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Modeling Groundwater Flow of the Mio-Pliocene Aquifer in the El-Outaya Plain, Biskra (Algeria)

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Abstract

El Outaya plain is located on the southern flank of the Aures Mountains, as part of the Saharan Atlas. It has an arid climate (less than 200 mm of rainfall / year). The Mio-Pliocene aquifer associated with this plain is an important resource for irrigation and drinking water.

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Achieving the first hydrodynamic model of the Mio-Pliocene ground water in El Outaya plain, with different operating scenarios and using the Visual Mod-flow code, shall contribute to the development of an action plan for a rational management of water resources.

In addition, the model was calibrated to steady state conditions and then transient state conditions in order to prepare conductivity and porosity maps that characterize the spatial variability, in relation with the geological heterogeneity of the aquifer. Different operating scenarios indicated that the northern part of the plain is fairly vulnerable to feeding and exploitation conditions.

Keywords**:** Modeling; free groundwater; calibration; groundwater assessment; management

1. Introduction

Nowadays, governments and economists all over the world agree that the operation and quality of water resources constitute two of the biggest problems all humanity will face in the coming decades. Groundwater exploitation, in particular, is a major challenge for many countries. Therefore, in the Saharan areas, where it does not often rain and the surface water resources are almost inexistent, groundwater exploitation remains the only way to ensure satisfaction of various needs.

This article contributes to the determination of the behavior of one of the aquifers in the northern Sahara, of Mio-Pliocene age, in the plain of El Outaya (Biskra, southeastern Algeria), from a recharge and discharge point of view, as well as the nature of its relationship with the external environment. This can be done by developing the first digital model in this region, based on finite differences so to present scenarios for managing these water resources. Many researchers have tried to identify the lithologic nature of the Mio-Pliocene formation, the recharge rate of the aquifer and its water quality [1, 2, 3, 4, 5].

The tool used for modeling is the Visual Modflow (4.0.0121), developed by Nilson Guiguer and Thomas Franz in 2003 and which runs on a Visual Basic interface. This program has the advantages of being simple to use, modular and reliable as it is extensively used worldwide, to identify the hydrodynamic characteristics of aquifers in porous media, and determine the areas of propagation of pollutants in order to provide adequate measures for all situations that may affect the quantity and quality of the groundwater under study [6, 7, 8, 9, 10, 11].

2. Physical environment of the study area

2.1. Presentation of the site

The plain of El-Outaya is 470 km, southeast of Algiers, with a total area of 1104 Km^2. It is bordered to the north by Jebel (promontory) Moddiane, to the west by Jebel Deba, to the south by Jebel Gouara and Jebel Menchar and to the east by Jebel Bou Ghezal and Jebel El Mhor (Figure 1). The hydrographic network of the region is not very dense, with a main body, Oued Biskra, which belongs to the closed basin of chott Melghir and receives on its left bank a few tributaries from the Aures and Jebel Mellah. Most of the hydrographic network is dry throughout the year, except during exceptional rainfall [12, 13, 14].

As for the climate, the plain of El Outaya has an arid climate, characterized by a low rainfall in winter (less than 22mm) and a hot summer, with temperatures exceeding 40 °C. It can be noted that low-intensity rainfall does not play an important role in ground water recharge through infiltration and a high proportion of water evaporates, except for the heavy rain which may contribute to refill the ground water of the Mio-Pliocene [1].

2.2. Geological and hydrogeological context

Figure 2 revealed the study area is a subsiding plain, slightly oriented E.N.E - W.S.W [15, 16] and located between two anticlines. It lies to the north of Jebel Bou Rhezel Anticline (Biskra) and to the south of the dome of Jebel El Melah, near the town of El-Outaya. This plain was a sedimentation basin throughout the entire Neogene [2, 17, 16]. It consists of a laguna marine formation at the base, of low Miocene age, covered by the middle and upper Miocene, sandy and fluvial, and by Pliocene conglomerates. The abovementioned terms, particularly Pliocenes, are strongly inclined towards the center of the basin where they disappear under a considerable thickness of the Quaternary [14, 16]. On the other hand, the Eocene and Senonian formations make up the reliefs of the plain.

The geophysical prospecting on the profile of the electrical survey (SE) D, H and N, which crosses the faults, showed that these do not cause a complete closure that prevents groundwater flow (Figure 1). The other faults that affect the study area must go through some additional geophysical prospecting in order to clearly identify their behavior vis-a-vis the groundwater movement in the aquifer.

Recharging the aquifer seems to originate, on one hand, from the rainfall runoff on the surface, which ranges from 150 to 200 mm/year [18]. On the other hand, considerable contributions, brought upstream by Wadi Biskra during floods, cross the thin muddy cover and infiltrate, to reach the Mio-Pliocene.

This recharge, from the sides and through the permeable formations that surround the plain, became negligible, after the construction of the dam "La Fontaine des Gazelles", north of the plain [13].

