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Research Article

OPTIMIZATION FOR NUMBER OF VERTICAL DRAINAGE WELLS IN HIGHLY HETEROGENEOUS AQUIFERS

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ABSTRACT

Groundwater studies have become of great concern especially in arid and semi-arid areas as they rely heavily on groundwater as a main source. In Egypt there are many aquifer systems of which the Nile Delta aquifer is considered as one of the most important aquifers. However, there are several environmental problems such as salinization, water pollution, logging and mounding of groundwater levels affect the development in eastern Nile Delta region. The region of concern in this study is El-Obour City which is located about 37 km Eastern of Cairo and lies on the hydrologic basin of Heliopolis. It comprises part of the desert area to the east of the Nile delta and covers about 530 Km^2. Due to the low permeability of some layers and the leakage from water networks and the seepage from the green areas near to the city the 6th and 7th districts suffered of the groundwater levels rise and logging. Vertical drainage wells were suggested to drain water from the higher layers to the lower layers which have more permeability. However, the optimum number of the drainage wells is one of the big issues in such projects for the practical point of view and for economic purposes. In order to simulate the study area and the existing conditions a simulation package of GMS 7.1 was used. The vertical drainage wells were represented by large vertical hydraulic conductivities with respect to the horizontal conductivities. It was concluded that the ratio of kh/kv should not be less than 0.1, because after this ratio there is no drop in the water level. In order to select the optimum number of wells, five different scenarios have been applied with various numbers of wells (35, 30, 27, 24 and 20 wells). The optimum number for the drainage wells was selected so as to be the minimum number after which the groundwater levels do not change significantly (less than 5 %). Finally, the optimum number of the vertical drainage wells was taken 27 wells to be implemented in this area.

INTRODUCTION

Nile River is considered the main and the most important source of water in Egypt. In the last decades, groundwater reservoirs have become of great concern because of the highly promising storage of good quality water that can be considered the second main water source in Egypt. These reservoirs are in Nile Delta aquifer, Upper Egypt aquifer, Greaten Cairo aquifer, Western Desert aquifer, Eastern Desert aquifer and the Nubian sandstone reservoirs. Due to the nature of the reservoirs of Nile Delta and its valley which are composed of several successive alluvial deposits, there are many silty clayey of very low permeability which can be found with different depths all over the reservoirs. The existence of the low permeability layers hinders the recital flow of water between the water bearing formations of the aquifer system arising many environmental problems such as water logging and water mounding conditions and pollution problems. In order to overcome these problems and to mitigate their negative impact on environment and development projects, intensive studies are carried out. These studies are morphological, hydrological, geological and geotechnical studies which define the factors affecting groundwater flow and water pollutions in the aquifer system. The present work concerns with the water mounding and logging problem in highly heterogeneous aquifers in new cities, this problem appears in many places in Egypt especially in El-Obour City.

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To simulate the existing hydrogeological conditions and the solution of using vertical filter drains as a solution of water logging problem a numerical groundwater modeling package MODFLOW (GMS) was applied

Literature Review

Numerical modeling is one of the important methods that are used in evaluating ground water resources. The numerical model can be used to predict the impact of hydrological equilibrium of a groundwater basin. The dewatering process is divided into different cases according to the type of aquifer and method of dewatering. Cannorton and Reed (1978) developed a numerical model for the prediction of term well yield in an unconfined chalk aquifer. Factors modeled included the detailed spatial distribution of aquifer. Optimization of monitoring network design is divided according to thedifferent implementation approaches into three main categories: 1) hydrogeological, 2) geostatistical, and 3) hydrogeological-statisticalapproach.The hydrogeological approach to groundwater monitoring network designuses groundwater modelling, and is sometimes coupled with a costoptimization model. This approach depends on identification of maximumvariance in the area by groundwater modelling or by statistical analysis.
Several types of models have been used to study and simulate groundwater flow systems. These models used to simulate aspects of groundwater supply such as the direction and rate of flow, change in water levels, surface water-groundwater interactions, and the interference effects of production wells.

