LAND RECLAMIATION VIA AQUIFER PERFORMANCE EVALUATION, CENTRAL PART OF DARB EL ARBEAIN, SOUTHERN WESTERN DESERT, EGYPT

Gamal H. El Saeed[1], Neveen B. Abdelmageed[1], Peter Riad[2,3], M. Komy[1]

Faculty of Engineering, Shoubra, Banha University, Egypt

Grassland Science and Renewable Plant Resources, University of Kassel, Germany

Irrigation and Hydraulics Dept. Faculty of Engineering, Ain Shams University

Abstract: In this research, an attempt was carried out for land reclamation in the central part of Darb El Arbeain through evaluation of aquifer performance. The study area occupies the middle part of Darb EL-Arbeain and bounded by long. 30^o 15/ and 30^o 25/ E and lat. 23^o 55/ and 24^o 05/ N, it has an area of about 120 Km^2. In this study four suggested scenarios of pumping rates have been explored to fit with the Egyptian ministry of irrigation using the three dimensional finite difference flow model (MODFLOW 2005) to simulate the flow system. These scenarios include running the model with abstraction from the aquifers equal 1.1, 1.8, 2.8, and 3.7 of calculated initial recharge. The results indicated that the head stabilising time is around 65 years at 1.1 pumping scenario and around 100 years at 3.7 of pumping rate of the calculated aquifer recharge, and the stabilizing drawdown time is around the half value of the aquifer head stabilizing time. The best recommended area for drilling more water wells is the north eastern parts and the southern western area. The study introduced new classification for confined aquifer classification where set that any confined aquifer exploiting 100 000 m^3/day with less than 20m aquifer drawdown, aquifer response, is classified as high potential, meanwhile under same exploitation rate with 20-40 mt as aquifer response is considered as moderate potentiality, and the rest is low in potentiality.

1.Introduction

Land reclamation in Egypt is very vital due to over population and unavailability of water resources in the vast deserts. Middle part of Darb El Arbeain area is accessible through a paved road starts from Baris-Kharga Oasis and extends towards the south direction for about 185 km. This research was thus initiated with the objective of attempting for evaluating of the aquifer performance in the middle area of Darb El Arbeain through monitoring the stabilizing time for the piezometric head and the groundwater level equilibrium. Reclamation was suggested through recommendation more well in the high potentiality parts and reduce exploitation rates in the low potentiality area. The target of this study is to introduce new classification of confined aquifer taking in consideration the quantity of water exploitation possibility versus drawdown and considering the confined aquifer specifications.

2. Description of The Study Area

In Darb El Arbeain the ground surface slopes gently from NW to SE with about 5.0 m/Km. The rainfall rarely exceeds 1 mm / year and the maximum temperature exceed 40 ^oC at summer and 30 ^oC at winter while, the minimum temperature ranges from 15 to 18 ^oC at midnight. Darb El- Arbaein is subdivided into three geomorphologic units, the western Atmur peneplain; the southern Naklai-Sheb pene-plain and a plateau surface (Issawi 1971). Geologically, the exposed rocks range from Quaternary sediments to Pre-Cambrian to (CONOCO 1989). Darb El-Arbaein area is related structurally to the Red Sea and south western regions (EGSMA 1987a and b). Issawi (1971) has identified the faults in E-W, NE-SW and NW-SE and three anticlines (Bir Kiseiba, Rage, and Shirshir) (Fathy et al.,2002). The litho-stratigraphic successions from base to top (CONOCO 1989, Fathy et al., 2001, Koranyet al., 2002, Ghazal, 2002 and El-Gammal, 2004): 1) PreCambrian basement 2) Paleozoic-Mesozoic sandstone; 3) Lower Cretaceous; 4) Upper Cretaceous; 5)Paleocene; 6) Eocene; and 7) Quaternary.

Fig. (1): Middle Part, Darb El Arbeain Map, Google Earth.

3- Model Description and Calibration for Middle Part of Darb El Arbeain;

3-1 The governing partial differential equation for a confined aquifer used in MODFLOW is (WHI, 2002):

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

Where; K_{xx}, K_{yy} and K_{zz} are the values of hydraulic conductivity along the x, y, and z coordinate axes (L/T), h is the potentiometric head (L), 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 (L^3T^{-1}), S_S is the specific storage of the porous material (M^{-1}); and t is time (T).

3-2 For the steady flow in porous anistropic saturated medium subsitution of Darcy law for v in x, y and z direction yields to;

$$\partial/\partial x \; (K_x \; \partial h/\partial x) + \partial/\partial y \; (K_y \; \partial h/\partial y) + \partial/\partial z \; (K_z \; \partial h/\partial z) = 0$$

for the isotropic medium ; $K_x = K_y = K_z$ and for homogenious medium K (x,y,z) = constant.

3-3 Trsnsit flow conservation law in a saturated porous medium

The net rate of fluid mass into any element control volume = the changes time rate in the stored fluid mass within the element, and continuity equation will be;

$$(-\partial(\rho v_x)/\partial x) - (\partial(\rho v_y)/\partial y) - (\partial(\rho v_z)/\partial z) = n(\partial\rho/\partial t) + \rho(\partial n/\partial t)$$

Where; $n(\partial\rho/\partial t)$; the effect of density (ρ) chages on the expansion of the produced water mass rate, which is controlled by fluid compressibility β. And $\rho(\partial n/\partial t)$; the effect of the porous medium compaction due to changes of porosity n, which is controlled be the aquifer compressibility α.

