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Management of Groundwater Aquifers along the Mediterranean Sea in Sinai Peninsula

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Abstract

Sinai Peninsula is located at the Northern-Eastern part of Egypt and is presenting about 16% of Egypt's area. Water resources in Sinai Peninsula are mainly groundwater and flash floods that fall on the mountainous areas. Flash floods water flows through the different Wadis inside Sinai until it reaches to the Mediterranean Sea in the North, (delta wadi El Arish), the Gulf of Aqaba in the East and the Gulf of Suez in the West. This water is considered the main source for recharge of the groundwater aquifers in Sinai Peninsula. Since 1981 there are several field studies and sustainable development plans started to be prepared and the proposed development plans were considered the water resources issues, economic and social aspects. Several geological, hydrological, geo-physics and hydro-geological studies have been performed for understanding the groundwater aquifers system in Sinai. Following these studies in the different aquifers, groundwater abstraction and potetiality plans were performed to manage and control drilling of wells specially in the coastal aquifers at El Arish, Rafah and Bir ElAbd areas along the Mediterranean sea. The current paper presents a case study for evaluation the Quaternary groundwater aquifer and introducing the interaction between water resources development and the sustainable development. The successful narrative for water resources development in this study area its impacts on life style along with many years of effort are presented. The research presented through a comparative study of the aquifers between 1988 and 2006. As indicated from these comaparisons signifcant improvement of the community standard of life status in Sinai has been noticed due to the sustainable development.

Key Words: Aquifers Management, ElArish, Rafah-ElShiekh Zuwyied, BirEl Abd, Sinai,

Introduction

The groundwater is the main issue in development in the Sinai Peninsula in addition to the seasonally flash floods. The Quaternary deposits (sand, gravel & calcareous sandstone) and the Holocene-recent sand dunes are the main aquifers extending along the Mediterranean from Rafah due East to Bir El Abd and from Bir El Abd to El Qantara due West respectively.

The Quaternary aquifer is well defined at two areas along the north sinai coast, first, the area from Rafah to El Shiekh Zuwyied and the second is the delta wadi El Arish.

The second aquifer is well define at the area from Bir El Abd to Rommana due west, fig.(1). The three areas has different hydrogeological conditions and depositional environment.

The thickness of the Quaternary aquifer ranges from 80m to 120m at Rafah and El Shiekh Zuwyied. The thickness of the Holocene-Recent dune aquifer ranges between 20-30m. The rainfall is the main source of recharge to the aquifer in addition to the return irrigation and domestic water. The rainfall precipitation ranges from 60mm/y due west at Bir El abd to about 300mm/y due east at Rafah. The management of this aquifers depends on the periodical inventory especially the water level and the groundwater extraction. The presence of these aquifers along the sea coast to be opposites the deterioration problem (sea water intrusion). A comparisons between the situation in 1988 and 2006 using the groundwater modeling were done by WRRI - BRGM consultant 1988 and WRRI 2005-2006 through the implementation of the Islamic Bank study in Rafah- El Shiekh Zuwyied area. This research depends on the groundwater data modeling in those areas of the aquifers from 1988 untle 2006 and introduces solutions for deferent problems especially in Rafah and El Arish areas. Now, the discussion of the results through applications of groundwater modeling in Rafah-El Shiekh Zuwyied and delta wadi ElArish aquifer and groundwater balance for sand dune aquifer at the area from Bir ElAbd to Rommana due west.

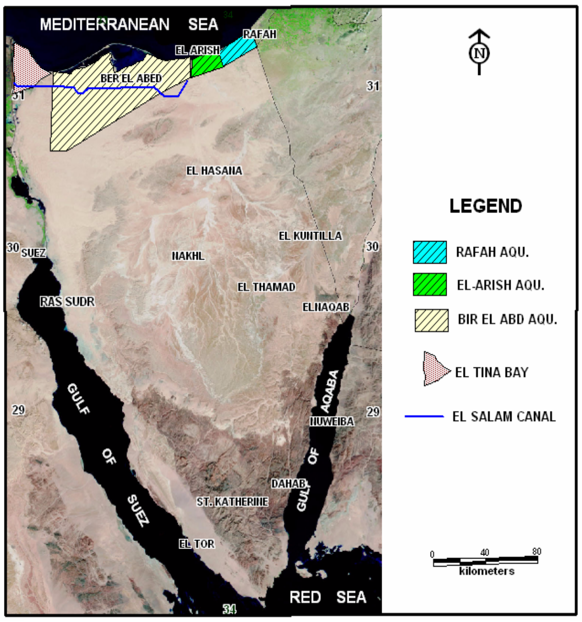

Figure 1, Location Map of the Study Area.

1-Groundwater Flow Modeling of Rafah-El-Sheikh Zuwyied Aquifer

1-1 Background

The key components of a groundwater model are a conceptual model and a mathematical model. The conceptual model is a descriptive representation of our hydro-geological understanding of how water flows into, through and out of a groundwater system. This is usually presented in the forms of diagrams and maps of the physical characteristics of the geological formation geometry and flow systems/directions. Based on more than 37 borehole data, the study area is characterized to reach to the most representative conceptual model. Lithology is grouped into three main units, namely, sand/gravel, clay and Kurkar (calcareous sandstone); Figure (2). Based on the site characterization study, it is concluded that the sand/gravel (sand dunes, old beach deposits, and alluvial), and the Kurkar formations are the lower part of the Quaternary (Pleistocene) and hydraulically connected where in many boreholes data the clay layer between the two formations is absent or exist in lenses in which it works as a semi-confining layer for the Kurkar formation. The two layers have been merged to constitute a single equivalent layer with an equivalent hydraulic conductivity and a thickness equal to the sum of their thicknesses.

1-2 Numerical modeling of groundwater flow

The Modular three dimensional groundwater FLOW computer code (MODFLOW) has been selected for numerical modeling of the groundwater flow regime in the study area. The MODFLOW software is originally developed by the U.S. Geological Survey (USGS) in the early 1980's [McDonald & Harbaugh, 1984].