However, prospecting for water resources in the Mio-Pliocene formations, within El Outaya plain, must be carried out in the eastern part first, where the coarse formations are significantly thick, and then in the western part. Prospecting for a hydraulic potential in the southern part is irrelevant, as this area consists of salt formations (clay or gypsum sand).

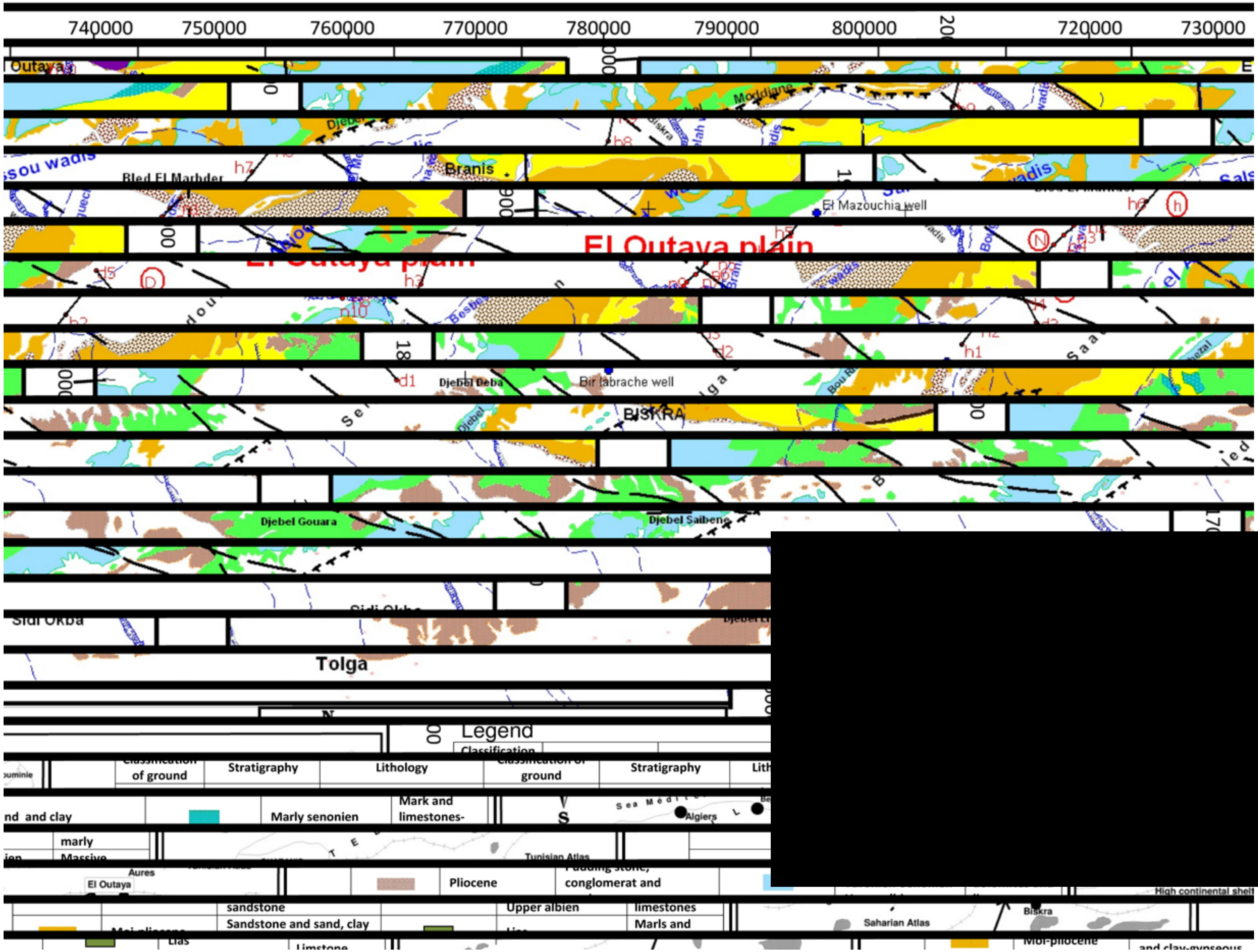

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Fig.1.Geographical location and geological map of the study area

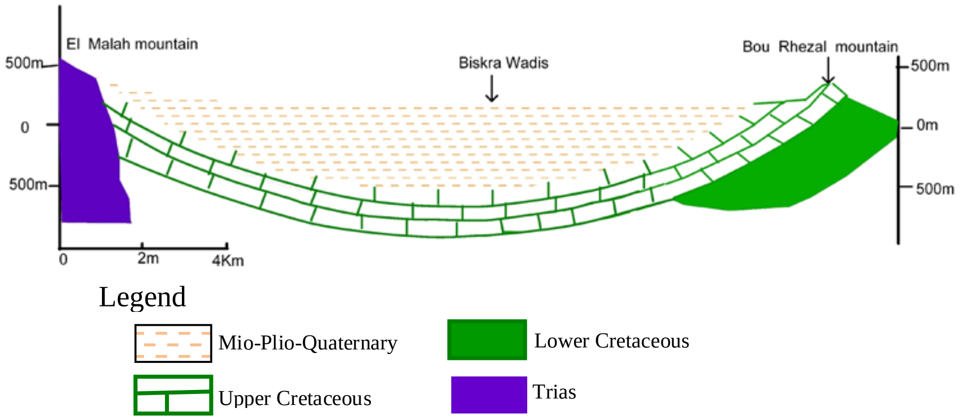


Fig.2. Section in the study area according to the profile (AB)

