Sea Water Intrusion in Nile Delta in Perspective of New Configuration of the Aquifer Heterogeneity Using the Recent Stratigraphy Data

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Abstract: Egypt is considered an arid country. The main and almost exclusive source of water is the River Nile. The second source of water is groundwater whereas a variety of aquifer systems exist. Nile Delta aquifer is a large freshwater reservoir which is mainly replenished from irrigation activities. A proper management and development of such aquifers should be directed to satisfy water requirements. Groundwater development in the northern region is restricted due to the risks of inland movement of saline water/ fresh water interface to properly manage groundwater in this region. To achieve the proper management of groundwater resource in this region, it is important to understand the patterns of seawater movement and mixing between fresh and saline groundwater. In order to understand the salinity distribution and seawater movement, the actual heterogeneity and stratigraphy of the Nile Delta aquifer should be determined. The conventional modeling concept of the Nile Delta aquifer had assumed the aquifer as a homogenous media of graded sand and gravel with a clay cap at the top. In this study, assessment of recent stratigraphy of the Nile Delta aquifer is carried out using litho-logical data from the new drilled groups of multi depths wells. These wells has been designed and implemented especially to investigate the actual litho-stratigraphy and heterogeneity of the aquifer in the northern and middle region of the Nile Delta as a part of National Groundwater Quality Monitoring program, by Research Institute for Groundwater (RIGW). In this study, new configuration of the Nile Delta aquifer system has been obtained by assessing the Hydro-geological stratification of Nile Delta aquifer using ***RockWorks*** software. The study concluded that the northern part the aquifer is devolved into multi-layered aquifer system while in the southern part; the aquifer constitutes sand and gravel facies. Furthermore, this study assessed the Hydrochemistry status of the groundwater in the Nile Delta aquifer by using the results of chemical analysis of multi depths points (25- 650 m) of the National Groundwater Quality Monitoring network. This assessment confirmed that there is a multi wedge system for the sea water intrusion in the Nile Delta aquifer. The shape and direction of the wedges differs between the different layers of the aquifer according to the salinity and density of the groundwater present in each layer. This new multi system wedge can be used to model and simulate the new conceptual and configuration of the Nile Delta aquifer to fulfill proper groundwater development and management.

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Key words: Nile Delta aquifer, Aquifer Heterogeneity, Multi-layered aquifer system, Multi sea water intrusion wedge, Sea water intrusion, Groundwater quality.

1. Introduction

The Nile aquifer system in the Nile Delta is a huge groundwater reservoir extending to cover the entire Nile Delta region. Previously, most of the Nile Delta aquifer studies neglected the geological stratification inside the aquifer either for: 1. Lack of enough litho-logical stratification data for multi depths observation points, 2. Difficulty at that time of studying and simulating the aquifer with the detailed geological stratification.

The aquifer was only considered in all the previous studies as a sand and gravel aquifer with a variable clay top cap. Figure (1) shows the typical cross section of the Nile Delta aquifer that was used before in most of the aquifer studies.

According to this simple conceptual cross sections along the Nile Delta aquifer, the hydro-geological units that were considered in studying the Nile Delta aquifer before were summarized as follows:

a. Top unit of Holocene clay aquitard;
b. Quaternary and late Tertiary gravels and sands unit (aquifer);
c. Basal unit of Pliocene clay aquiclude.

In the last two decades, some authors have given attention to the geological history of the stratigraphy of the Nile Delta region due to the sea shore movement and the Nile river progresses and behavior during the recent thousands years. During these thousands years, the old deltatic of Nile river branches and the regression and transgression of the sea shore caused the subsystem aquifer in the Nile Delta.

Amer and Sherif, 1995, proposed and called a multi layer aquifer system for the middle of the Delta. Shata and Hefny, 1995, have also proposed a multi layer aquifer system based only on the historical geology and background of the Nile Delta region and their experiences in spite of the lack of drilling data and groundwater quality data from multi-depths monitoring point. The proposed section at that time is characterized by five continuous clay layers starting from the Mediterranean Sea and vanishing at Tanta. They proposed that the system is divided into five interacting aquifers in the northern parts of the Delta and then merge together into one aquifer in the southern parts. The proposed adjusted aquifer configuration for the middle of the Delta was first proposed by a single sea water wedge (figure 2). However, after some investigations of the same authors, it was adjusted to Multi Sea water Wedge (figure 3). They emphasized that the quaternary section is underlained by Pliocene clay beds which seem to be impermeable. In the southern part, the aquifer constitutes sand and gravel facies while in the northern part the aquifer is devolved into alternating thin bedded sand and clay designating general deltaic conditions. He added that the quaternary sediments acts as a multi-layered aquifer system and the Pliocene clays act as an aquiclude. This aquifer system is called the Nilotic aquifer system.

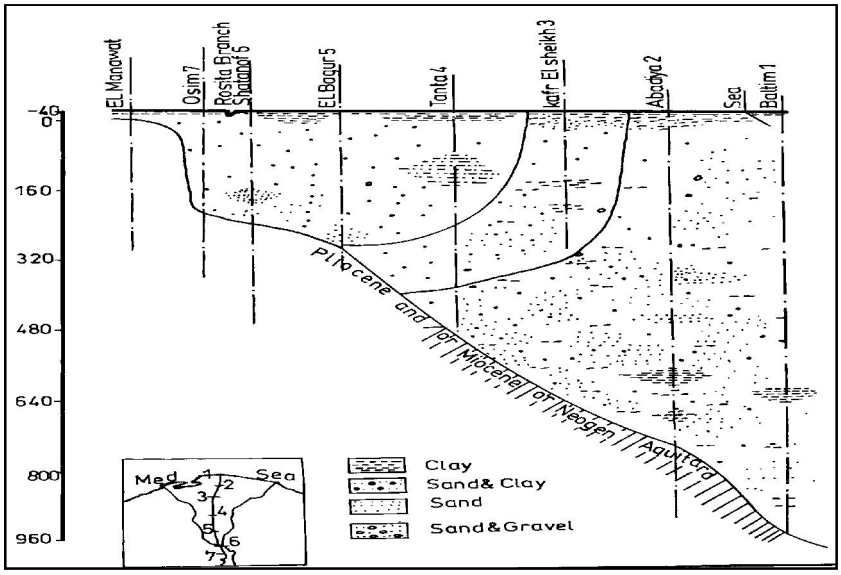

Figure 1: Old typical cross section of the Nile Delta aquifer.