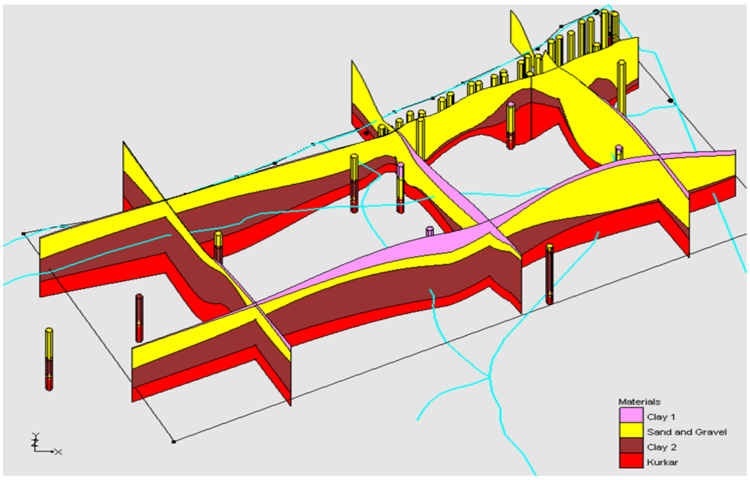

Fig. (2) Cross Sections (Fence diagram)

1-3- Designing and laying down the grid

The hydrogeologic cross section, as shown in fig. (2) is the basis for building the MODFLOW model. Since there are no direct field measurements that support flow in the vertical direction, it is common to adopt a 2-D modeling approach where hydraulic parameters (e.g. hydraulic conductivity) and state variables (e.g. water level) are vertically averaged. The model has been constructed with a rectangular grid system of 500 × 500 *m*. It covers an area of 20500 *m* length along the shore line and 14000 *m* perpendicular to it, fig. (3). the grid size has been selected compromising resolution and computational time.

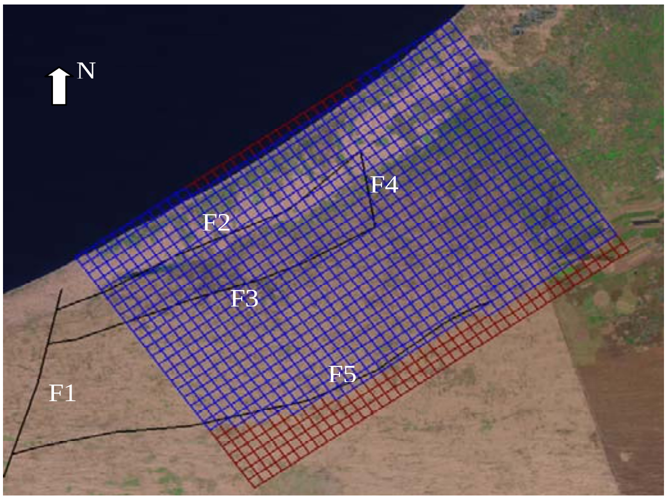

Fig. (3)   Grid system in plan view

1-4- Boundaries and Boundary conditions

The Mediterranean Sea borders the model area in the north. So, this boundary is modeled as a constant head boundary. At the east and west side of the model the boundaries are chosen in such a way that they follow the regional direction of the groundwater flow. Although it is well recognized that pumping wells will generate a local flow at such boundaries, effects of these local flow systems will be ignored here. Ideally, model boundaries are located far enough from pumping wells to minimize their effects at the boundaries. In the south, the boundary follows one of the major faults (F5) in the study area; Fig. (2). this fault is considered permeable and can transfer water inside the modeling domain. Consequently, this boundary is simulated as a general head boundary. General Head boundary conditions are specified by assigning a head and a conductance to a selected set of cells. If the water table elevation rises above the specified head, water flows out of the aquifer. If the water table elevation falls below the specified head, water flows into the aquifer. In both cases, the flow rate is proportional to the head difference and the constant of proportionality is the conductance. Head measurements, in time and space, at and close to this fault are used to assign head values at this boundary. Although such measurements are limited, they are interpolated and/or extrapolated to reach to reasonable values of the time variant head at the required cells.

1-5- Steady state calibration

In this research it's important to use the water level measurements collected on 1988 to calibrate a steady state model of the study area. As explained by Segiun and Bakr, 1992, the evolution of the water levels does not show a significant decrease from 1988 to 1992. Water level measurements collected in 1988 counted to 123 data points and are obtained from Cairo University (1989a). Most of these data points are located along the coast and around the city of Rafah. So, the major part of the computational grid is not provided with data. Density of wells along the coast is rather high; several wells can be located in the same mesh showing different values. Water levels measurements are smoothed in space using block mean (GMT, 2000) of 500 × 500 *m*. This operation leads to 62 smoothed water levels measurements. Fig. (4) Shows a histogram of the smoothed data with their basic statistics. Pumping test data and their interpretation are also available in several reports (i.e., JICA, 1992; ACSAD, 1998). Based on these data, hydraulic conductivity values vary between 8 and 43 *m*/*d*.

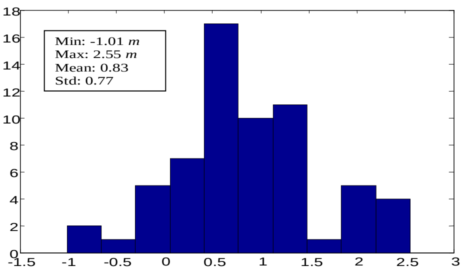

Fig. (4), Histogram of water levels measurements, 1988.

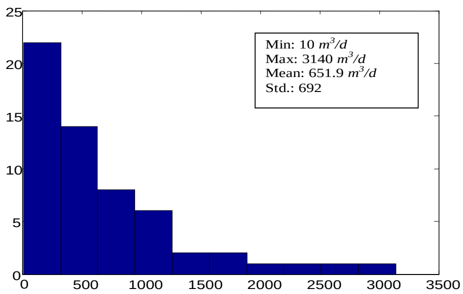

Fig. (5), Histogram and statistics of pumping rates per model cell,1988

Constructing a numerical model requires also information about sinks and sources in the area under study. Fig. (5) Shows a histogram and basic statistics (per model cell) of pumping rates in 1988. These values include both irrigation and domestic uses.

1-6- Calibration Results

Calibration target of this study is to calibrate the spatially variable hydraulic conductivity and recharge, and hydraulic conductivity of the general head boundaries.

The hydraulic conductivity field is parameterized using the pilot point method while the other two are paramerized using zonation. Zones of recharge are selected based on a Geo-Cover color composition of a LANDSAT scene acquired 1998. Such color composition shows vegetated areas where expected returned irrigated water can recharge the aquifer. Calibrated recharge values should reflect recharge due to rainfall, returned water from different water uses and possible unknown recharge from other underlying formations not accounted here. Calibration is done iteratively which lasted for 20 times, see Fig. (6) with a total residual error between measured and calibrated heads of 9. Fig. (6) Shows the natural-logarithm transformation of the spatially distributed calibrated hydraulic conductivity. The figure shows that the log-transformed hydraulic conductivity has ranged -2 and 4.5 which correspond to 0.14 and 90 *m*/*d*. The figure also shows that high hydraulic conductivity zones exist in south east, north east and the middle distance between Rafah and Sheikh Zuwyied cities.

