Effect of planned marina on Enfidha groundwater (Tunisia)

A local-scale groundwater modeling

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Abstract— The coastal Enfidha plain is located in the centre-east of Tunisia. A marina is planned downstream the plain and is likely to induce a risk on groundwater. A large scale modeling has been developed and used to evaluate the effect of the marina on the totality of the aquifer. Flow and solute transport models were built. In order to have results with higher precision, a local-scale modeling is developed by refining the mesh nearby the marina region. The sub-model is calibrated over the period 1972–2005. Simulations are carried out for a 50-years period, to assess the impact details of the planned marina on groundwater quality. Results show an additional salinity increase reaching 10 g/l by the year 2055 around the planned marina. Affected areas are located mostly in the marshes regions.

Keywords—Groundwater; Flow modeling; Solute transport modeling; Local-scale modeling; Enfidha plain.

I. INTRODUCTION

The Enfidha coastal aquifer is located in the Centre-East of Tunisia. It extends over an area of 1200 km² (Fig. 1). It is characterized by Mediterranean climate with an annual average rainfall of 340 mm. Groundwater resources contained in shallow and deep aquifers are estimated to 16 10^6 m^3/y. A marina is planned in the northern part; downstream the plain, over an area of 30 km^2. The 20 m depth basin to be dragged on the Mediterranean Sea, would affect groundwater quality in the Enfidha plain.

A large-scale groundwater flow model, coupled to a transport model, was developed and calibrated to evaluate the impact of the planned marina on groundwater quality [1; 2]. The main objective of this paper is to simulate the impact of the marina using a refined local-scale model.

II. HYDROGEOLOGIC CHARACTERIZATION

The hydrogeologic information is based on the large-scale modeling study [1; 2]. Two aquifers are considered. The superficial unconfined aquifer, known by the phreatic aquifer, corresponds to alluvial fillings of wadis, sand dunes and continental or marine sediments of the old Quaternary. The deep confined aquifer is contained in the Mio-Plio-Quaternary sediments overlying the bedrock formed by middle Miocene marls. The two aquifers are separated by a semi-pervious layer.

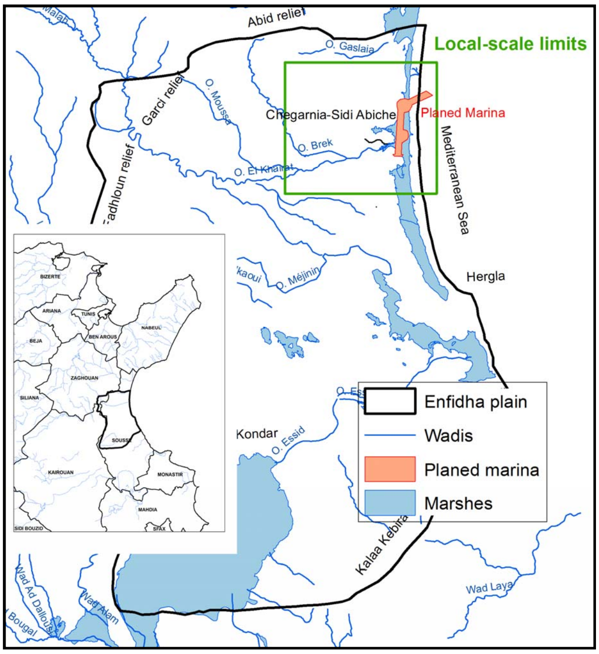

Fig. 1: Location map

The depth of the aquifers can reach up to 500m in the east-northern plain at the level of Chegarnia-Sidi Abiche region (Fig. 2). The thickness of the semi-pervious layer varies between few meters and 50m. The geological database is used to elaborate several lithostratigraphical cross sections, and to map elevation of aquifer's base. Aquifers are recharged by direct rainfall infiltration through permeable surface soil, upstream the plain, through surface runoff and along the sandy littoral. Piezometric maps are established by the means of measured data for the year 1972 during which the aquifers were considered to be in a state of equilibrium. Over the period 1973-2005, monitoring groundwater levels with a biannual frequency, were used for analyzing evolution trends.

