THE IMPACT OF IRRIGATION CANALS COVERING ON GROUNDWATER IN THE NILE DELTA, A CASE STUDY: ABU KEBIER CITY, SHARKIA, EGYPT

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ABSTRACT

In Egypt, irrigation water is scarce and development in agricultural, industry and population growth increasing the demands. The agriculture sector consumes the greatest part of available surface water. This consumption estimated by 85.6% by 2006/2007. This forced decision makers to rationalize the usages in this sector. An important side of the rationalization was to save canals water losses. Canals lost great amounts of water through seepage to the groundwater aquifer, also by evaporation. So irrigation canals covering used in many villages and hamlet to solve several problems. These problems are canals contamination mainly, and seepage losses. This paper aims to evaluate the effect of irrigation canals covering on groundwater levels. This is done by comparing the cases of covering and not- covering. The area of study is Abu Kebier City, Sharkia Governorate, Egypt. The numerical model, MODFLOW was used in the simulation process. The simulation was carried out for maximum and minimum water levels in irrigation canals for November and December. However, the field measurements were done in December to get the groundwater levels. The program was run and calibrated. The calibration indicated that the field measurements located between the maximum and minimum water levels. The results proved that the covering process has small effect on groundwater levels. The differences in groundwater level were 4cm and 3cm as an average value for the cases of maximum and minimum water levels consecutively.

Keywords: Groundwater levels, irrigation canals covering, MODFLOW, Abu Kebier City, Egypt.
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1 INTRODUCTION

Irrigation canals covering were a rapid solution to overcome many problems. Irrigation canals covering aims to achieve three main goals. The first is saving the losing amounts of water due to evaporation. The second is reducing the seepage from the irrigation network to the aquifer. The last one is preventing canals contamination. Generally, the groundwater levels may be affected by the preventing of seepage. To study the impact of irrigation canals covering on groundwater levels, comparisons were done between cases of covering and non- covering for both maximum and minimum water levels in the study area. A number of studies concerned with the applications of MODFLOW in the simulation of groundwater flow through aquifers. **Yanxun(2011)** used MODFLOW for groundwater simulation in Balasu water source. The calibration results of the numerical model indicated that the model could reflect the actual hydrogeological conditions, and could be applied in predicting the future groundwater flow conditions.

Shake (2007) aimed to develop and apply the MODFLOW model of the Murzuq aquifer systems in Libya. The model was capable of adequately reproducing historic water levels within the aquifer. The model was then used to assess the impacts of medium and long-term water abstractions at Irawan on the piezometric levels in the aquifer. The results showed that, with current farming practices at Irawan, the piezometric surface in the centre of the field closest to the cluster of the pumping wells will stabilize in year 2033 at 470 m above sea level, representing a maximum drawdown of 30 m. Hassan (2012) used MODFLOW to find a solution for the groundwater uprising in Al-Fustat area, Old Cairo, Egypt. The simulations included pumping rate of 200 m3/day achieved 2:3 m drawdown which met the target. Number of researchers focused on field measurements of ground water levels. Kovar (1996) stated that the well calibrated groundwater model would have an allowable error of 0.23m. O.W.R.D. (2009) stated that the static water was a stable water level when the well did not pump. Fulton (2002) approved that agricultural and domestic production wells can be used for measuring groundwater levels.

Nguyena (2013) clarified the groundwater flow system in Tay Island, Vietnam using groundwater simulation. The results showed that the groundwater flow system strongly affected by seasonal changes in Mekong River water levels. This paper studied the effect of covering canals on groundwater levels. This is done through selecting a suitable study area and a numerical simulation model. The model calibrated through two cases. The simulations are including both maximum and minimum surface water levels. Some comparisons were done to get a clear effect of covering on groundwater levels. Bruce (2014) reported that in northern Victoria, farmers are the biggest users of groundwater. Interviews with 30 irrigation farmers in two study areas, analyzed using qualitative social research methods, showed that the overwhelming majority of groundwater users agreed with the need for groundwater management and thought that the current plans had achieved sustainable resource use. Fuzhong (2011) used the standard visualization software Visual MODFLOW in order to put forward a reasonable mining scheme to ensure the safety of Bulang River-Red Stone Bridge water source, the standard. The model identification and verification results indicated that the model can reflect the actual hydrogeology conditions, and can be used to forecast groundwater flow. Based on comparative analysis of the prediction results of mining schemes, a reasonable scheme with exploitation quantity of 35000 m^3/d is determined to ensure the normal operation of the water source, under which neither the local ecological environment nor the Hailiutu River flow is influenced.

