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Hydrogeological Evaluation of Massive Salty Lagoons, (Case Study: Qattara Depression)

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ملخص

في بداية القرن العشرين تم إعداد عدد من الدراسات المختلفة عن توصيل مياه البحر المتوسط إلى منخفض القطارة خلال قناة وذلك بهدف توليد الطاقة الكهربية الناتجة عن فرق مناسيب المياه في المنخفض والبحر وفي البحث الحالي: أ) يتم دراسة تأثير تجميع المياه في المنخفض على صرف المياه من الدلتا ، ب) دراسة تأثير تجميع المياه المالحة في المنخفض على نوعية المياه في الخزان الجوفي.

وقد تمت الدراسة الحالية باستعمال الأدوات الحديثة للتحليل التي لم تكن متوفرة في وقت الدراسات السابقة مثل النماذج العددية ذات الكفاءة العالية ونظم المعلومات الجرافية ونماذج الارتفاعات الرقمية وقد تم حساب البخر من المياه المالحة المتجمعة في المنخفض وقد تم الاستعانة بعدد واحد وعشرون جسة عميقة بعمق متوسط ٣٩٠٠ متر في بناء قطاعات جيولوجية تبين طبقات الخزان الجوفي في المنطقة كما تم حساب معامل التوصيل الهيدروليكي من الجسات الاختبارية العميقة التي تم حفرها بواسطة شركات البترول وتم تطبيق الميزان المائي على المنخفض بعد ملئه وذلك كل عام منفصل لمدة خمسون عاماً مع تطبيق نموذج (Seawat via MODFLOW) المعتمد على الكثافة وذلك لمدة خمسون عاماً مع تطبيق النمذجة العددية كل سنة منفصلة وذلك لقيم ملوحة مختلفة في المنخفض وذلك لمناسيب مياه مختلفة في المنخفض ثم تكرار الدراسة مع وجود حقول آبار بين المنخفض والدلتا مع فرض مصافي الآبار في طبقة المغرا ثم في طبقة الحجر الجيري ثم عميقاً في طبقة الحجر الرملي النوبي وقد أظهرت الدراسة أن ملء المنخفض لن يؤثر على كفاءة الصرف في الدلتا كما أن الملوحة المتجمعة في المنخفض لن تصل إلى الدلتا وإنما تصل بتركيز بسيط أعلى الخزان الجوفي النوبي تحت منطقة المنخفض بسبب طبقة الطين التي تعلوه كما أن الملوحة لن تنتشر لمسافات بعيدة عن المنخفض.

Abstract

At the beginning of the 20th century, several studies were performed to deliver the Mediterranean Sea water to the Qattara Depression through a canal for hydropower generation by utilizing the difference in the water levels. Main objectives of the current study are to: a) study the hydrogeological conditions of Qattara as a drainage lagoon for the Delta, And b) study the effect of saltwater lagoon on the Nile Delta, and the groundwater reservoir.

The study methodology has been performed utilizing the recent tools, of analysis, that had not been available for the previous studies of the project such as; efficient numerical models, geographic information system (GIS), and Digital Elevation Models (DEM). The effect of salinity on evaporation, from the lagoon, was calculated. A number of twenty one boreholes, with average depth of 3900 m, were employed to construct the geological stratification. Hydraulic conductivity values and groundwater levels have been collected from the available boreholes and deep exploratory wells drilled by the oil companies. Mass balance of the lagoon saltwater was performed, every separate year during a period of 50 years.

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Density dependent model (SEAWAT) via MODFLOW has been employed for duration of fifty years. The simulation was done every separate year. The simulation was repeated for different water filling levels, and when having several well fields between the lagoon and the Nile Delta. The wells screen was assumed in the Moghra, the limestone, and the deep sandstone aquifers. The results revealed that the lagoon does not affect the Nile Delta drainage efficiency. The lagoon accumulated salinity does not reach the Nile Delta. The study, also, revealed that the effect of the lagoon salinity, on the lower sandstone reservoir, is minor because of the confining shale layer and the salinity diffusion does not reach the Nile Delta.
The study, also, revealed that the effect of the lagoon salinity, on the lower sandstone reservoir, is minor because of the confining shale layer and the salinity does not diffusion horizontally towards the Nile Delta.
Keywords: Qattara Depression, salinity, density dependent model, mass balance, Nile Delta drainage, saline lagoons.

Introduction

Qattara Depression is a desert basin within the northwestern desert of Egypt, in Matruh Governorate, lying within the triangle formed by El-Alamein, Mersa Matruh and the Siwa Oasis. It is 200 km west of Cairo, and 75 km east of Siwa Oasis as shown in Figure 1. The depression deepest floor level is 133 m below sea level. It contains the second lowest point in Africa (The lowest is Lagoon Assal in Djibouti). The depression covers a surface area of about 19,500 km² (7,000 square miles). Its maximum length is 298 km with width of 145 km. (Ezzat, M.A., 1977).
The bottom of the depression consists of a salt pan (sabkha). The floor of the Qattara Depression rests, predominantly, in the Lower Miocene Moghra formation, which consists of a complex sequence of relatively coarse sediments of tertiary age as shown in Figure 2. These sediments merge with the Western Plateau Complex in the north-western side of the Lagoon.(Ball,J., 1933).
Within the depression, there are saline marshes under the northwestern and northern escarpment edges. The major oasis in the depression is Moghra oasis, which is uninhabited and has 4 km² brackish zones (LAHMEYER, 1981).Salt marshes, also, occur and occupy, approximately, 300 km². It is situated in the easternmost part of the depression, forming a small, local depression within the main Qattara Lagoon (Abdel Azeem, et al., 2016).

Study area

The investigated area is the shaded area, Figure 1, which covers the Qattara Depression (Lagoon after filling) which is a major physiographic feature in the Sahara Desert. Dimensions of the study shaded area are 647,297 meters, in east- west direction, by 332,714 meters in north- south direction.
The area has been subdivided, into a grid, of 400 rows by 500 columns including 20,000 cells, in plan. The hydrogeological system has been subdivided into four layers in the vertical direction as shown in Figure 3. The aquifers from top to bottom are Moghra, limestone, shale, and sandstone (Hellstom, 1940 and EURCONSULT PACER Consultant, 1983). The corresponding thickness of these aquifers is 800, 1000, 200, and

2000 meters, respectively. Thus, the total number of cells in the simulated domain amounts to 800,000cells. The top aquifer is considered a phreatic one.