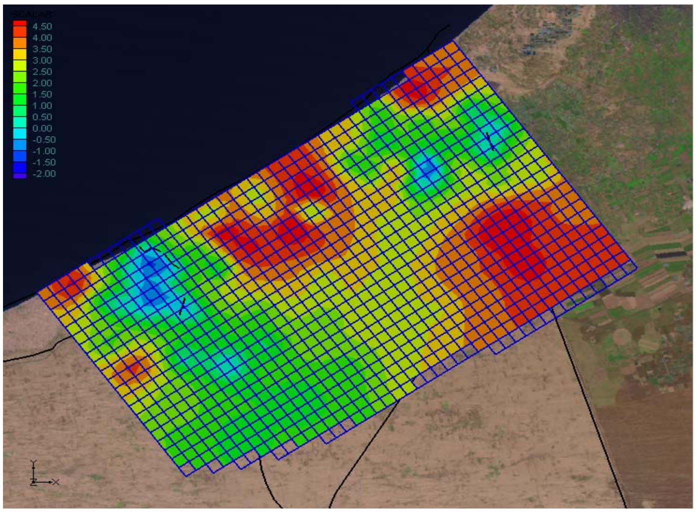

Figure 6, Log-transformed calibrated Hydraulic conductivity

However, it should be clear that this calibration is rather local because most of the data points exist basically along the shore line. Fig. (7) shows calibrated recharge. The figure shows that recharge has a maximum value of 3×10^{-3} m/d in the north / east of the study area.

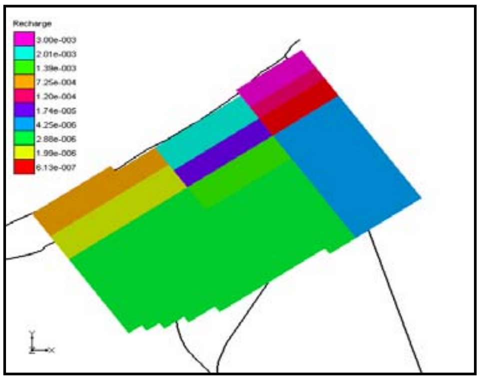

Figure 7, Calibrated recharge Zones (*m*/*d*).

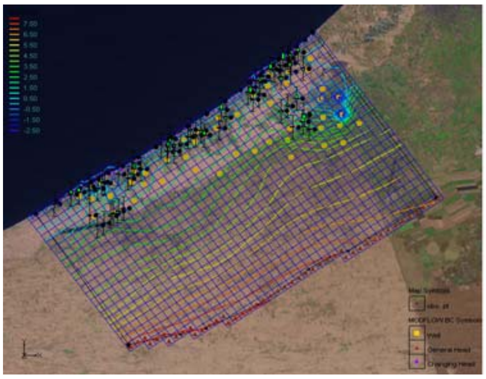

Figure 8, Calibrated head contours (*m*), 1988.

This is consistent with the fact that maximum rainfall is in this part of the study area and high infiltration rate is observed there. Fig. (8) shows the calibrated head contours and a bar for each observation showing the difference between the observed and the calibrated heads.

Table (1) Volumetric Budget For Entire Model (m^3/d).

IN:		OUT:	
STORAGE	0	STORAGE	0
CONSTANT HEAD	510.8606	CONSTANT HEAD	50172.93
WELLS	0	WELLS	34880
HEAD DEP. BOUNDS	22713.1	HEAD DEP. BOUNDS	0
RECHARGE	61828.99	RECHARGE	0
TOTAL IN	85052.95	TOTAL OUT	85052.94
IN – OUT = 1.56E-02			
PERCENT DISCREPANCY = 0			

Finally, table (1) shows volumetric budget of the entire model in m^3/day. The table shows a localized salt water intrusion of 510 m^3/day. Such water intrusion occurs north east of the study area, see Fig. (10). The table also shows an estimated recharge of 61829 m^3/day. This recharge accounts for infiltrated water from rainfall, returned irrigation and domestic use water, and other possible leakage from underlying formations. The last item shown in the table is an estimation of flow from the time dependent boundary. The model estimates it as 22713 m^3/d.

1-7- Transient state calibration

In this state we use water level measurements collected on 1988 (used previously for steady state calibration) and those collected by the WRRI team on June 2005 to calibrate a transient state model. The data collected by the WRRI cover areas that have not been covered by 1988's data. Fig. (9) shows contoured groundwater levels measured by

the WRRI on June 2005. The figure shows high variability of the current groundwater levels; see circled areas in the figure. This may be attributed to measurement errors, effects of pumping, or structural geology at some boreholes.

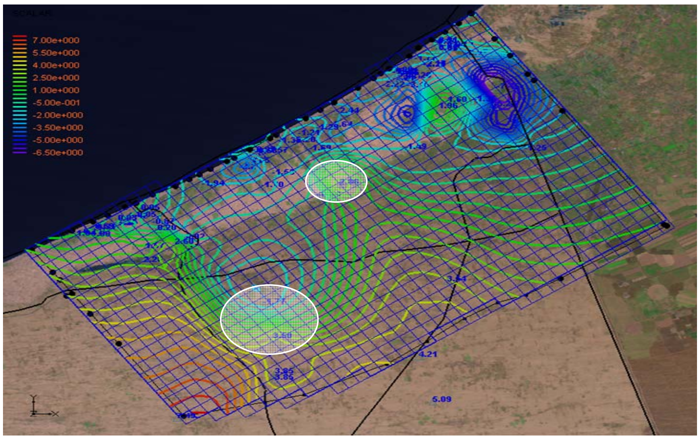

Fig. (9), Contoured water level measured June 2005.

A transient model needs many data. Among these data are historical groundwater extractions. Based on a survey conducted by the WRRI team, current total extraction from the quaternary aquifer system is estimated as 221630 m3/d (150575.75 m3/d is in the modeling area). Fig. (10) shows evolution of total extraction in El Sheikh Zuwyied / Rafah area.

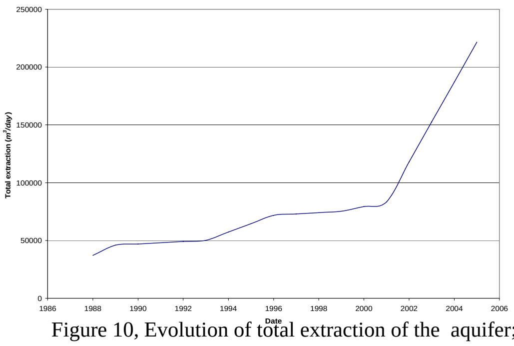

Figure 10, Evolution of total extraction of the aquifer; 1988 – 2005

1-8- Calibration Results

A transient model with the same spatial configuration as the steady state model is used. To make use of the head data of 1988 and 2005, the model is constructed such that this period is included in the simulation. The model simulates response of the system from 1960 to 2005. Initial head is calculated based on steady state solution where recharge and hydraulic conductivity obtained from the steady state calibration are used to model the head in 1960 (where zero pumping is assumed). Extractions from pumping wells are interpolated in time to obtain a stress period of one year. Assuming recharge obtained from the steady state calibration present the average long term recharge to the system, hydraulic conductivity is adjusted to honor both head data of 1988 and 2005. This procedure is done iteratively with modified initial heads according to the obtained hydraulic conductivity at each iteration. Like the state calibration discussed earlier, transient calibration of the hydraulic conductivity is obtained using the Pilot point approach. Fig. (11) shows calibrated hydraulic conductivity obtained for transient simulation. Comparing this figure with Fig. (6) shows that main features are the same. This is especially noticeable for high hydraulic