Numerical modeling was used by Bair and O'Donnell (1983) in the design and licensing of dewatering and depressurizing systems by simulating changes in hydraulic head produced by the interference patterns of various configurations and pumping rates of wells, well points, or ejectors. The total quantity of water that must be pumped to achieve the desired draw down was predicted. France, (1974) presented a numerical method for simulating the three-dimensional groundwater flow problem under steady state and transient conditions. He used the Galerkin approach in the finite element process and used cubic isoparametric elements in discrediting the problem domain. Choi, E.C. (1978) used a two-dimensional finite element model to study the problem of seepage over a sloping impermeable bed in unconfined aquifer. He compared the results obtained from the model with the Pavlovsky's and Child`s equations and concluded that the finite element method gives less accurate results in the case of large slopes.

Faucent and Mercer (1980) discussed the advantages and disadvantages of the finite element and finite difference methods. They concluded that the finite element is more flexible in simulating the irregular boundaries than the finite difference. France (1980) used a simple numerical technique for locating free surface using a fixed element domain in two dimensions. He concluded that this procedure avoids recomputation of the element characteristics during the iterative procedure, which can be efficient and economical in comparison with the conventional approach. Neumann *et al*. (1982) demonstrated a quasi three-dimensional finite element model for the analysis of groundwater flow and land subsidence due to pumping in the multi-aquifer systems. An adaptive explicit-implicit method was used to handle the flow problem through both aquifer and aquitard. Their approach resulted in a virtual decoupling of the aquifers from each other during any time step.

Abberra (1983) applied the finite element with a four node linear quadrilateral isoparametric surface element in order to examine the numerical solution of the behavior of discrete time steps in digital computer analysis of square aquifers containing pumped wells. He examined a solution of the regular linear four node quadrilateral mesh by using the finite element and finite difference methods. He compared between the two numerical schemes and noticed a remarkable similarity. Gupta *et al*. (1984) applied a three-dimensional isoparametric, finite-element scheme to construct a computer model (FE3DGW) to simulate the steady state and transient behavior of large, natural, multilayered groundwater systems. They simulated the groundwater reservoir beneath long island, New York, USA, using this model (FE3DGW). They compared the results obtained by the model with an electric analog model for the same region and they concluded that the numerical solution is considerd more effective and flexible than the electric analog model.

Huyakorn *et al*. (1986) presented an improved three-dimensional finite element model designed to alleviate computational restriction. The model formulation was general and capable of accommodating complex boundary conditions associated with seepage faces. Included in this formulation is an improved Picard algorithm designed to cope with severely nonlinear soil moisture relations. They used a vertical slicing approach in conjunction with simple rectangular and triangular prism elements to perform spatial discretization. Also they used, transient drainage from a square block, three-dimensional flow in a drained field and flow in an unconfined aquifer subjected to pumping, to verify the finite element model and to demonstrate its capability for performing three-dimensional analysis of variably saturated flow problems. They concluded that the finite element approach can be applied to a wide range of saturated-unsaturated flow problems.

Hassan (1988) developed a two-dimensional finite element model in order to simulate the groundwater flow through porous media. He applied this model to two field problems, one of them in the federal republic of Germany and the other in the Nile-delta in two-dimensional. He concluded that the backward time scheme gives a solution that is more stable and accurate than those obtained by both halfway or Galerkin schemes. Tullio (1989) proposed an algorithm for the semiautomatic generation of three-dimensional groundwater tetrahedral finite element models. He represented the plan of the aquifer by means of a triangular mesh then subdivided each triangular prism into many others according to the layers actually intersected by the prism. The final tetrahedral decomposition generated by the code guarantees the conformity of the element. He concluded that this method is very suitable for the input data generation of complex aquifer systems.

