Applying Integrated Ground- And Surface- Water Management (Case Study: Nubaryia Basin, West Delta, Egypt)

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Abstract: This research was initiated with the objective of evaluating the current water potential and predicting the future groundwater potential till 2020in order to solve the shortage of water problems, especially in the ends of the Nubaryia Canal and its branches. A numerical Groundwater flow model MODFLOW package was employed to study the aquifer system of the Nubaryia Basin after calibrating it against historical groundwater heads that were observed during the last 18 years. The study area was divided into seven sub surface areas (zones) with the help of geographic information system (GIS). Confident with the calibration process, the model was used to simulate three different development scenarios to determine the safe withdrawals locations and quantities. The results indicated that the region is promising in terms of the presence of groundwater and the sustainable recovery of groundwater levels throughout the prediction period. Accordingly, it was recommended to drill wells to solve the shortage of water in the study area.

[El Arabi N. E. and Morsy W.S. **Applying Integrated Ground- and Surface- Water Management (Case Study: Nubaryia Basin, West Delta, Egypt).** *J Am Sci* 2013;9(6):43-53]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 6

Keywords: Integrated management, Mathematical model, Ground and surface water, Potential zones, Nubaryia basin

1. Introduction

Integrated management of groundwater and surface water is of great importance to efficient and flexible use of water. This integration needs to be incorporated into the water management framework in Egypt. Due to the rapid increase in population versus the shortage of fresh surface water, in addition to the extensively and continuously reclamation and development, it is important to depend on the groundwater to compensate the shortage of fresh surface water and to reclaim new lands along the desert fringes of the Nile Delta and Valley.

The North Western Delta is one of the most promising areas that can be reclaimed depending on the water of Nubaryia Canal and its branches which takes water from the Nile (Riyah El Bihary and Riaha El Nassery). The water discharged to Nubaryia Canal is about 8 Million cubic meters per day. It is 23 Million cubic meters per day during the maximum requirements (summer season). Those quantities of water are used in agriculture, drinking, domestic, industry, and navigation. Those quantities of water will not satisfy the needs for reclaiming old and new lands and constructing new villages.

To relieve the pressure on the Nile Valley and Delta, the government has embarked on ambitious programs to increase the inhabited area in Egypt by means of horizontal expansion projects in agriculture and creation of new industrial areas and cities in the desert fringes. Such new projects increase the demand for water too. On the other hand, fresh water resources in Egypt are limited mainly to the River Nile (surface water) and therefore the supply is almost fixed. Groundwater aquifer systems overlain by rivers constitute normally one hydrogeological entity, because of the interconnection between aquifers and surface water.

This research was thus initiated with the objective of evaluating the current water potential and predicting the future groundwater potential till 2020 in order to solve the shortage of water problems, especially in the ends of the Nubaryia Canal and its branches.

The executed research steps are presented in this paper under the following headlines:

- Visiting the study area and describing it.
- Investigating the physical and hydrological conditions of the study area.
- Modeling the study area numerically.

2. Site Visits and Study Area Description

Several site visits were carried out to the study area, (Figure1), in order to perceive a complete data picture about it. During these visits, observations were documented, data was assembled, investigations were executed and photos were captured.

Based on the site visits, the study area could be described, as follows:

- The study area (Nubaryia basin) is located at the North West of the Nile Delta. This Region is an area of high development potential.
- The area includes both old delta lands, previously flooded by the river before the construction of the Aswan High Dam, and other more recently reclaimed lands during the last fifty years.
- Nubaria Canal is the largest main canal in Western Nile Delta. It is mainly fed from the Nile River. Serving a total area of 373,800 hectare, the canal has been developed several times to cope with the horizontal expansion in the newly reclaimed areas in western desert fringes (MWRI, 1992) and (MWRI, 2007).
- Nubaryia Canal and its branches are the main water source for the horizontal expansion projects in the North West Delta Region.
- The water duties of these canals almost satisfy the current needs from irrigation, drinking and other uses.
- The water duties are insufficient at the ends of the canals. To increase the water duties of those canals, the groundwater potentialities of the surrounding branches is considered the main water supply to feed those canals.

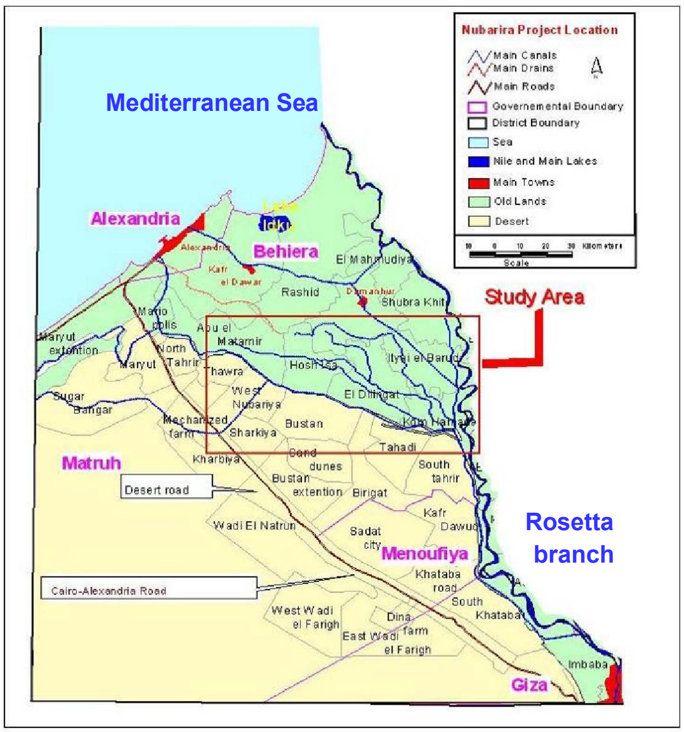


Figure (1): The study area.