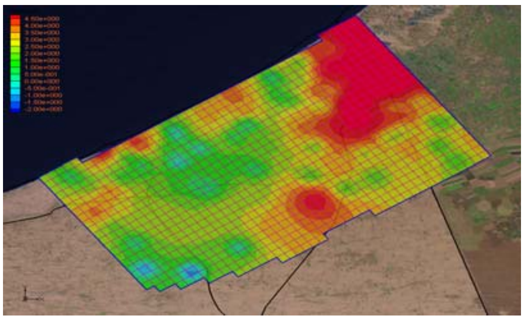
Fig. (11), Natural logarithm of calibrated hydraulic conductivity for transient state

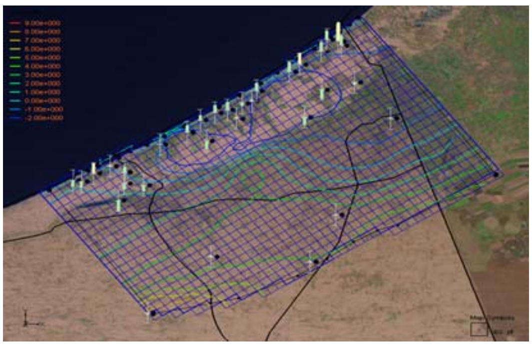
Figure 12, Simulate groundwater level contours 1988

conductivity zone at the eastern boundary of the model. Comparing observed versus calibrated heads show good results for both data sets used in this calibration (20 for steady state and 70 for transient), the transient calibration produces excellent and robust results. Fig. (12) and Fig.(13) show simulated heads for 1988 and 2005, respectively. The figures also show bars at measurement locations with their heights present discrepancy with the measured values.

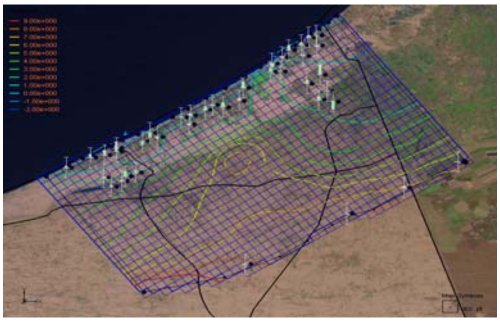

Fig. (13), simulated groundwater level contours, 2005

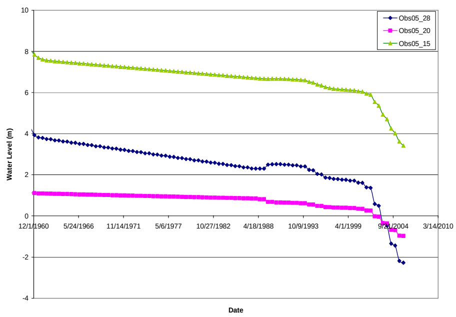

Fig. (14), Evolution of piezometric water level at some observation points

Finally, Table (2) shows volumetric water budget for the entire model for both cumulative volumes since starting the model and rates for the first time step in 2005 (first half of the year). The table shows that volume of sea water intrusion to the aquifer is significant.

Table (2) Volumetric budget for entire model; transient simulation 1960-2005

CUMULATIVE VOLUMES (L^3)		RATES FOR THIS TIME STEP (2005) (L^3/T)	
IN:			
STORAGE =	5305861.5	STORAGE =	1984.505
CONSTANT HEAD =	46564300	CONSTANT HEAD =	67167.34
FLOW BOUNDARY =	377238976	FLOW BOUNDARY =	22715
RECHARGE =	1025704000	RECHARGE =	61761.44
TOTAL IN =	1454813184	TOTAL IN =	153628.3
OUT:			
STORAGE =	318219.3438	STORAGE =	0
CONSTANT HEAD =	935692288	CONSTANT HEAD =	3052.521
WELLS =	518801792	WELLS =	150575.8
TOTAL OUT =	1454812288	TOTAL OUT =	153628.3

2- Groundwater Flow Modeling of El-Arish Quaternary Aquifer
2-1- Background

Based available borehole data, the study area is characterized to reach to the most representative conceptual model. MODFLOW was applied to construct an equivalent single layer two-dimensional mathematical model of the aquifers under study using all the available hydrogeological, hydrological and pumping and climate data developed from the extensive investigation programs carried at Water Resources Research Institute (Faculty of Engineering, Cairo University, 1989a; Faculty of Engineering, Cairo University, 1989b; JICA, 1992 & Islamic Bank and groundwater sector 2005). Numerous data to characterize the aquifer have been collected, from these data; three different formations have been distinguished from a lithological point of view. There are namely:

1) Sand 2) Gravel and Sand 3) Calcareous sandstone (Kurkar).

The three layers have been merged to constitute a single equivalent layer with:

- an equivalent permeability,
- a thickness equal to the sum of the three layers thicknesses.

This approach of an equivalent single monolayer model is, however, consistent with hydraulic head measurements which didn't show any significant difference in the three formations. The calibration is done in steady state where the evolution of the water levels does not show a significant decrease from 1988 to 1992. So the year 1988 has been chosen to realize a calibration in steady state.

2-2- Computational grid

The hydrogeologic conceptual model is the basis for building the MODFLOW model. Since there are no direct field measurements that support flow in the vertical direction, it is common to adopt a 2-D modeling approach where hydraulic parameters (e.g. hydraulic conductivity) and state variables (e.g. water level) are vertically averaged. Fig.(15) shows the 2-D MODFLOW model in a plan view. The model has been constructed with a rectangular grid system of 500 × 500 *m*. It covers an area of 16 km east and 20 km north.

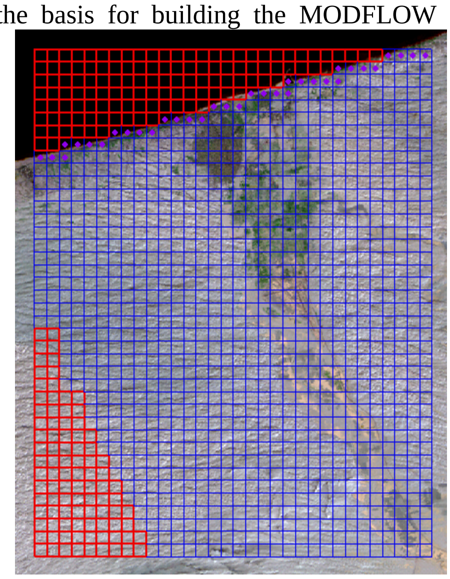

Figure 15, Girding system

2-3- Boundaries and Boundary conditions

The Mediterranean Sea borders the model area in the north. So, this boundary is modeled as a constant head boundary. At the east and west side of the model the boundaries are chosen in such a way that they follow the regional direction of the groundwater flow.
These two boundaries are modeled as no flow boundary. In the south, impervious boundary corresponding to the limit of the aquifer extension has been taken into

account leading to adopting a no flow boundary. However, only the inlet of wadi El-Arish at the south boundary of the study area has been consider as flow boundary whose value is obtained from Seguin and Bakr, 1992.