3. Materials and methods

The inherent motivation to construct a hydro-geological model arises from the need to solve problems of practical interest. They concern management issues of situations involving water flow and pollutant transport in the saturated-unsaturated zone [6, 7, 8, 9, 10, 11]. Good management requires a tool to make predictions about the consequences when a particular decision is made. This tool is the model of the studied system.

Visual Modflow is a physically based deterministic model that can give three-dimensional single-phase flows in multilayer systems [10]. It can solve the groundwater flow diffusion equation, with partial derivatives, in porous media (combination of Darcy's law and the continuity equation) using the finite difference method [7, 8, 11]. To do so, the aquifer must be discretized into quadrilateral elements and some boundary conditions must be imposed [9]. The number and size of these elements depend on the expected accuracy as well as the nature and source of data (number, distribution, quality).

Developing a model for groundwater flow is undoubtedly one of the most relevant work, but at the same time the most difficult to achieve. The development of a mathematical model must be done according to the following steps

3.1. Construction of the model

Figure3 show the model is obtained by dividing the aquifer into two layers and three horizons; the first horizon (top layer) represents the topography of the area and the last one gives the shape of the substratum. The thicknesses of the aquifer layer are proportional to the distance (Z) that separates the roof from the bedrock. The flow domain is discretized into rectangular elements, 2 km long and 1 Km wide.

The aquifer area of the Mio-Pliocene is represented by conglomerates of sand and clay, sometimes gravelly, in some places. It is divided into 552 active blocks, thus representing an area of 1104 km^2 which can be studied as a monolayer. The domain boundaries are shown in Figure 6 and shall consist of:

Incoming Flows: the specified head boundary allows presenting the flow entries, either in the northern part, through the gritty-sandy formations of the Mio-Plio-Quaternary of the Aures, or in the western part, from limestones of the lower Eocene, or in the east through the conglomerates and sandstones of the Pliocene.

Outflows: the specified head boundary represents the remaining water that continues its course towards the south, in the limestone formations of the Eocene and Lower Senonian.

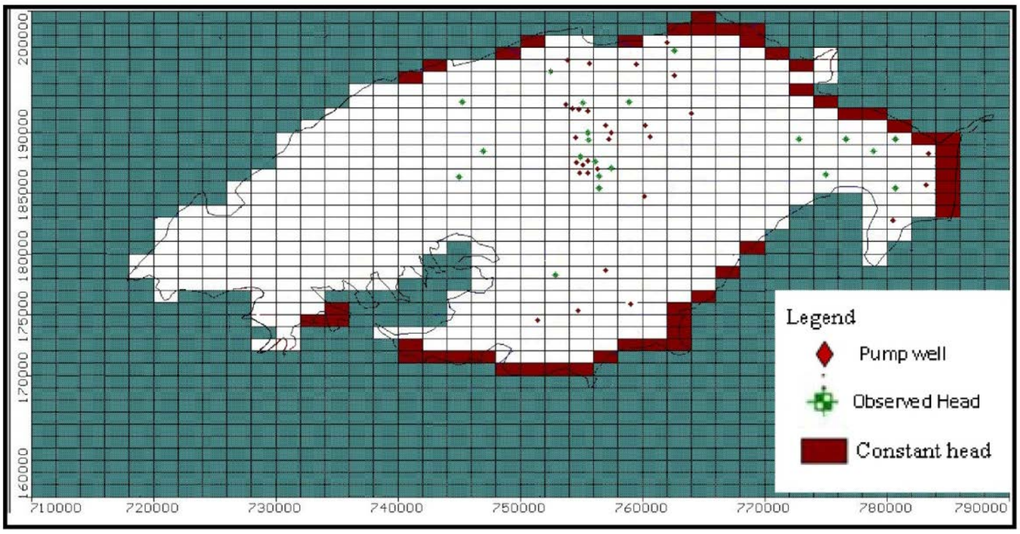


Fig. 3. Spatial distribution of observation and drilling points in the study area

*3.2. C*alibration of the model

The model was calibrated in steady state, then in transient regimes. The reference state that served to calibrate the model in the steady state regime is the piezometric head, measured in March 2008. The points of piezometric observations are concentrated in the central part, to the east and north of the plain; this makes the calibration very difficult to realize.Considering the lack of history of pumping rates of the wells in the plain, the operating flow of each well was considered to be constant, from its commissioning until March 2010 (date of the last piezometric campaign).