Powire and Robertsz (1990) investigated the use of an ejector well dewatering system for pore water pressure relief applications in fine soils, since the system could operate at relatively low pumped flow rates, creating a vacuum at depth inside the well. A field trial of an ejector well dewatering system was carried out in laminated glacial lake deposits at Conwy, North Wales, in connection with the construction of the A55 Conwy crossing. During the trial groundwater extraction flow rates and pour water pressure were monitored. Some of the ejector wells terminated in the bedrock underlying the lake deposits: in many of these, the groundwater extraction flow rates were high and the drawdowns achieved were relatively low. Back-analysis using conventional methods modeled closely the observed response of near-by piezometers. On the other hand, wells terminating in the lake deposits yielded low groundwater extraction flow rates and vacuums at about 500 millibar developed. In this case, converntional analysis substantially over predicated both the rate and magnitude of drawdown in the surrounding ground. The reasons for this were uncertain: nonetheless, the results of the trial demonstrated clearly the influence of the hydraulic conditions on the performance of a dewatering system.

The U.S. Geological Survey (USGS) has been an important contributor to the development and application of both simulation and simulation-optimization models for assessment of ground-water flow systems. These models advance our understanding of hydrologic systems and hydrologic processes, and provide a scientific basis for determining how water-resource development affects hydrologic systems. Recently, simulationoptimization models have been applied to the important issue of ground-water sustainability—a broad topic that includes the interaction between hydrologic systems, water-resource management decisions, environmental impacts, and emerging technologies (National Research Council, 2000). Chen *et al*. (2008) indicated that the most methods developed to represent water flow phenomena in an unconfined aquifer with a fully penetrated pumping well were either numerical or experimental; analytical models of a partially penetrated pumping well were rare.

His study employed the linearalized Richards equation as the governing equation with the aid of fourier integral transformation, to obtain an analytical solution of the water content distribution in an unconfined aquifer with a partially penetrated pumping well. The results from his study could serve to substantiate in some sense results from numerical models. In addition, the theory developed could be modified to simulate a vacuum-pressurd pumping well since it was derived by considering, among others, the location and length of a well screen with fluxes.

Jiang *et al*. (2013) used two-dimensional groundwater simulation model is built to characterize the groundwater flow of the study area. A steady-state model was applied to the observed data (head and discharge) to verify and calibrate the groundwater model. The pilot point method, with a regularization option provided by parameter estimation, was used to identify the hydraulic conductivity field. Afterward, a groundwater optimization model is integrated with the calibrated simulation model to realize groundwater dewatering optimization in the studied open-pit coalmine, and an optimization method called modified Pareto dominance-based real-coded genetic algorithm is adopted. Taking into account the safety of the mine, slope and dewatering wells, seepage discharge is added to objective function and the maximum aquifer saturated thickness is set as the constraint condition in the optimization model. The results indicate that the dewatering optimization procedure developed in this paper can serve as a useful template and framework for solving mining related water problems.

In orderto minimize the total cost in the method of pumping wells, a simulation-optimization approach is applied. The proposed modelintegrates MODFLOW as the simulation model with Firefly as optimization algorithm. In fact, MODFLOW computes thedrawdown due to pumping in aquifer and the Firefly algorithm defines optimum value of design parameters which are number,pumping rates and layout of the designing wells. The developed Firefly-MODFLOW model is applied to minimize cost ofdewatering project for the ancient mosque of Kerman city in Iran. Repetitive runs of the Firefly-MODFLOW model indicatesthat drilling two wells with total rate of pumping 5503 m3/day is the result of minimization problem. Results show thatimplementing the proposed solution leads to at least 1.5 m drawdown in the aquifer beneath mosque region. Also, thesubsidence due to groundwater depletion is less than 80 mm. Sensitivity analyses indicate that desirable groundwaterdepletion has enormous impact on total cost of project. Besides, in a hypothetical aquifer decreasing the hydraulic conductivitycontributes to decrease in total water extraction for dewatering (Javad andMojtaba, 2015).