3. Investigating the Physical and Hydrogeological Conditions of the Study Area

During the site visits, the physical and hydrological conditions of the study area were investigated. It was found that:

- Nubaryia Basin is located in Behira Governorate. It is situated by Longitudes 30° 05'and 30° 45' East, and Latitudes 30° 30'and 31° 00' North
- Temperature ranges between 26.7 C° in May and 14.2 C° in January
- The level of annual rainfall is 168.1 mm in Damanhour City.
- The average humidity ranges between 45% in May and 68% in November
- The average evaporation ranges between 6.6 mm in January and 14.0 mm in May. (Embaby, 2003).
- Land use of the study area is divided into five classifications according to water resources (RIGW/ IWACO, 1991a and Authority of Reclamation, 2012), table (1).
- The area represents a part of the old alluvial plain; this plain is characterized by a rolling surface sloping to the north and northeast and consists of land clay sedimentary modern configuration of deposits silt of the Nile while west lands and the south west of the study area formed of the sand, Conco, (1987) and Embaby, (2003). Depending on the information data obtained from (RIGW) the figure (2) was drawn.

Regarding the hydrological conditions, it was found that:

- The basin is distinguished by three hydrological units:
  - First unit is the whole part of the large aquifer under the Nile River Delta (Quaternary aquifer), where there is groundwater in this aquifer in case of semi-confined.
  - Second unit is residing mainly in the southern part which is characterized by moderate productivity of groundwater, where there is groundwater in this aquifer in Free State (unconfined).
  - Third unit is residing in the southwestern parts which are characterized by low productivity of groundwater (Moghra aquifer), RIGW/IWACO (1992).
- The groundwater levels are usually oscillating up and down affected by one or more of the following, levels of water in the canals and its distributors, method and frequency of irrigation, horizontal and vertical agricultural extensions, and groundwater extraction.
- The surface water, in the basin, consists of Rosetta Branch, Nubaryia Canal and its branches, figure (3).

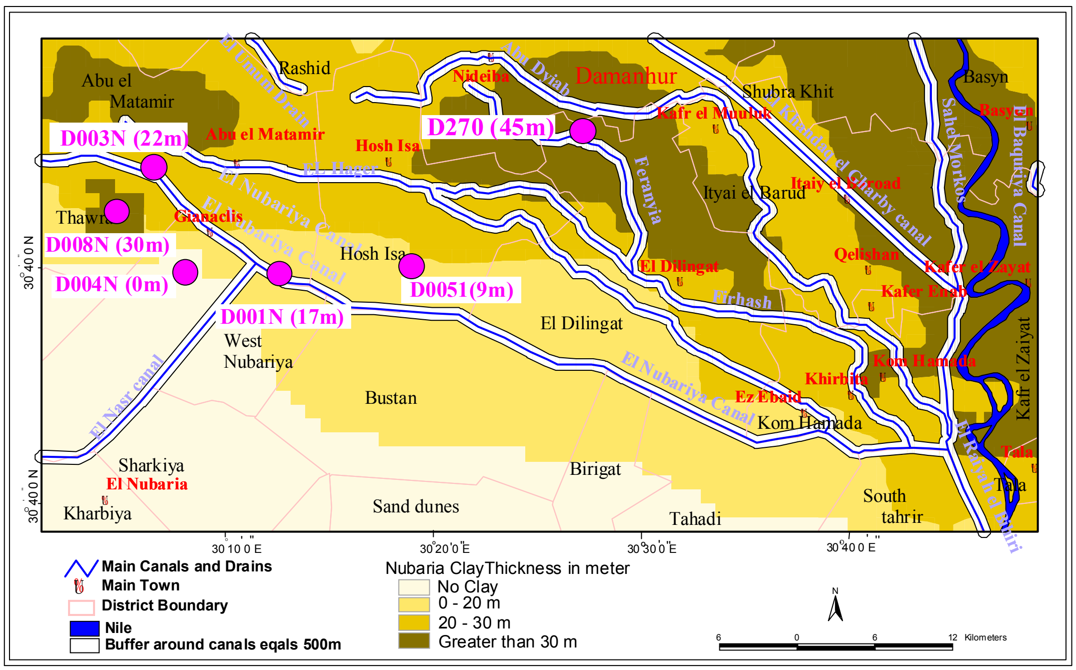


Figure (2): Clay thickness layer in Nubariya Basin.

Table (1) Land use classification according to water resources of Nubaryia Basin.

	% Area from total area	Sources of Irrigation		Land use subareas
		Surface water (S.W)	Ground water (G.W)	
Old lands	60 %	90%	10%	Hosh Esa and Dillingat Eastern region(the most fertile areas of Egypt)
Land reclaimed by surface water	28%	85%	15%	Bustan and West Nubaryia and around Nasr canal
Land reclaimed by ground water	3%	12%	88%	Beregat
joint use reclaimed land	4%	50%	50%	South Tahrir and Tahady
Urban and non-viable	5%	0%	0%	Main cities and the various villages and Sand dunes