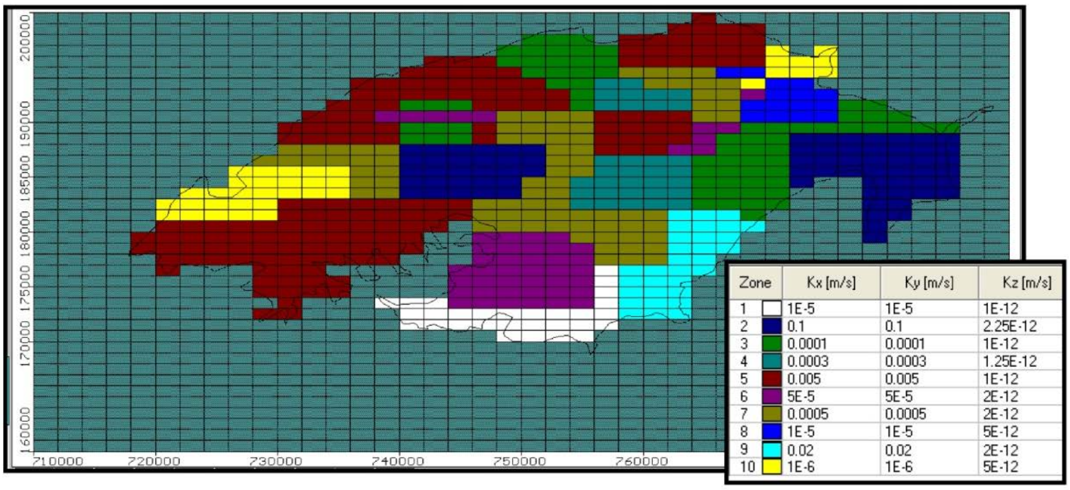
A recharge was imposed on the Mio-Pliocene groundwater system, by rainfall with 15.47 mm/year; this represents 12 % of rainfall at the station of Biskra. This value, given by [18], was determined by the method which consists in combining the spatial data about the various factors governing the recharge of aquifers (vegetation, lithology, Hydrography, slope, soil). The ground water recharge by waters from Biskra River, which crosses that plain, became negligible after the completion of the dam "*La Fontaine des Gazelles*", upstream of the plain.

4. Results and discussion

4.1. The steady state regime:

Figure 4 revealed the adjusted permeabilities in steady state regime reflect the heterogeneity of the aquifer; they range from 10^{-6} to 0.1 m/s.

Conductivity in the eastern part is good to very good (10^{-4} and 10^{-1} m/s), while the other parts of the plain are characterized by poor to good permeabilities (10^{-6} and 2 x10^{-2} m/s), and sometimes very good, in the central part (10^{-1} m/s) [19].



Zone	Kx [m/s]	Ky [m/s]	Kz [m/s]
1 □	1E-5	1E-5	1E-12
2 ■	0.1	0.1	2.25E-12
3 ■	0.0001	0.0001	1E-12
4 ■	0.0003	0.0003	1.25E-12
5 ■	0.005	0.005	1E-12
6 ■	5E-5	5E-5	2E-12
7 ■	0.0005	0.0005	2E-12
8 ■	1E-5	1E-5	5E-12
9 ■	0.02	0.02	2E-12
10 ■	1E-6	1E-6	5E-12

Fig. 4. Spatial distribution of conductivity, after calibration

Measured and calculated potentials

Figure 5 show the measured and calculated potentials for the reference state (March 2008) show that the deviations between them are acceptable upstream and at the center of the plain, where the data are available. However, the potentials are important downstream. The lack of information on that part of the plain does not allow a better calibration.

Two zones of dry meshes are noted; they represent regions where the piezometric level is lower than that on the coast of the bedrock.

Table 01 allowed us to deduce that the Mio-Pliocene groundwater is mainly recharged through the edges, in the North, from the gritty-sandy formations of the Mio-Plio-Quaternary (Aures side), from the east by the conglomerates and sandstones of the Pliocene, and from the west through the limestones of the Eocene.

4.2. The transient regime

The calibration of groundwater flow, in the transient regime, consists in reproducing, through calculations, a piezometric state consistent with a piezometry initially measured as Figure 5.

For the calibration period adopted, the behavior of the system was simulated for the period extending from the initial situation, i.e. March 2008, to March 2010, distributed over semestrial periods. Due to a lack of semestrial operational flows and a poor monitoring of the piezometry of El Outaya groundwater, we considered the piezometric campaign of March 2010, only. So we assumed that the operating flows are constant, between March 2008 and March 2010.

Table2 show during this simulation stage, we adopted the semestrial averages of the infiltrated volume. Infiltration in the plain is estimated to be 12% of rainfall at the station of Biskra [18].