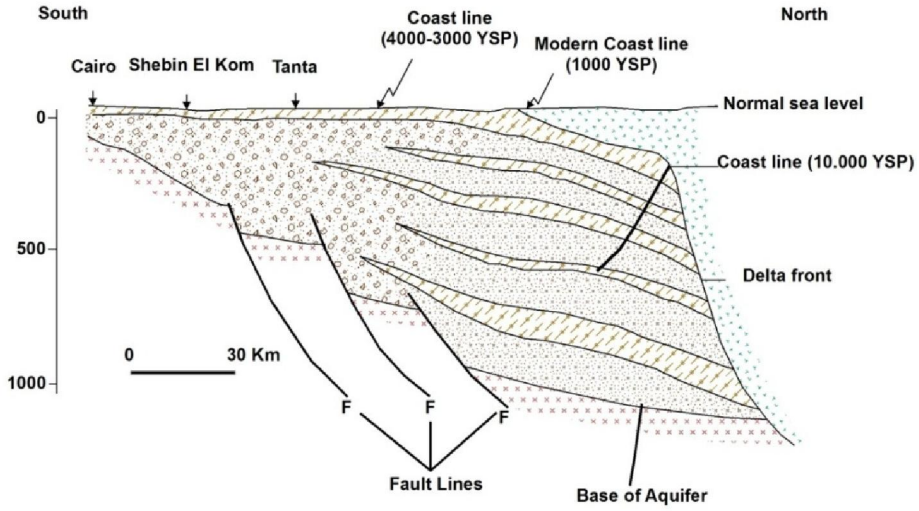

Figure 2: Proposed aquifer configuration for the middle of the Delta with Single Sea water Wedge (Shata and Hefny, 1995)

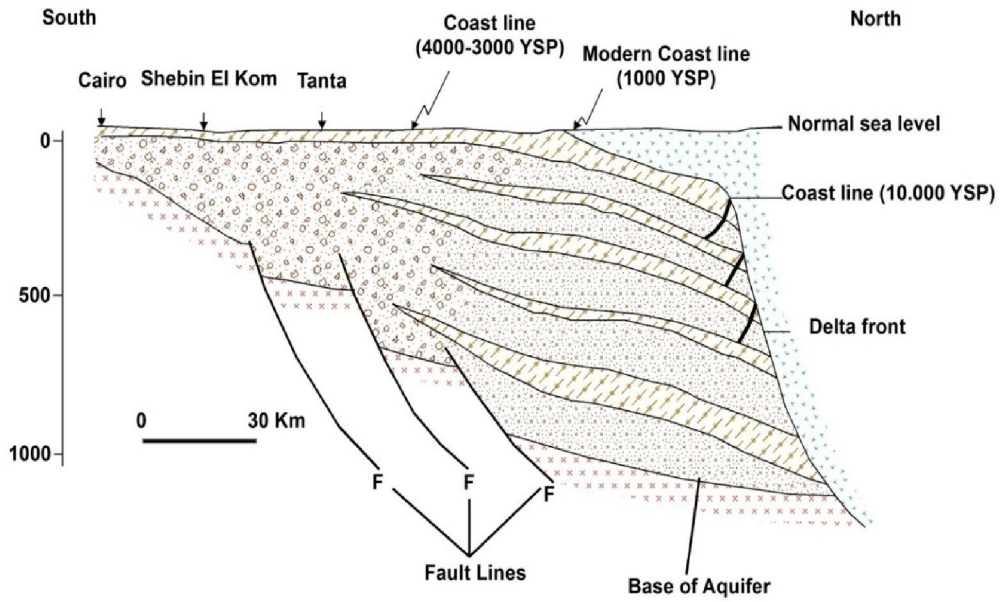

Figure 3: Proposed adjusted aquifer configuration for the middle of the Delta with Multi Sea water Wedge (Shata and Hefny, 1995)

In this paper, recent investigations and new implemented observation wells with multi depths tapping different zones into the Nile Delta aquifer were used to develop a newly verified aquifer configuration. To determine the actual hydro-geological stratification of the Nile Delta aquifer, a detailed assessment was performed based on a number of lithological stratification from the multi depths deep monitoring wells in the Nile Delta region. In addition to that, a detailed assessment of salinity distribution in the Nile Delta region will be conducted.

2. Detailed assessment for Hydro-geological stratification of Nile Delta aquifer using RockWorks software

RockWork software was First developed in 1985 by RockWare Inc, RockWorks is used by the mining, petroleum, and environmental industry for subsurface visualization, borehole database management as well as the creation of grids, solid models, calculating volumetric analysis, etc.

The strata of hydro-geological importance belong essentially to the Quaternary (about one million years ago), (Said, 1981). Data is collected and interpreted, from the litho-logical stratifications of the multi depths monitoring wells, to outline the hydro-geological environment of the Nile Delta groundwater aquifer. In this study RockWorks software is used to determine the variable stratifications in the Nile Delta aquifer.

RockWorks model for the Nile Delta region is prepared using all the multi depths available monitoring wells data, Lithology and stratigraphy, in the Nile Delta region. The depths of the observation wells used in this model range from 48 to 655 meters. Figure (4) shows the distribution of the Used Multi-depth observation points in RockWorks model. Figure (4) also presents the location of the cross section which will be generated by the model.

The model used the multi depths observation wells litho-logical data to generate a number of disconnected intercalated clay layers as shown in figure (5).

Results of using Rock Works model has been generated detailed horizontal hydro-geological cross section with the intercalated clay layers in the Nile Delta aquifer, as shown in figures (6). This detailed lithological stratigraphy is used to properly determine and understand the behavior of salt/fresh water interfaces and consequently properly manage the groundwater resource from possible expected sea water intrusion. This detailed generated cross sections are used to process a simplified vertical cross section of the different litho-logical stratigraphy the Nile Delta aquifer, Figure (7). This simplified cross section will be used in the modeling of the Nile Delta aquifer. This multi-layered aquifer system will be used to simulate the Nile Delta aquifer achieving the proper understanding and determining the behavior of saline / fresh water interfaces. Consequently, this assessment will be properly managing the groundwater resources under possible sea water intrusion.