3-4 Initial model input (first assumption);

The hydraulic conductivity; Kx = Ky = 2.1 m/day Kz = 0.21 m/day, no of aquifers; 1 (divided into 4 layers, no of rows = 250, no of columns = 190 (each cell is 50*50 mt), Average Specific storativity = 0.0001 m-1, Average total porosity = 0.3, average effective porosity = 0.15 (El-Beih, 2007), Piezometric level; taken from Korany et al. 2002 (Fig. 2), currently average pumping rate of the 27 wells is around 2000 m3/ day. Boundary conditions (Fig. 3); the western boundary; consist 2 segments, line a-b represent constant head 135 mt, mean while line from b-c represents 131 mt. the eastern boundary; line g-h represent constant head 123 mt, line h-i represent, Constant head 119 mt, and line i-j represent Constant head 117 mt, the northern boundary; line d-e represent constant head 125 mt, line e-f represent Constant head 129 mt. the southern parts represent no flow boundary. Area two target is to reclaim around 4000 feddans. **calibration (Fig. 4) involved comparison of the model results and observed heads at 24 observation points (taken from pumping wells) from a piezometric head map to run in a steady state simulation, once the model**

calibrated, the calculated hydraulic heads were used as initial heads for the transient flow scenarios.

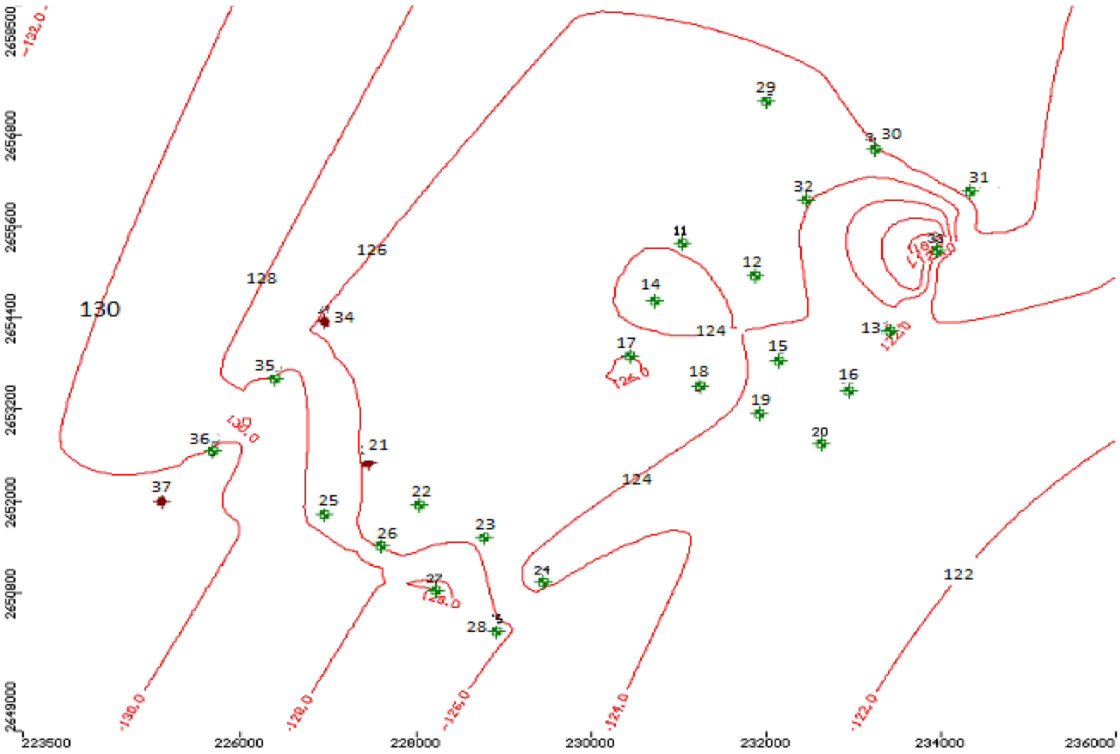


Fig. (2): piezometric levels in area two, Darb El Arbeain

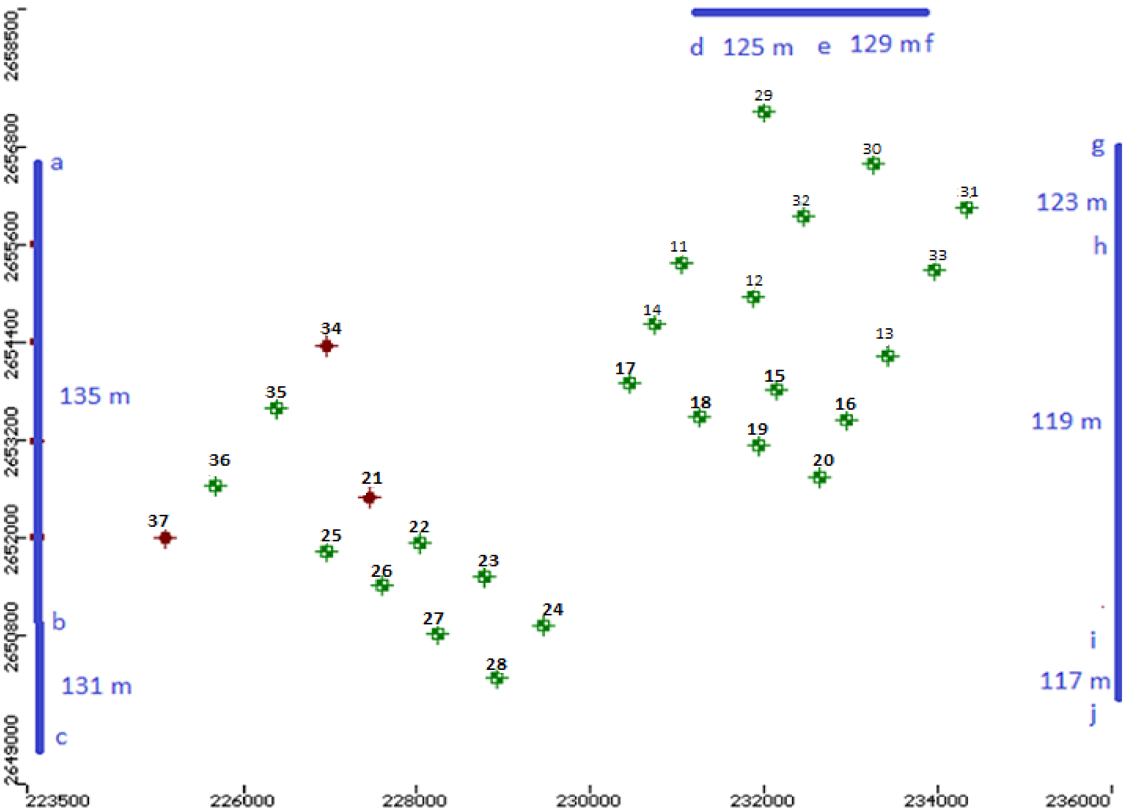


Fig. (3): boundary condition heads in area two, Darb El Arbeain

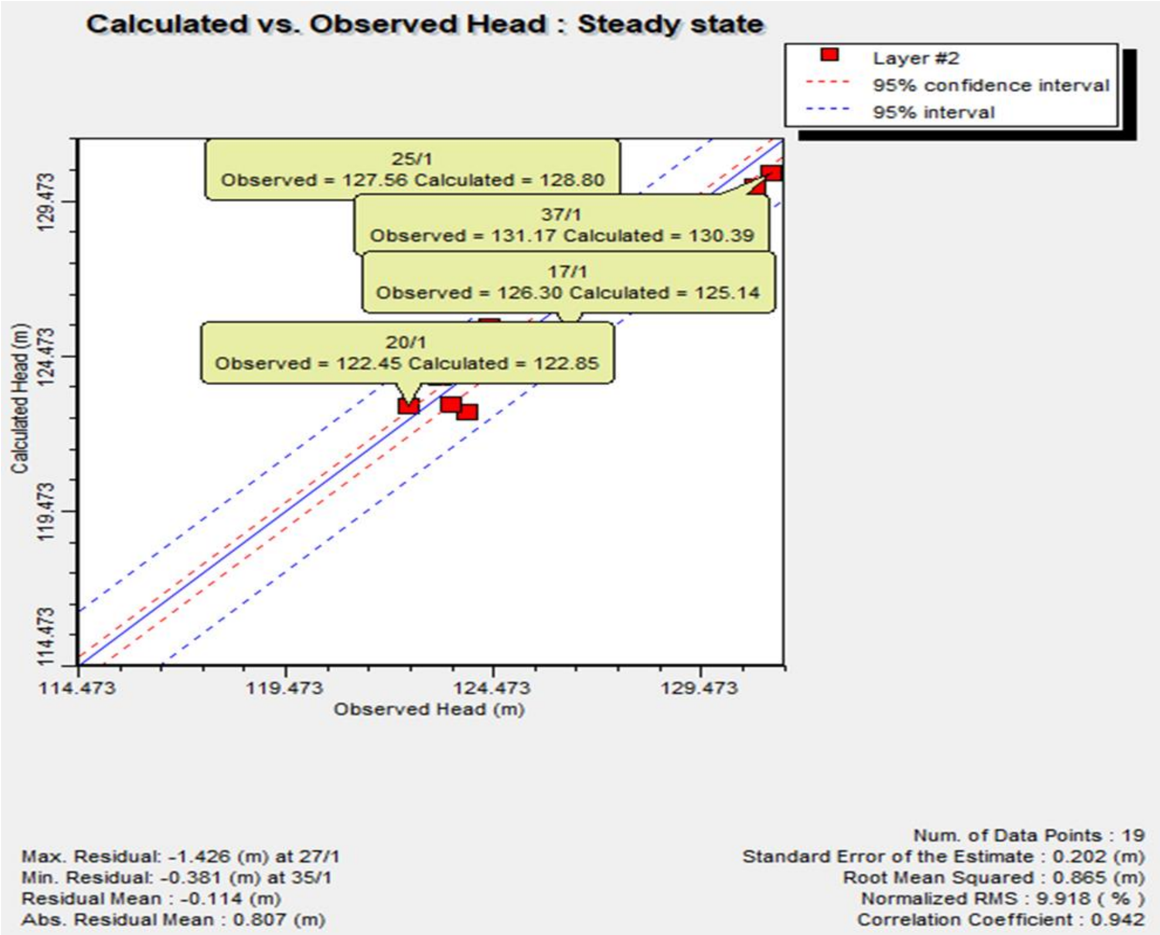


Fig. (4): calibration result to area two, Darb El Arbeain

4- Different Pumping Rates and Aquifer Respond

4-1 All wells pumping out = 1.1 of initial recharge

4-1-1 monitoring well heads stabilizing

The time for head stabilizing is around 65 years (Fig. 5).