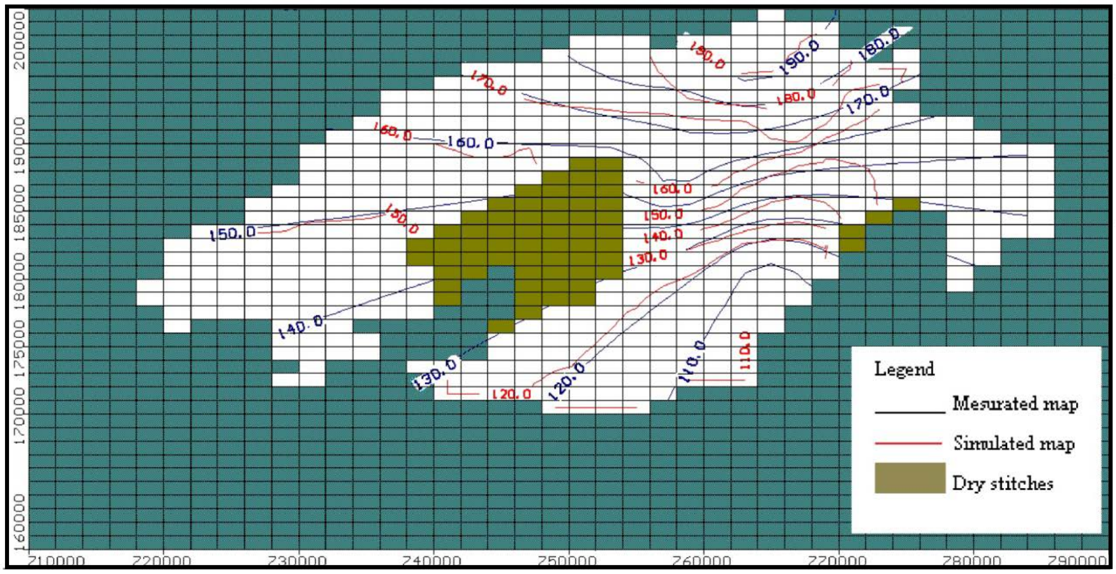


Fig.5. Piezometric map measured and calculated after calibration steady (March, 2008)

Table1. Resistivities of formations in El Outaya Plain, after calibration

Age	geological characteristics	Resistivities
Mio-Pliocene (recovery)	Piedmont scree	Several hundreds of Ω.m
	Conglomerates, gravel, limestone	100 to 300 Ω.m
	Sand, marl, sandy clays	5 to 30 Ω.m
	Saliferous clays and sands	0.5 to 5 Ω.m
Middle Eocene	Interbedded limestone, anhydrite and gypsum	100 to 500 Ω.m
Lower Eocene	Marly limestone and marl	2 to 10 Ω.m
	Marly limestone and marl	40 to 60 Ω.m
	Limestone and dolomites	100 to 400 Ω.m

Table 2. Seasonal distribution of rain

Semester	April - September 2008	October -March 2008/2009	April -September 2008	October -March 2009/2010
Rainfall	28.45	103.65	59.69	72.89
Infiltration	3.41	12.36	7.16	8.75

The restitution of the simulated piezometric map of March 2010 consists in initializing the calculation, which is affected by pumping and recharge variations, with the simulated piezometric state in the steady state regime. Figure 6 revealed a good adjustment of the effective porosity allowed us to find again a good superposition between the measured and the calculated potentials. A look at figure 7 the spatial distribution of the effective porosity obtained shows that:

The North and West parts are characterized by an effective porosity between 10% and 40%, while the eastern part exhibits a porosity between 34% and 40%. The southern part has a porosity that varies between 24% and 40%.

The central part of the plain has an extremely variable porosity that varies between 24%, 34% and 40%.

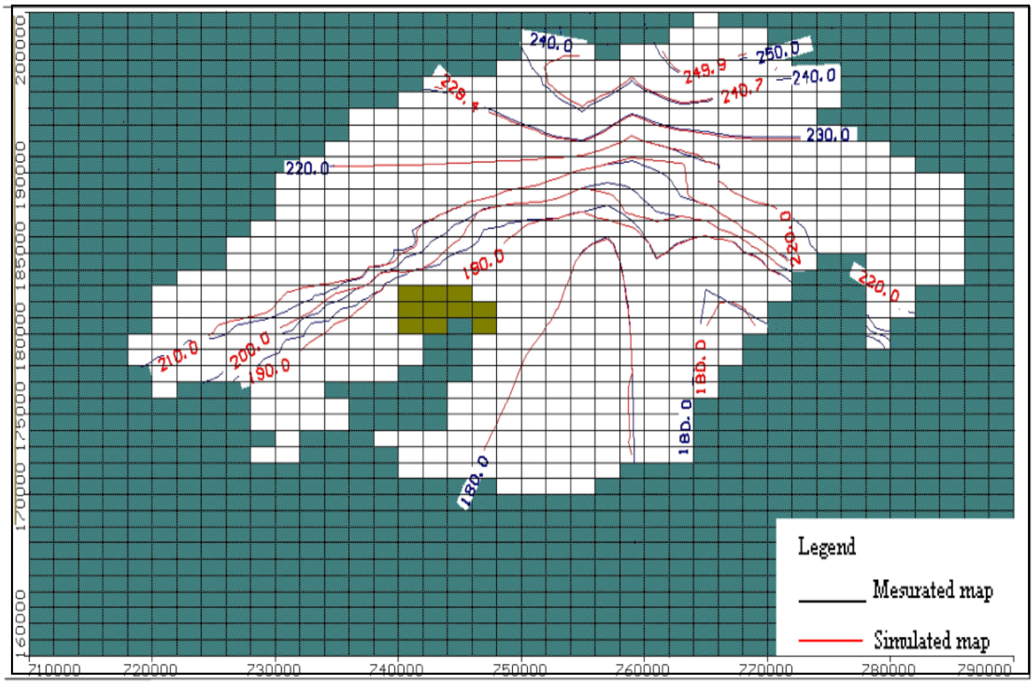


Fig.6 Piezometric map, measured and calculated after calibration, in transient regime (March 2010)