2-4- Available data

2-4-1- Hydraulic conductivity:

The water level measurements were collected on 1988 counted to 40 data points to calibrate a steady state model of the study area. As explained by Seguin and Bakr, 1992, the evolution of the water levels does not show a significant decrease from 1988 to 1992. These water levels range from -3m (area of pumping) to 2.6 m near the south boundary. Most of the values are below the sea level. When several points were located in a same cell of the model grid, an average value has been considered. Pumping tests data and their interpretation are also available in several reports (e.g., JICA, 1992). Based on these data, hydraulic conductivity values vary between 20 and 260 *m/d*. According to these data, an intermediate value of hydraulic conductivity of 43 *m/d* has been chosen to assign to the hydraulic conductivity at a set of chosen pilot points.

2-4-2- Abstraction:

In 1988 abstraction was about 52000 m^3/d where 25500 m^3/d was for domestic use while the rest (26500) was for irrigation. In this research we adopt 50% return coefficient for irrigation water at the cells of pumping. Although return water from domestic is also expected, it is not necessary occur at the locations of pumping wells. Fig.(16) shows cells of abstraction in the modeling grid; note that, those cells at the south east are recharging wells simulating recharge from the inlet of the wadi to the study area.

2-4-3- Recharge:

Spatially distributed recharge also exists in the study area. There are several sources of such recharge including infiltration from rainfall, return water from imported Nile water to the area for drinking and recharge due to domestic water use. In 1988, the imported water from the Nile was about 10450 m^3/d. Meanwhile, average rainfall in the study area is estimated as 105 mm for the period between 1936 and 1967; Cairo University Report, 1989a. Also, vegetation and their distribution may have impacts on the amount of distributed recharge through evaporation and other processes that may take place in the vadose zone even though that we consider irrigation return coefficient taken place in the point sink items in the model.

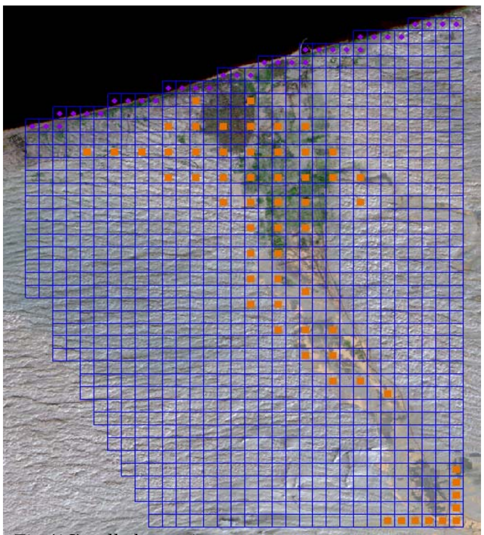
Fig.(16) cell abstraction

2-4-4- Calibration Paramètres:

In this study we calibrate, simultaneously, recharge and hydraulic conductivity. Recharge is parameterized using zones. In defining these zones several factors were considered; for example, surface geology, density of vegetation and general land use. Fig.(17) shows parameterization of recharge (left) and hydraulic conductivity (right) adopted in this study. The figure (left) shows different zones of recharge where their values are to be estimated in the calibration, while the (right) shows the pilot points representing hydraulic conductivity with initial values of 43 *m/d*. Values of hydraulic conductivity at those points are to be estimated in the calibration of the model.

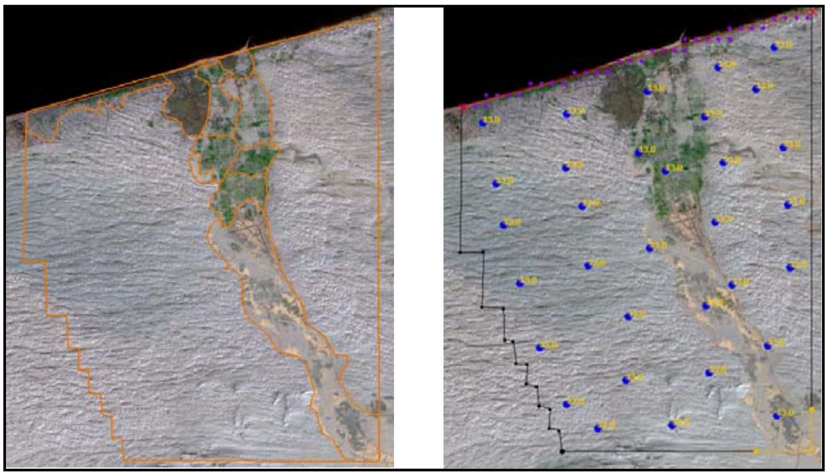

Fig. 17, Recharge zones (left) and Pilot points of hydraulic conductivity (right).

2-4-5- Calibration Results:

As stated before, the calibration target of this study is to calibrate the spatially variable hydraulic conductivity and recharge. Calibration is done iteratively which lasted for 16 iterations and gave 8.55 of sum of squared weighted residuals (all dependent variables), fig.(18). The figure shows very good results for all of the observation points. Fig.(19) shows calibrated parameters where it shows recharge (left) and log-transformed hydraulic conductivity (right). The figure shows that recharge varies between 1.62×10^{-5} *m/d* which exists in areas of recharge due to infiltration solely from rainfall and 3.5×10^{-3} *m/d* which comprises combination effects of rainfall, irrigation and other possible sources that are not accounted for directly in this study. It

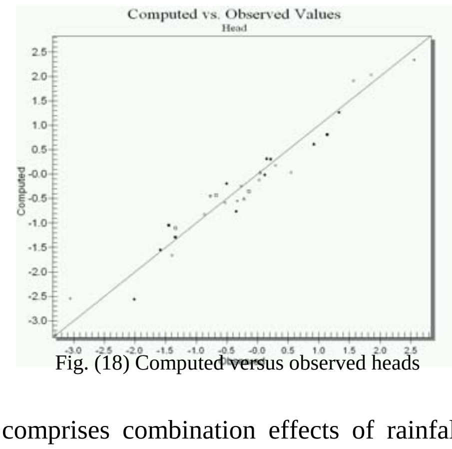

Fig. (18) Computed versus observed heads also should be noted that recharge in urban area (city of El-Arish and surrounding areas) present amount of return water from domestic wells. The estimated value of this recharge is 0.0002 m/d. This corresponds to about 7% of the total domestic abstraction. Fig.(19) (right) also shows the log-transformed hydraulic conductivity (ln(*K*)).