Sindhua (2012) developed a numerical model for groundwater flow and contaminant transport using Visual modflow and SEAWAT and predicted the groundwater heads and extent of intrusion during 2011-2020 through scenario analysis. The case study was Trivandrum which is one of the fastest growing cities of South India. These models, will aid to project the behavior of coastal groundwater system with respect to the future environmental challenges and to evolve suitable measures to control the saltwater intrusion into coastal aquifers of Trivandrum. Cho (2010) developed MODFLOW to simulate the interaction between surface water and groundwater. The study area was in the Nomini Creek watershed located in the Coastal Plain of Virginia. He concluded that the proposed approach was useful for evaluating the impacts of agricultural on the entire surface water-groundwater system. Koch et al., (2012) used MODFLOW for the upper Chiang Rai aquifers by the year 2009. For estimating the future permissible groundwater yield. The result showed that the permissible yield was 1600 m^3/day.

From the above literature, the impact of irrigation canal covering on groundwater levels in the Nile Delta was not estimated which is done in this study.

2 THE STUDY AREA

The study area is located in Sharkia governorate, Egypt. The center of the study area is far from the northeast of the capital of Sharkia Governorate by 22 km. The longitude and latitude pass through it are 30°43'30" N and 31°40'17" E, Maps-Atlas.Org. (2013). Main and legal resources of irrigation water in the study area are Bahr Mouies and Bahr Facous. Both of them are considered as main canals, “Fig. 1”. Sharkawi (2008) discussed that the study is a part of Nile Delta Aquifer. The rainfall is the only recharge for the study area and evaluated by 10 mm/year. The Nile Delta aquifer consists of three layers. The aquifer system generally is a complex groundwater system. It is a leaky one, with an upper semi-permeable boundary. The study area belongs to the semi- confined aquifer. Where, It is covered with Holocene silt and clay (first layer, Semi-confined) with a thickness of 10 m as shown in “Fig. 2-a”. The aquifer thickness is 400m as shown in “Fig. 2-b” (second layer) is underlain by Pliocene marine clay (lower impermeable boundary). The saturated thickness (third layer) of the aquifer is 390m.

The discharge from the aquifer is done by illegal random wells. They consist of wells for irrigation, domestic and drinking purposes. Actually, the groundwater users did not use irrigation pumping wells to compensate the shortage in surface water during November and December. The irrigation experts indicated that November and December crops did not require excess irrigation water. Sherif (2001) estimated the hydraulic parameters of the Nile Delta Aquifer through field and laboratory experiments. Accordingly, the hydraulic conductivity ranges from 25m/day to 200 m/day. Initially, an isotropic and homogeneous aquifer assumed to get single values for the used model. The specific storage ranged from 1.28×10^{-4} m^{-1} to 10.2×10^{-4} m^{-1}. The specific yield for the aquifer ranged from 0.1 to 0.3. An effective porosity of 0.3 and total porosity of 0.43 considered to represent the aquifer medium Sharkawi (2008).

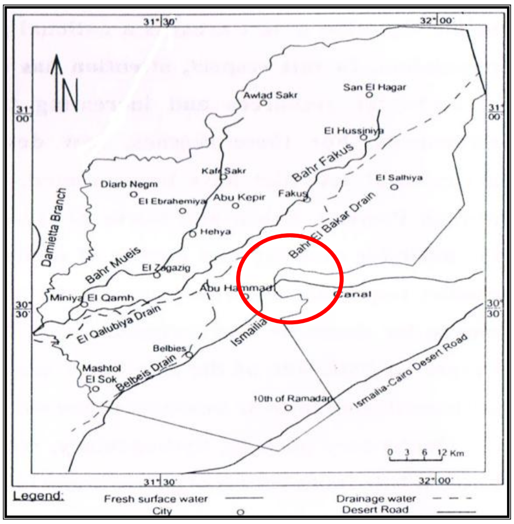
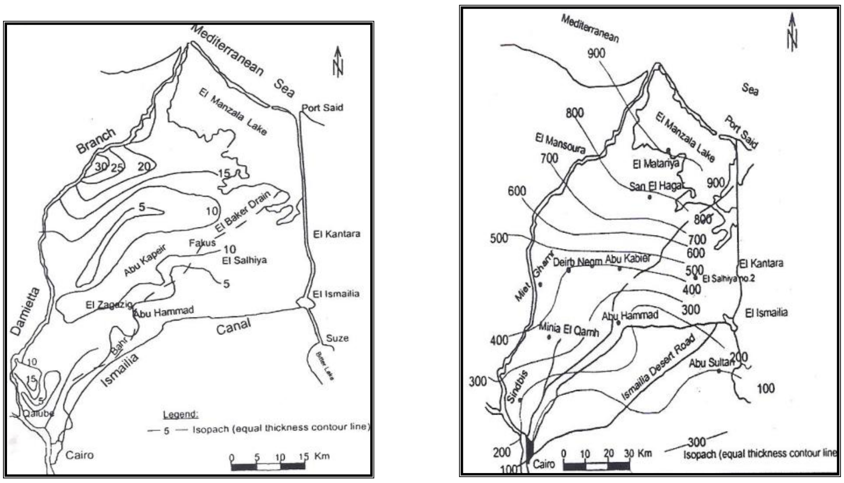