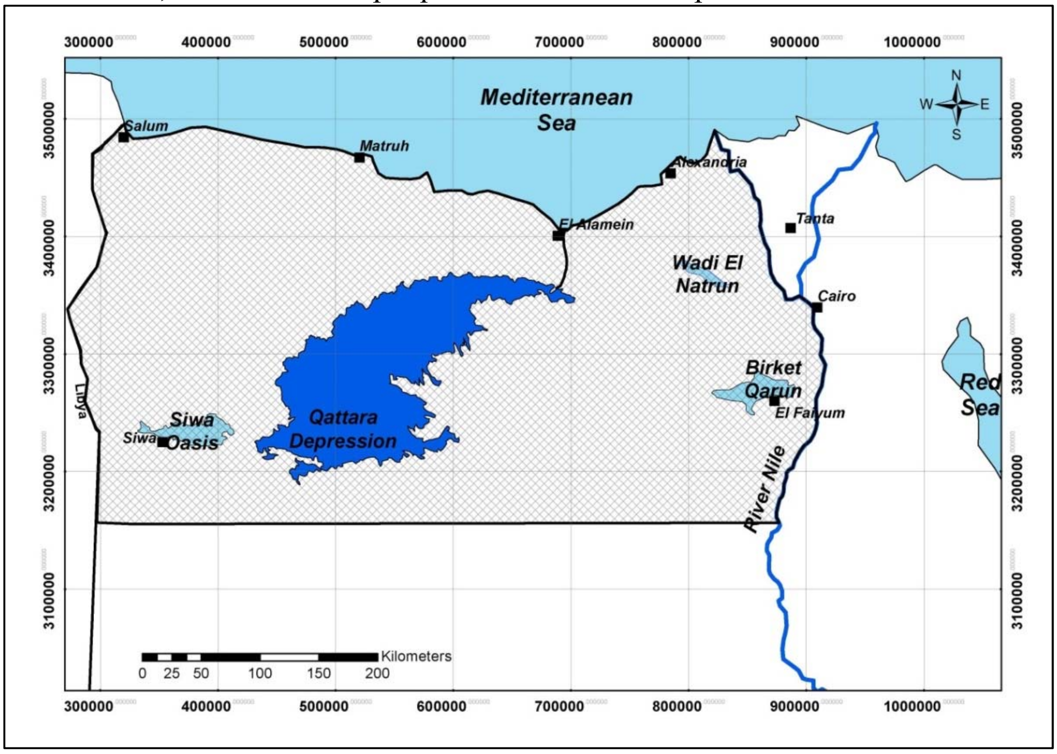

Fig. 1.Qattara Depression location in the investigated area

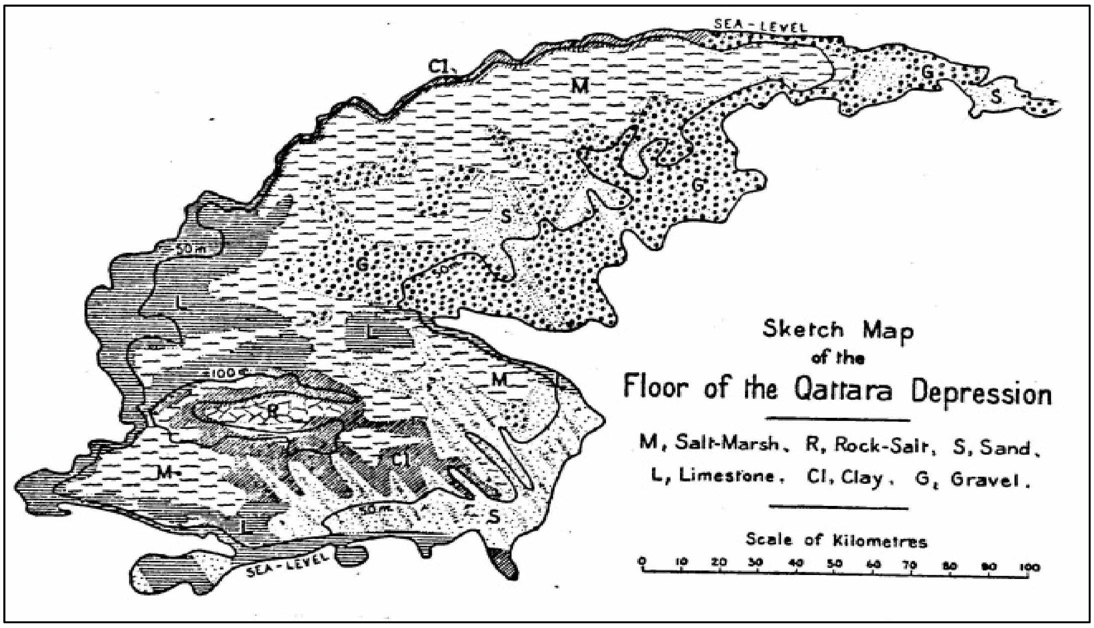

Fig. 2.The floor of Qattara Depression
(Ball, J., 1933)

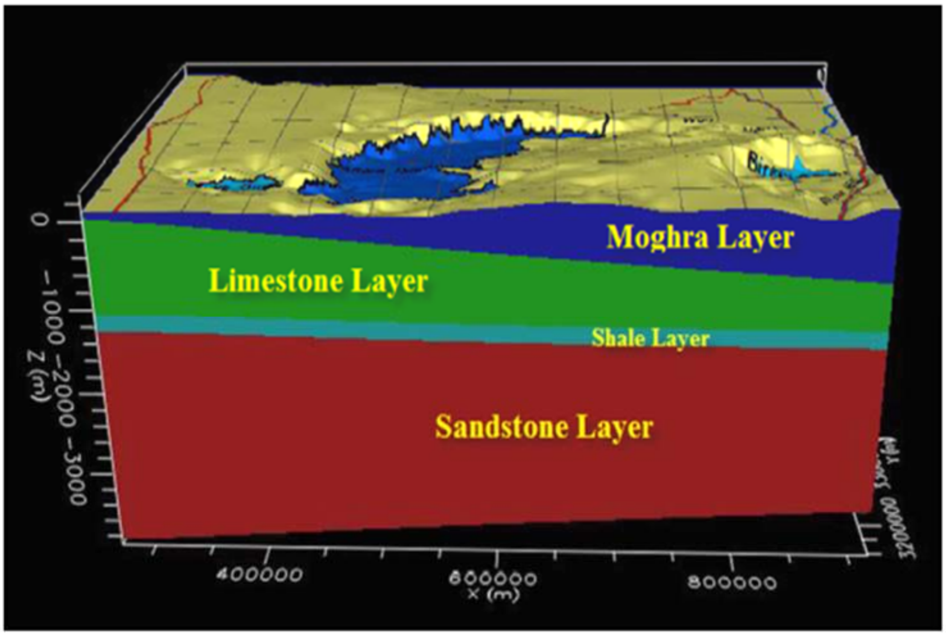

Fig.3.Aquifers in the study area

Stratigraphy of Qattara Lagoon

A number of twenty one existing deep boreholes with average depth of 3900 m (El Shazly, 1976) were employed to construct the geological stratification in the modeled area. Figure 4 shows thirteen of the existing boreholes in the East – West direction while Figure 5 shows eight of the existing boreholes in the North- South direction.

The Rockworks program was used to manage, analyze, and visualize the geological data for the existing boreholes. A 3-D view of the existing boreholes in the modeled area is shown in Figure 6 while Figure 7 is showing the existing boreholes with the groundwater aquifers in the modeled area. The aquifers from top to bottom are Moghra formation, limestone, shale, and sandstone. Figure 8 shows the soil stratification in the longitudinal direction.