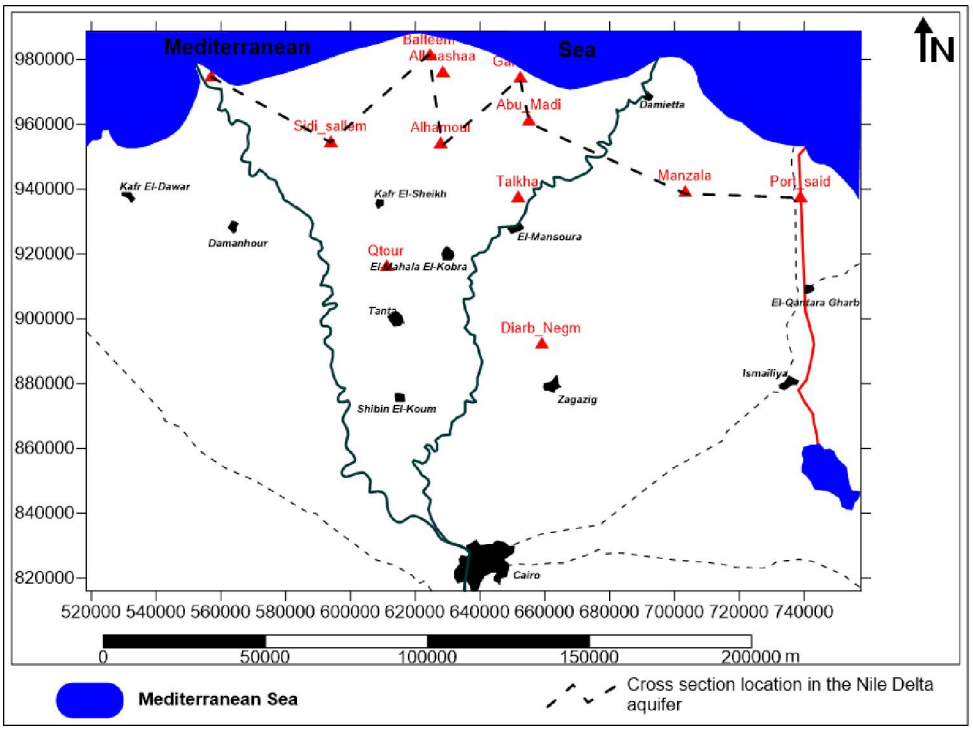

Figure 4: Used Multi-depth observation points in RockWorks model.

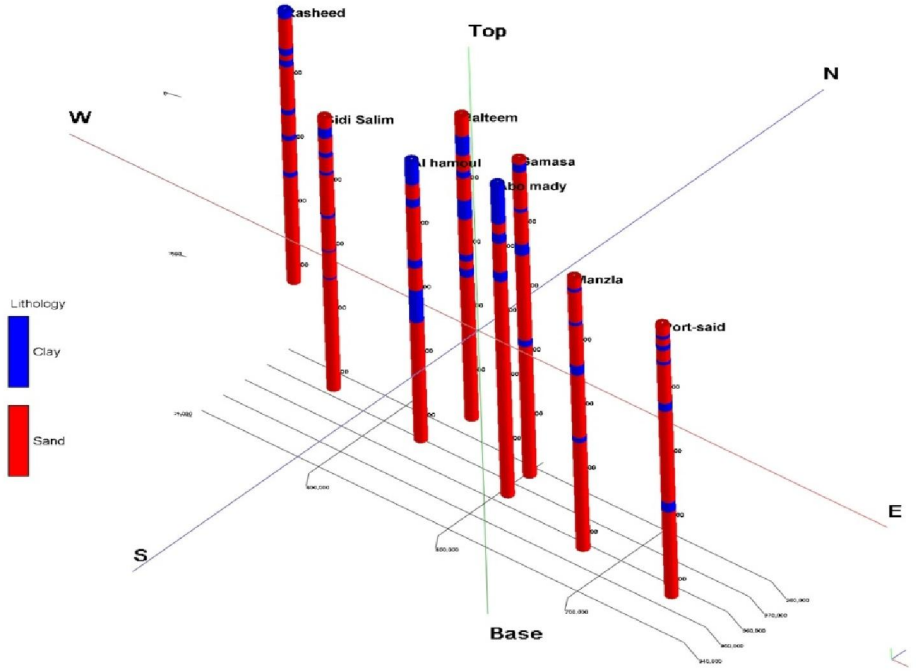

Figure 5: Different stratigraphy and lithology for the multi depths observation wells using the model

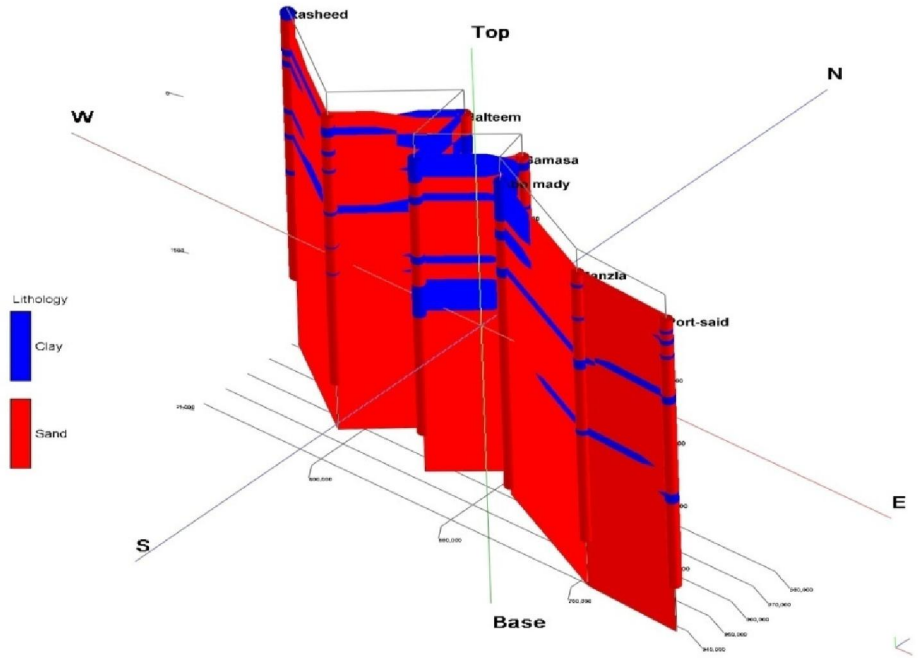

Figure 6: Generated detailed horizontal hydro-geological cross section in the Nile Delta aquifer

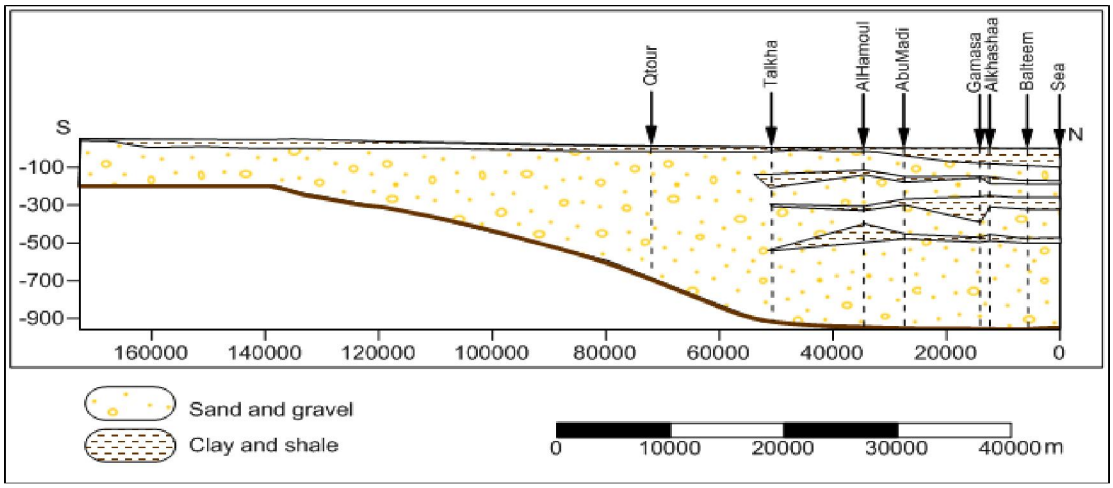

Figure 7: Generated simplified vertical cross section in the Nile Delta aquifer.