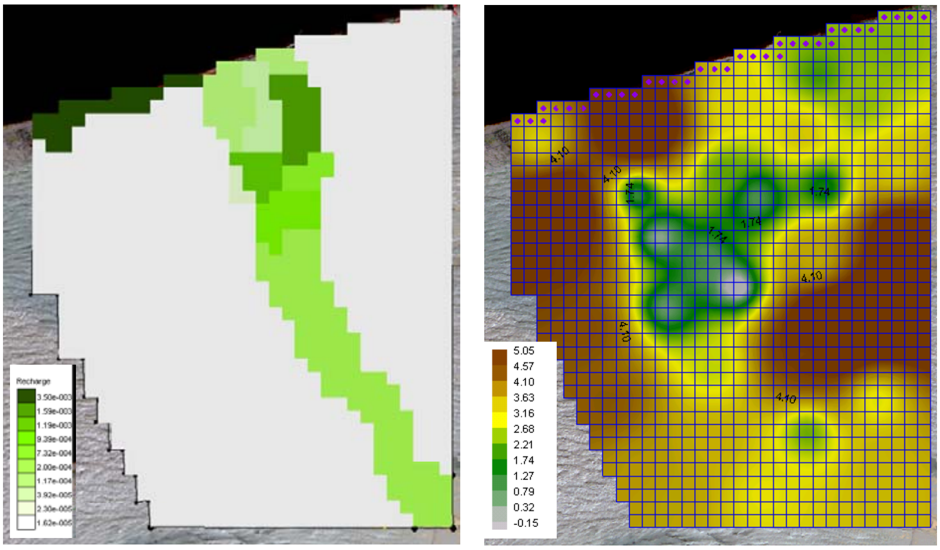

Fig. 19, Calibration results: recharge (left) and log-transformed hydraulic conductivity (right).

The figure shows that the calibrated ln(K) ranges between -0.15 and 5.05 (this corresponds to 0.86 and 156 *m/d*). It shows that the middle part of the study area has the minimum to average hydraulic conductivity while higher values exist in west-north and middle-east of the study area. Finally, fig.(20) shows calibrated piezometeric heads for 1988. The figure shows that the aquifer is subject to aggressive pumping where many locations of negative water levels do exist. Table (2) shows volumetric budget for the entire model at 1988 assuming a steady state solution. The table shows that the long term average for recharge is 34228.8 *m/d*. It also shows that there are local salt water intrusions that amount only 9381.6 *m/d*.

Table 2, volumetric budget for the entire model at 1988 assuming steady state.

	IN	OUT
CONSTANT HEAD	9381.6221	4926.9243
WELLS	1350	40033.5
RECHARGE	34228.8008	0
TOTAL	44960.4219	44960.4258

2-4-6- Transient Simulation

In this section we examine transient flow in the period between 1988 and 2006. Based on available pumping rates and locations of wells in 1988 and 2006, we linearly interpolate the rates for a yearly stress period. This gives 18 stress periods. This linear interpolation assumption is consistent with available data for irrigation and domestic wells between 1988 and 2006 where they show a trend of linear relationship. Amount of abstraction introduced in the model of this study for the year 2006 in this study is 52555 m^3/d. In this simulation we still use 50% return coefficient for irrigation water. We also assume that calibrated recharge, presented in the previous section, is constant over the simulation period between 1988 and 2006. However, we change recharge in urban area to zero as from 2002 where sewerage system in El-Arish city has started operating since that time.

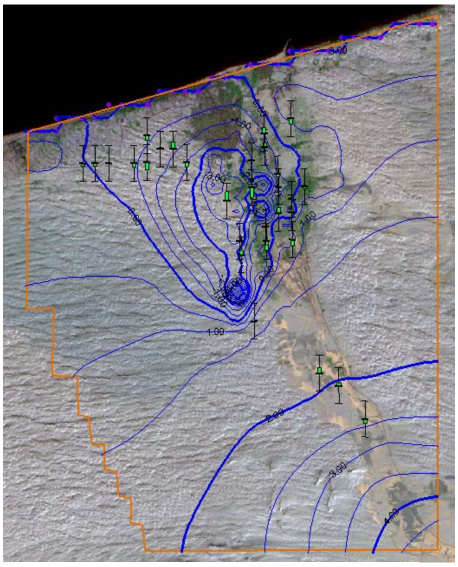

Fig. (20) Calibrated water level for 1988

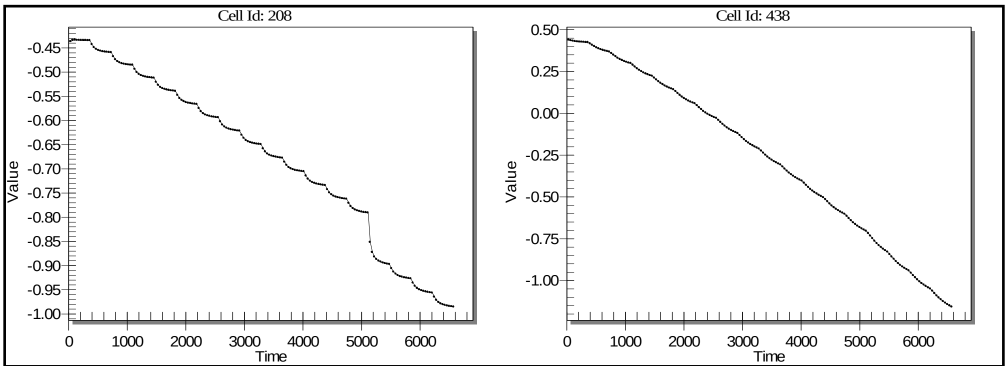

Fig.(21), Piezometric level time series for two cells in the model; left is for a cell within the urban area of El-Arish city and right is for a cell almost middle of the study area.

Fig.(21) shows time series of piezometric water level at two cells in the study area. The figure shows a cell in the urban area of El-Arish city (left) and a cell in the agriculture area close to the airport almost middle of the study area. Both plots show drop in the water levels between 0.6 m and 0.75 m. The graph to the left at the urban area also shows a sudden drop in 2002 due to stopping recharging the aquifer by the return of the domestic water use. Such drops in the water level indicate possible sea water intrusion which also supported by the volumetric water balance given in table (3). Finally, this also can be anticipated from the simulated piezometeric levels for 2006 shown in fig.(22).

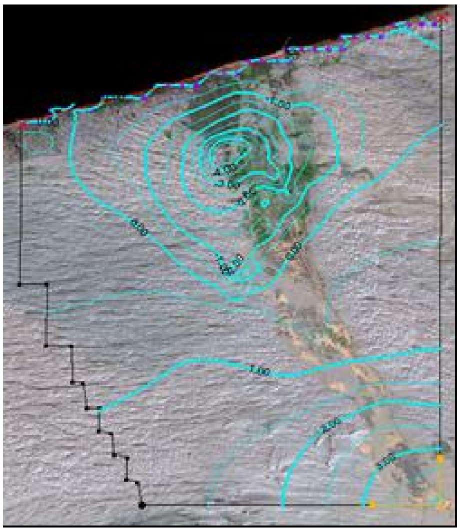

Fig.(22), Simulated piezomeric levels in 2006.

