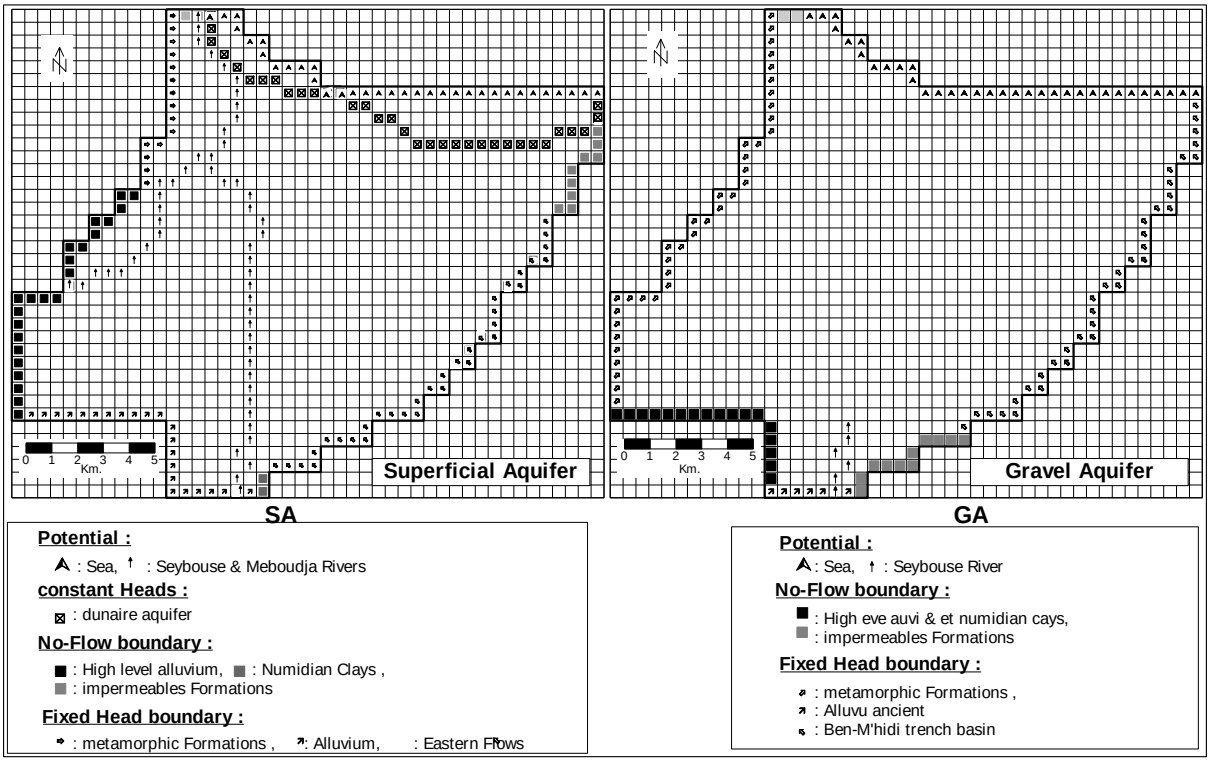


**Figure 4.** Cells and boundary conditions used by Modflow

Under steady-state conditions (Fig. 5), the correspondence between simulated and observed water levels is generally good (average difference of 0.4 m).

Under transient state, the model indicates that groundwater pumping induced a continual water-level decline.

The used Model is to simulate the natural state over the period 1991-2009 in order to apprehend the behaviour of the system against the variability of water supplies. During this period, the output water volume is supposed to be zero. All the meshes of the model show a decrease of around 0.7 m for the two aquifers from 1991 to 2000 (Fig. 6). From 2000 to 2004, water levels tend to increase from 1 to 1.3 m in SA and 0.5 to 0.9 m in GA. A tendency to a decrease restarts from 2004, followed by in increase of amplitude (from 0.6 m in SA and 0.4 m in GA).