Figure 1. Location map of the study area, Sharkawi (2008)



a. The Contour map of the clay cap **b. Contour map of the Nile Delta aquifer thickness**

Figure 2. The Contour map of the clay cap and the Nile Delta aquifer thickness, Sharkawi (2008)

3 THE NUMERICAL MODEL

MODFLOW is used for the simulation of the study area. MODFLOW is the U.S. Geological Survey modular finite-difference flow model, which is a computer code that solves the groundwater flow equation. The program is used by hydrogeologists to simulate the flow of groundwater through aquifers. The code is public domain free software, written primarily in Fortran, and can compile and run on Microsoft Windows, **WWT (2014)**.

3.1 The model Input

The Input allows the user to assign graphically all of the necessary input parameters for building a three-dimensional groundwater flow and contaminant transport model. The input menus (shown above) represent the basic 'building blocks' for developing a model data set for MODFLOW, MODPATH and MT3D. These menus are displayed in a logical order to guide the user through the steps required to design a groundwater mode.

3.2 Run the model

The Run allows the user to modify the various MODFLOW, MODPATH and MT3D parameters which are run-specific, such as selecting initial head estimates, setting solver parameters, activating the re-wetting package, specifying the output controls, etc. Each of these menu selections (as shown below) has default settings which will run most simulations.

3.3 Solution method

MODFLOW is a computer program that numerically solves the three- dimensional groundwater flow equation for a porous medium by using a finite- difference method. Visual MODFLOW 3.1 is the version used in the simulation. MODFLOW solved the general form of the three-dimensional groundwater flow equation which was a combination of the water balance equation and Darcy’s law. The governing equation was:

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+W=S_S\frac{\partial h}{\partial t}$$

(1)

Where

K_{xx}, K_{yy}, and K_{zz}: Hydraulic conductivity along the x, y, and z coordinate axes.

h: Head.

t: Time.

W: is a volumetric flux per unit volume representing sources and/or sinks of water, where negative values are extractions, and positive values are injections (T^{-1}).

3.4 The Model Output

The Output allows the user to display all of the modeling and calibration results for MODFLOW, MODPATH and MT3D. The output menus (as shown below) allow to select, customize and overlay the various display options for presenting the modeling results.

4 THE METHODOLOGY

The work included 4 main steps. These steps are field work, setting up the model, calibration of the model, and the comparisons.

4.1 Field work

This step included determining number of domestic or drinking wells, discharge from the study area and groundwater levels in the study area.

4.1.1 Determining number of domestic or drinking wells in the study area

Random irrigation and domestic wells represented the discharge from the study area. Irrigation wells were not in use in this season. Where the surface water is enough to face the irrigation needs in this time of year. So the domestic and drinking wells represented the discharge from the study area. A questionnaire done for estimation the number of wells used for domestic and drinking purposes. The questionnaire presented in appendix (1). It was taken into consideration that the sample spreaded allover the study area, **Mellenbergh (2008).** The number of sample was 152 persons. The results of the questionnaire proved that 49% from the population in the study area used domestic or drinking wells. The population of Abu Kebier city was 393.991 thousands by the year 2012. This number of people used these domestic and drinking wells were 193000 (=393.991* 49%). This number of population did not represent the number of wells. One family or one building could use one well. People divided into groups through the questionnaire. These groups were ≤ 5 individuals, (6:10) individuals, (11:15) individuals, and (16:20) individuals, as shown in appendix (1)

The first row of "Table 1" showed the number recorded for each groups in the sample. The second row showed their percentage in the sample. These % multiplied by the whole number of population used these types of wells (193000), as in the third row. Then the values in the third row divided by average number into each group such as dividing by 13 for the group (11:15) individuals, as seen in the forth row. The number of wells must be integer. For that an approximation done in the fifth row. The last row show the total number of wells. Which were approximately 35230. Actually this estimated number of domestic and drinking wells could not be simulated. The simulation was done by only ten wells. These ten wells had discharge equivalent to the discharge of the total estimated wells.

Table (1). Estimating the number of domestic and drinking wells in the study area.

	individuals	less than 5	06:10	11:15	16:20
1	No. in sample	56	44	32	20
2	% in the sample	37%	29%	21%	13%
3	Total No. of population used wells	193000			
4	No. of individuals used wells	71125.74368	55884.51289	40643.28211	25402.05132
5	Average No. of individuals	3	8	13	18
6	No. of individuals	23708.58123	6985.564112	3126.406316	1411.225073
7	Approximate no. of individuals	23708	6985	3126	1411
8	Total No. of wells	35230			

4.2.1 Estimation of Discharge for drinking or domestic purposes in the study area

An individual consume 150 to 200 lit/ day. This means that every person consume about 0.175 m^3/day as an average value. Hence 193000 from the population of the study area depended in their drinking and domestic purpose on groundwater. Then the daily consumed for the study area was 33775 m^3/day (= 193000*0.175). So the discharge from every well was 3377.5 m^3/day.