This study emphasizes that the new drilled wells in the northern and middle parts of the Delta, in addition to, the heterogeneity assessment gave reliable hydro-geological information about the actual multi-layers aquifer system in the Nile Delta aquifer. This new configuration of the multi-layered aquifer system in the Nile Delta, using the actual stratigraphy drilling data, proved the hypothetical concept which was proposed and discussed by Shata and Hefny,1995, based on historical geology of the Quaternary age and the strata of the hydro-geological of this study (millions of years).

3. Description of the Hydro-geological units of the Nile Delta aquifer

According to the generated cross section, the hydro-geological units of interest in studying the Nile Delta aquifer are as follows:

A. Top unit of Holocene clay aquitard
B. Multi layers aquifer system in the northern part of the aquifer consisting of four main zones separated by three thin clay layers. The aquifer system is formed of Quaternary and late Tertiary gravels and sands unit (aquifer). The multi layers aquifer system is changed to homogenous sand and gravel facies at the southern part of the aquifer.
C. Basal unit of Pliocene clay aquiclude.

Top unit of Holocene clay and fine sand (aquitard)

The top boundary of the deltaic deposits is a formation belonging to the Holocene (10,000 years). This formation is made up of a semi-pervious clay and silt aquitard. It acts as a cap for the main Quaternary aquifer. This unit represents the Nile alluvium deposits that belong to the Holocene time. It is generally heterogeneous and anisotropic. This unit mainly consists of Nile silt, sandy clay, clayey sand, occasionally with fine sand intercalations (Farid, 1980). The clay content in the topsoil layer ranges between 5 and 50 percent, while the silt between 5 and 95 percent in most of the area. The thickness of this top layer varies generally from 40 m in the north middle and West Delta region, increase towards the East to reach 90m near Damietta and totally absent at some points as in the Nile Delta fringes and turtlebacks. According to the field data compiled and processed by (RIGW, 1980). The average vertical hydraulic conductivity of the clay cap is 2.5 mm/day, and the average horizontal hydraulic conductivity is between 50 and 500 mm/day (RIGW, 1992). From the new implemented and existing monitoring observation points, the clay thickness contour map for the Nile Delta aquifer is created as shown in figure (8).

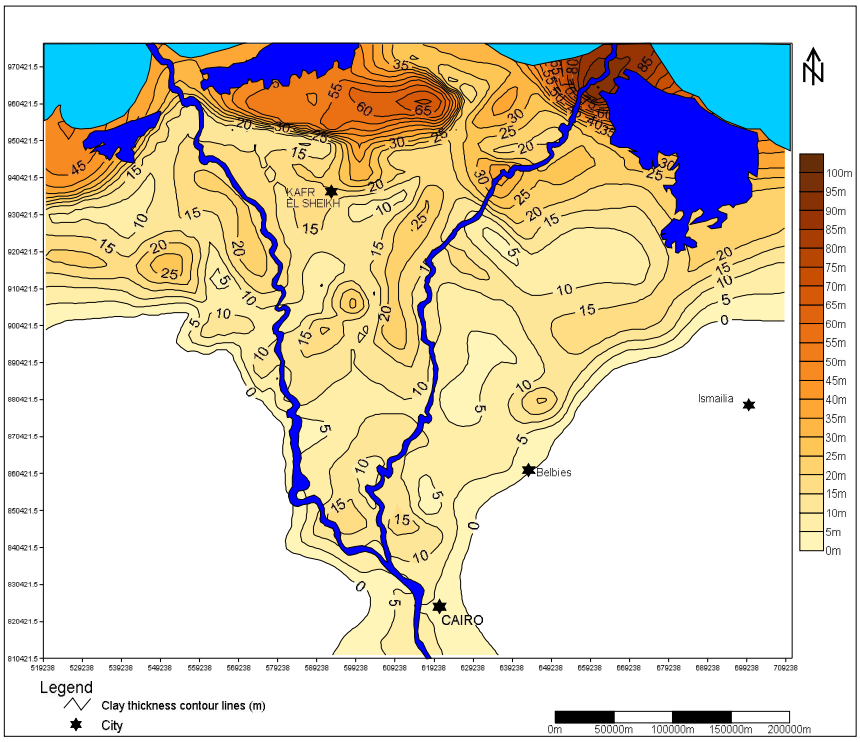

Figure 8: Clay thickness contour map for the Nile Delta aquifer

a. Quaternary and late Neogene gravels and sands unit (aquifer)

This is a thick unit consists of coarse sand and gravel with a number of clay lenses intercalations. It underlies the Holocene top clay layer and overlies the lower marine clay deposits of Neogene impervious clay. It belongs to Pleistocene and its lower part to late Pliocene time. The thickness of this strata increases northward. It ranges between about 150 m. at El-Kanater El-Khairiya in the south and more than 500 m. near Tanta increasing northward until reaching more than 1000 m near the coast. Also, the aquifer decreases in thickness towards the southeastern and western fringes of the Nile Delta.

The hydraulic conductivity "K" of these aquifer sediments increases northward and eastward. It ranges between less than 50 m/day in the south of El-Bagur and increases northward to be more than100 m/day. The porosity of these sediments varies between 25% and 40% (Farid, 1980). The slope of the aquifer at its base is about 4 m/km. This slope is about 40 times that of the ground surface as well as the hydraulic gradient.

This unit forms the main groundwater aquifer in the Nile Delta region, which is considered a semi-confined (leaky) aquifer in most Nile Delta region where the clay cap covers the aquifer. Unconfined (phreatic) groundwater aquifer is present in the fringes of the Nile Delta where the quaternary sediments are not covered with clay cap. Leakage and infiltration from the surface water system are the main processes of feeding the aquifer with a very great recharge rate.

However, the groundwater in this aquifer is discharged naturally; along some areas on the Rosetta branch and to the western desert, Suez canal, and the Mediterranean Sea; or mechanically by pumping for irrigation, drinking, and/or industrial purposes.

b. Basal unit of Pliocene clay (aquiclude)

The base of the deltaic deposits rests unconformable on a thick and dense clay section, which belongs to the Pliocene age. This clay section acts as an aquiclude, (Said, 1990).

4. Assessment of Salinity distribution using the National Groundwater Quality Monitoring points in the Nile Delta region

Quantitative aspects of groundwater have been investigated with extensive attention in Egypt for many years. Qualitative issues started to gain attention during recent years and will continue to do so as Egypt's scarce groundwater resources need to be managed in an environmentally sound way. Environmental management of groundwater resources requires information on groundwater quality (NAWQAM / RIGW, 2008). A groundwater quality monitoring network and information system is a major tool for development and support of environmental management of water resources. Thus Egypt has established the National Groundwater quality program in 1998, which was funded by Egypt- Dutch project (NGWQMP).

