Assessment of Groundwater Resources in Rmel Coastal Aquifer (Morocco) by SEAWAT

A. Larabi[1], *M. Faouzi*[1] and *A. H. -D. Cheng*[2]
[1]LIMEN, Ecole Mohammadia d'Ingénieurs, Rabat
[2]Department of Civil Engineering, University of Mississippi, USA

ABSTRACT

The Rmel coastal aquifer is located in the north of Morocco, and is a part of the main sub-Atlantic coastal aquifers. The aquifer supplies good quality groundwater that is easily accessible. This favorable situation has increased pumping, and caused environmental problems, such as water table decline and salt water intrusion. For the purpose of planning and management, the SEAWAT, which is a variable density solute transport computer code, is used to study the groundwater quantity and quality. The simulation shows that in order to improve water quality, surface water recharge is needed.

INTRODUCTION

Groundwater quality in the Rmel aquifer is generally good. However, overexploitation due to agriculture activities has resulted in saltwater intrusion, which poses serious threat to future water supply. Hence, it is necessary to develop tools for predicting the response of coastal aquifers under different pumping scenarios. The objectives of this study is to develop a computer model that allows us to understand the conditions that govern the behavior of freshwater/saltwater transition zone in the coastal aquifer subject to the various input conditions, and to test management scenarios based on various economic assumptions. The best scenario will be presented to the regional water resources authorities for the recommended economic and water resources development.

DESCRIPTION OF THE RMEL AQUIFER

The Rmel is a part of the Moroccan coastal plain. It is located in the north of Morocco, to the south of the Larache city along the Atlantic coast, with an area of about 240 km^2, and length approximately 20 km. Climate in the region is semi-arid, but influenced by the Atlantic Ocean. The average mean temperature ranges from 24°C in summer to 12°C in winter. The average annual rainfall is around 700 mm, but most of the rainfall occurs in the period from October to April, and the rest of the year is almost completely dry. The annual mean of the evapotranspiration in the study area is estimated to be 500 mm/yr. The hydrogeology of the Rmel coastal aquifer consists of plio–quaternary sands and sandstone, but the bottom is composed of blue marls (Bentayeb, 1972).

Groundwater system characteristics

The regional groundwater flow is mainly SW-NE, discharging towards the Atlantic Ocean. However, due to groundwater pumping, the flow pattern is locally modified to the north, due to a cone of depression. The analysis of the piezometric records between 1980 and 2005 shows fluctuations due to surface water recharge from irrigation and pumping wells. The major source of renewable groundwater in the aquifer is rainfall and irrigation return flow. The total recharge to the aquifer is estimated to be 1,796 l/s, while the groundwater abstraction from the pumping wells was estimated to be 1,800 l/s, based on a field investigation in 2000. The outflow towards the Atlantic Ocean is estimated to be 459 l/s in 2000. The results of a hydrogeochemical analysis conducted between 1985 and 1992 show that the groundwater salinity values are different between the water table level and the bottom for some coastal observation wells, varying between 1 to 6 g/l.

MODELING SEAWATER INTRUSION IN THE RMEL AQUIFER

Mesh discretization

The model developed, based on SEAWAT code (Langevin and Guo, 2002), simulates the transient variable density groundwater flow and solute transport for a period from 1972 to 2003, using a database developed by Larabi (2004). Regular spaced finite-difference cells of $500\text{m}\times500\text{m}$ size on the horizontal plane are used. The final grid consists of 42 rows and 31 columns in the horizontal, and 4 regular spaced layers in the vertical direction.

Boundary conditions and aquifer parameters

Based on test conducted in the area (DRPE 1995), the hydraulic conductivity ranges from 6.5×10^{-6} to 2.9×10^{-4} m/s. For storativity, only 13 values are available in the center and the northwest part of the aquifer, with measured values ranging from 0.17% to 3.6%. In the rest of the aquifer, parameters were estimated from Moroccan hydrogeological literature for similar type of soils. Constant head of 0 m and constant concentration of 35 kg/m^3 are specified to the cells along the Atlantic coast. In the rest of the aquifer, a no-flow boundary is specified except at the eastern boundary, where rivers are specified as drains. Internal hydrological stresses for the corresponding layers are included in the aquifer. The aquifer bottom is a no flux boundary, while on the top of the aquifer a recharge influx is assigned. The northern and southwestern boundaries are assumed to be no flow boundaries, due to the existence of impervious layers.