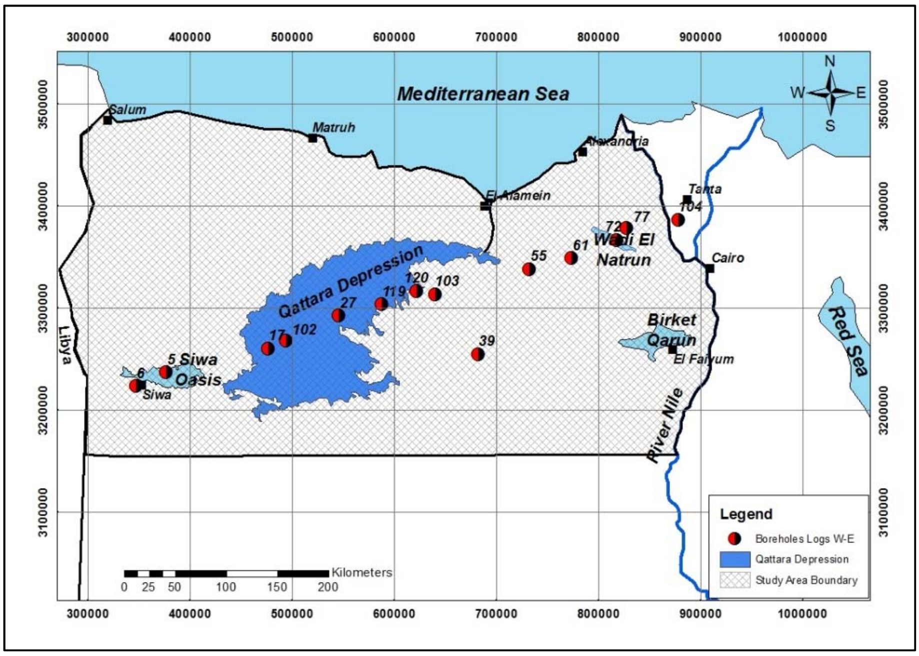

Fig.4.Existing boreholes crossing the lagoon in longitudinal section

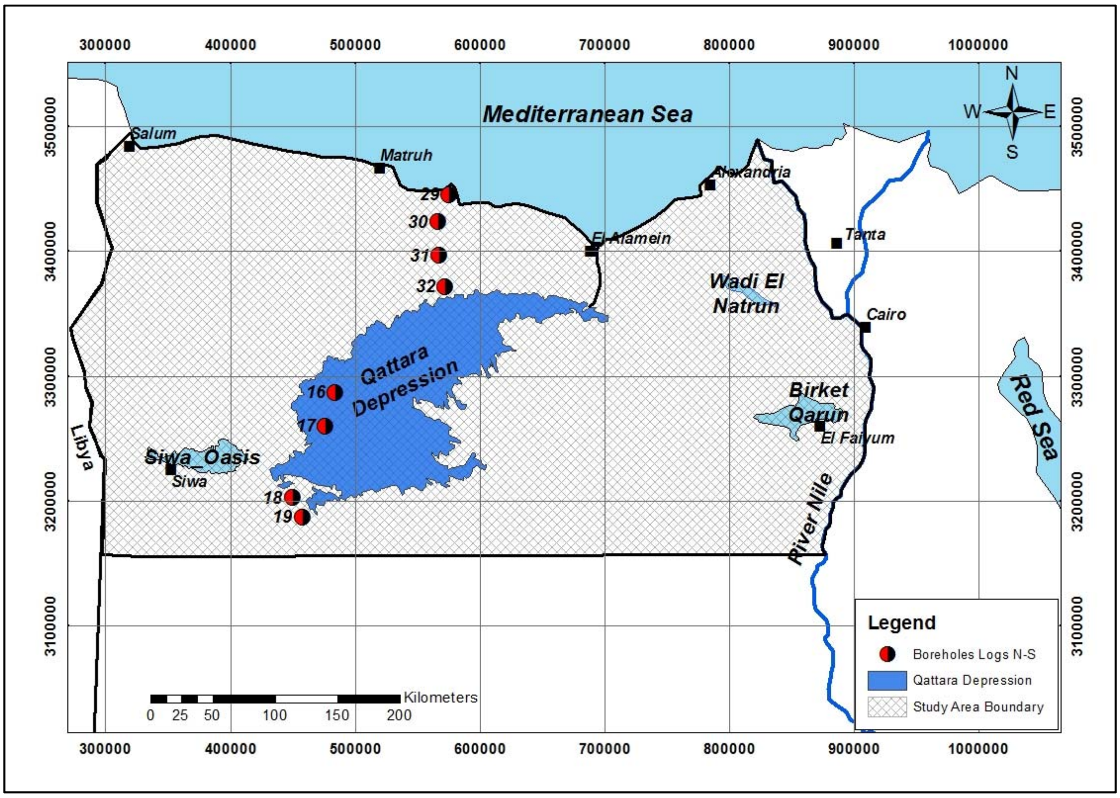

Fig. 5.Existing boreholes crossing the lagoon in lateral section

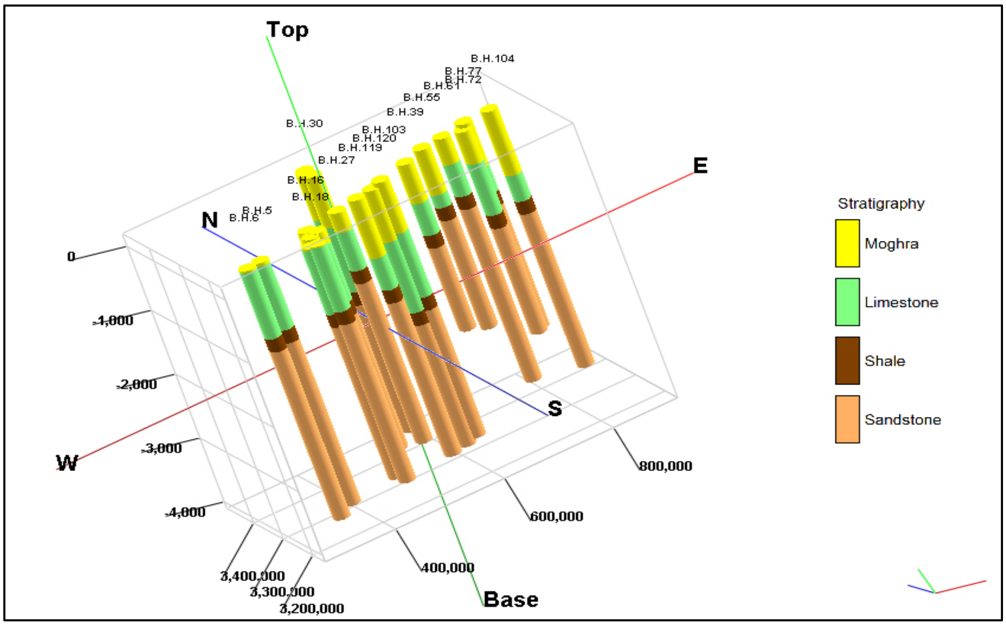

Fig.6. 3-D view of existing boreholes in the modeled area

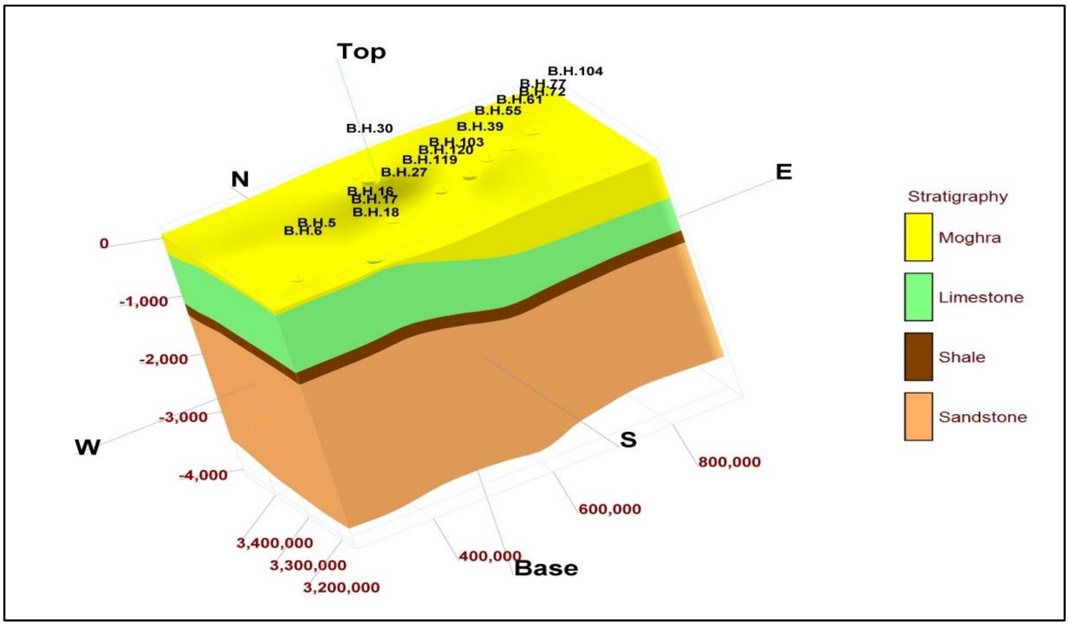

Fig.7. 3-D view of aquifer with existing boreholes

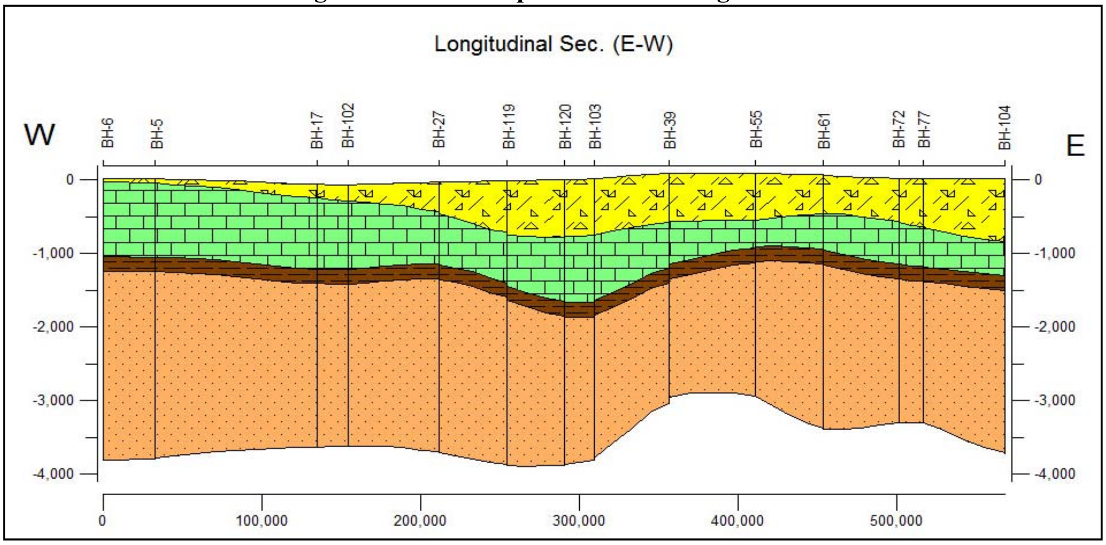

Fig. 8.Longitudinal section with existing boreholes showing the modeled area stratigraphy

Salt Concentration-Density Dependency

Density of saltwater, ρ is not constant. It is function of the salt concentration, C . It is calculated as:

$$\rho = \rho\,(\mathrm{C}) \cong \quad \rho_O \; + \frac{\partial_\rho}{\partial_{\mathrm{C}}} \; (\mathrm{C} - \mathrm{C}_O)$$

Where ρ_o ; is the density at some base concentration C_o

Different scenarios for simulating the hydrogeological conditions in the modeled area, using Density Dependent Module (SEAWAT) via a numerical model (MODFLOW), are performed. These scenarios and their results are discussed in details as follow:

Hydrogeological simulation of Qattara Lagoon;

First Scenario: Lagoon filledat level of 50.0 m (b.m.s.l)

The impact of filling Qattara Lagoon on the hydrogeological conditions is performed, when the lagoon water level is 50 meters below mean sea level.

The hydrogeological simulation has been achieved every separate year during a period of 50 years to consider the accumulated saline water in the lagoon as a boundary condition through the simulation. The presented results, in this paper, are after 50 years of simulation.

The study showed that there is salinity diffusion out of the Qattara Lagoon. Figure 9 shows the salinity diffusion out of the Lagoon in Moghra formation.