4.3.1 The groundwater levels in the study area

The observations of levels used for five points in the study area. The measurements were the depth of groundwater and ground level in these five points. They were all pumping wells. Where in this period (December), the pumping wells considered observation wells**, O.W.R.D.(2009).** The location of these wells determined during field work by using Surveying devices. “Fig. 3”.shows observation wells in green color, and pumping wells in red color. The field measurements agreed with unpublished data from Educational Buildings Authority by the year 2012**.**

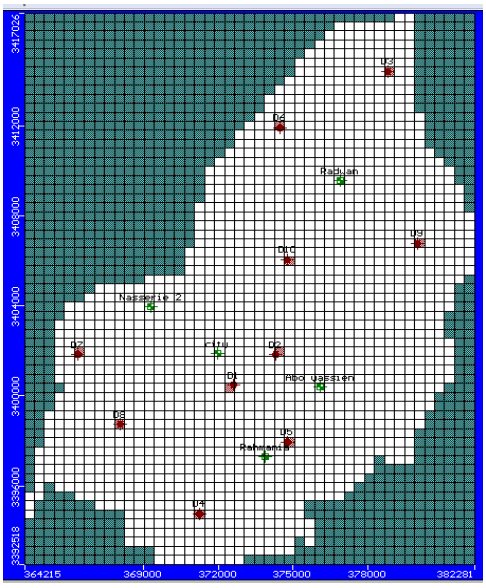


Figure 3. Observations and domestic wells.

5 MODEL SIMULATION

5.1 INPUT

5.1.1 Grid

To define the study area in Modflow program, units were entered and corrected, a DXF extension map imported, and geometry model grid was 45 Column * 61 Row (The was cell size nearly 401.5 m*401.5 m. In “Fig. 4”, the study area appears with white color and defined as active cells.

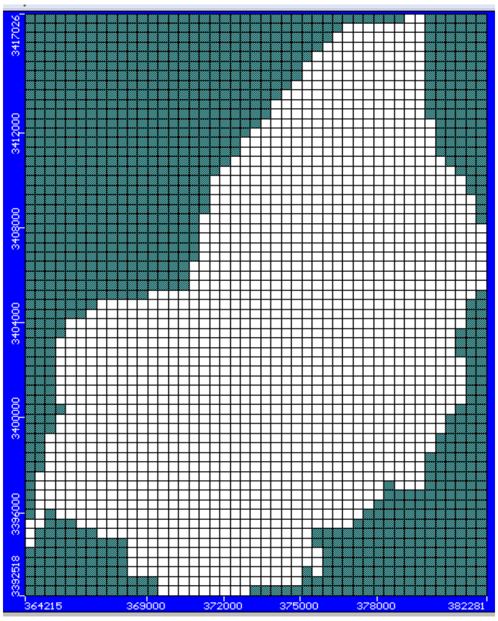


Figure 4. The grid, active and inactive cells

5.2.1 Canals and drains

The simulation of canals and main drains required to know its characteristics, such as surface water level, bed level, bed width, conductance, data of canals inlet and outlet. "Table 2" represents an example for canals data required in the simulation. The maximum and minimum surface water levels (w.l.) in canals for November and December used in the simulation. Because of groundwater levels measuring in field was on December. "Fig. 5" shows the irrigation network and main drains in the study area.

Table (2). Canals data required for the simulation

No.	Canal name	Max.w.l.		Min.w.l.		Bed level		K_z (m/d)	Bed width
		inlet	outlet	inlet	outlet	1n	out		
1	Gannabia Abo hattab	6	5.98	5.45	5.43	5	4.81	0.025	1
2	Gannabia Shershima	6.1	6	5.25	5.15	4.3	4.3	0.025	1.5