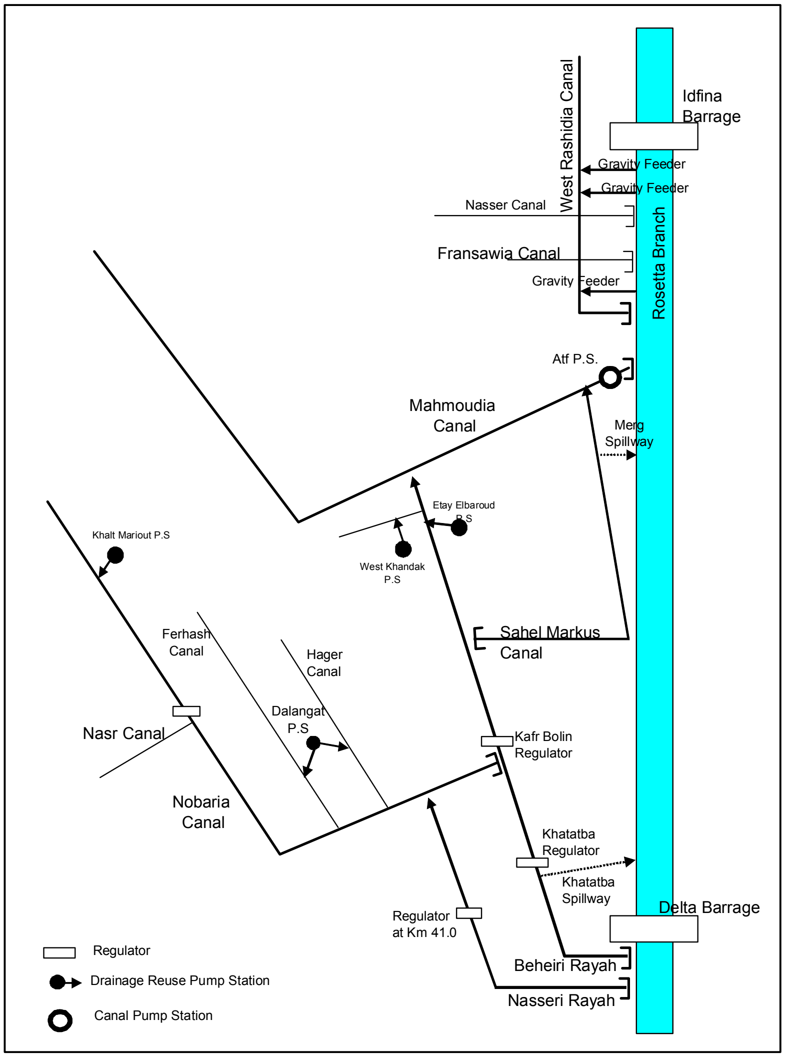


Figure (3): Main canals of Nubaryia Basin.

4. Modeling the Study Area Numerically

To study the groundwater and surface water situation of the study area and predict the behavior of the aquifer when the operation of the various solutions, a three-dimensional steady state and transient groundwater flows numerical model of multi-aquifer system was built and calibrated to simulate Nubaryia basin and examine three scenarios of water management.

4. A. Implemented Model and It's Input

A digital model Visual MODFLOW2000 code, Harbaugh *et al.* (2000) which is considered the most suitable package for satisfying the study objectives was used. This model package was used to represent the groundwater flow and movement system, and relationship with surface water in the study area based on the finite difference method (Finite Difference Method). Model grid input parameters and results were prepared using GIS.

4. B. Model Extent, Grid and Boundaries

The mathematical model covers an area of approximately 5900 km^2 of Nubaryia Basin. The model grid consists of 68 952 rectangular cells; relative small cells were used in the significant areas, (Figure 4). The cell size is small enough to reflect both the density of input data and the desired output details and large enough for the model to be manageable.

The aquifer boundaries were chosen far from the study area by sufficient distance to minimize the boundary effect. The aquifer boundaries are delineated as follows:

- Specified head boundary with seasonally head variations in the eastern boundaries along Rosetta Branch.
- The Constant head boundary condition was used to fix the head values in selected cells along the boundaries of the model. The constant head data

were obtained from the hydro-geologic map for the Nile delta, (RIGW 1992). This Constant head boundary is used for the Northern and Southern boundaries.

- No flow boundary is applied for the western boundary as the water contour lines from previous studies are vertically with the model boundary RIGW/IWACO (1990a).

4. C. Simulation of Model Input and Layers

The data that was input to the model include all the details about the nature of the region (ground and surface water system) which were obtained from multiple sources of Research Institute for Groundwater RIGW, previous studies, environmental survey results, field work, and satellite images.

In general, the main inputs data was topographic data of the basin that was defined in details from survey maps of scale 1:100, 000 for most of Nile Delta area. The elevation of the study area ranges between -5 m mean sea level (MSL), in the North at the city of Kafr El Dawar, and + 60 m above mean sea level, at the western south near Alex Desert road, (Figure 5).

In order to obtain more accurate results many points, concerning topographic level of Eastern and Western bridges, were represented in the model (i.e. each 1 kilometer along path of canals and branches).

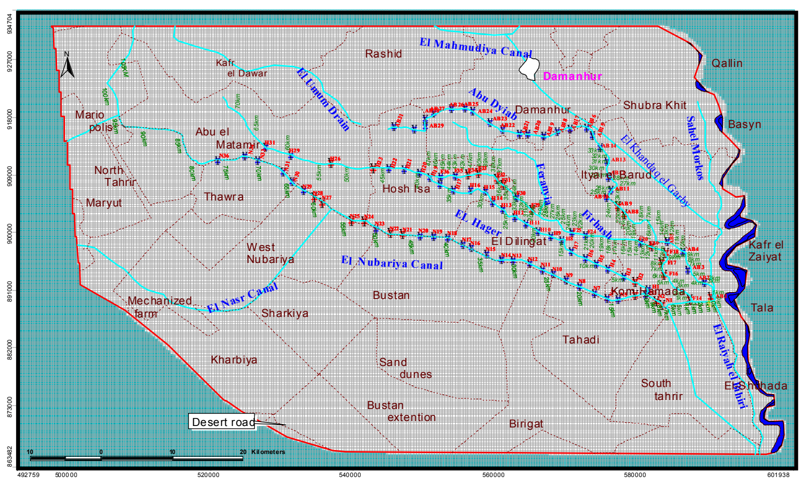


Figure (4): Delineations of model grid for study area including Nubaryia Canal and its branches and proposed wells.