The salinity is diffused vertically to the limestone aquifer underlying the moghra formation as shown in the cross section passing the southern part of the lagoon. Figure 10 shows the salinity diffusion in the vertical direction. The vertical section shows that the salinity is diffused with a distance of 170 km towards the Delta, East the Qattara Lagoon, in moghra and limestone aquifers and has a slight effect on sandstone aquifer.

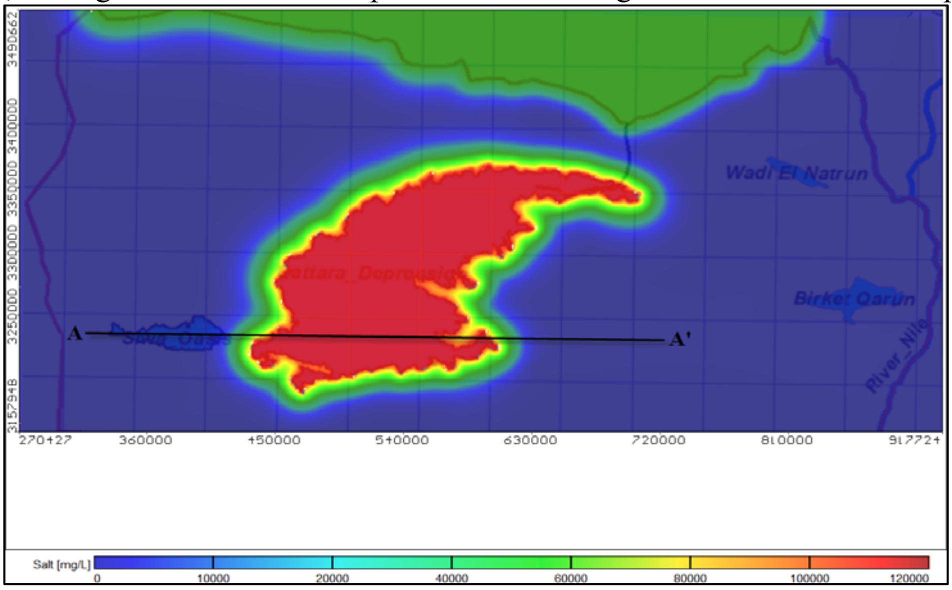

Fig. 9.Salinity diffusion out of Qattara Lagoon, in Moghra Formation after filling the lagoon at level -50.0 m

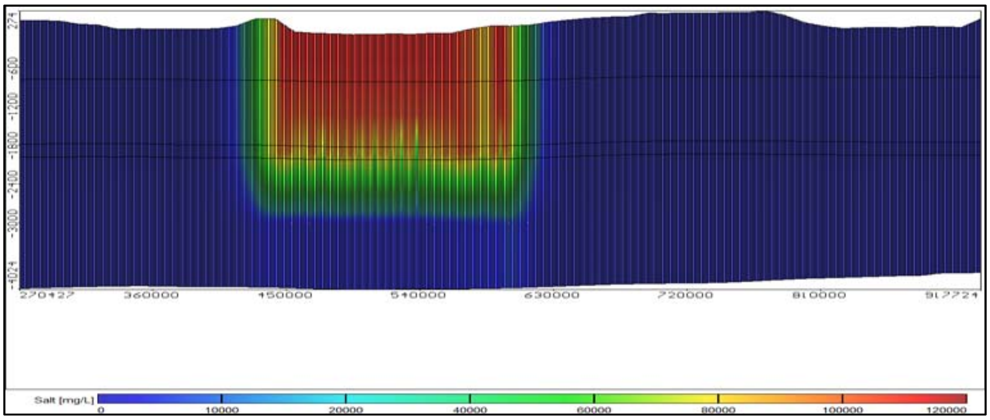

Fig.10. Section A-A' shows the salinity diffusion out of Qattara Lagoon after filling the lagoon at level -50.0 m

<u>Second Scenario: Lagoon filled at level of 60.0 m (b.m.s.l)</u>

Studying the effect of the filling Qattara Lagoon on the hydrogeological conditions, after 50 years when the lagoon water level is at 60 meters below mean sea level, is

repeated. The hydrogeological simulation is achieved every separate year during a period of 50 years to consider the accumulated saline water of the lagoon as a boundary condition. The study showed that there is salinity diffusion out of the Qattara Lagoon with salt concentration higher than ones of filling the lagoon at - 50 meters. Figure 11 shows the salinity diffusion out of the Lagoon in Moghra formation. The salinity diffused vertically to the limestone aquifer underlying Moghra Formation as shown in the cross section passing through the southern part of the lagoon. Figure 12 shows salinity diffusion in the vertical direction.
The vertical section shows that the salinity is diffused at a distance of 170 km towards the Delta, East the Qattara Lagoon, in Moghra and limestone aquifers and had a slight effect on sandstone aquifer.
Figures 13 and 14 present 3- show dimensional of salinity diffusion after filling the Lagoon at levels of -50 and - 60 meters, respectively. Figure 15 presents the steady state conditions of the groundwater table when the Lagoon water level is at - 50.0 meter below mean sea level.