4-1-2 The New Specification of the Aquifer When Reach Equilibrium

a- average new hydraulic gradient in the area;

= average initial hydraulic gradient + average initiated due to pumping

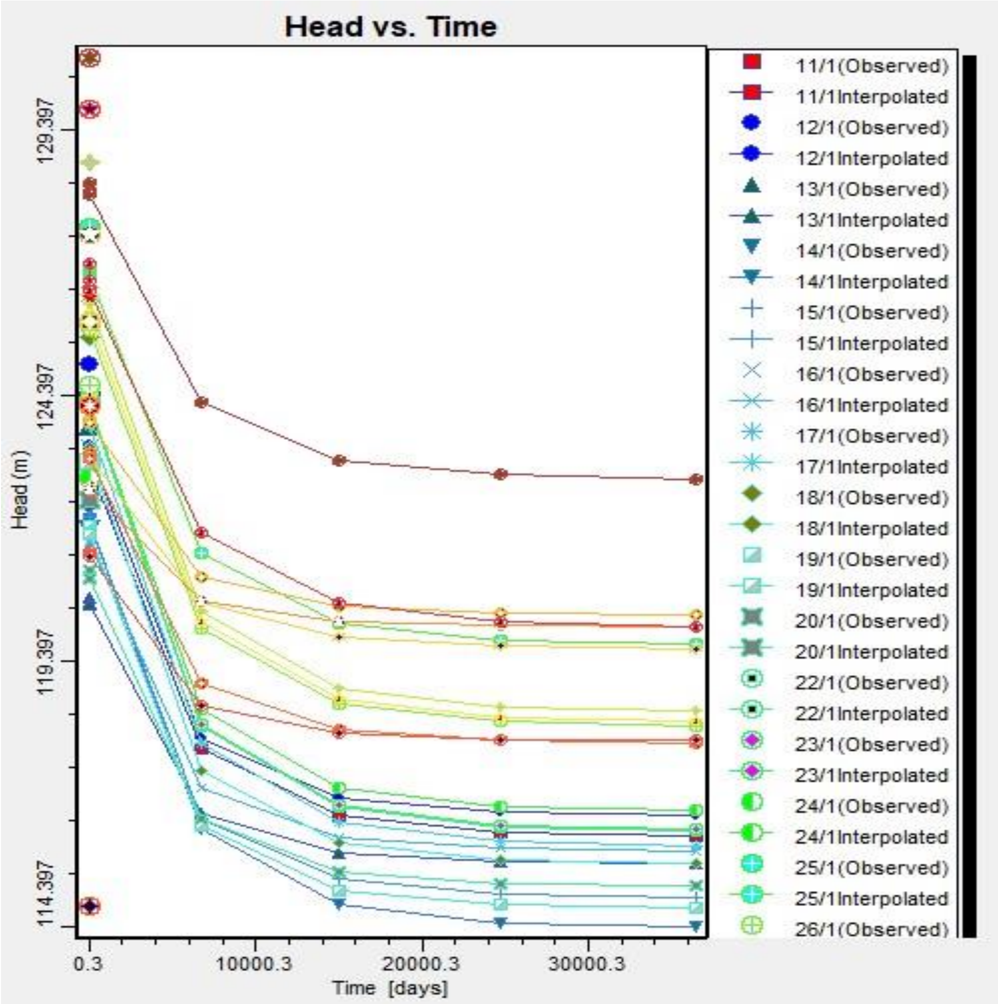
= initial hydraulic gradient + (average max. drawdown / total length of the area)

= 0.00857 + (6.5 / 12500) = 0.00909

b- to calculate new average transmissivity value;

Q = TIW (Darcy's Law); T: Transmissivity (T=KD, where, K: hydraulic conductivity, and D: Total thickness). W: Width of area, I: Hydraulic gradient. **New average transmissivity**= (Q / I *W) = 32400/ (0.00909 *9500) = 375 m^2/day. (old value 344 m2/day, Korany,2002)

Fig. (5): The Stabilizing of aquifer head when Pumping Out = 1.1 initial recharge



c- to calculate new average hydraulic conductivity value;

K = T / D = 375/215= 1.74 M/ day (old average value 1.71 M/ day, Korany,2002)

d. To calculate new average flow rate in the discharge area;

V = K*I =1.74*0.00909= 0.01585 m/day (old average value=0.01465 m/day, Korany, 2002)

4-2 All Wells Pumping Out = 1.8 Of Initial Recharge

4-2-1 Monitoring Well Heads Stabilizing

The time for head stabilizing is around 83 years (Fig. 6).