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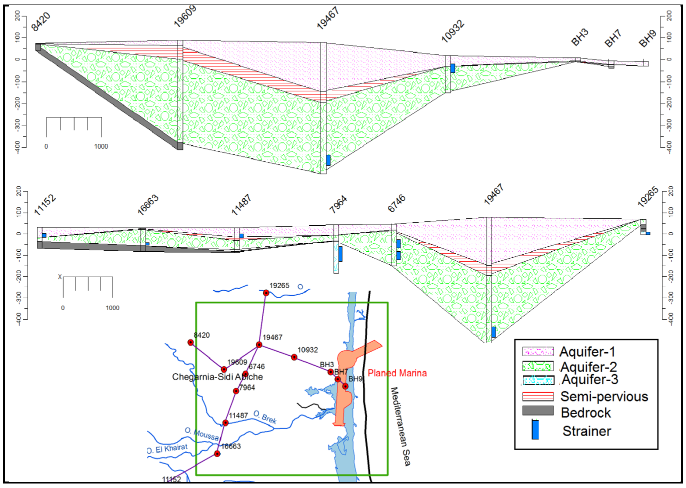

Fig. 2: Hydrogeological Cross sections

III. GROUNDWATER MODELING

A. Flow model

A quasi three-dimensional finite-difference flow model is developed using MODFLOW-2000 [3] to resolve groundwater flow equation [4]:

$$\frac{\partial}{\partial x}\left[T_{x,i}\frac{\partial hi}{\partial x}\right]+\frac{\partial}{\partial y}\left[T_{y,i}\frac{\partial h_i}{\partial y}\right]+\lambda_{i+1}(h_{i+1}-h_i)+\lambda_{i-1}(h_{i-1}-h_i)=S_i\frac{\partial h_i}{\partial t}+q_i \qquad (1)$$

where h_i, h_{i+1} and h_{i-1}, the hydraulic heads [L] of layers i, $i+1$ and $i-1$; $T_{x,i}$ and $T_{y,i}$, the transmissivities [LT^{-1}] along x and y axis within a layer i; λ_{i+1} and λ_{i-1}, the leakage [T^{-1}] between layers i and $i+1$, and between layers i and $i-1$; S_i, the storage coefficient [-] of layer i; q_i, the source/sink of water [LT^{-1}] in layer i; x and y, the Cartesian coordinates [L]; and t [T],the time.

Processing MODFLOW [5] is used for model pre and post processing. Calibration is established in the year 1972 for steady state, and during the period 1973-2005 for transient state. Measured groundwater level in monitoring network, are used for flow model calibration. Calibration parameters are the horizontal transmissivities, storage coefficients, leakage between phreatic and deep aquifer and hydraulic resistances between phreatic aquifer and soil surface along the wadis.

B. Solute transport model

For the solute transport model, the MT3DMS model [6] is used. It simulates the transport equation [4] by considering the advection and dispersion of conservative substances:

$$\frac{\partial}{\partial x_i}\left(D_{i,j}\frac{\partial C}{\partial x_j}\right)-\frac{\partial}{\partial x_i}(Cv_i)-\frac{C'q}{\omega_e}=\frac{\partial C}{\partial t} \qquad (2)$$

Where C, the solute concentration [ML^{-3}]; D_{ij}, the dispersion coefficients [L^2T^{-1}]; v_i, the velocity [LT^{-1}]; ω_e, the effective porosity [-]; C', the source concentration [ML^{-3}]; q, the source/sink term [T^{-1}]; x_i, the Cartesian coordinates [L]; and t [T], the time.

Initial salinity is based on geochemical surveys during May and September 1972 [7] and on deep well's surveys. Observed groundwater salinities are used for transport model calibration.