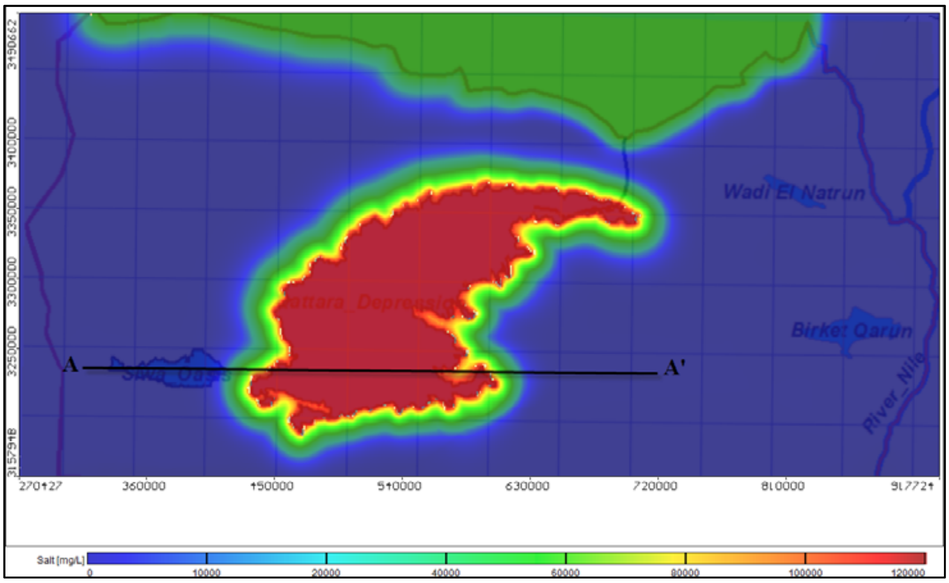

Fig. 11.Salinity diffusion out of Qattara Lagoon, in Moghra Formation after filling the lagoon at level -60.0 m

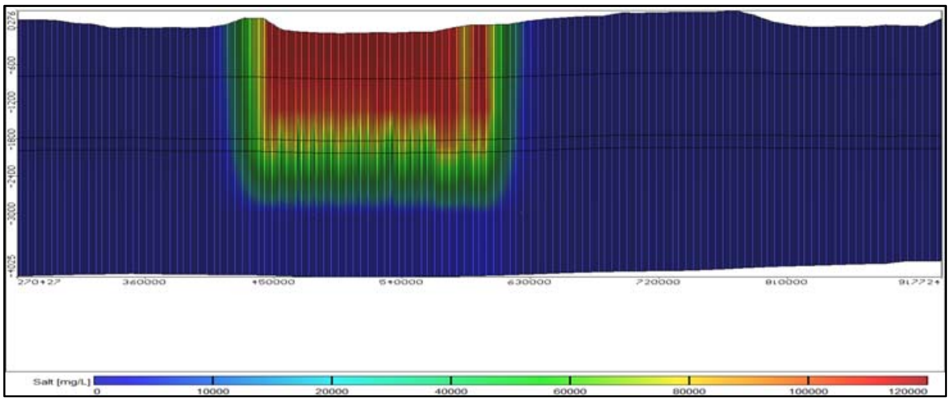

Fig.12. Section A-A' shows the salinity diffusion out of Qattara Lagoon after filling the lagoon at level -60.0 m

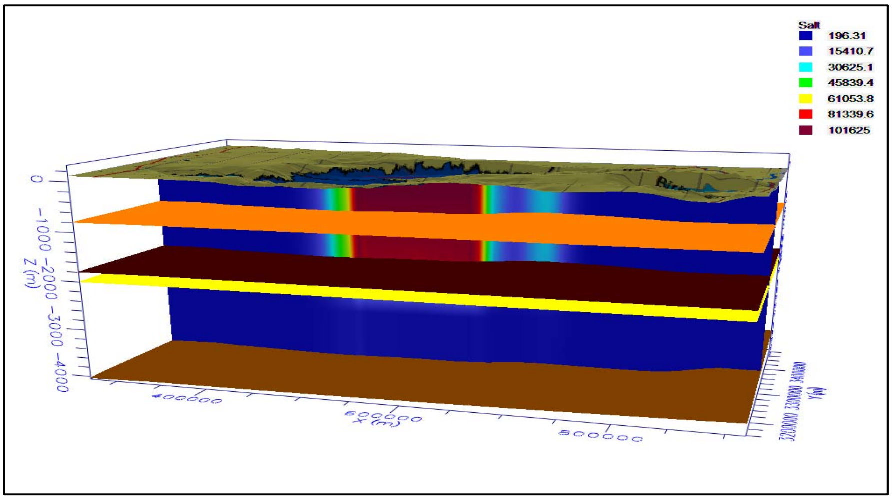

Fig. 13.Salinity diffusion after filling the Lagoon at level - 50

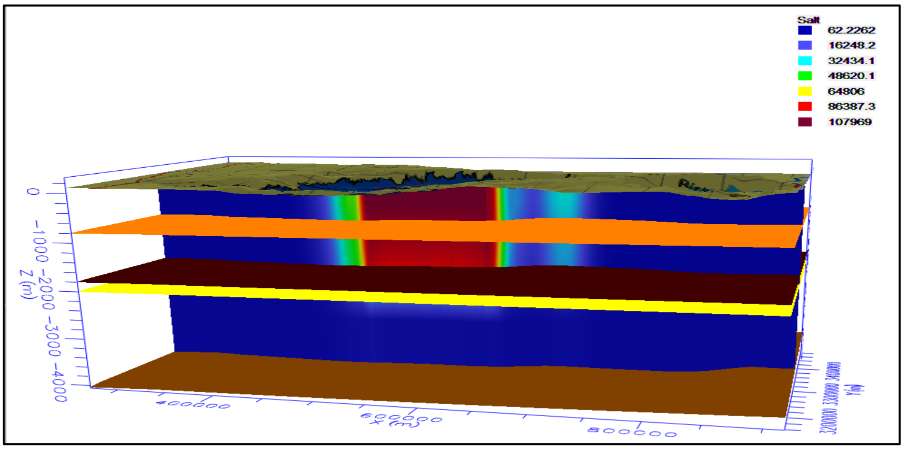

Fig. 14.Salinity diffusion after filling the Lagoon at level - 60 m

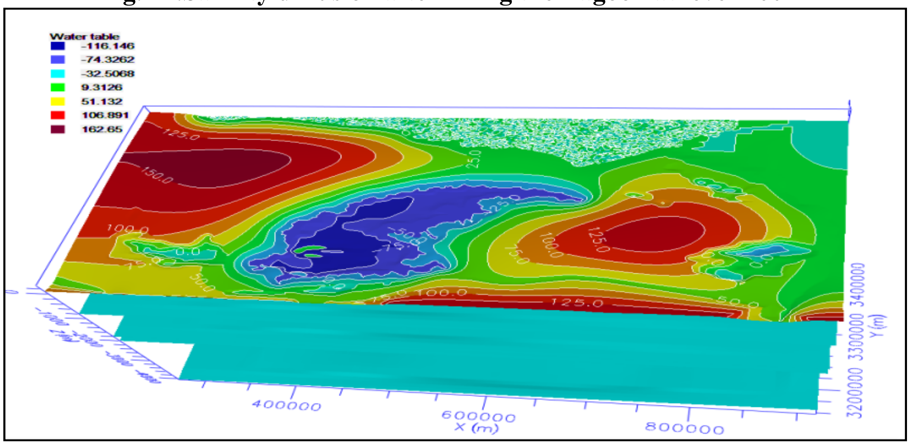

Fig. 15.Effect of filling the Qattara Lagoon at level - 50.0 m on the groundwater table (Steady state condition)

<u>Third Scenario: Simulation of the study area when having well fields between the lagoon and the Nile Delta</u>

Group of well fields is proposed, between the Qattara Lagoon and the Nile Delta, to investigate the effect of those wells on the salinity diffusion either in the groundwater aquifer, or in the Delta. They include a number of 90 wells with pumping rate 2400 m^3/day from each well. Three scenarios for the location of wells screens were studied;

first one was by locating the wells screen in the Moghra Aquifer as shown in Figures 16 and 17 while the second scenario is locating the screen in the Limestone Aquifer as shown in Figures 18 and 19 and the third one by locating the screen in sandstone aquifer as shown in Figures 20 and 21.