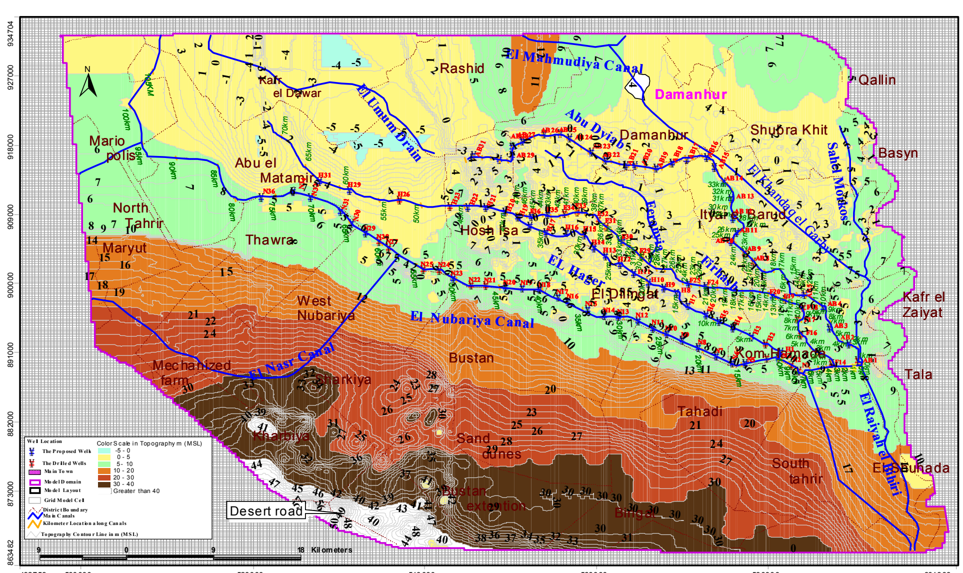


Figure (5): Ariel topographic map of Nubaryia Basin.

Model layers were simulated consisting of six layers in the vertical direction to present the different lithological structure to simulate two aquifers. The first layer represents the Holocene clay. Three other layers represent the Quaternary aquifer and the six one represents the Moghra aquifer, in addition to the fifth one represents the clay layer between Quaternary aquifer of the Nile Delta and Moghra aquifer. Figure (6) and figure (7) show the North-South and East-West vertical and lateral sections of model layers, respectively.

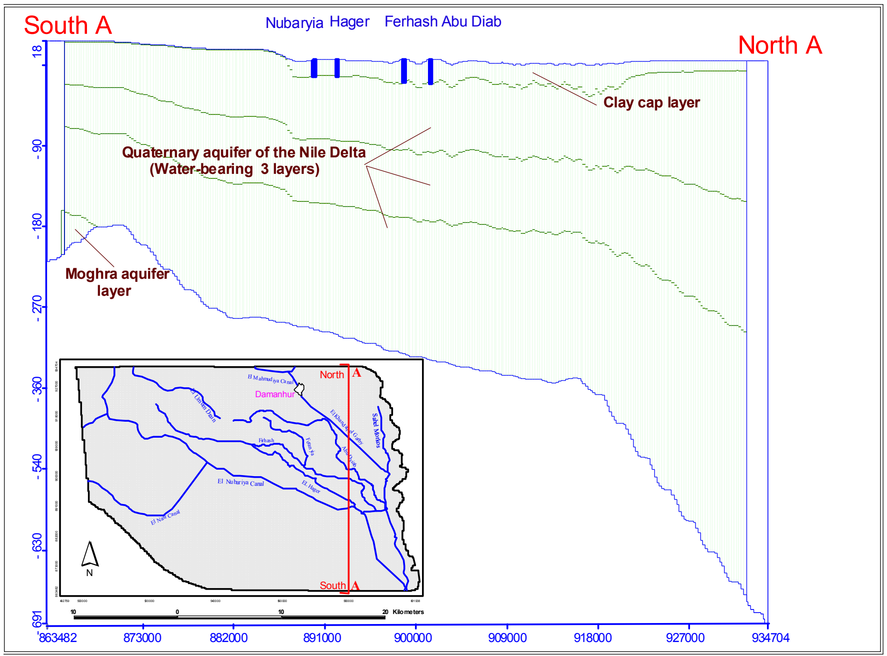


Figure (6): Vertical section (A-A\) of modeled layers.