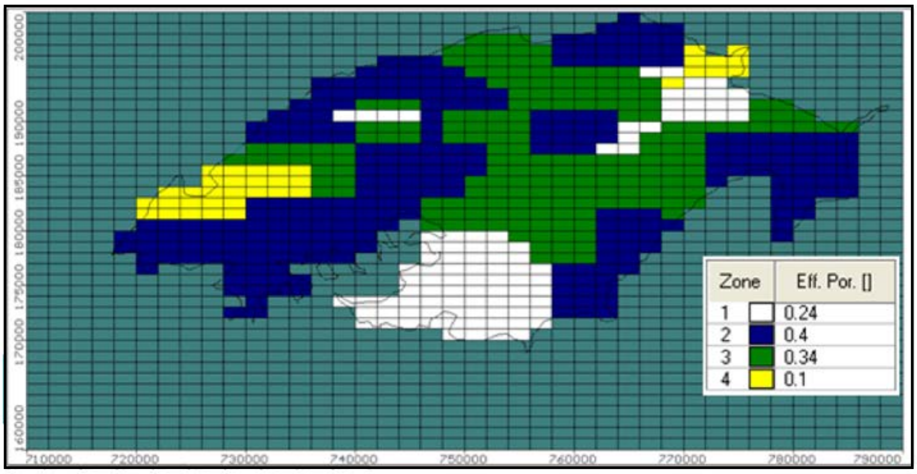


Fig.7. Spatial distribution of porosity, after calibration

Water balance in the transient regime

As for the equilibrium between input and output, this groundwater balance study (Table 03) gives more or less satisfactory results.

Table 3. Water assessment from the Mio-Pliocene (m^3/day)

Inputs	**Volumes (m^3/day)**		**Outputs**	**Flow rates (m^3/day)**
Recharge in the north part	360215		Southern part of the plain	1250296
Storage	7.02267E+08		Destocking	6.921446E+08
recharge from rainfall	9824.02		Pumping	411.525
TOTAL	7.03E+08		TOTAL	6.93E+08

5. Operating scenarios

For a rational use of water resources from the Mio-Pliocene groundwater, three (03) scenarios were tested, for the same period (forecast for 2015).

5.1. Scenario 1 (Figure 8)

- Decreased lateral recharge flow of about 50%
- Increased pumping rates of about 200%

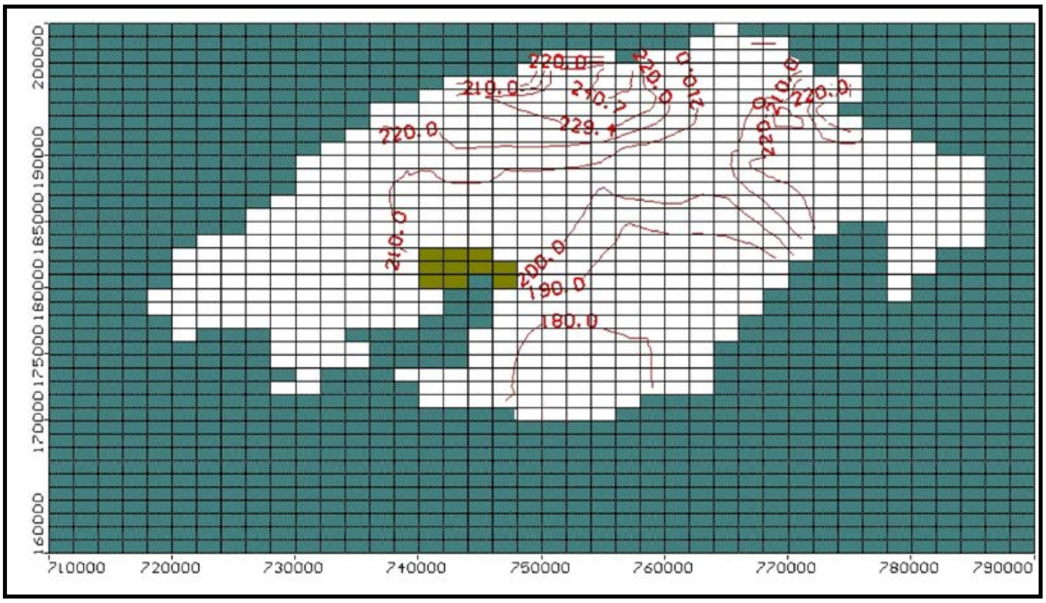


Fig. 8. Map of piezometric evolution, in scenario 01

5.2. Scenario 02 (Figure 9)

Recharge flows are simulated as follows:

- Increased recharge, by effective rainfall, of about 200%.
- Increased lateral recharge flow of about 200%.
- Stabilized pumping rates.