Calibration and model results

First, the numerical model is tested against steady state groundwater flow based on 1972 data. The results show good agreement between calculated and measured heads. Table 1 shows the resulting water balance of different components, including the discharge to the sea, which is estimated to be 356 l/s. It is observed from Table 1 that the main input component is the recharge from precipitation, and the main output component is the river drainage.

Table 1. Calculated water balance in steady state (year 1972)

	Water Balance Component	Volume in m^3/day	Volume in l/s
Input	Recharge by precipitation	119978	1389
	Return from irrigation	22853	264
	Total	146206	1692
Output	Agricultural withdrawals	31622	366
	Domestic water supply	8640	100
	Sea outflow	30746	356
	River drainage: Smid El Ma-El Kihel-Sakh Sokh	71878	832
	Total	142887	1654

Transient simulations are then conducted using the 1972 steady state condition as the initial head. The initial concentration in the aquifer is assumed to be 0 kg/m^3. Calculation is performed for the 1972-2003 target period (31 years). The results of the transient calculations show satisfactory agreement between measured and calculated heads in different observation wells for the considered simulation period. The simulation shows the beginning of the seawater intrusion and its evolution, the contamination concentration, the seawater intrusion volume, as well as other components of the mass balance. Table 2 illustrates the water balance between 1972 and 2003, which shows that aquifer has more freshwater storage between 1972 and 1980, and a reduction takes place during 1980–1990. As a consequence, seawater advances inland in 1983 and 1992 (Fig. 1). It also shows that intensive groundwater pumping, especially since 1995, resulted in increasing seawater intrusion. The following invaded zones have been identified: (1) The first zone invaded by the seawater intrusion between 1995 and 2000 is located west of the ONEP pumping wells. Afterward, this invaded zone extended along the inshore line, to about 10 km of length and 1 km of width. (2) The aquifer is contaminated on the N-W coastal zone, in which the toe reaches about 1 km inland. Beyond these zones, the contamination of the aquifer is limited.

Table 2. Calculated water balance for the transient simulations 1973-2003.

	Water balance (Mm^3/year)	1972	1975	1980	1985	1990	1995	2000	2003
INPUT	Inflow storage variations	0	8.79	16.9	1.04	0.0054	13.4	6.95	3.89
	Returns from irrigation	0.577	0.577	0.577	16.5	16.5	16.5	16.5	16.5
	Seawater intrusion	0.0	0.0057	0.0125	0.0041	0.0002	0.736	2.12	2.66
	Recharge by precipitation	43.8	12.6	6.27	22.5	26.5	3.92	7.25	7.25
	Total	**44.4**	**22.0**	**23.7**	**40.0**	**43.0**	**34.5**	**32.8**	**30.2**
OUTPUT	Outflow storage variations	0	0	0	5.28	5.21	0	0.0005	0
	Net pumping	6.93	6.93	6.93	6.18	6.18	12.0	13.2	13.2
	Discharge to Atlantic Ocean	11.2	5.24	5.11	10.7	12.0	7.82	7.39	6.90
	Drainage by rivers: oueds Smid El Ma-El Kihel-Sakh Sokh	26.2	9.84	11.7	17.8	19.6	14.7	12.1	10.1
	Total	**44.4**	**22.0**	**23.7**	**40.0**	**43.0**	**34.5**	**32.8**	**30.2**

RATIONAL WATER MANAGEMENT

Three planning scenarios schemes were designed to simulate the future changes in drawdown and salinity concentrations in a period of 20 years. The first scenario assumes that the same conditions are maintained and the pumping from the aquifer of about 1.24 Mm^3/y will continues until 2020. The evolution of the groundwater quality of the aquifer is analyzed in order to define the affected area by seawater intrusion. The second scenario consists of increasing pumping rates to satisfy the increasing water demand of the Larache population until 2020. The third scenario increases even more groundwater abstractions until 2020 to satisfy the water demand of two urban centers, Larache and Ksar El Kebir cities.