C. Local-scale modeling

The local-scale model is developed by refining the mesh around the region nearby the planned marina (Fig. 3). The modeled region covers an area of 100 km². Grid spacing in both directions is 125m. All information and boundary conditions are derived from large-scale model. Fixed head condition is used along the boundary cells to reproduce inflow fluxes from the bordering regions. Head is fixed to zero for the entire coast. Cauchy condition is used to reproduce the phreatic aquifer drainage by the wadis and by evaporation. Groundwater abstraction occurs by wells.

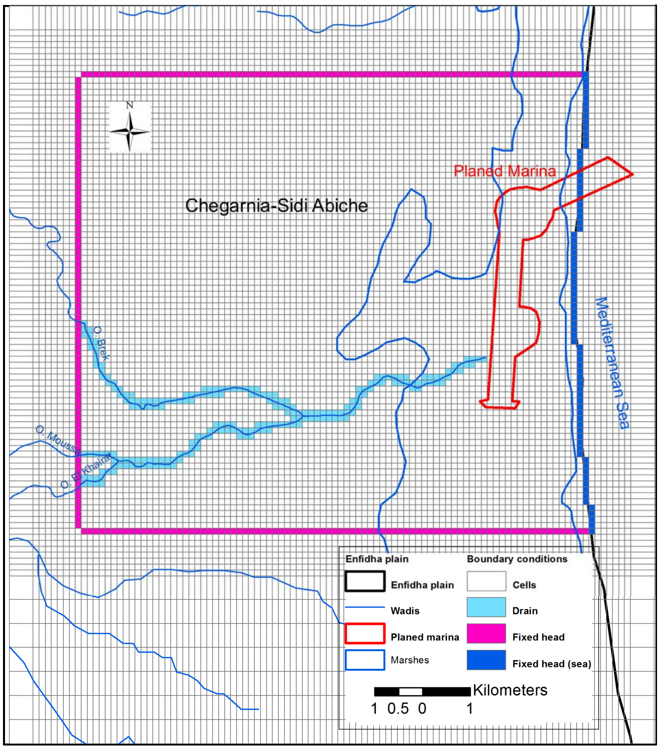

Fig. 3: Mesh refining and boundary conditions

IV. RESULTS AND DISCUSSION

A. Steady state

Within the selected subset area, fluxes from the bordering regions constitute the boundary condition inflows during steady state (Tab. 1). Well's pumping is 98 l/s whereas 90 l/s are lost to the sea through the constant head boundary. The computed drainage by wadis is null. Recharge and evapotranspiration are weak. Simulated evapotranspiration area is found to be close to the marshes location (Fig. 4).

The general groundwater flow is west-east to the marshes and the sea (Fig 5). Piezometric depressions in the deep aquifer indicate strong abstraction in field's pumping. Calculated heads in both aquifers are closed indicating high hydraulic connection in a great coastal area of the submodel where semi pervious layer is thin (see Tab. 1).

Tab. 1: Water balance (l/s)

	Phreatic		Deep	
	IN	*OUT*	*IN*	*OUT*
Constant head	0	65	0	25
Exhange (Upper)			56	35
Exhange (Lower)	35	56		
Pumping		38		60
Inflow from bordering area	129		63	
Drains	0	0		
Recharge	4	0		
Evapotranspiration	0	9		
Total	168	168	119	119