Study Area

The region of El-Obour City located about 37km East from Cairo and lies on the hydrologic basin of Heliopolis is selected as a case study. It comprises part of the desert area to the east of the Nile delta covers about 530Km^2. This area is bounded northward by Gabal Hamza ridge (Lat. 30^{o}15$^/$ N) and southward by Gabal Sawanet El-dibba ridge (Lat. 30^{o}6$^/$ N), it`s limited by Wadi Moftah and Wadi El-gafra in the East (long. 31^{o}40$^/$ to 31^{o}45$^/$E), and from the west it is bounded by the cairo international airport, El-Khanka and Gabel El-Asfar area (long. 31^{o}24$^/$ to 31^{o}20$^/$E) as shown in Figure 1.

For the scant hydrogeologic information on the area, it's here intended to give a detailed study of the so called Heliopolis basin. This is done through intensive field work and laboratory study including geology of the area, geomorphology, hydro-sedimentary nature, geo-electrical properties…etc. Heliopolis Basin lies in the Eastern Nile Delta bounded by Damietta Nile Branch from West, Suez Canal East, Lake Manzal North and limestone ridges (Mokatam Formation) South as shown in Figure 2.

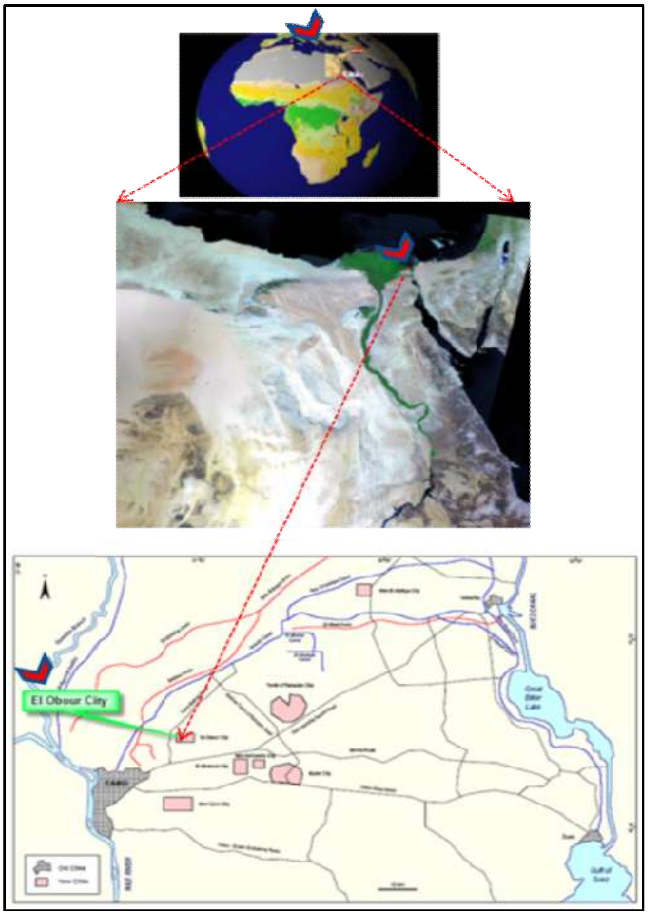

Figure 1. Heliopolis Basin

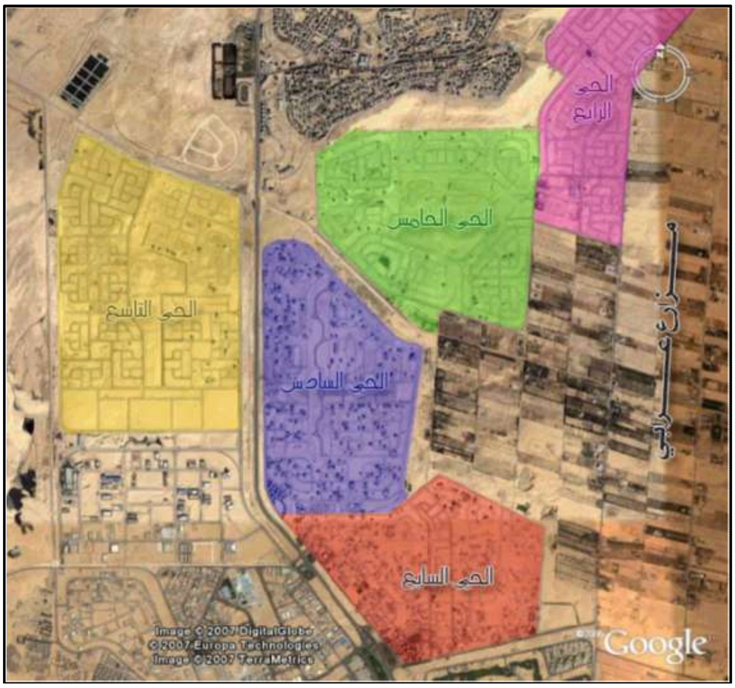

Figure 2. El Obour City

Mathematical approach

Darcy (1856) concluded that the specific flow rate, in an isotropic porous media, is proportional to negative head gradient. It can be written in general form that expresses the flow in porous media as follows:

$q_i = -k_{ij}\frac{\partial h}{\partial x_j}$,I , j = 1 , 2 , 3 ………………………………………………………………………………………….. (1)

Where;

q_i: The specific flow rate in the i-direction [L/T],
k_{ij}: The hydraulic conductivity tensor, means [L/T],
$k_{ij} = 0$ for all I ≠ j, i.e, when domain axes are principal axes,
h : The hydraulic head [L],
$\frac{\partial h}{\partial x_j}$: The hydraulic gradient in the j-direction; and the negative sign means that the flow in the direction of decreasing hydraulic head. The hydraulic head is expressed as (p/gγ+z) where z is the elevation of the point, p is the pressure, and γ is the volumetric weight of the water. k_{ij} , depends on the chosen coordinate system. The hydraulic conductivity can be expressed as k ρ g / μ ,

where;