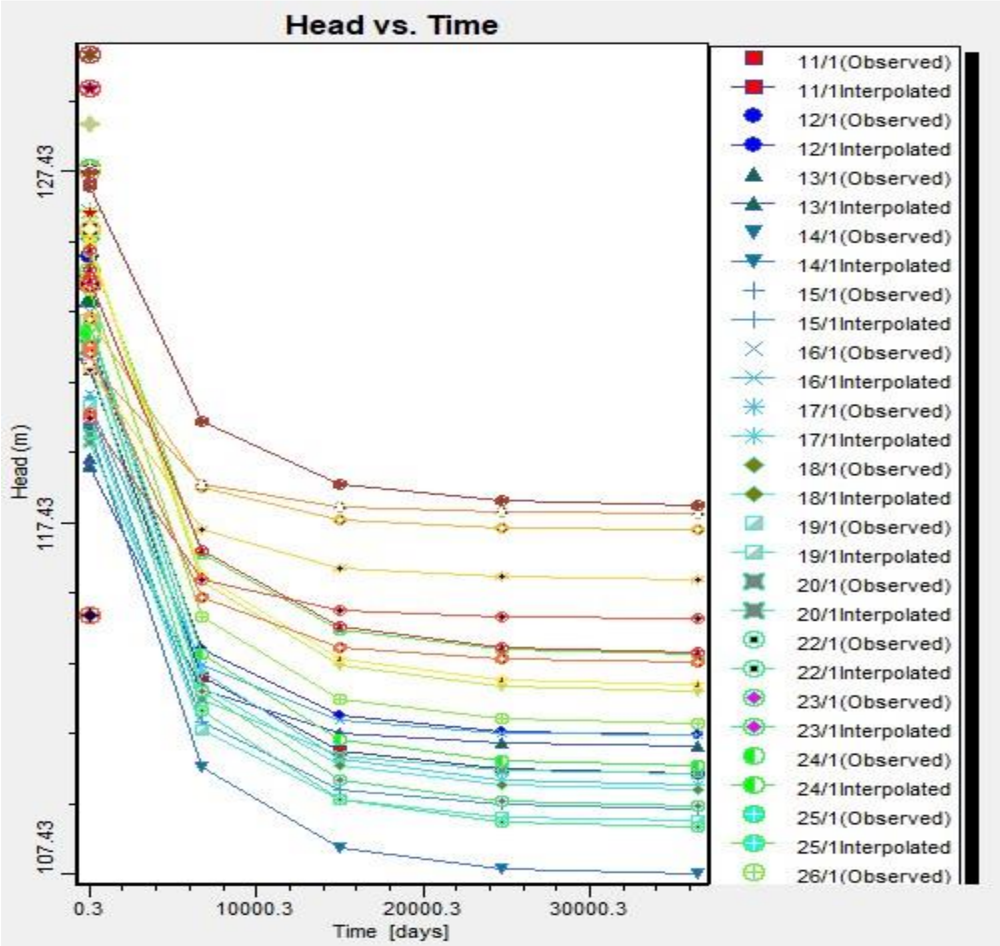
4-2-2 The New Specification of the Aquifer When Reach Equilibrium

= average initial hydraulic gradient + average initiated due to pumping

= initial hydraulic gradient + (average max. drawdown / total length of the area)

= 0.00857 + (13.5 / 12500) = 0.00965

Fig. (6): The Stabilizing of aquifer head when Pumping Out = 1.8 initial recharge



b- to calculate new average transmissivity value;

Q = TIW (Darcy's Law); T: Transmissivity (T=KD, where, K: hydraulic conductivity, and D: Total thickness). W: Width of area, I: Hydraulic gradient.

New average transmissivity= (Q / I *W) = 54000/ (0.00965 *9500) = 589 m^2/day.

(old value 344 m^2/day, Korany,2002)

c- to calculate new average hydraulic conductivity value;

K = T / D = 589/215= 2.73 M/ day (old average value 1.71 M/ day, Korany,2002)

d. To calculate new average flow rate in the discharge area;

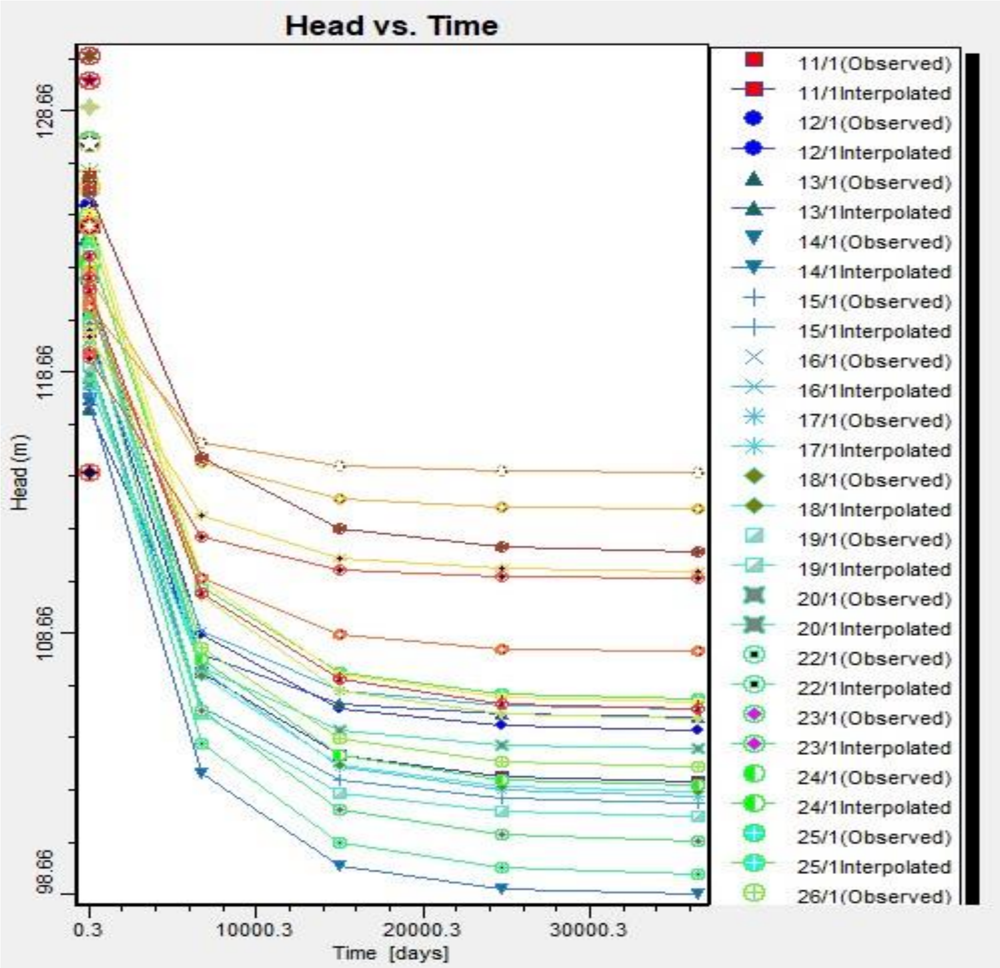
V=K *I =2.73 *0.00965 =0.0264 m/day (old average value=0.01465 m/day, Korany,2002)