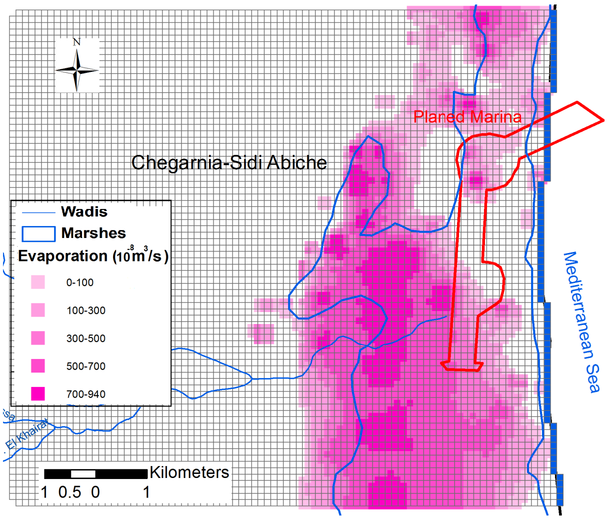

Fig. 4: Calculated evapotranspiration

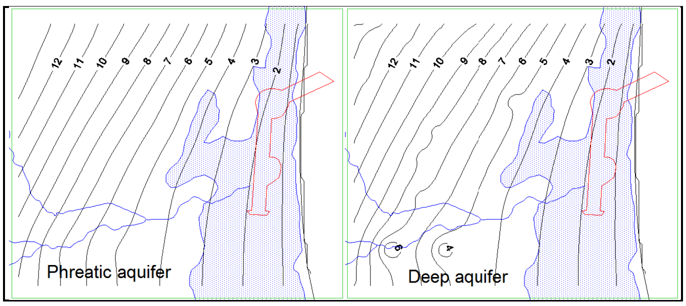

Fig. 5: Calculated head during steady state (contour lines in meter)

For solute transport model, initial conditions were reproduced with a long transient simulation (100000 years) and by referring to measured salinity in 1972 (Fig. 6) according to [7]. It reached high values (3 to 6 g/l) downstream indicating a zone of discharge with lower permeability. However, in Chegrarnia-Sidi Abiche region close to the recharge area of aquifers by wadis runoff infiltration, groundwater quality was less than 1 g/l.

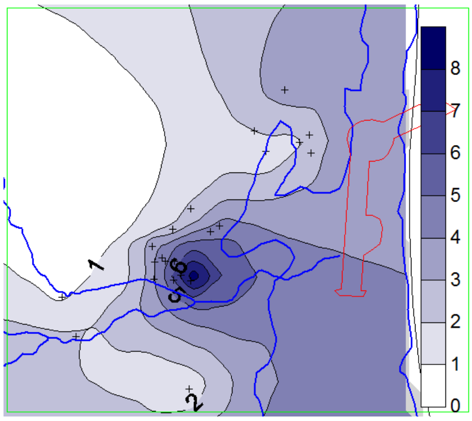

Fig. 6: Reference salinity in 1972

B. Transient state

During the period 1973-2005, well's abstraction increased from a minimum of 70 l/s to a maximum of 200 l/s in 1990 (Fig. 7). Shallow wells are mostly located in the Chegarnia-Sidi Abiche region, whereas deep wells are located near the El khairat wadi valley (Fig. 8). Transient state calibration is based on piezometric and quality network measures. Piezometric drawdown varies between 3 and 6 m in the exploited regions with slightly higher values near the El Khairat wadi due to local pumping in the deep aquifer (Fig. 9).