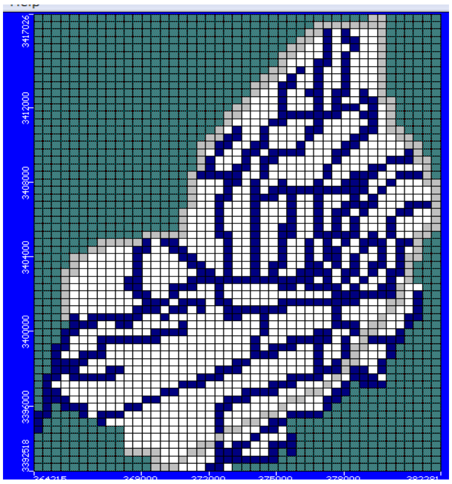


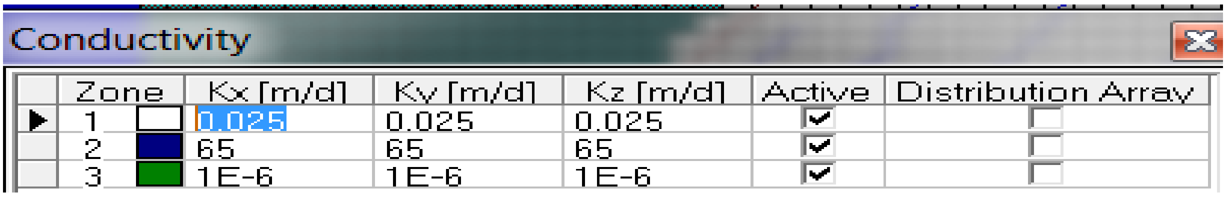
Figure 5. Canals network and main drains.

5.3.1 Soil properties

"Table 3" shows the initial hydraulic parameters entered for the simulation. "Fig. 6" shows the hydraulic conductivity for the three aquifer layer. "Table 4" shows the values of storage parameters for the three layers. "Fig. 7" shows the database of storage parameters. To evaluate the changes occurred in levels, other two important simulation achieved. For the maximum and minimum levels in December and November but with supposing that all canals were not covered.

Table (3). Initial hydraulic parameters, Sherif (2001)

Parameter	Unit	Value range	Entry
K	m/day	25: 200	65
Ss	m^{-1}	1.28×10^{-4} :10.2×10^{-4}	5×10^{-4}
Sy	---	0.1 to 0.3	0.2
N	---	---	0.43
N_e	---	---	0.3
ET	mm/year	---	27
recharge	mm/year	---	10

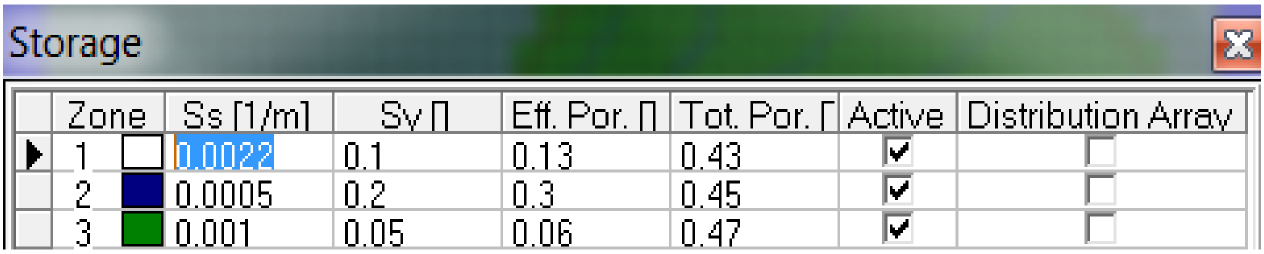

Conductivity

Zone		Kx [m/d]	Ky [m/d]	Kz [m/d]	Active	Distribution Array
1		0.025	0.025	0.025	☑	☐
2		65	65	65	☑	☐
3		1E-6	1E-6	1E-6	☑	☐

Figure 6. The database of hydraulic conductivity

Table (4). The values of the storage parameters.

layer	S_s (m^{-1})	S_y	P_t	$P_{eff.}$
First	$20.34*10^{-4}$: $25.59*10^{-4}$	0.06 : 0.2	0.34 : 0.57	0.01 : 0.39
Ave. value	0.0022	0.1	0.43	0.13
Second	$1.28*10^{-4}$: $10.2*10^{-4}$	0.1 : 0.3	0.25 : 0.53	0.18 : 0.43
Ave. value	0.0005	0.2	0.45	0.3
Third	10^{-2} : 10^{-4}	0.01 : 0.1	0.34 : 0.57	0.01 : 0.18
Ave. value	0.001	0.05	0.47	0.06


Storage

Zone		Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. [	Active	Distribution Array
1		0.0022	0.1	0.13	0.43	☑	☐
2		0.0005	0.2	0.3	0.45	☑	☐
3		0.001	0.05	0.06	0.47	☑	☐

Figure 7. The database of storage parameters

5.2 Model Calibration

The calibration is done for the levels. The red points appear in “Fig. 8-a” and “Fig. 8-b” represented the relationship between observed heads and calculated heads. The observed head were smaller than the calculated ones for the case of maximum water levels and canals covering with small difference, average difference was 0.02m , as shown in “Fig. 8-a” and “Table 5”. The observed head were greater than the calculated ones for the case of minimum water levels and canals covering with big difference (average difference was 0.694m), as shown in “Fig. 8-b” and tab. (4). Because of the measuring of levels were in days that canals had maximum water levels. “Fig. 8” and “Fig. 9” illustrate that difference. “Fig. 10” shows the head contours and the velocity direction for the two cases of covering. “Fig. 11” shows the mass balance for the two cases of covering.