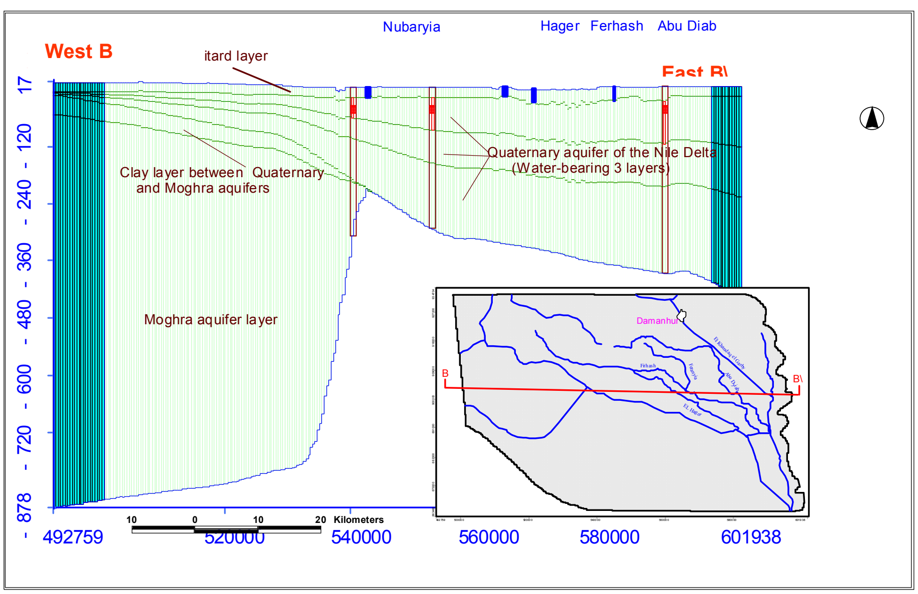


Figure (7): Lateral section (B-B\) of modeled layers.

Hydraulic parameters of the aquifer layers were used as input data based on previous studies and current aquifer pumping tests in selected location which were done by RIGW as shown in table (2).

Table (2) Hydrogeologic parameters of Nubaryia Basin

Layer Name	Horizontal hydraulic conductivity (K_h)	Vertical hydraulic conductivity (K_V)
Clay (Layer 1,5)	0.1 to 0.3	0.01 to 0.03
Nile Delta Aquifer (Layer 2,3,4)	20 to 95	2 to 9.5
Moghra Aquifer (Layer 6)	1 to 20	0.1 to 2

Initial values of recharge were assigned according to land use and the previous studies on Nile delta aquifer, John L. Wilson and Emad Rasmy (1978).Recharge rate ranged between 1.5 and 3.2 mm/day for old agriculture area where surface water development around Nubaryia Canal and ranged between 0.03 and 1.5 mm/day in new reclaimed areas where modern technical irrigation methods were used at south of the study area.

Nubaryia Canal and its branches are simulated as input components to the model using the 'river package'. Nubaryia Canal form a natural controlled head boundary to the aquifer system and it is conceivable branches also act as a controlled head boundary. 'River cells' incorporate stage level, bed level and hydraulic conductance of the surface water (ranges between 150 and 300 days). Some of canals are partially penetrating the first semi confining clay and some of them are fully penetrating the aquifer. These canals allocated through of the model cells in which they exist. This feature allows river nodes to simulate either gaining or losing due the interaction between the groundwater and surface water system depending on the head difference and the hydraulic connection between them.

Abstraction of groundwater was implemented in the model, by grouping as the abstraction rate to a relevant grid cell. Accordingly, the wells were divided to location groups distributed in metric coordinates all over the study area and each location may include few tens to more than 100 wells. The model layer from which the abstraction takes place was identified and used in the model according to their drilling depths and relevant screen. The current withdrawal was estimated to be 0.85 billion m^3/day from about 3399 production wells in the study area.

4. E. Model Calibration

During the calibration period, various inputs were adjusted, especially the hydraulic parameters and recharge, taking into consideration available results of aquifer tests, geological studies and geophysical logs. The numerical model was run in a steady state and transient status for the period from 1992 to 2010 and has final calibration based on match an average piezometric water level to groundwater with those measured from monitoring observed wells. Adjustment of canal conductance and branches conductance had minimal effect on the model runs. Considering this fact, the qualitative evaluation, documented range for each parameter and the understanding of the conceptual model plays an important role in selecting the most appropriate set of parameters. The main parameters contributing to the model simulations were the hydraulic conductivity and the distribution of the areal recharge rate. The simulated water levels generated by the calibrated model match the observed water levels quite well. The calibrated model reproduces the direction of groundwater flow and water levels in most parts of the study area to a good precession. The root mean square error was 0.62 %, on average. Simulated water level differs by about 45 cm from the observed water level. Calibration was accessed to the greatest possible accuracy it can use the model to apply policies extraction future and to assess their impact.

Figure (8) shows the calibrated groundwater head and velocity distribution of transient status in the study area. It is observed that the regional flow direction is from south to north. Groundwater mounds exist in areas with high recharge from local reclamation water conveyors in old reclamation projects using surface water are situated the piezometric has risen due to the downward seepage of excess irrigation water and leakage from irrigation canals.

5. Results

5. A. Water Balance

Water balance is one way to express the results of model. Water Balance data provide both an indication of the relative magnitude of flow components within the study area, as well as a means to check that the model solution has remained stable. The water balance of groundwater system of the Nubaryia Basin comprises several components including boundary flux, extraction wells, recharge, canals interaction and change in aquifer storage (transient). The relationships between inflow and outflow components for stability phase in the form of pie chart of percentage contribution of each component of the water balance are given in pie chart (1). It is observed that the main components of inflow are net recharge which equal to 88% of the total inflow due to the excess irrigation water. The infiltration from the canals to aquifer are equal to 5% which is relatively small compared to the gain of the aquifer system due to low vertical permeability of the top clay layer.

In the other hand , the main outflow components are the well extraction that equal to 38 % of total outflow, it also remarkable that the seepage from the aquifer to canals are 4%.