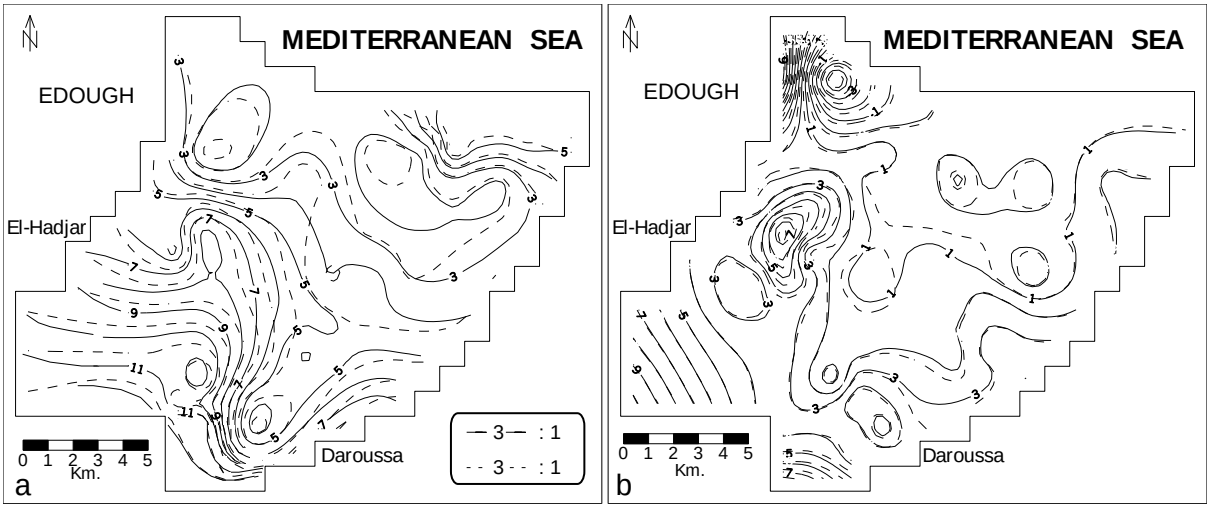


**Figure 5.** Piezometric map of SA and GA under steady-state. 1 : observed lines, 2 : Simulated lines

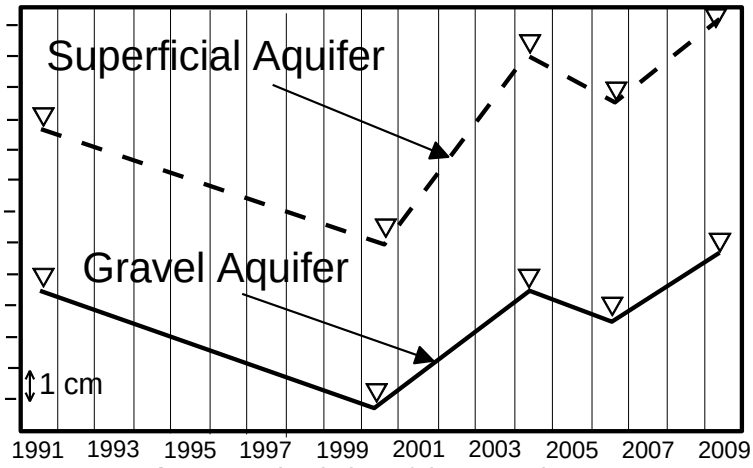


**Figure 6.** Simulation of the natural state

This confirms that the decrease of piezometric levels cannot be related wholly to the intensive pumping, but the dryness over the last decades contributes also to the observations mentioned above.

The comparison between water budgets from 1996 to 2009: The intensive exploitation of the GA caused:

- *Recovery of a great amount of natural outflow,*
- *A relatively important contribution of the reserves,*
- A decrease of about 8 m in GA,
- A hydraulic exchange variation between the two aquifers :
  - first, the leakage towards the GA, in the South (recharge zone) equilibrates with the leakage towards the SA in the North (discharge zone),
  - However, in 2009, the leakage is mainly downwards, thus, showing the contribution of the SA to the whole plain.