Table (5). G.W.L. resulting from the two simulation and the observed values.

Well name	unit	Radwan	Abo-Yassien	City	Nasserie	Rahmania
Observed	m	4.45	4.58	4.59	4.61	4.62
Max.	m	4.47	4.6	4.62	4.62	4.64
Mini.	m	3.73	3.89	3.91	3.91	3.94

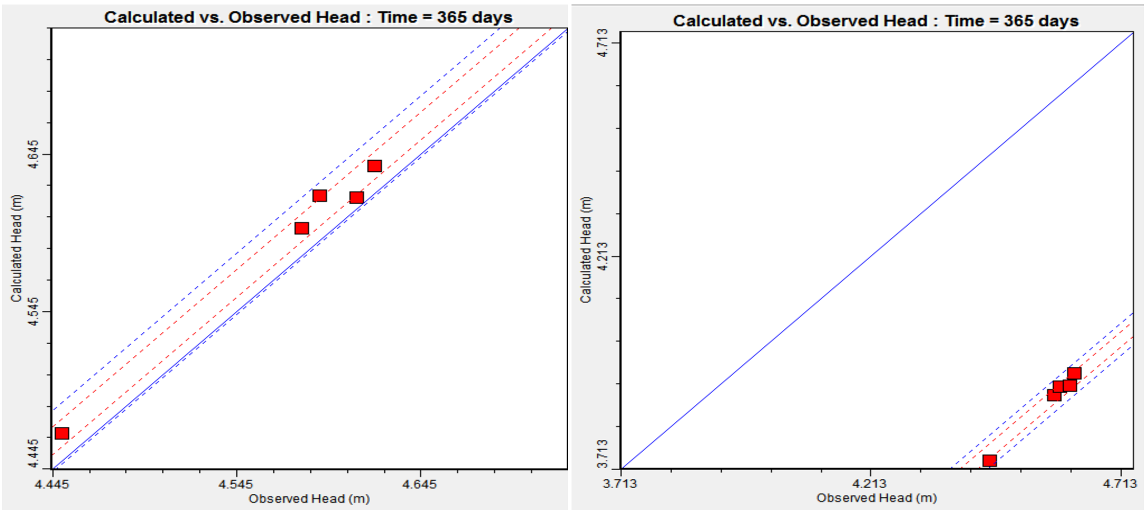


Figure 8-a. The calibration for the maximum case Figure 8-b. The calibration for the minimum case

Figure 8. The calibration

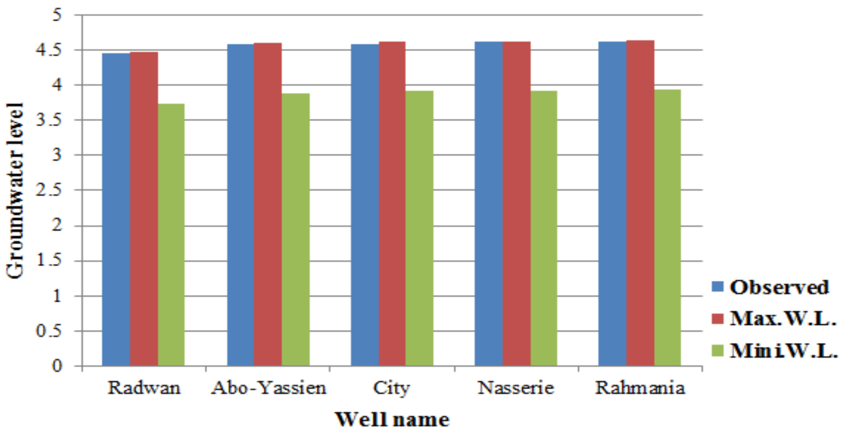


Figure 9. The observed and the calculated heads for the two cases of covering.