Results of simulations

Table 3 shows the predicted saltwater volume intruded into the aquifer. It is clear that for scenario 1, the seawater intrusion volume decreases from 2003, but the equilibrium is not yet established in 2020. The groundwater quality in the northwestern sector becomes highly saline, and the contaminated area would extend more (Fig. 2). The results of scenarios 2 and 3 are also given in Table 3, which shows that the seawater intrusion volume increases progressively. The result of scenario 3 is presented in Fig. 3, which shows that the northwestern sector of the coastal part will be intruded with high salinity (15–25 g/l). The seawater would reach the first group of wells in 2010 with an expected salinity greater than 1.5 g/l.

CONCLUDING REMARKS

The coupled flow and transport code (SEAWAT) was applied to study seawater intrusion in the Rmel coastal aquifer in both qualitative and quantitative aspects. The results showed that seawater intrusion started in 1992 in the northwestern sector, due to intensive pumping from the wells and reduced recharge. The model is also applied to test the aquifer response to three planning scenarios for a period of 20 years. It is predicted that the first scenario will reduce the quantity of seawater intrusion, but without improvement of the groundwater quality. The other two scenarios predict a considerable quantity of seawater intrusion with deteriorating water quality. It should be cautioned, however, due to the missing aquifer data that need to be estimated, and the lack of field water quality data to validate the model result, more field measurements, such as vertical salinity profile and trace element studies for dispersivity need to be performed in order to increase the reliability of the model. Also, optimization model for rational management of the aquifer needs to be developed.

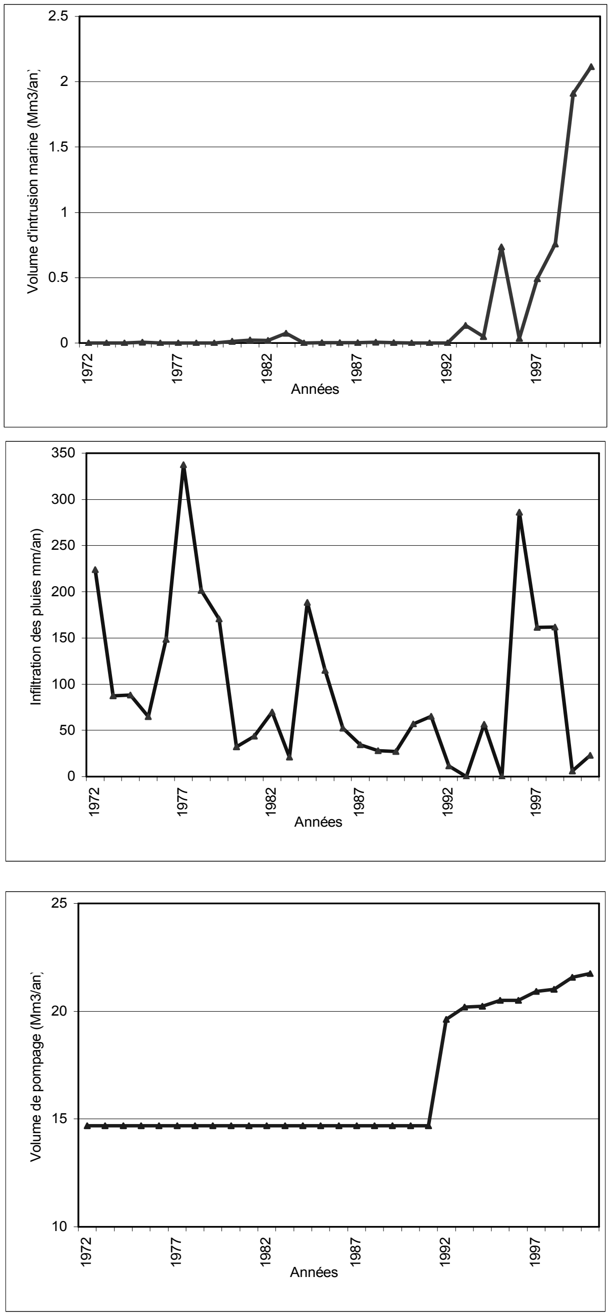
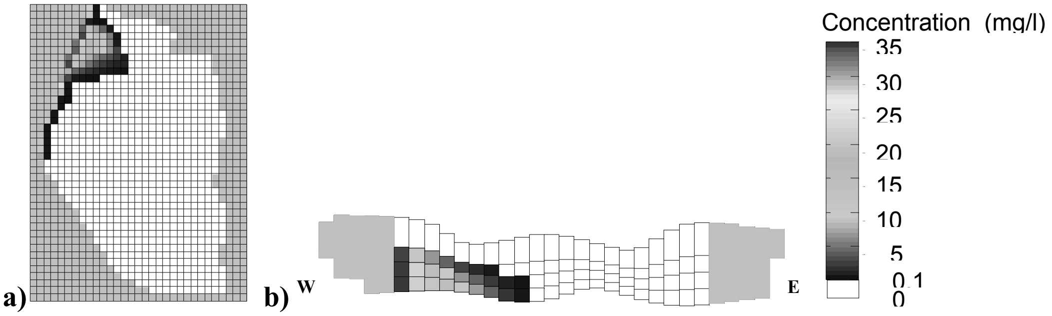
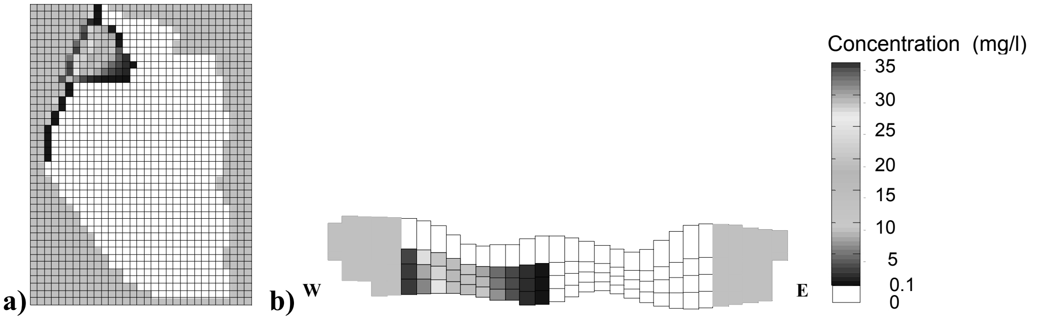