4-3 All wells pumping out = 2.8 of initial recharge

4-3-1 monitoring well heads stabilizing

The time for head stabilizing is around 90 years (Fig. 7).

Fig. (7): The Stabilizing of aquifer head when Pumping Out = 2.8 initial recharge



4-3-2 The New Specification of the Aquifer When Reach Equilibrium

a- average new hydraulic gradient in the area;

= average initial hydraulic gradient + average initiated due to pumping

= initial hydraulic gradient + (average max. drawdown / total length of the area)

= 0.00857 + (17 / 12500) = 0.00993

b- to calculate new average transmissivity value;

Q = TIW (Darcy's Law); T: Transmissivity (T=KD, where, K: hydraulic conductivity, and D: Total thickness). W: Width of area, I: Hydraulic gradient.

New average transmissivity= (Q / I *W) = 81000/ (0.00993 *9500) = 858 m^2/day. (old value 344 m2/day, Korany,2002)

c- to calculate new average hydraulic conductivity value;

K = T / D = 858/215= 3.99 M / day (old average value 1.71 M/ day, Korany,2002)

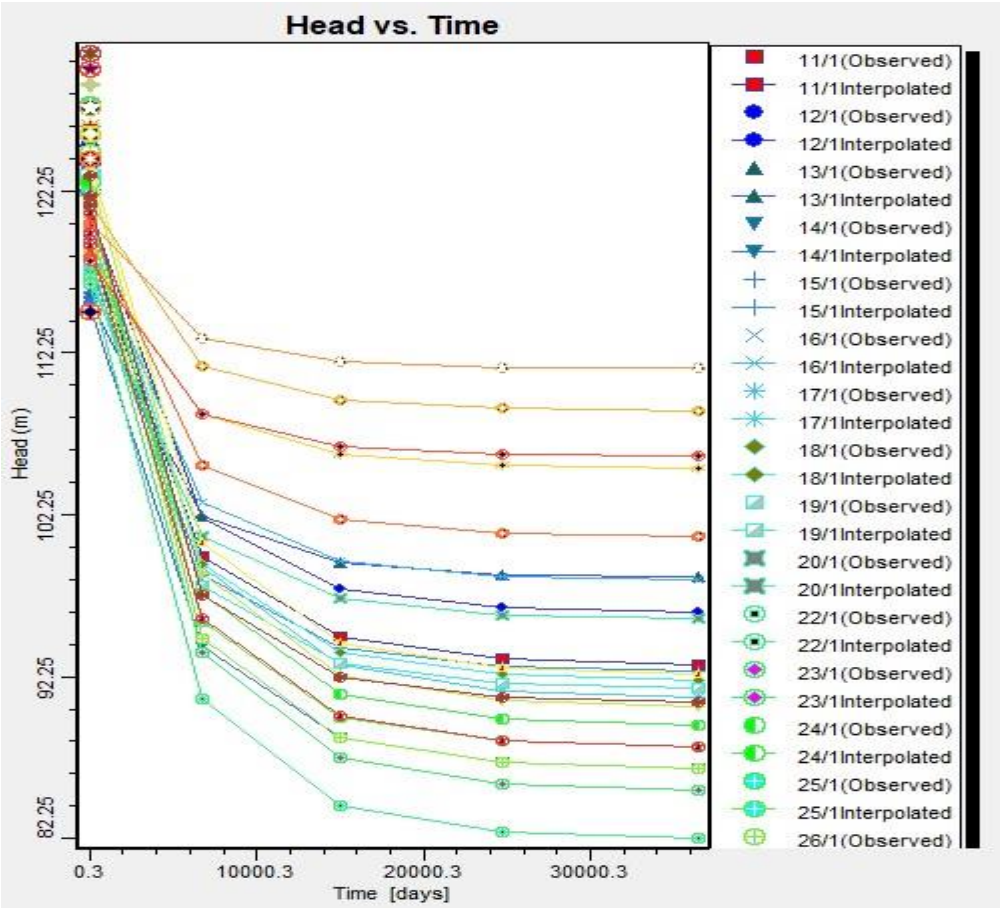
d. To calculate new average flow rate in the discharge area;

V = K * I =3.99*0.00993=0.03965 m/day (old average value=0.01465 m/day, Korany,2002)

4-4 All wells pumping out = 3.7 of initial recharge

4-4-1 monitoring well heads stabilizing

Fig. (8): The Stabilizing of aquifer head when Pumping Out = 3.7 initial recharge



The time for head stabilizing is around 100 years (Fig. 8).