The goal of the National Groundwater Quality Monitoring program (NGWQMP) is to provide information needed for planning, management, and development of ground-water supplies to meet current and future water needs and ecosystem requirements. This information provided from National Groundwater Quality Monitoring program since 1998 is used in this study to assess the groundwater quality in the Nile Delta region specially the coastal zone which is covered by new multi depth monitoring points during the last four years as base line for future monitoring of the impacts of sea water intrusion and sea level rise. Figure (9) shows the National Groundwater Quality Monitoring Network points (NGWQMN) in the Nile Delta region.

In this work, groundwater samples were collected from the observation points in National Groundwater Quality Monitoring Network taping the Quaternary aquifer at different zones ranging from 25 to 650 m from the ground level. These samples were subjected to complete chemical analyses to assess the vertical salinity distribution of the different layers of the aquifer and determining the shape of the wedge system for the sea water intrusion in the Nile Delta aquifer.

The Total dissolved solids, (TDS), is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular (colloidal sol) suspended form. TDS is the total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water, expressed in units of mg per unit volume of water (mg/L), also referred to as parts per million (ppm).

A complete salinity assessment was conducted to determine the vertical and horizontal distribution of the groundwater salinity in the Nile Delta aquifer. Wide range of variations were detected for total dissolved solids in the collected water samples from multi depths Sampled Points in Nile Delta ranges from 4900 to 108000 PPM representing the horizontal and vertical distribution of the subsurface water in the Quaternary aquifer in the Nile Delta region. Table (1) shows the classification of water salinity (Hem, 1985) to help in determining the seawater intrusion wedge in Nile Delta aquifer based on actual data. These variations are well illustrated as salinity changes in different depths of the Nile Delta aquifer as shown in Figure (10).

The existence of this brine groundwater in the northern region of delta reveals that this is old sea water trapped in these layers of the coastal zone during the transgression of the sea for thousand years of the geological history of the Nile delta aquifer. This trapped water was exposed for evaporation process resulting in increasing the salinity more the salinity of the sea water. This phenomenon needs detailed study using isotopes techniques and age tracer such as radio carbon(C-14) and krypton.

Table (1), Based on Hem, 1985 for water salinity classification:

Fresh water	0 - 1000 PPM
Brackish water	1000 - 3000 PPM
Moderately saline	3000 - 10,000 PPM
Very saline	10,000 - 35,000 PPM
Brine	more than 35,000 PPM

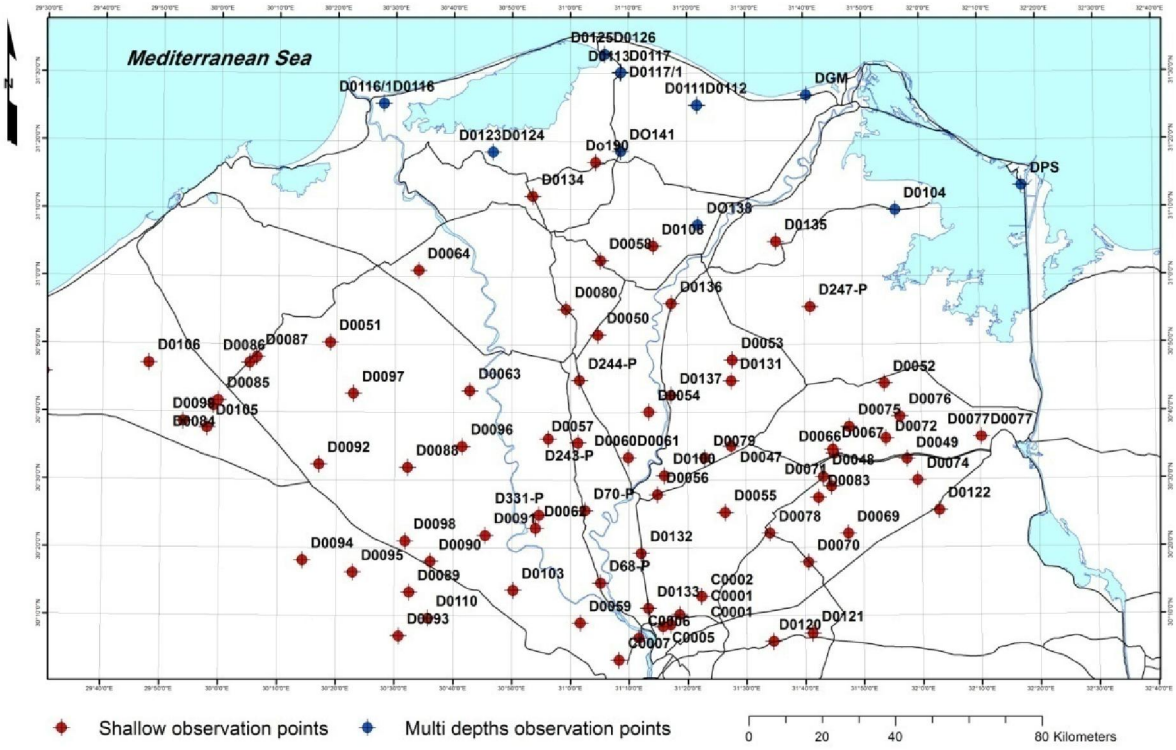

Figure 9: National Groundwater Quality Monitoring Network points in the Nile Delta region