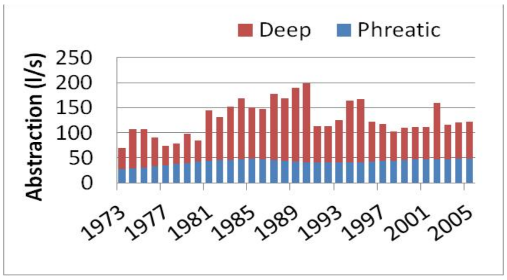

Fig. 7 : Well's abstraction evolution

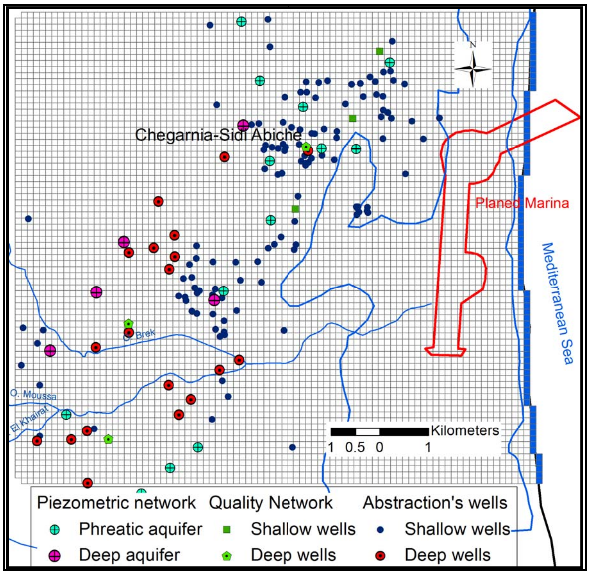

Fig. 8 : Pumping and observation well's location

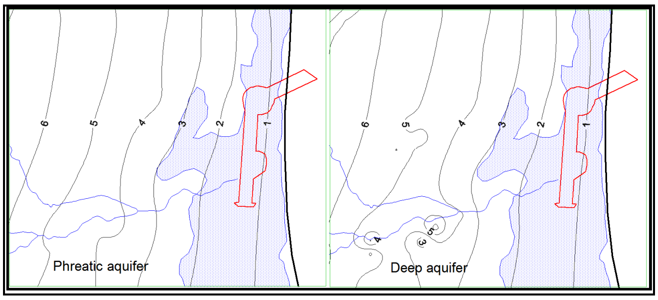

Fig. 9: Piezometric drawdown in meter (1972-2005)

Because of the short salinity monitoring period (since 1995), transport model calibration focused on a general reproduction of natural salinization processes. We noticed stability in salinity for almost the monitoring network, with a general high salinity along the coast due to the low permeability of the aquifers and the groundwater evaporation in the marshes. The observed trends of the constant salinity are reproduced in the transient calibration.

C. *Impact of the planned marina*

Flow and transport models are used to evaluate the impact of the planned marina on the groundwater. Two 50 year's simulations S1 and S2, respectively without and with the planned project, were carried out to assess its impact. Boundary conditions were maintained constant for the whole period. The actual pumping in 2005 is assumed to be constant over the period 2005-2055. In the simulation S2, null heads and 38 g/l salinity were fixed in the area of the planned marina. Comparison between simulation's results of flow and solute transport models in 2055, revealed a drawdown increase of about 0.5 m and a salinity increase up to 10 g/l near the planned marina for the phreatic aquifer (Fig. 10). This situation is estimated to worsen if well's pumping increase.

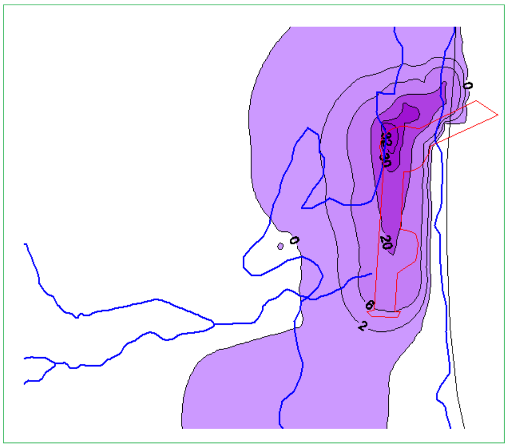

Fig. 10: Salinity increase (g/l) in 2055 for the phreatic aquifer

V. Conclusion

Flow and solute transport refined models near the planned marina are used to assess its impact on groundwater. Piezometric results indicate a strong hydraulic connection between the phreatic and deep aquifer in the coastal area. Simulation's results after 50 year's period show an increase of salinity reaching 10g/l near the planned marina. The influence zone doesn't exceed 5 km large. The affected area is basically located in marshes areas where aquifer permeability is low and groundwater is still salty and not useable. The exploited regions (Chegarnia-Sidi Abiche and El Khairat wadi), characterized by a good groundwater quality, will not be affected by salty water degradation due to the planned marina. However, these results are based on the hypothesis that groundwater pumping remains the same and does not increase in the future. The effect of the planned marina will more likely be pronounced if well's pumping increase in the future.

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