Figure 1. Evolution of seawater intrusion, natural recharge and withdrawals in the Rmel aquifer.



a) Calculated salinity for Scenario 1 in layer 2, **b)** Transversal section of salinity simulated in row 9.

Figure 2. Predicted salinity distribution for Scenario 1 in 2020.



a) Calculated salinity for Scenario3 in layer 2, **b)** Transversal section of salinity simulated in row 9.

Figure 3. Salinity distribution of calculated salinity predicted by the model for Scenario 3 in 2010.

Table 3. Evolution of sea water intrusion volumes (2004 -2020)

	Volume in Mm^3/yr				
	2004	2005	2010	2015	2020
Scenario 1	1.5068	1.2480	0.7908	0.4492	0.3905
Scenario 2	2.9996	3.7544	4.5457	4.7273	4.9428
Scenario 3	3.0139	3.8145	4.7860	5.0961	5.7462

ACKNOWLEDGMENTS:

The authors are thankful to the Direction de la Recherche et de la Planification des Eaux for the fruitful collaborations between the University and the Administration. This study is also partially supported by the U.S. National Science Foundation grant OISE 0422868.

REFERENCES

Bentayeb, A, (1972). Etude hydrogéologique de la nappe côtière de Rmel avec essai de simulation mathématique en régime permanent. Thèse Univ. Scien. Tech. du Languedoc, Montpellier.

DRPE (1995). Etude hydrogéologique et modélisation mathématique de la nappe de Rmel côtière, Direction Générale de l'Hydraulique, Rabat (Internal report).

Langevin, C.D. and Guo W. (2002). User's Guide to SEAWAT, A computer program for simulation of three-dimensional variable density groundwater flow. U.S Geological Survey, Open-File Report 01-434, Tallahassee, Florida.

Larabi, A. (2004), Programme de gestion des ressources en eau : Modélisation de l'Intrusion Marine dans la Nappe de R'mel (région de Larache, Maroc), Rapport FAO (internal report).

Contact Information: Abdelkader Larabi, Ecole Mohammadia d'Ingenieurs, Laboratory LIMEN, B.P 765, Agdal, Rabat, Morocco, Phone: 21237772647, Email : larabi@emi.ac.ma