Figure 22 through Figure 25 present three-dimensional views of aquifers without having wells, aquifers having wells screens in Moghra Aquifer, in Limestone Aquifer, and in Sandstone Aquifer, respectively. Figure 26 shows the lagoon salt concentration (PPM) during 50 years for lagoon filling levels of 50 m and 60 m (b.m.s.l.). Figure 27 presents evaporation rate from the accumulated saline water (mm\year) during 50 years for lagoon filling levels of 50 m and 60 m (b.m.s.l.)

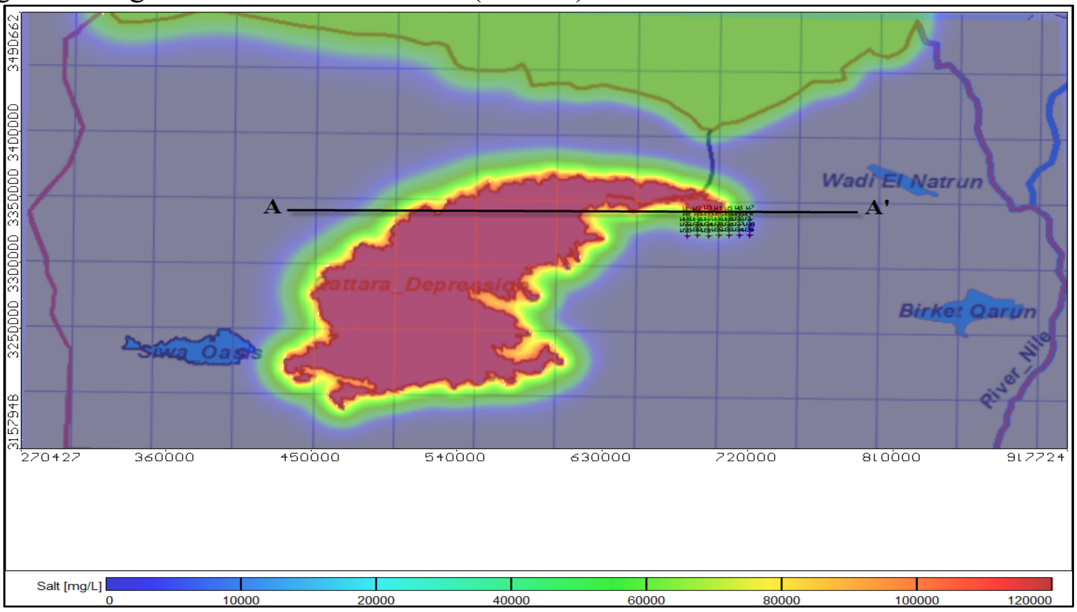

Fig. 16.Location of wells screen in Moghra Aquifer

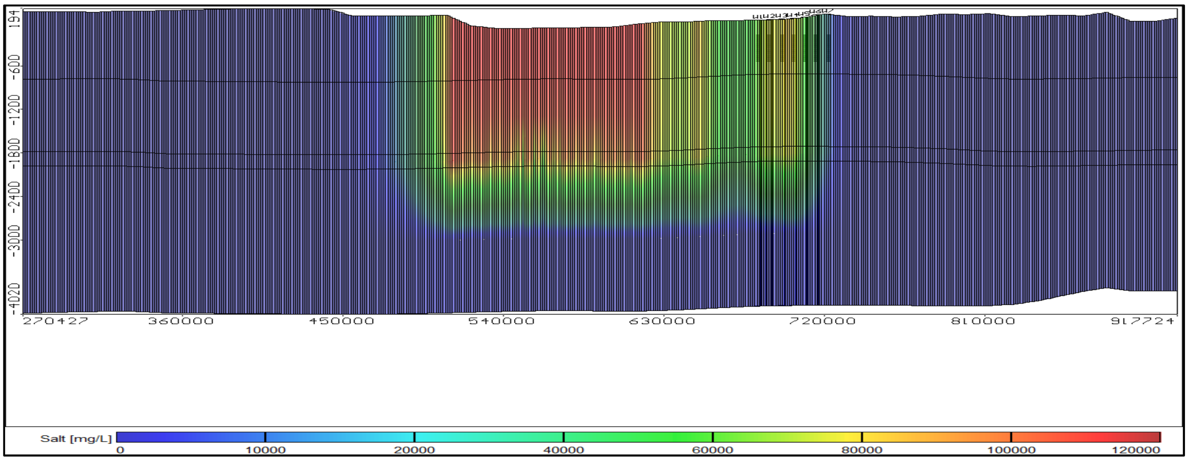

Fig. 17.Section A – A' showing the wells screen and the salinity diffusion in Moghra Aquifer

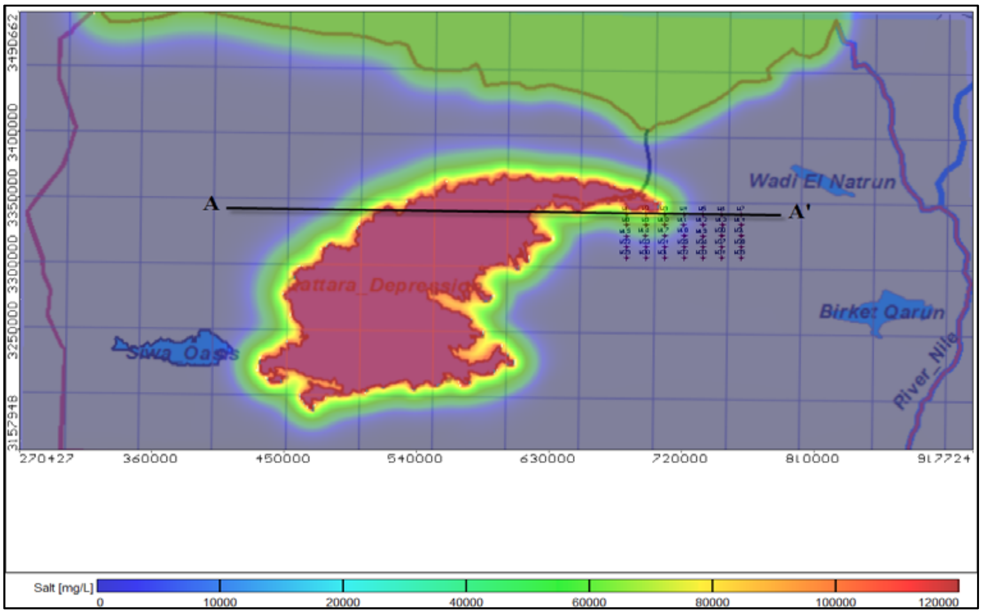

Fig. 18.Location of wells screen in Limestone Aquifer

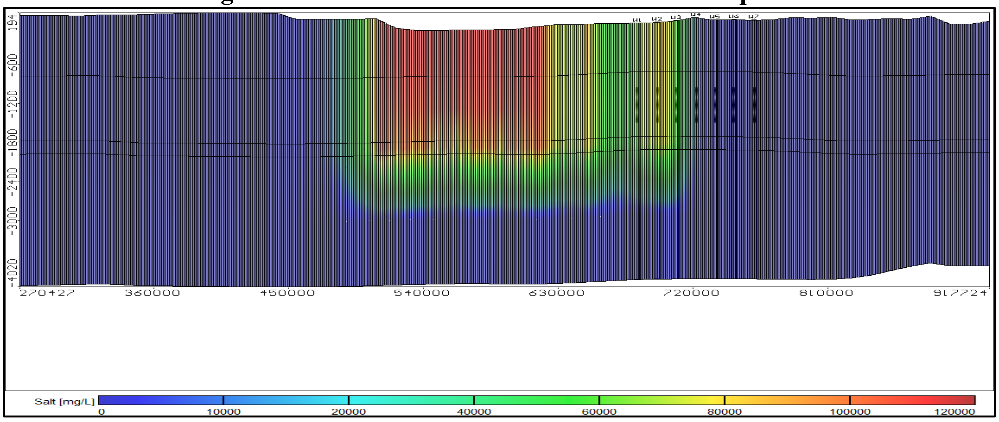

Fig.19. Section B – B' showing the wells screen and the salinity diffusion in Limestone Aquifer