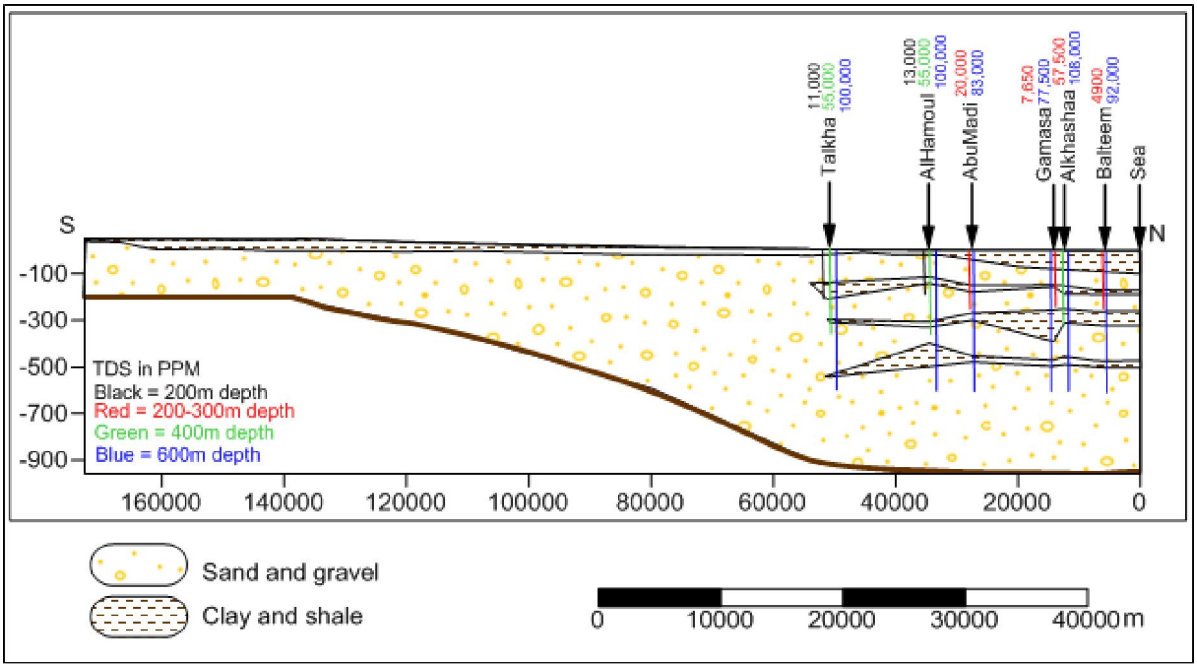

Figure 10: Total Dissolved Solids (TDS) distribution along cross section in Nile Delta region

As a conclusion of the detailed assessment of salinity distrubution along the Nile Delta aquifer. Figures (11 to 14) summarizes a complete picture of the salinity distribution for the different layers of the Nile Delta aquifer, from shallow depth (up to 125 m), 200 m, 400 m and 600 m.

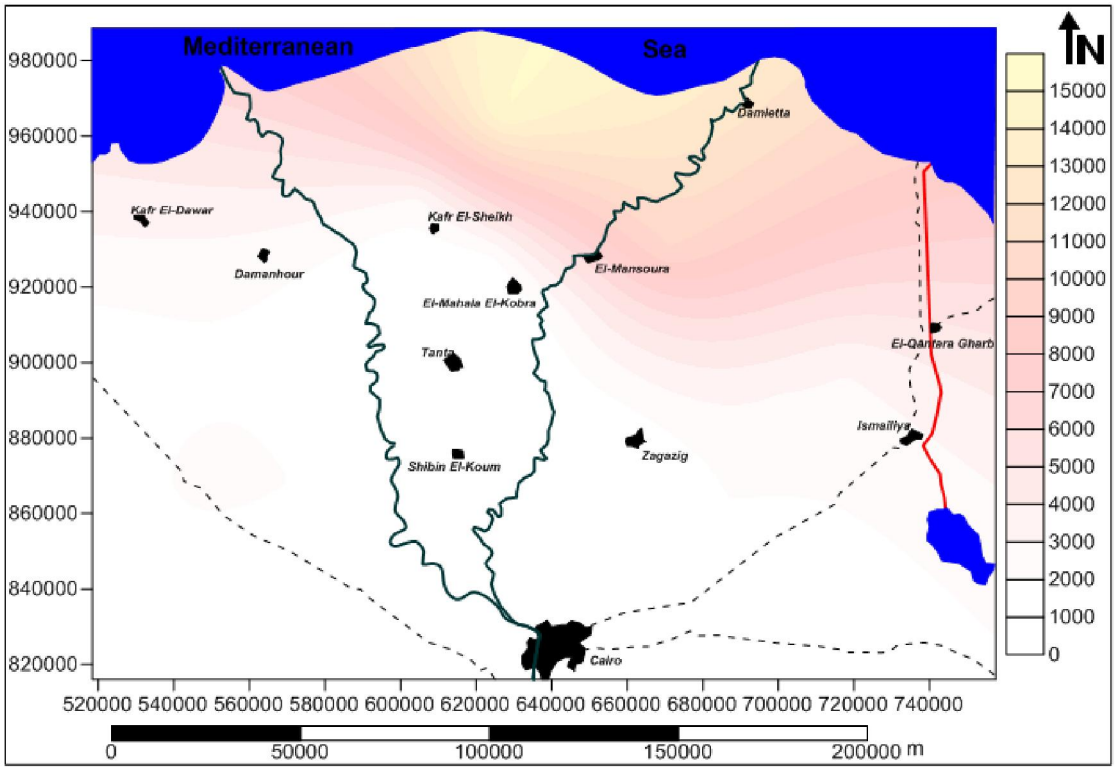

Figure 11: Salinity distribution for shallow groundwater in Nile Delta aquifer (up to 125m)

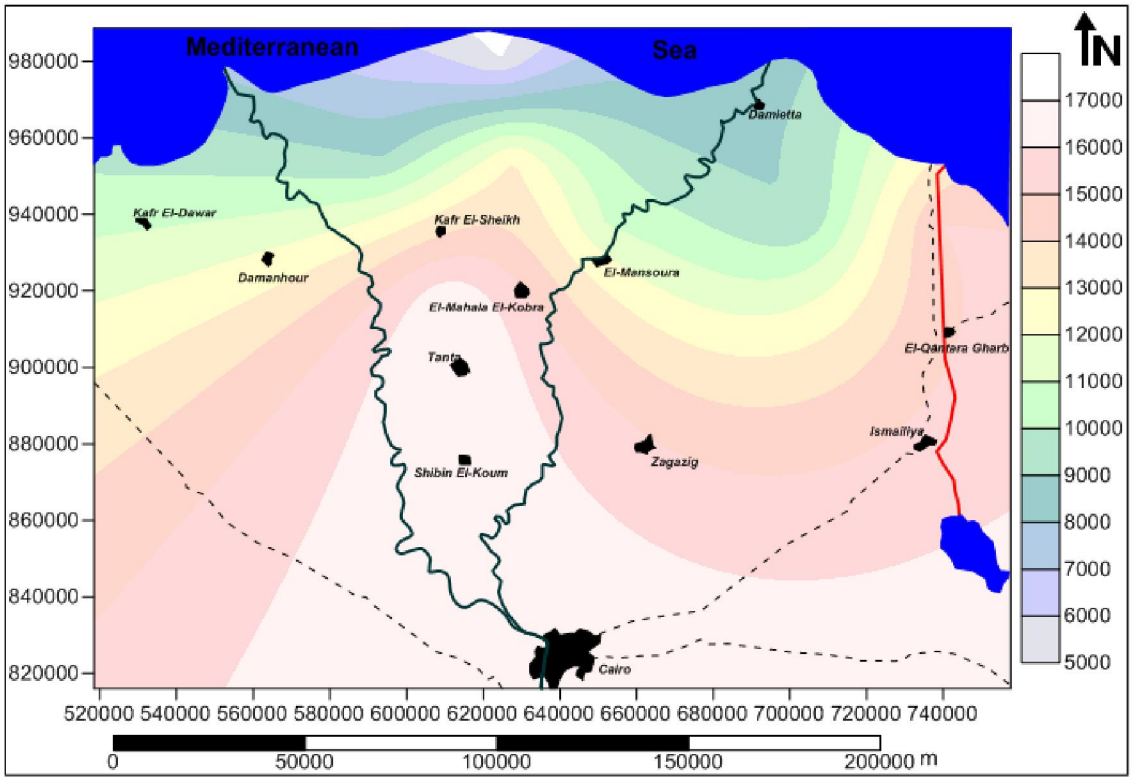

Figure 12: Salinity Distribution for 200 meter depth groundwater in Nile Delta aquifer