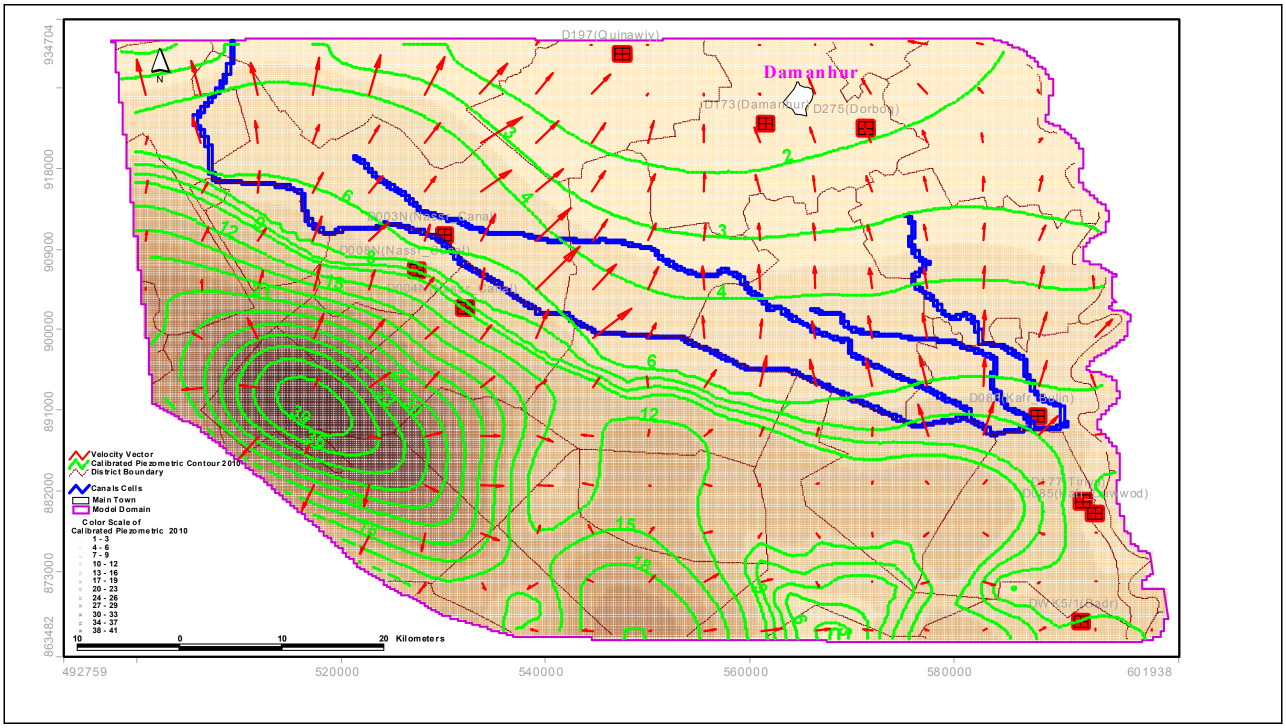
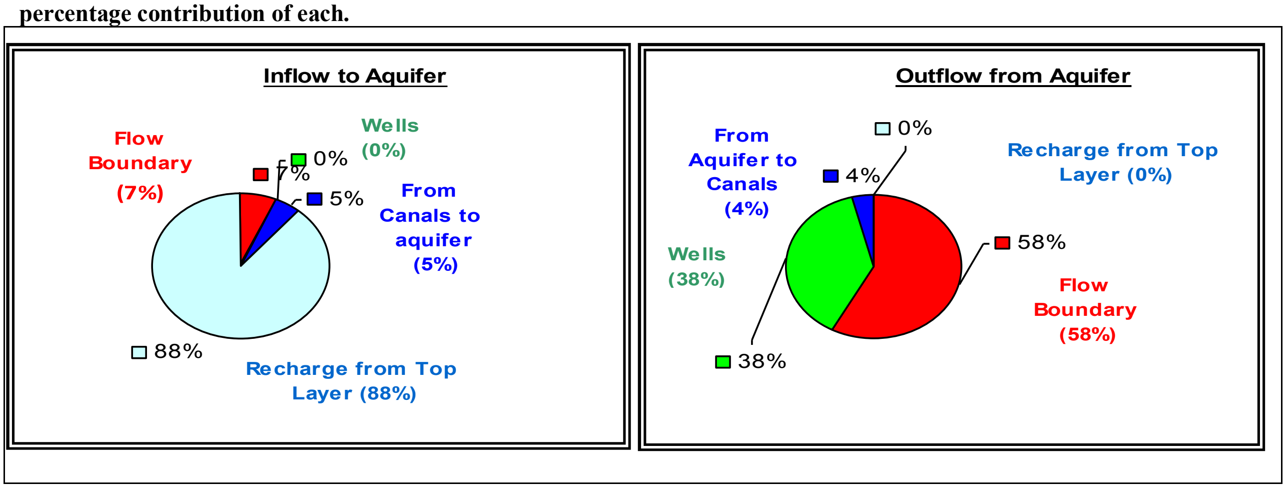


Figure (8): Calibrated groundwater head contour map and velocity distribution.

Pie chart (1) the relationships between inflow and outflow components for stability phase in the form of pie chart of percentage contribution of each.



5. B. Water Budget Basin Zones Using the Model

The study area was subdivided into seven surface zones based on hydrological and buffers around Nubaryia Canal and its branches through total mathematical model, five zones covering Nubaryia Canal basin and its branches where each zone was divided around canal path and include the proposed wells around canal path (Zone No.2 covered Nubaryia Canal - Zone No.3 covered El Hajer Canal - Zone No.4 covered Ferhash Canal - Zone No.5 covered El Feranyia Canal - Zone No.6 covered the Abu Diab canal), table (3). In addition to the north and south basins Nubaryia canal basin which is (Zone No.1 covered North basin - Zone No7 covered South basin). It was calculated water budget of each different zone alone after running total model in phase change with time in the period from 1992 to the year 2010 as shown in figure (9). The water budget of zone (7) which covered South basin was the largest budget while the lowest budget was that of zone (5) which covered El Feranyia Canal.