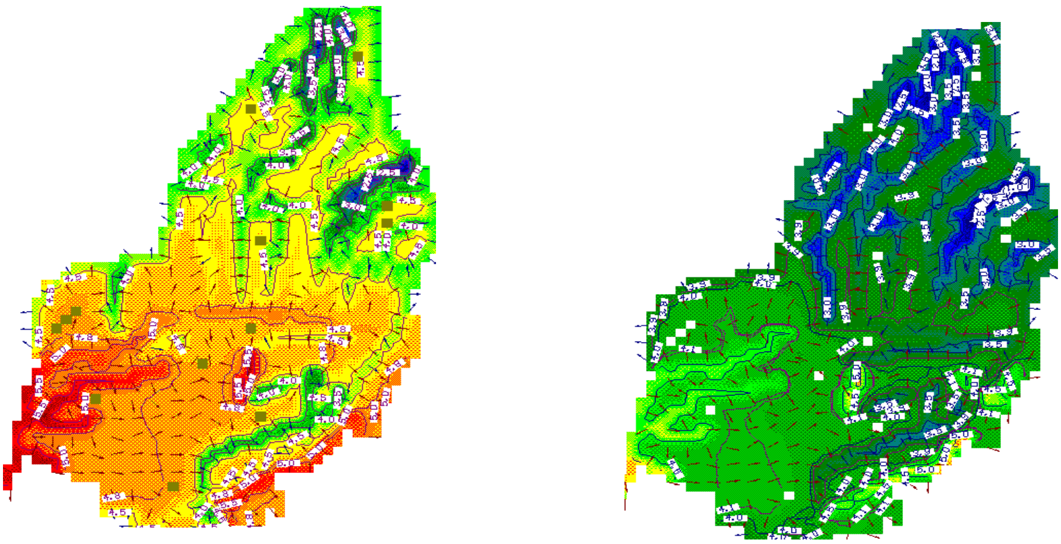


Figure 10-a. The head contours and the velocity directions for the maximum case

Figure(10-b)The head contours and the velocity directions for the minimum case

Figure (10) The head contours and the velocity directions for the maximum and minimum cases

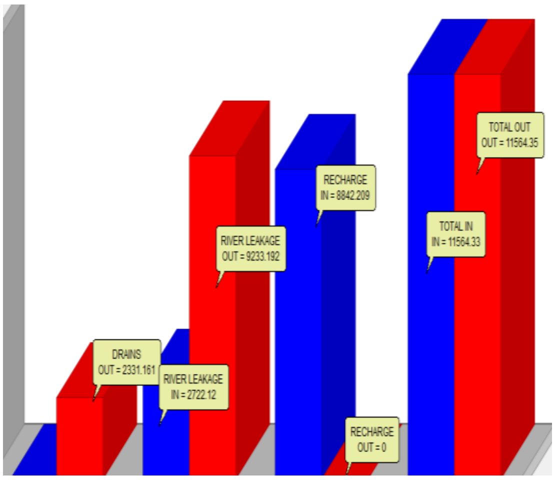


Figure 11-a. Mass balance for the maximum case

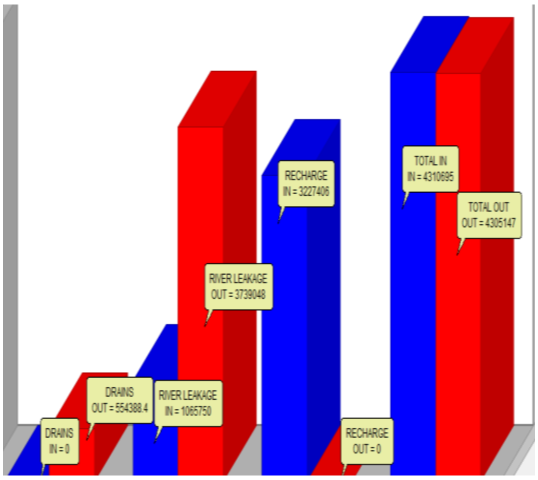


Figure 11-b. Mass balance for the minimum case

Figure 11. The mass balance for the maximum and minimum cases

6 RESULTS AND DISCUSSIONS

The results of simulation divided to:

6.1 Groundwater levels (Head) for maximum water level cases

Comparisons done between the two cases of maximum water levels.

Table (6). The levels for the two cases of maximum water levels.

Well name	unit	Radwan	Abo-Yassien	City	Nasserie	Rahmania
First case	m	4.47	4.6	4.62	4.62	4.64
second	m	4.5	4.64	4.66	4.66	4.68
Difference	m	0.03	0.04	0.04	0.04	0.04

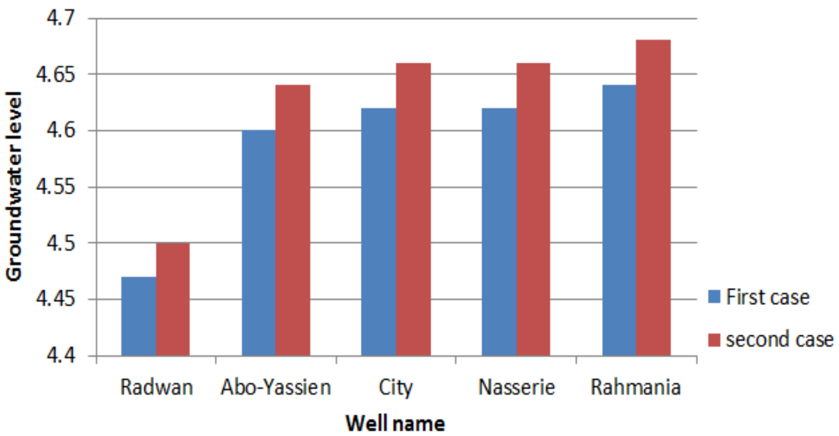


Figure 12. Comparison between the cases of maximum water levels.