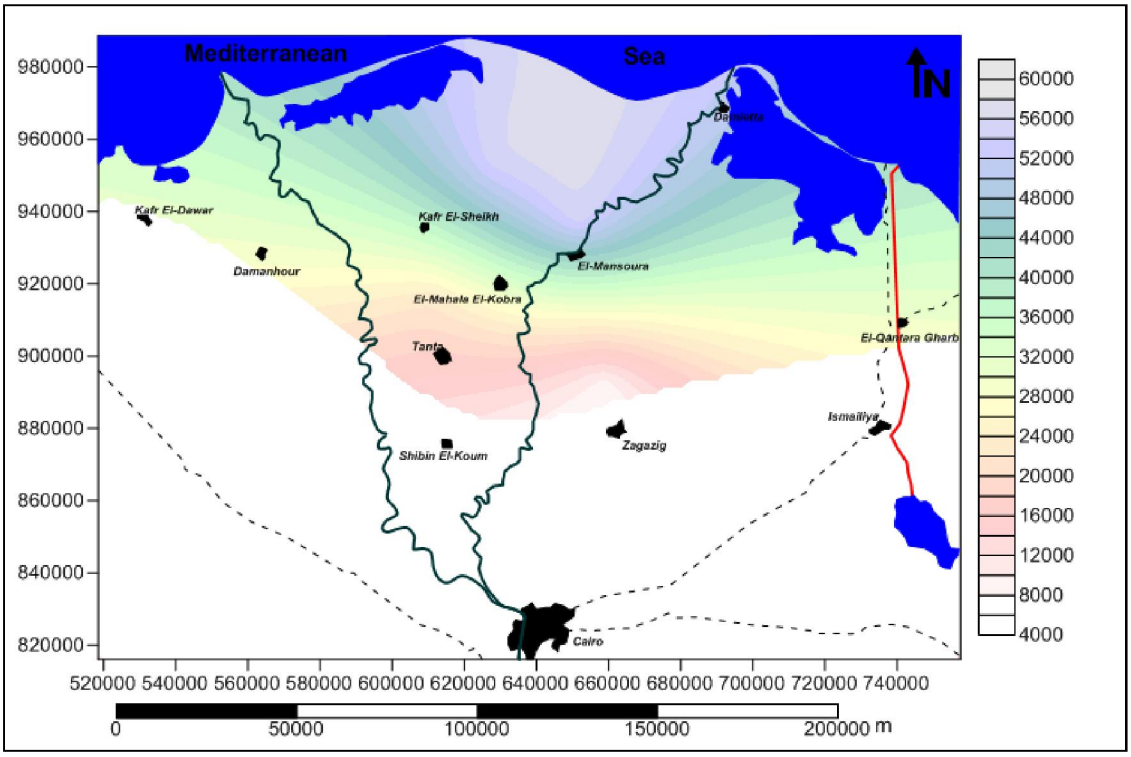

Figure 13: Salinity Distribution for 400 meter depth groundwater in Nile Delta aquifer

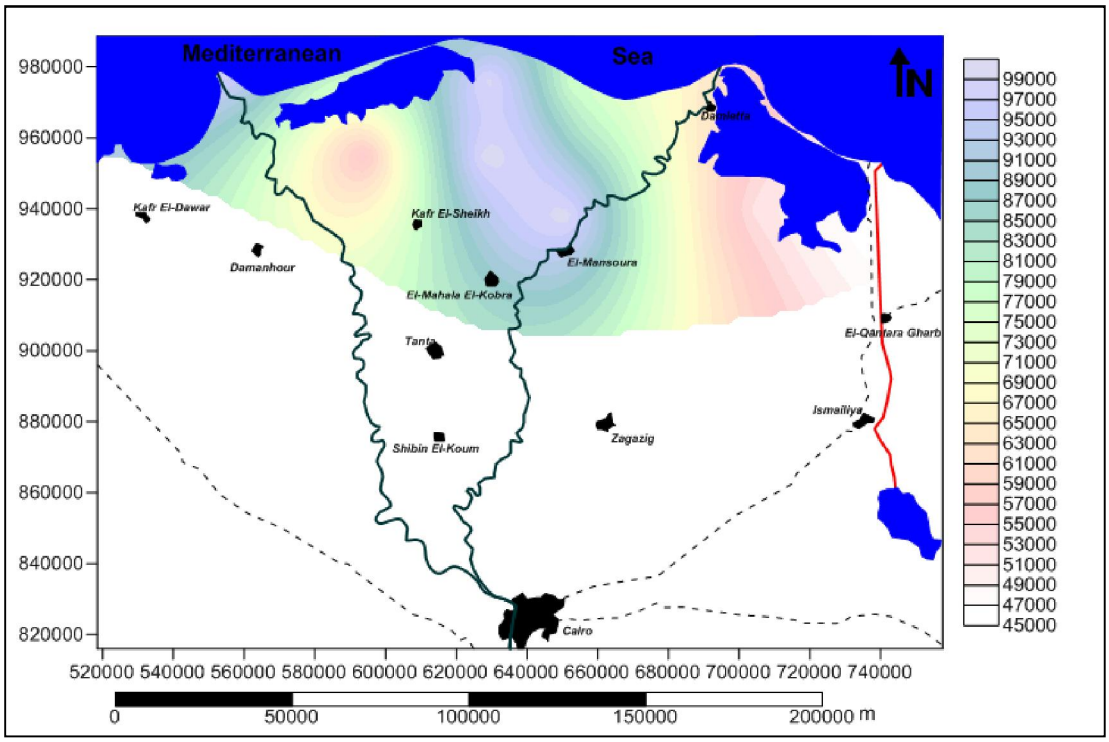

Figure 14: Salinity Distribution for 600 meter depth groundwater in Nile Delta aquifer

From this assessment of the salinity distribution based on actual data and information extracted from multi-depths observation points covering the northern and middle region of the Delta, it can be concluded that:

- Northern part the aquifer is devolved into multi-layered aquifer system while in the southern part, the aquifer constitutes sand and gravel facies as homogenous aquifer,
- The occurrence of large variation of the salinity values in the different layers of the aquifer, especially in layers more than 400 m depths, which contains salinity values more than sea water value has affected the shape of the saline wedges in the multi layer aquifer.