4-4-2 The New Specification of the Aquifer When Reach Equilibrium

= average initial hydraulic gradient + average initiated due to pumping

= initial hydraulic gradient + (average max. drawdown / total length of the area)

= 0.00857 + (35 / 12500) = 0.01137

b- to calculate new average transmissivity value;

Q = TIW (Darcy's Law); T: Transmissivity (T=KD, where, K: hydraulic conductivity, and D: Total thickness). W: Width of area, I: Hydraulic gradient.

New average transmissivity= (Q / I *W) =108000/ (0.01137 *9500) = 1000 m^2/day. (value 344 m^2/day, Korany,2002)

c- to calculate new average hydraulic conductivity value;

K = T / D = 1000/215= 4.65 M / day (old average value 1.71 M/ day, Korany,2002)

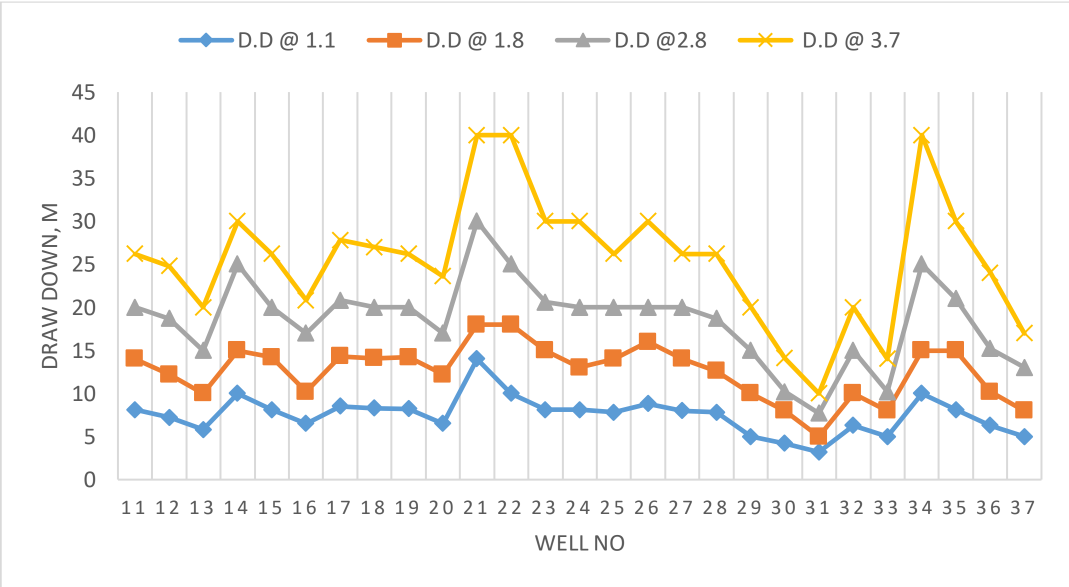
d. To calculate new average flow rate in the discharge area;

V = K * I=4.65*0.01137=0.05288 m/day (old average value = 0.01465 m/day, Korany,2002)

4-2 Drawdown under different pumping rates

The drawdown in area two under different pumping scenarios are best illustrated in Fig. (9). The maximum drawdown is recorded in wells 14, 21, 22, (central area) and 34 (western area). And the less Drawdown is recorded in wells 30, 31, and 33) and south western parts (especially the extension area around well 37)

Fig. (9) Drawdown (D.D), M versus different pumping rates



4-3 introducing Equation governing head stability time

In confined aquifer of area two, Time required for head equilibrium could be represented in the follow equation, and best illustrated in Fig. (10).

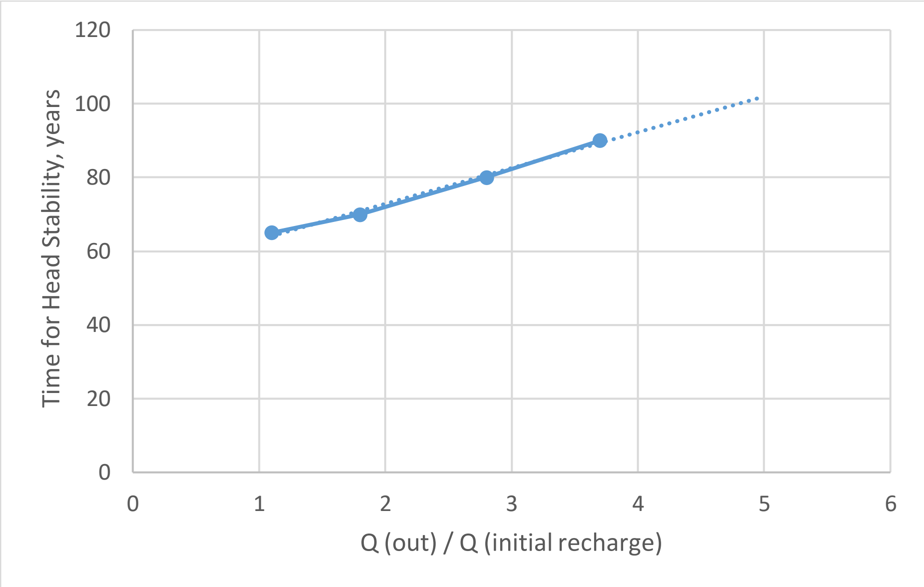
$$T_{years} = \text{constant } Q_{out} / Q_{in}$$