Table (3) Discretion of sub basin represented in model.

Canal Length (KM)	Total Area (Represented inside the model)		Land Level (MSL)	Total Cultivated Land (feddan)	Basin (have Canal Represented inside the model)	
	Percentage (%)	Area (KM^2)			ZoneNo.	Name
111.4	13%	700	0 : +12	130,000	2	Nubaryia
72	7%	400	0 : +8	90,000	3	Hager
64	3%	170	+2 : +7	40,000	4	Ferhash
9	2%	77	0 : +7	17,000	5	Feranyia
51.4	6%	370	0 : +7	80,000	6	Abu Diab

5. C. Scenarios Analysis Zones and Future Policies

The mathematical model through the application of 3 different development scenarios has been tested for the aquifer and identifying suitable locations and quantities of safe withdrawal of the proposed wells to feed the branches with the future's policy and predict the falling down and/or rising up water levels change and presented water balance for each zone. A conclusion of flow in and out and relationship to Nubaryia basin zones and each other has been done. These three scenarios are considered the disposal of the wells daily 3000, 2000, and 1000 m^3/day, respectively. The calibrated model was run under the effect of these three scenarios for 10 years for each basin to predict the rate of change in groundwater drawdown.

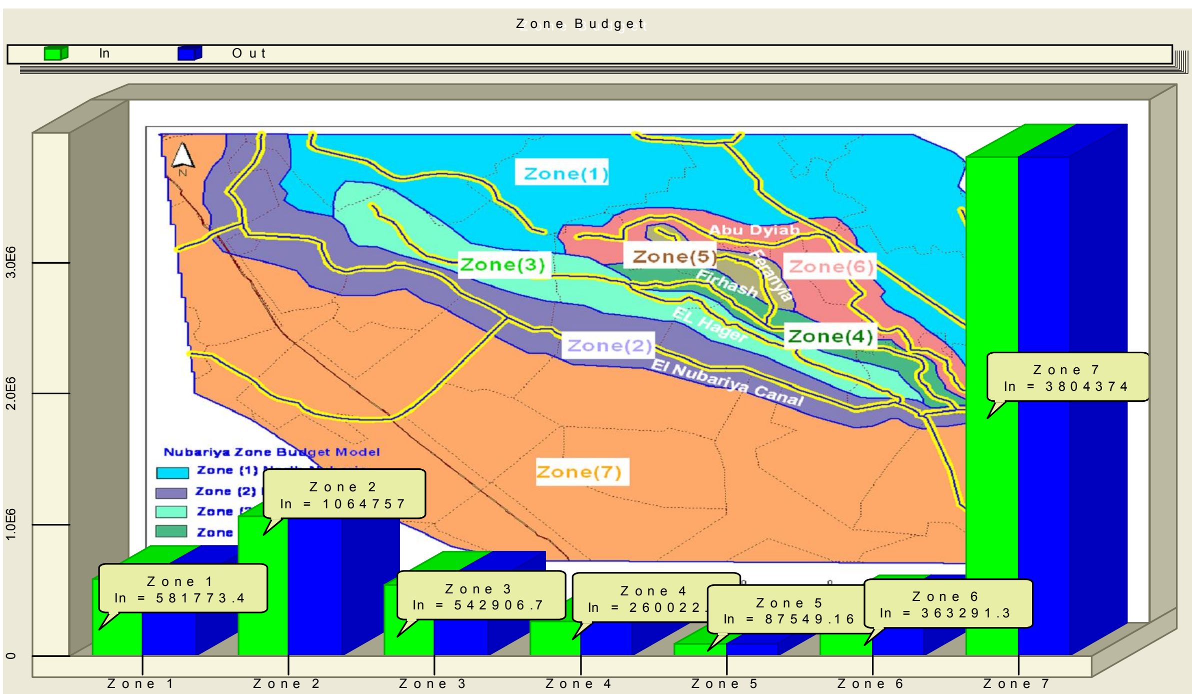


Figure (9): The relative volumetric water budget of different subdivisions basins (zones) predicted from the model in m3/day.

5. d. PROPOSED POLICIES

The calibrated model was used to evaluate groundwater potentiality and to test three alternative management scenarios for the study area. The current water budget showed that the available groundwater potential is 240, 388.65, 198.16, 67.66, 32.00, and 132.00 million m^3/year for North Nubaryia canal basin (zone 1), Nubaryia canal basin (zone 2), Hager basin (zone 3), Ferhash basin (zone 4), Feranyia basin (zone 5), Abu Diab basin (zone 6), respectively. Tables (4) illustrate predicted model results after applying the proposed three scenarios. Figure (10) show the different sub basin of Nubaryia canals and its branches. It illustrates network of small branches related to each sub basin, proposed productivity wells sites, grid model, and flow relationship in and out of Nubaryia sub basin canal and other basins.

Table (4) Results of proposed scenarios.