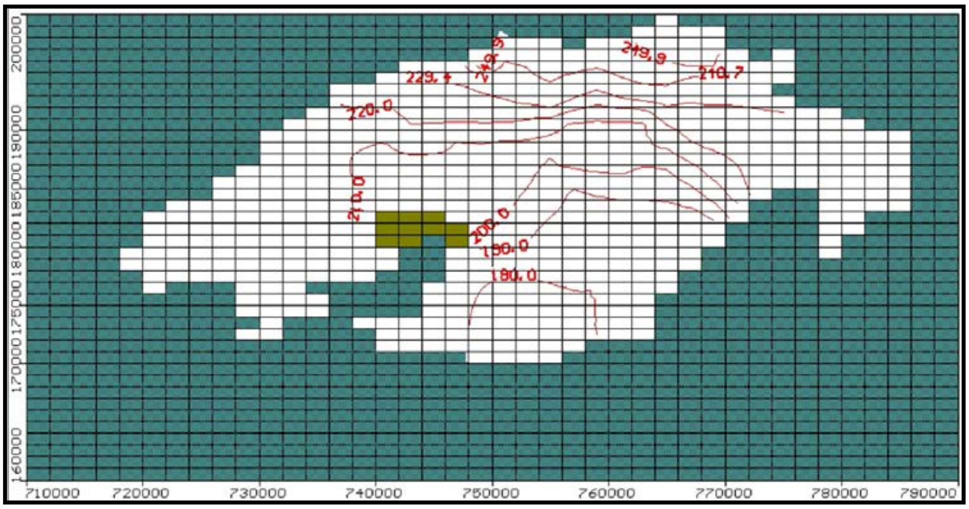


Fig.9. Map of piezometric evolution, in scenario 02

5.3. Scenario 03 (Figure 10)

To predict the impact of the overall increase in groundwater production from wells, linked to demographic trends, production was increased about three times, which corresponds to a total production of 1233 m^3/day.

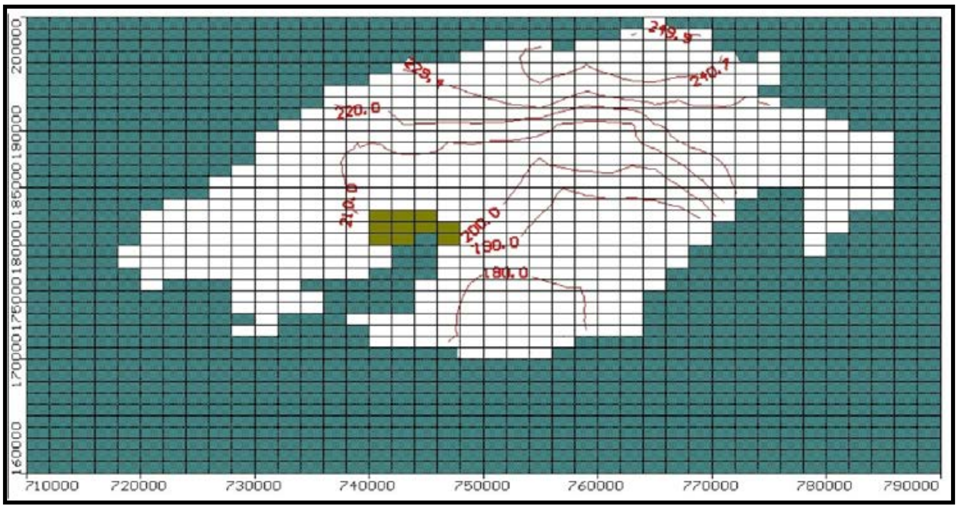


Fig.10. Map of piezometric evolution, in scenario 03

5.4. Summary of results

Simulating the operating scenarios under different conditions showed that this area will undergo a ten meters drawdown in the northern part of the plain. However, the other zones may retain their piezometric levels (Figures 6, 10), even if the operating speed is tripled (scenario3).

Decreasing the lateral recharge by half and increasing the operating speed twofold (scenario 01), will cause a drawdown of more than 30 m in the northern part, while some areas in the southern part will experience a 10 m increase in their piezometric levels (Figures 6, 8).

Scenario 02 shows a slight increase in the piezometric level in the northern part, as well as in some other areas of the southern part (Figures 6, 9).

6. Conclusion

This hydrodynamic model addresses some questions related to the behavior of the ground water. Moreover, the results obtained by various simulations on this aquifer highlighted the following points:

* Adjusting the hydrodynamic parameters, through the steady state, showed that the eastern part has the best permeability of the region. It is characterized by a good conductivity (10^{-4} to 10^{-1} m/s), except for the north-eastern part of the plain which shows a poor permeability of 10^{-6} m/s [19].