These two factors yield to the fact that there is a multi wedge system for the sea water intrusion in the Nile Delta aquifer. Figure (15) shows the multi wedge system for the sea water intrusion in the Nile Delta aquifer. The shape and direction of the wedge differs between the different layers of the aquifer according to the salinity and density of the groundwater present in each layer. The system shows the occurrence of four saline wedges intruding from the sea side towards the aquifer. At the first and second layers of the aquifer, contain the fresh and brackish groundwater successively, the shape of the wedges are in the regular shape where saline water is intruding into less dense water. The shape of the first two wedges shows that the saline water is crawling under the fresh water as a result of the difference in density values. While the shape of the last two wedges are different from the regular sea water wedge as the sea water is intruding into more saline water and consequently, more dense water. When the sea water wedge is intruding into brine water, it floats over the brine water (higher in density) as the brine water crawls under the saline water according to the difference in density.

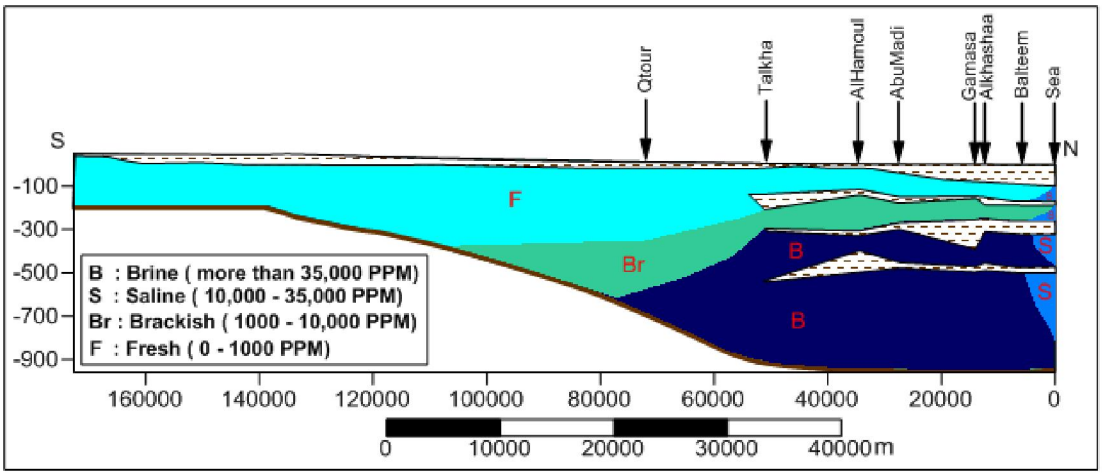

Figure 15: Multi wedge system for the sea water intrusion in the Nile Delta aquifer

The new configuration of the Nile Delta aquifer with the new multi layers aquifer and multi system wedge shows that the fresh available groundwater stored in the aquifer mainly exists in the first layer extending to the South of Delta. Brine groundwater comprises a great share of the stored groundwater in the Nile Delta aquifer. The rest of the stored groundwater in the aquifer is brackish groundwater. Furthermore, the saline groundwater is only found adjacent to the sea resulting from the intrusion of the seawater into the groundwater, based on Hem, 1985. These results will affect the groundwater development in the Nile Delta aquifer in the northern region of the Delta to achieve a proper environmental management of the groundwater resources.

Conclusions and recommendations:

Detailed assessment for Hydro-geological stratification of Nile Delta aquifer using RockWorks software was used to determine the variable stratifications in the Nile Delta aquifer using the new data collected and interpreted, from the litho-logical stratifications of RIGW multi depths monitoring wells tapping different zones into the Nile Delta aquifer which ranges from 48-650 meters.

This study concluded a new configuration of the Nile Delta aquifer heterogeneity using the actual recent stratigraphy of the new drilled wells in the northern and middle parts of the Delta and the reliable geological and hydro-geological information about the concept of multi layered aquifer system (Shata and Hefny, 1995). The study concluded that in the northern part the aquifer is devolved into multi-

layered aquifer system while in the southern part, the aquifer constitutes sand and gravel facies as a homogenous aquifer.

Hydrochemistry assessment of multi depths points in National Groundwater Quality Monitoring Network were performed using groundwater samples collected from the multi depths observation points taping the Quaternary aquifer at different zones ranging from 25 to 600 m from the ground level.

The results of the hydrochemistry assessment conclude that extreme salinity recorded is clearly appearing in the depths of 600 meter reaching 100,000 ppm; where the concentration of salt content exceeds the Mediterranean Sea water and the water is clearly brine. It is clear that the salinity increases with depth.

In this study, a multi wedges system for the sea water intrusion in the Nile Delta aquifer is determined depending on the large variation of the salinity values in the different layers of the aquifer and the heterogeneity assessed in the aquifer.

Also, the new multi system wedge shows that the fresh available groundwater stored in the aquifer mainly exists in the first two layers. Brine groundwater comprises a great share of the stored groundwater in the Nile Delta aquifer. The rest of the stored groundwater in the aquifer is brackish groundwater which can also be utilized nowadays for different purposes as an addition and supplementary water resources to minimize the gab in water demand and availability.

This study developed a newly verified aquifer configuration and multi wedge system to be used in simulating an actual detailed numerical model for the Nile Delta aquifer to achieve the proper management of the groundwater in the Nile Delta region.

From the results and conclusions which have been achieved in this study, important recommendation and activities for proper management of this important region should be carried out as summarized below:

- Using a reliable groundwater model to simulate this complex situation of multi-layered aquifer system and multi wedge system for the sea water intrusion in the Nile Delta aquifer.
- Design and implementation of more mutli-depths observation points along the coastal aquifer to have more details for the coastal aquifer to be used to determine the relationship between the aquifer and the sea.
- investigate the source and the age of this brine water evolved in the Nile delta aquifer to have a proper understanding of the groundwater aquifer systems and to achieve future properly management.
- Formulate strategies and policies to develop this aquifer under the risk of climatic changes / sea level rise and decreasing the inflow of the Nile River.

References:

Amer, A., and M.M. Sherif, 1995, “Behavior of sea water intrusion in the Nile Delta aquifer “, First interim report.

Farid, M.S.M., 1980, Nile Delta Groundwater Study, M.Sc. Thesis, Faculty of Engineering, Cairo University.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey, Water Supply Paper 2254. https://en.wikipedia.org/wiki/Rockworks.

NAWQAM / RIGW, 2008, National water quality monitoring component, Final technical report, WQ-TE-0812-023-FN, National Water Quality and Availability Management (NAWCAM).

RIGW, 1980, Studying the safe yield of the groundwater aquifers in the Delta and Nile valley Project.

RIGW, 1992, Hydrogeological map of Egypt, Nile Delta Scale 1: 50000000 Cairo, Egypt.

Said R., 1990, "The Geology of Egypt". For The Egyptian Gen. Pet. Cor., Conoco Hurghada Inc., And Repsol Exploracion, Balkema, Rotterdam, Netherlands.

Said, R., 1981, “The Geological Evolution of The River, New York, NY, USA, Springer – Vertug. V.44, p381.

Shata, A., and Hefny, K., 1995, Strategies for planning and management of groundwater in the Nile Valley and Nile Delta in Egypt. Working Paper Series No. 31-1, Strategic Research Program (SRP), NWRC-MPWWR, Cairo.

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