Proposed scenarios	Time Period (Year)	Extraction well (m3/day)	Nubaryia Basin		Hager Basin		Ferhash Basin		Feranyia Basin		Abu Diab Basin	
			Number of proposed wells	Maximum Drawdown (m)	Number of proposed wells	Maximum Drawdown (m)	Number of proposed wells	Maximum Drawdown (m)	Number of proposed wells	Maximum Drawdown (m)	Number of proposed wells	Maximum Drawdown (m)
1	10	3000	33	2.9	22	3.1	23	2.8	4	1.5	23	2.3
2	10	2000	33	2.1	22	2.3	23	2.2	4	0.8	23	1.7
3	10	1000	33	0.7	22	1.2	23	0.9	4	0.4	23	0.6

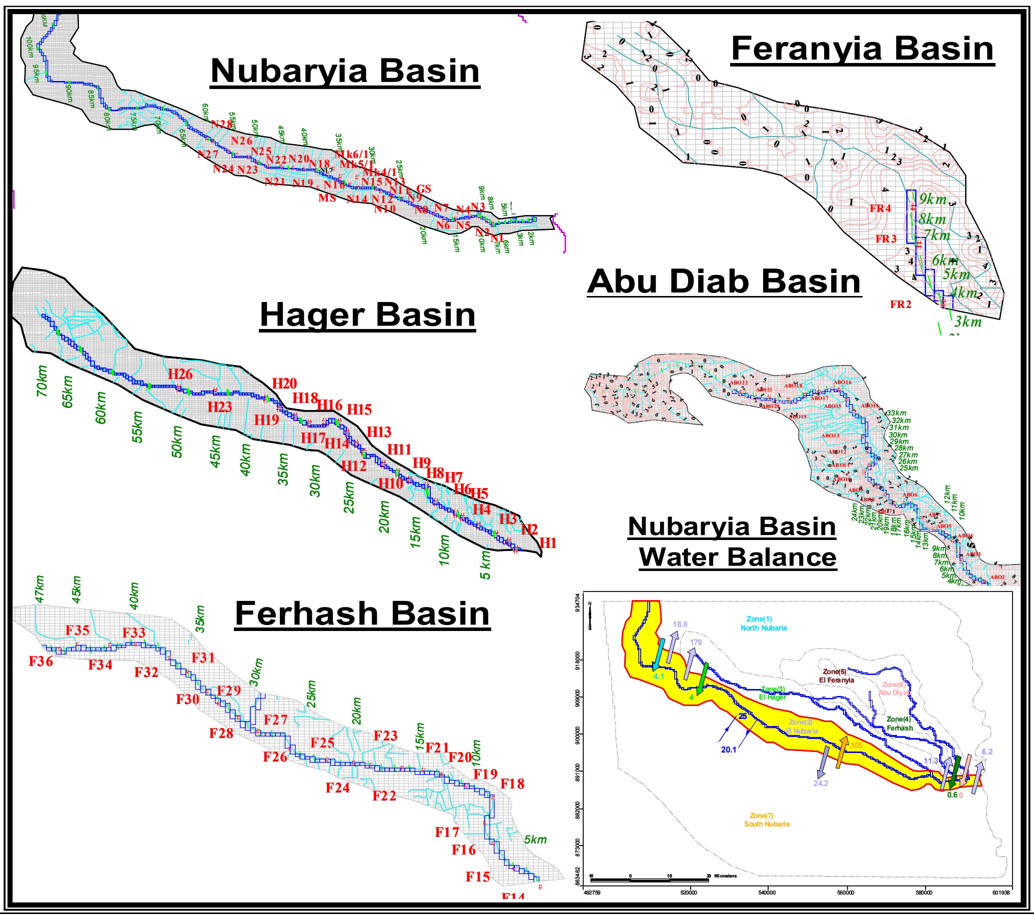


Figure (10): Different sub basins of Nubaryia Canal and it's branches.

6. Conclusion and Recommendations

In this study, a numerical groundwater model was constructed to evaluate and predict the current and future groundwater potential up to 2020. In this regard, a MODFLOW package was utilized to simulate three proposed scenarios. The model was calibrated for steady state and transient flow conditions and acceptable accuracy was achieved. The calibrated model was run under the possibility to withdraw groundwater quantities in the study area to feed Nubaryia canals and its branches under the effect of three scenarios for 10 years to predict the rate of change in groundwater drawdown. The obtained results were analyzed. Consequently, conclusions were deduced. These were:

- The regional flow direction is from south to north. Groundwater mounds exist in areas with high recharge from local reclamation water conveyors in old reclamation projects using surface water due to the downward seepage of excess irrigation water and leakage from irrigation

- The main components of inflow are net recharge which equal to 88% of the total inflow due to the excess irrigation water. The infiltration from the canals to aquifer are equal to 5% which is relatively small compared with gain of the aquifer system due to low vertical permeability of the top clay layer. In the other hand , the main outflow components are the well extraction that equal to 38 % of total outflow, it also remarkable that the seepage from the aquifer to canals are 4%.
- The current total available groundwater potential for all basins without basin seven is 2.9 million m^3/ day.
- The proposed daily abstraction from groundwater are about 3000, 2000, 1000 m^3/ day for each well for the first, second and third scenarios, respectively.
- The results from three proposed scenarios show that the total required amount of groundwater abstraction is less than groundwater potential and the decline in groundwater drawdown will vary from 0.4 to 3.1 m after running the calibrated model under the effect of the development plan for the next ten years. The three scenarios can be considered safe but scenario 1 is risky with respect to expected drawdown for a long time.
- Groundwater can share and compensable the quantities of surface water needed for reclaiming new areas.
- This model and obtained results can be considered as preliminary regional evaluation for develop a plan proposal for the integration management of ground and surface water in the Nubaryia region and other regions to be incorporated into the water management framework in Egypt.

According to the achieved results, it is recommended that the area is promising in terms of the presence of groundwater and it was further recommended to drill productive wells beside canals to feed canals and solve the shortage of water problems, especially at the ends of the Nubaryia Canal and its branches during the season of maximum requirements for irrigation water. It is required to get detailed studies to determine salt concentration and possible environmental consequences for best understanding of the integrated water management scenarios in the basin.

4/29/2013

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