* The transient calibration allowed noting that the effective porosity in the eastern part varies between 34% and 40%; however, in the north, west and center areas, it is significantly variable and ranges between 10% and 40 %, while it is between 24% and 40% in the south.

* Analysis of piezometric maps (March 2008 and March 2010) and the transient assessment results show that the Mio-Pliocene ground water recharge is mainly provided, in the north, by the infiltration of Wadi Biskra waters during floods, or by the Mio-Pliocene formations (Region of Aures). The eastern part, also contributes to ground water recharge from the lower Eocene limestones; however, in the western part, the groundwater is recharged through the Eocene limestones. Moreover, this analysis made it possible to note that lower Eocene and Senonian limestones drain water from this groundwater body.

* Calibration in steady state and transient regime, allowed deducing that conductivity and porosity are well distributed over the areas where the observation points exist.

* In order to improve this model, additional observation sites should be created in the western and southern areas, to determine the aquifer characteristics (hydrodynamic parameters, lithological types, piezometric levels).

* This model is a tool for managing and forecasting the future development of groundwater resources from the Mio-Pliocene of El Outaya plain. It can be said, in this connection, that the potential of this aquifer will be influenced in the northern part of the plain, under extreme conditions (Scenario 01).

* Under these circumstances, it seems appropriate to develop an operating groundwater software program which allows for a rational and sustainable use, because an overexploitation may lead to negative changes in the characteristics of the aquifer.

References

[1] A, Haouchine. “Hydrogeology in semi-arid and dry zone at Biskra region, Algeria.”Doctoral thesis, Bab Ezzouar University, Algeria, 2010.

[2] M. Chebbah. “Sedimentologic and geochemical of the Neogene, on all sides the south accident Atlasique, region of Biskra.”Doctoral thesis, Mentouri University, Algeria, 2007.

[3] N. Brinis.”Characterization of the salinity of a complex aquifer in dry zone, case of the aquifer of El Outaya, Northwest region of Biskra, Algeria.”Doctoral thesis, Mentouri University, Algeria, 2011.

[4] N. Brinis and al. “Statistical and hydrochemical classification of groundwater of the plain of El Outaya Wilaya of Biskra Algeria.”*Journal of national geology agency*, vol 11, pp 41-46, Nov.2011.

[5] N. Chabour. ”Hydrogeology of the domain of transition enters Saharan Atlas and flat Saharan shape East of Algeria.” Doctoral thesis, Mentouri University, 2008

[6] A. Dassargue. *Mathematical model in hydrogeology*: Science of the water, Bucharest, Romania, 1995, pp.20-67.

[7] H. Wang and al. (2013, Nov.). “Modeling the Impact of Soil and Water Conservation on Surface and Groundwater Based on the SCS and Visual Modflow.” *Plosone*. [On line].Aviable: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0079103.

[8] J. MARGAT and K. SAAD. “The use of the not renewable groundwater resources for the development.” 4th international conference on the planning and the management of waters, Marseille, French, 1982, pp.25-31.

[9] L. Elango. *Numerical Simulation of Groundwater Flow and Solute transport*: Department of Geology Anna University, India, 2005, pp.10-120.

[10] M. Thangarajan. *Groundwater Resource Evaluation, Augmentation, contamination, Restoration, Modeling and Management:* National geophysical Research Institute, Hyderabad, India, 2007, pp.23.

[11] Xiaoyin and al. (2010, Apr.). “Data model for system conceptualization in groundwater studies.” *Geographical Information Science*. [On- line], pp.677-694.Aviable: http://dx.doi.org/10.1080/13658810902967389

[12] D H W “Direction of hydraulics of the wilaya of Biskra.” Sounding report of the well at El-Outaya plain, Algeria, 2004.

[13] D P A T “Direction of planning and arrangement of the térritoire.”El Outaya report, Algeria, 2009.

[14] D S E H S “Direction of the studies of environment and the hydraulic search.” Manual of the hydrogeologic map of Biskra region, Algeria, 1978.

[15] G.C.G “General Company of Geophysics.” Study geophysics of the plain of El-Outaya, Algeria, 1971.

[16] R.Guiraud. “Post Triassic evolution of before country of the alpine chain in Algeria, according to the study of the basin of Hodna and the close areas, Algeria.” *Journal of national geology agency*, vol 3, pp 250-259, 1990.

[17] M. Chebbah and al. “Sedimentology of facies and paleogeography of the pond of El Outaya in the Neogene in the Saharan Atlas, Algeria.”*Journal of national geology agency*, vol. 19, pp.235 – 244, Jan 2008.

[18] A. Haouchine. “Cartography of the potential refill of aquifers in dry zone, case of the El Outaya plain, Biskra region, Algeria”. *European journal news papers*, Vol.45, pp. 1-13, Mar 2011.

[19] G. Castany. *Hydrogeology, principles and methods*: Dunod, Paris, 1982, pp. 100-238.