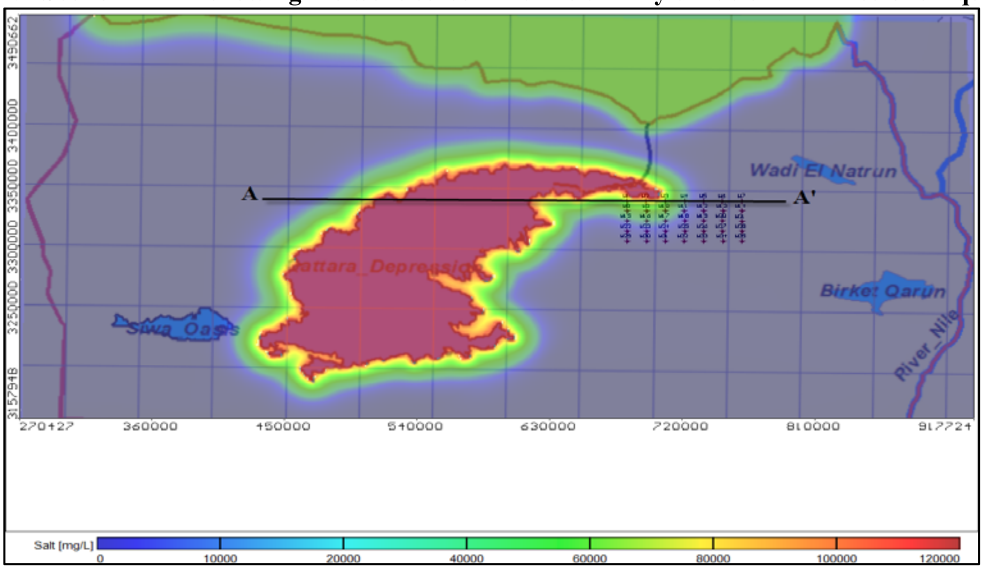

Fig. 20.Location of wells screen in Sandstone Aquifer

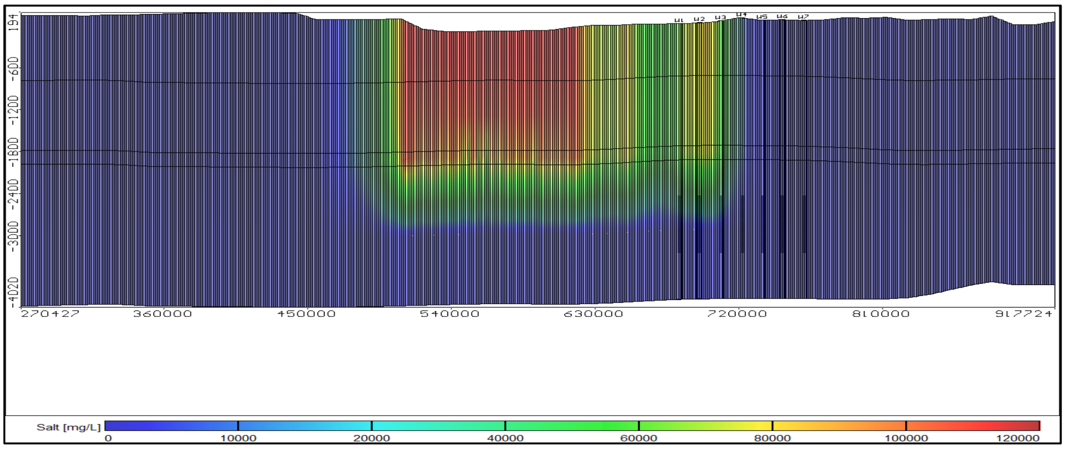

Fig. 21.Section C – C' showing the wells screen and the salinity diffusion in Sandstone Aquifer