***But how would be the consequences on the aquifer if the actual situation stands still?***

To answer this question, a solute-transport model (Pollock, 1989; Domenico *et al.*, 1990; Gurunadha, 2001; Neuman, 1990; Panagoulia and Dimou, 1996) was used to study aquifer contamination from salty intrusion in coastal sectors; it was extended to the year 2030 by simulating an optimistic hypothesis that maintains present pumping until 2030. The model indicates that the head decrease of the alluvial phreatic and deep confined aquifers will be 4 m and 5 m respectively (Fig. 7).

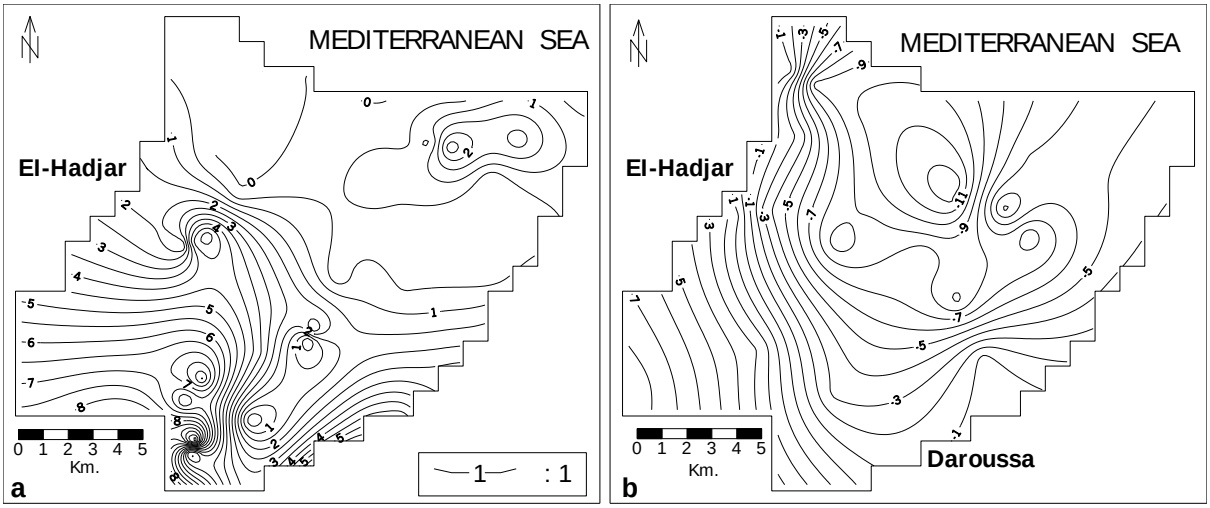


**Figure 7.** Computer model prediction of the heads a) SA and b) GA in 2010. 1 : Simulated lines.

The simulated piezometric distribution illustrates the vulnerability of the aquifer in coastal sectors where flows with an important concentration of chloride may be observed, mainly towards the Salines wells field. The solute concentration in the deep confined aquifer will increase from 1 $g.l^{-1}$ (prior to 2009) to 5 $g.l^{-1}$ in 2030 (Fig. 8).

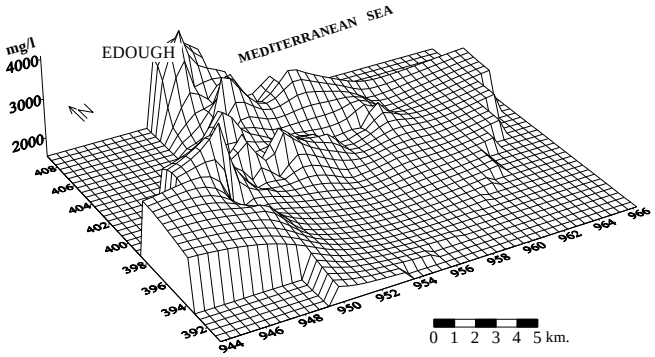


**Figure 8.** Computer model prediction of the salinity in 2030

## CONCLUSIONS

The mathematical modelling of the coastal aquifer highlights a continual water-level decline. It shows also a contamination of the aquifer by the salty waters in coastal sectors where flows with an important concentration of chloride may be observed, especially towards the Salines wells field.

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