Table 3, Volumetric budget for entire model at end of time step 10 in stress period 18

FLOW ITEMS	CUMULATIVE VOLUMES (L^3)	RATES FOR THIS TIME STEP L^3/T
IN		
STORAGE	5732372	1057.7019
CONSTANT HEAD	87865016	18935.6914
WELLS	8874900	1350
RECHARGE	226271680	33641.4453
TOTAL	328743968	54984.8359
OUT		
STORAGE	194992.7969	0
CONSTANT HEAD	24216302	2778.397
WELLS	304332512	52206.4414
RECHARGE	0	0
TOTAL OUT	328743808	54984.8398
IN – OUT	160	-3.91E-03
PERCENT DISCREPANCY	0	0

3-Rommana-Bir ElAbd Aquifer

3-1 - Background.

The study area is located at the North western part of Sinai Peninsula and considered a huge sedimentary basin. The sedimentary column reaches about 3000m and the oldest rocks are the Jurassic near the southern border. The Quaternary deposits consist of a number of sedimentation cycles of sand, clay and silt; hence a number of sand lenses were formed. The transgression and regression of the Mediterranean Sea play the important role in the hydro -geological condition of the shallow groundwater aquifer, in that area. The Quaternary (Holocene-Recent) deposits will be described as follows:

3-1-1Sand dune

Movable and stabilized type takes the longitudinal, Barchans and complicated Shapes.

3-1-2 Sabkha deposits

Salt clay deposits at EL-Bardawiel lagoon. These deposits were formed due to high rate of Evaporation and consider the main source of sodium chloride salt.

3-1-3 Coastal sand dune deposits

Consists of silt and clay near the sea shore and named tongues due to the effect of sea currents. It's believed that these tongues was formed due extension of the old branch of Nile (pelusium) to this area and named Houras Trak.

3-1-4 Wadi deposits

Consist of rock fragments, sand, silt and clay and covered by sand dunes, these deposits are very important from hydrogeolgical point of view.

3-1-5 pluvial deposits

Consist also of rock fragment, sand, silt and clay which formed at the base of the wadis along the mountainous lopes. These deposits indicate to the hard effect of weathering factors in geological decade especially in Pleistocene epoch.

3-1-6 Desert lake deposits

Fine sand with silt formed at the low lands in desert which contain rain water, this type also indicates to the rainy weather in the old periods.

3-1-7 EL- Tina Bay

This Bay is formed due to the interface of the seawater and Nile water at the most Northern part of Sinai before many years ago. The deposits consist of silt and clays the transgression and regression of the sea forming a huge salty clay and silt section.

3-2-Hydro-geological Condition:

In 1988 and 1992 WRRI studied the hydro-geological characteristics of the dune aquifer through EEC and JICA projects. In 2006 the Islamic Bank for development founded a gift for studying the availability of water resources for Bedouin settlement in North Sinai governorate. The data were collected include, the aquifer extension, boundaries, water level, hydraulic parameters, recharge and discharge……etc. here, a general review will be done and suggestion of important recommendation for aquifer management.

3-2-1 Aquifer Hydraulic parameters

There is great difference between hydraulic parameters of the same aquifer especially the transmissivity values. These value ranges from 314 m2/d at well No. 8 south of Bir El-Abd (industrial zone) to 1767 m^2/d at well Qatia No. 56. The storage coefficient ranges from 716x 10^{-2} to 37 x 10^{-1} at wells EL-Masharif and Meriah wells respectively. Generally, the great deference due to variation of depositional environment

3-2-2- Water Level and flow direction for dune aquifer

Through the flow up the aquifer during 20 years ago, we found that the water table change or affected directly by rainfall and from winter to summer seasons. The water level ranges between 2 and 6m above mean sea level, but at some areas below the sea level (-1m.at EL-Shohat area). The flow direction is generally due North but in some areas such as sabkha and low areas, the flow towards these sabkhas (low lands or Hods). Due to the presence of El salam canal the hydrogeological condition of the dune aquifer will be affected by the irrigation water from this canal. The irrigation water will be infiltrated into the aquifer and will cause environmental impact to the aquifer. Figure (23) shows the isopotentiometric surface map of the groundwater into the aquifer.

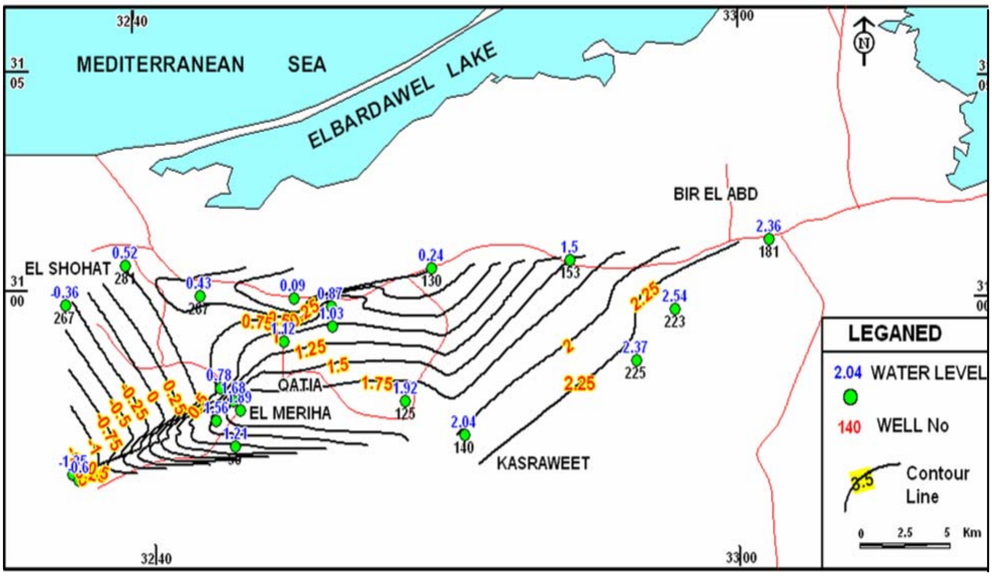

Fig (23) Isopotentiometric Surface Map of the Dune Aquifer

3-2-3-Water balance of the dune aquifer

The well data inventory were collected and estimation of recharge volume from rainfall by WRRI staff indicate that the total No. of wells is 680 and the operation hours ranges between 4-5 hour/day and the discharge of each well ranges between 5-15 m^3/h and the operation days 300 day/year, hence, the total discharge was calculated by about 31000 m3/day (9-10) $\times 10^6$ m^3/year. Most of the rain water infiltrates into the dune aquifer. The estimated net recharge from rainfalls precipitation is 15 million m^3/year. The deference between the recharge and the abstracted water is (5-6) million m^3/year, this not means that the aquifer in a good state due to the great extension of the aquifer area and the fresh water floats above the saline water into this aquifer; hence, the abstraction from this aquifer should be controlled for sustainable development.