The constant here is divided to 2 figures;

a- When Q out / Q in = 1.1 to 2, the constant is around 52
b- When Q out / Q in = 2 to 4, the constant is reduced to around 29

For any confined aquifer the head needs longer time to stabilize when start exploitation till around twice of initial recharge, and after that the time for stabilizing the aquifer head is significantly shorter. The constant for confined head stabilizing time is depending on the aquifer parameters and its heterogeneity degree, exploitation rate.

Fig. (10) time for head stabilizing Vs the percentage of water exploitation to the recharge



5- Summary of area two Performance

The central area performance could be summarized as below;

a- Under different pumping rates as shown in table (1), the time for Drawdown stability is usually less than the time required for head stabilizing, almost 50 %;

Table (1) stabilizing time for drawdown and head VS different pumping rates, area two

Q out/Q initial recharge	**Head stabilizing time, years**	**Draw Down equilibrium Time, years**
1.1	65	30
1.8	83	35
2.8	90	40
3.7	100	50

b- The Min drawdown values are in the upper north-eastern parts (especially the extension area around wells 30, 31, and 33) and south western parts (especially the extension area around well 37) which are highly recommend for drilling more wells.

c- The central area represents more drawdown which means low potentiality due to faults and highly recommended to reduce the pumping rate especially well 21, and 22.

d- The north western area, the extension around well no 34, not recommended at all to drill more wells, and urging to reduce the pumping rated of well no 34.

e- It is recommended to keep monitoring the wells performance.

6. Georhage (1979) classification

Georhage (1979) classification for confined aquifer potentiality as below in Table (2);

Table 2. Aquifer potentiality classification (Geohage, 1979)

Potentiality of the aquifer	Transmissivity (m^2/day)
High	➢ 500
Moderate	50 – 500
Low	5 – 50
Very Low	0.5 – 5
Negligible	< 0.5

The area classification as per Geohage, 1979 is moderate in potentiality.

The Disadvantages of Geohage, 1979 Classification That Did Not Take in Consideration;

1- The other aquifer hydraulic properties like hydraulic gradient, hydraulic conductivity.
2- The surface area extension of the field of the aquifer
3- The heterogeneity of the aquifer formation
4- It depends only on one-day maximum for testing and monitoring.
5- It is not taking in consideration running the wells in the same time which means it is ignoring the effect of affecting of the wells on each other.
6- The aquifer responds to pumping rate or exploitation rate. **The aquifer respond is new concept could be defined as; the average drawdown in the entire confined aquifer under pumping condition when reaching the equilibrium of water level.**

7. Introducing New Confined Aquifer Potentiality Classification

Introducing confined aquifer new classification depends on the quantity of water could be exploited in m^3/day versus the aquifer respond and tabulated in table 6 as follows;

Table 3. confined aquifer potentiality classification

Exploitation rate from entire area, m^3/day	Aquifer respond (average aquifer drawdown), m	Potentiality Classification for using
100 000	Less than 20 m	**High**
100 000	20 - 40	**Moderate**
100 000	More than 40	**poor**

The main advantage of new classification is;

1- **Making The correlation between all hydraulic parameters of the aquifer field.**
2- **Taking in consideration the aquifer surface area.**
3- **Taking in consideration the hetrogenty degree of the aquifer and the impact on the aquifer respond in the pumping conditions.**
4- **The classification considers the time of running wells.**

As per the new classification, so we can classify area two of Darb El Arbeain area as moderate potentiality.

8- Conclusions

In this research, an attempt was made for land reclamation to the middle part of Darb El Arbeain. Through applying visual modflow and applying different pumping rates, the results indicated that the best area for drilling more wells is the north eastern parts due to less drawdown, and strongly recommended to reduce pumping rates in the central area. For dynamic conditions, exploitation status, the time for head stabilizing is almost 2 times that time required for stabilizing the groundwater levels. The head stabilizing time is high when start from stationary till the exploitation rate become 2 time the initial recharge rate, meanwhile after that the time for head stabilizing time is significantly shorter. Introducing new confined aquifer potentiality which set that with exploitation rate of 100 000 m^3/day; with aquifer respond, average drawdown, less than 20 m the aquifer is considered high in potentiality, when the drawdown ranging between 20-40 m the aquifer is considered moderate, and when the drawdown of the aquifer increases more than 40 m it classified as low potentiality.

9- Recommendations

Since the groundwater is the sole source for water in the middle part of Darb El Arbeain Therefore, it is highly recommended to Discuss the results with the local people and developers, and continue appropriate monitoring of the confined aquifer performance. More studies are required for the type of agricultural and irrigation methods and for any management plan to be successful in any confined aquifer the classification must be addressed.

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