"Table 6" shows the groundwater levels for the two cases and the difference between them. It is clear that the covering process has a very weak effect on groundwater levels. As seen in "Fig. 12". The difference was nearly 4 cm, it could be negligible referring to the depth of the aquifer. The simulation was for one year, and it run for 5years, 10 years, 20years, 30years, 40years, and 50years. The results are the same as running the simulation for one year. That was to say, The two cases reached the steady state at the early time. Since the covering construction worked for many years before these simulations.

6.2 Groundwater levels (Head) for minimum water level cases:

Comparisons done between the two other cases of minimum water levels.

Table (7). The levels for the two cases of minimum water levels

Well name	unit	Radwan	Abo-	City	Nasserie	Rahmania
Third case	m	3.73	3.89	3.91	3.91	3.94
fourth case	m	3.75	3.92	3.94	3.94	3.98
Difference	m	0.02	0.03	0.03	0.03	0.04

“Table 7” shows the groundwater levels for the other two cases and the difference between them. It was clear that the covering process has a negligible effect on groundwater levels. As seen in “Fig. 13”. The difference is nearly 0.03 cm, and it is for one year through the simulation. The simulation run for 5years, 10 years, 20years, 30years, 40years, and 50years. The results were the same as running the simulation for one year.

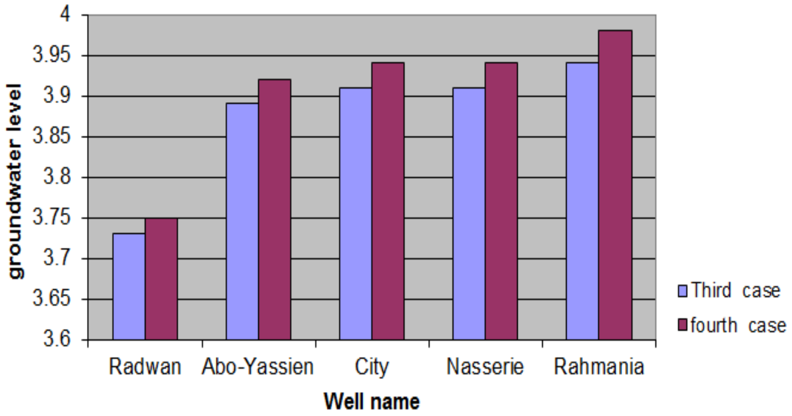


Figure 13. Comparison between the status of minimum water levels

CONCLUSION

Decision makers adopted irrigation canals covering to rationalize the usages of surface water. By preventing water losses to the groundwater aquifer, also by evaporation. Studying changes happened in groundwater levels due to covering process was done through this paper. Abu Kebier City, Sharkia Governorate, Egypt was the study area. The simulation proceeded using MODFLOW numerical model. Four simulations carried out. Two simulations were for maximum levels in irrigation canals for cases of covering and non-covering. The other two simulations carried out for minimum water levels in irrigation canals for cases of covering and non-covering. The field measurements and surface water levels were for November and December. The calibration indicated that the field measurements located between the maximum and minimum water levels. The comparisons between groundwater levels in cases of covering (actual case) and non- covering concluded that the covering process has a small effect on groundwater levels. Where it reduce groundwater levels by 3cm and 4cm for case of maximum and minimum water levels in irrigation canals consequently.

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APPENDIX (1)

Questionnaire

No.	Question	Yes	No	Remarks
1	Do you use groundwater well for drinking or domestic purposes?			
2	Do you use groundwater well for agriculture purposes?			
3	Are the participants with you less than 5 individuals?			
4	Are the participants with you ranged from 6:10 individuals?			
5	Are the participants with you ranged from 11:15 individuals?			
6	Are the participants with you ranged from 16:20 individuals?			
7	Are the operating hours ranged from 5:10 hours?			
8	Are the operating hours ranged from 11:15 hours?			
9	Is the capacity of the pump motor 1/2 hp?			
10	Is the capacity of the pump motor 3/4 hp?			
11	Is the capacity of the pump motor 1 hp?			
12	Is the depth ranged from 11:15 m?			
13	Is the depth ranged from 16:20 m?			
14	Is the depth ranged from 21:25 m?			
15	Is the depth ranged from 26:30 m?			
16	Is the depth ranged from 31:35 m?			
17	Is the depth ranged from 36:40m ?			
18	Is the depth more than 40m ?			