4-Water Quality Issue:

The management of coastal aquifers needs high caution during the groundwater extraction to avoid the sea intrusion or deterioration by saline water from deferent aquifers. The aquifer at Rafah-El shiekh Zuwyied has very good water salinity (500 - 700 ppm) especially at the most north eastern part due to the high rate of rainfall and presence of clay layer along the shore line (detected from geophysical studies). The salinity increase due west along the shore line due to the deterioration by sea water at El Shiekh Zuwyied (3000 ppm) and reaches 7000 ppm due south due to pumping from the calcareous sandstone layer (kurkar) due to its deposition in marine environment , hence , increases the water salinity . The aquifer of the delta wadi El Arish has different condition than of Rafah especially in water quality. The high salinity (>7000 ppm) occurs at the mouth of the delta and low salinity (<2500) occurs at the southern and southeastern parts of the delta. Generally intensive pumping creates a huge cone of depression and deterioration by high saline water from lower saline water (Miocene aquifer). The aquifer is in critical situation and should be control the groundwater exploitation and good management by searching new water sources especially drinking and domestic water from the Nile and El Salam canal or desalinization of sea water.

5- Environmental Impact of EL-Salam canal

Sinai national project includes the extending EL-Salam irrigation canal into Sinai to irrigates 400.000 feddan. The canal receives its water from EL-Sir and Hadous drains (drainage water) and mixed with Nile water (fresh) by 2:1 to decrease the salinity and dilution of drainage water. The canal reaches Bir EL-Abd until now and passing through the dune aquifer. The groundwater environmental system in that area will be change with presence of this canal due to the change of irrigation system and crops pattern. The chemical and biological characteristics will be change due to the infiltrated water from irrigation water. The Mediterranean sea and El Bardaweil lake due north will be affected by the groundwater flow due to disappearing of some types of organisms especially fishes and algae . It must by construct a complete or integrated environmental system before compellation of this canal to protect and avoid any negative impact.

Conclusion and Recommendation

1- Rafah-El Shiekh Zuwyied Aquifer:

The southern part of the modeled area has water level ranges from zero to 6m. (a.s.l). the thickness was estimated by 30m for the Kurkar layer. The area is equal to 120 km^2 (southern part). The total porosity is equal to 3%. Hence, the storage is equal to 108 x 10^6 m^2 if the water level decreases by 2m. We can extract about 7.2 x $10^6 m^3$. It's recommended to drill 10 wells at the southern part of the aquifer to extract about 0.6 x $10^6 m^3$/year. Also it's recommended to drill 20 piezometers distributed in whole aquifer especially along the eastern border to flow up the water level fluctuation.

2-Delta Wadi El Arish Aquifer

The Quaternary aquifer of delta wadi El Arish is subjected to main tow problems, the increasing of population and sea water intrusion. The measured and observed water level through the model indicates that high lowering at the central part south of the town and above the sea level due south and small lowering near the shore of Mediterranean sea due to sewage and irrigation water. Due the south at inlet of the aquifer and southwestern part, the water level above the sea level by 2m, hence, it's recommended to study the buried channels which recharge or feed the aquifer from the southwestern part and complete finishing the sanitation network of ElArish town and its surroundings.

3- Rommana- Bir El Abd Aquifer

The sand dunes are considering main good aquifer in this area. The aquifer extends or occupies an area about 3000 km^2 and has especial hydrogeological conditions. The recharge is mainly from rainfall and exceeds the extraction by about (5-6) millions m^3/y its recommended to drill a small shallow wells at depth (15-20) m. to extract the floating fresh water and avoid the deterioration by lower brackish and sea water. Also drill a number of peizometers to flow up the fluctuation of water level and control the extraction from this aquifer. The aquifer was classified into three zones of different types of water quality as follows:

*** First zones**

Friable sand at the topmost part and contains silt and clay at the lower part. The thickness of this zone ranges between 20m due north increases to 100 m due South, the infiltrated rain water passing from this zone to the Second zone directly and some fresh water (1000-2000 ppm) remains as local aquifer.

*** Second Zone**

The thickness of this zone reaches 20m. and considered the main aquifer in the study area. The aquifer is un-confined type. The salinity of the water into this zone ranges between 2000 and 4000 ppm.

*** Thrid Zone**

This zone represents isolated sand lenses ranges between 20- 140 m. The salinity of the water reaches 10.000 ppm, due to the effect of sea intrusion and sea water depositional, of environment.

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إدارة الخزانات الجوفية المتواجدة على ساحل البحر المتوسط في شبه جزيرة سيناء

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معهد بحوث الموارد المائية – المركز القومي لبحوث المياه – القناطر الخيرية – مصر

تقع سيناء في أقصى الشمال الشرقي لجمهورية مصر العربية وتشغل حوالي 16% من مساحة مـــصر الكليـــة. الموارد المائية في شمال سيناء تتكون أساساً من المياه الجوفية والمياه السطحية (العواصف المطيرة) والتي تنساب في الأوديـــة والتي تصب في البحر الأبيض المتوسط وخليج العقبة وخليج السويس. وتعتبر المياه السطحية هي المـــصدر الرئيـــسي في تغذية الخزانات الجوفية المختلفة في شبه جزيرة سيناء. ولقد تم إجراء العديد من الدراسات الحقلية منذ عام 1981 والتي بناءاً عليها تم البدء في العمل مخططات التنمية المستدامة والتي أخذت الموارد المائيـــة في الإعتبـــار الأول مـــع المـــردود الإقتصادى والإجتماعى كذلك. بالنسبة لتقييم الخزانات الجوفية. فإن الدراسات الجيولوجية والجيوفيزيقية والهيدرولوجية والهيدروجيولوجية قد ساهمت في تعريف وتحديد هذه الخزانات وبمتابعة هذه الدراسات ومتابعة الـــسحب مـــن هـــذه الخزانات نظراً للزيادة السكانية المطردة في مناطق العريش – رفح – بئر العبد. وهذا البحث يوضح كيفية إدارة الخـــزان الجوفي في هذه المناطق وذلك من خلال حساب كميات التغذية والسحب والسحب الآمن لعدم تدهور هـــذا الخـــزان وتداخل مياه البحر فيه كما يوصى هذا البحث مدى التفاعل بين الموارد المائية والتنمية المستدامة في المنطقة من خـــلال مقارنة في الفترة ما بين 1981 وحتى 2006 ومدى تحسين مستوى المعيشة بسبب التنمية المستدامة.

الكلمات المفتاحية: إدارة الخزانات – العريش – رفح – بئر العبد – سيناء