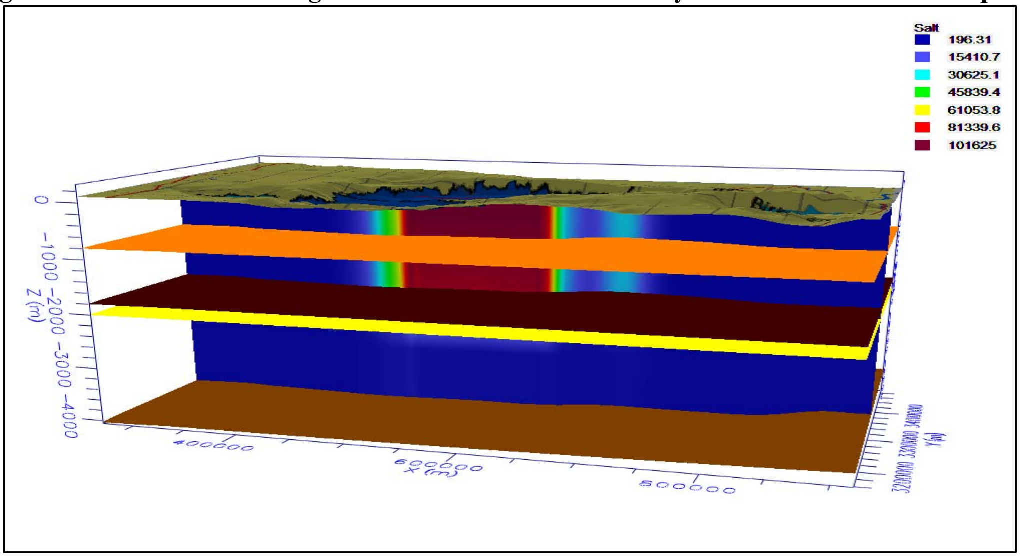

Fig. 22.Aquifers without wells

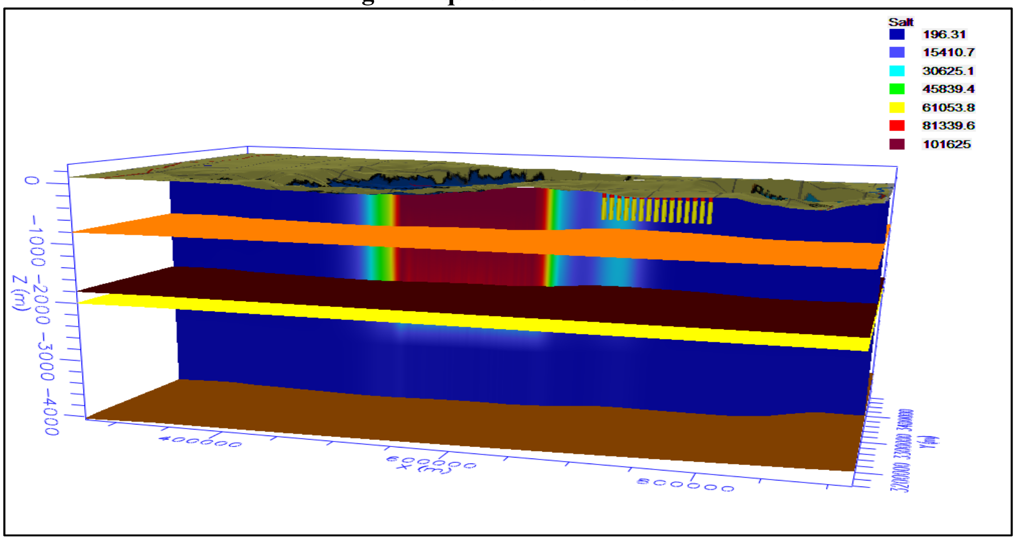

Fig. 23.Aquifers with wells screen in Moghra

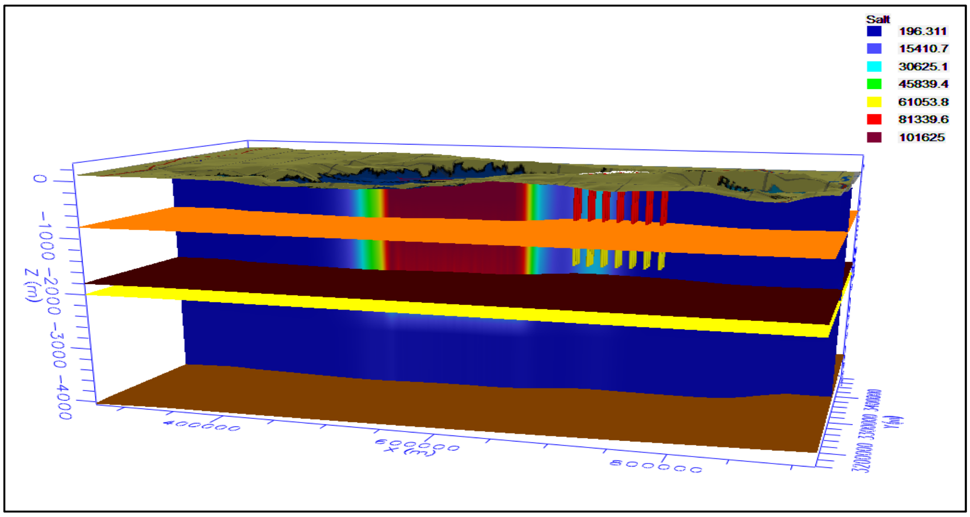

Fig. 24.Aquifers with wells screen in Limestone

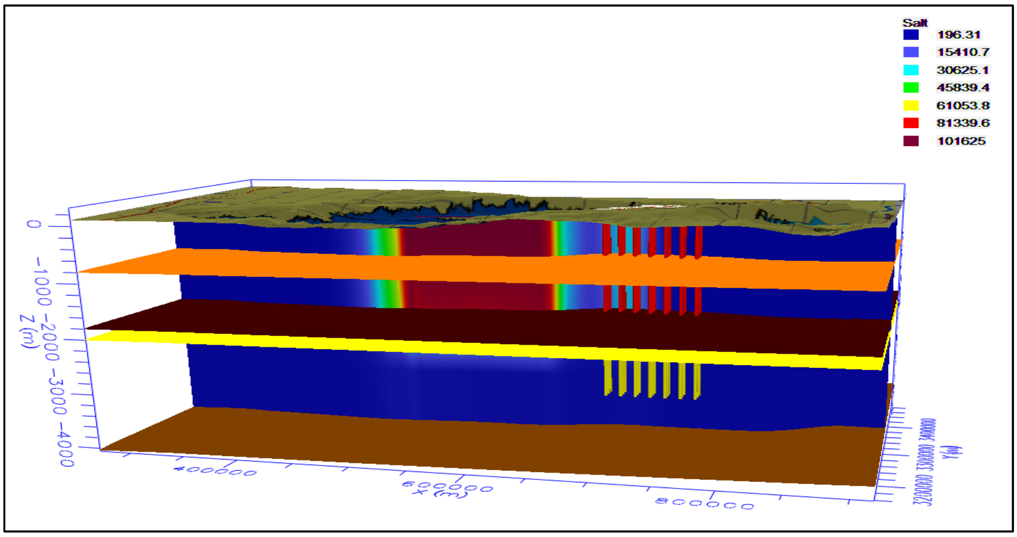

Fig. 25.Aquifers with wells screen in Sandston

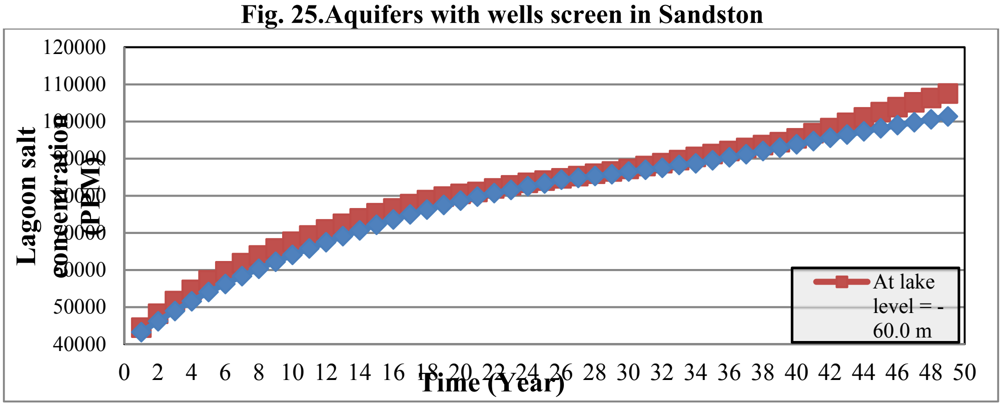

Fig. 26.Lagoon salt concentration (PPM) during 50 years for lagoon filling levels 50 and 60 m (b.m.s.l)

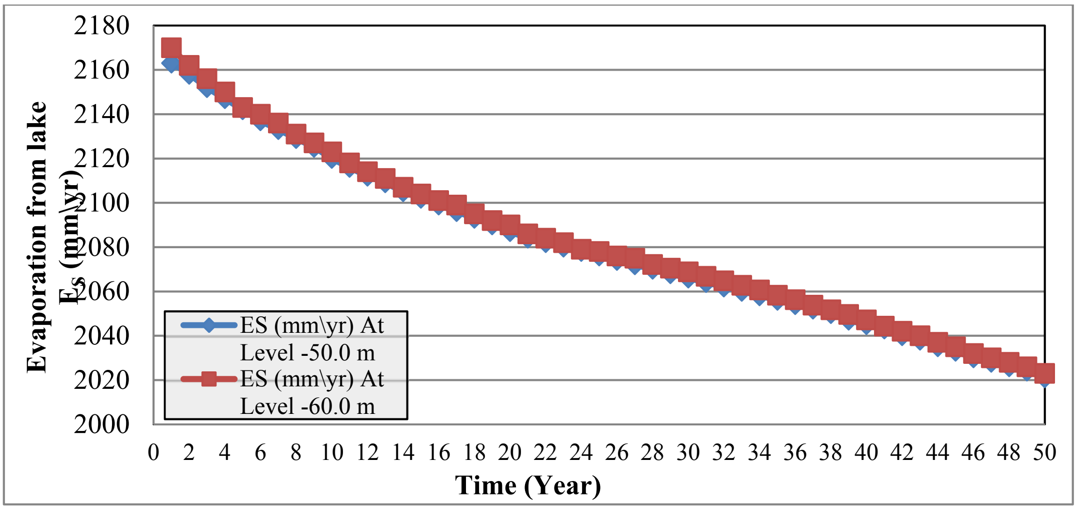

Fig. 27.Evaporation rate from the saline water in the lagoon (mm\year) during 50 years for lagoon filling levels 50 and 60 m (b.m.s.l)

Conclusion

A data bank, for Qattara Depression characteristics, has been built, using GIS, including morphological, meteorological, geological, and hydrogeological characteristics. Three-dimensional numerical model of the lagoon has been built using the code SEAWAT that is a density dependent module via the program, MODFLOW. The model showed that the filled lagoon will not affect the drainage capacity from the Nile Delta. Also, salinity in the lagoon will not diffuse to the Nile Delta even if well fields exist between the Qattara Lagoon and the Nile Delta. Results of the model showed that the sandstone aquifer will be, slightly, affected by the lagoon accumulated saline water because of the confining shale layer. Also, salinity, in the Sandstone Aquifer, does not travel outside the lagoon zone.

Acknowledgments

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