K: The permeability [C] a domain characteristic,
μ:The viscosity [M/LT]
g: The gravitational acceleration [L/ T^2]

The differential equation of flow is derived by applying mass balance around infinitesimal control volume of a porous media, which having the prismatic shape of dimensionsΔx , Δy, andΔz. Over the time interval,Δt, the net flow entering the control volume must balance out the increase in water stored in the control volume.

Water entering the control volume is counted positive; water leaving the control volume is counted negative. Therefore, the net change in the discharge rate in the x direction may be expressed by $(\frac{\partial q_x}{\partial x})\Delta x\Delta y\Delta z = (\frac{\partial q_x}{\partial x})\Delta V$. Similar expressions may be written for y and z directions. Summation of the net change in the three directions, the three expressions for the total excess of mass inflow over outflow during Δt is written as:

$\Delta t(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z})\Delta V$ …………………………………………………………………………………………… (2)

Where:

$\Delta V = \Delta x\ \Delta y\ \Delta z$ is the volume of the control volume.
By dividing the above expression by ΔV and taking the limits$\Delta t \rightarrow 0$. The net change through the control volume becomes

$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z} = \frac{\partial q_i}{\partial x_i}$ ……………………………………………………………………………………………………… (3)

Since

$S_0\frac{\partial h}{\partial t}$ expresses the increase in water mass per unit volume of porous media per unit time, then the continuity equation can be written as follows:

$-\left(\frac{\partial q_i}{\partial x_i}\right) = S_0\frac{\partial h}{\partial t}$, i=1, 2, 3 ……………………………………………………………………………………...... (4)

Where,

x_i : refers to the Cartesian coordinate in the i-th direction,
[L], ($x_1 = x$, $x_2 = y$, $x_3 = z$) ,
q_i : Average discharge in the direction I [$L^3/T/L^2$],
$S_0 = \rho g (a + nb)$; (specific storativity) [1/L],
ρ: The density of water [M/L^3],
g: The gravity acceleration [LIT^2],

Model Description

Model Grid Geometry

The model area covers a part of EL-Obour city including of 6th, 7th district with grid dimensions of 4758 m * 3297 m and the grid consists of 217 rows × 151 columns as shown in Figure 3.

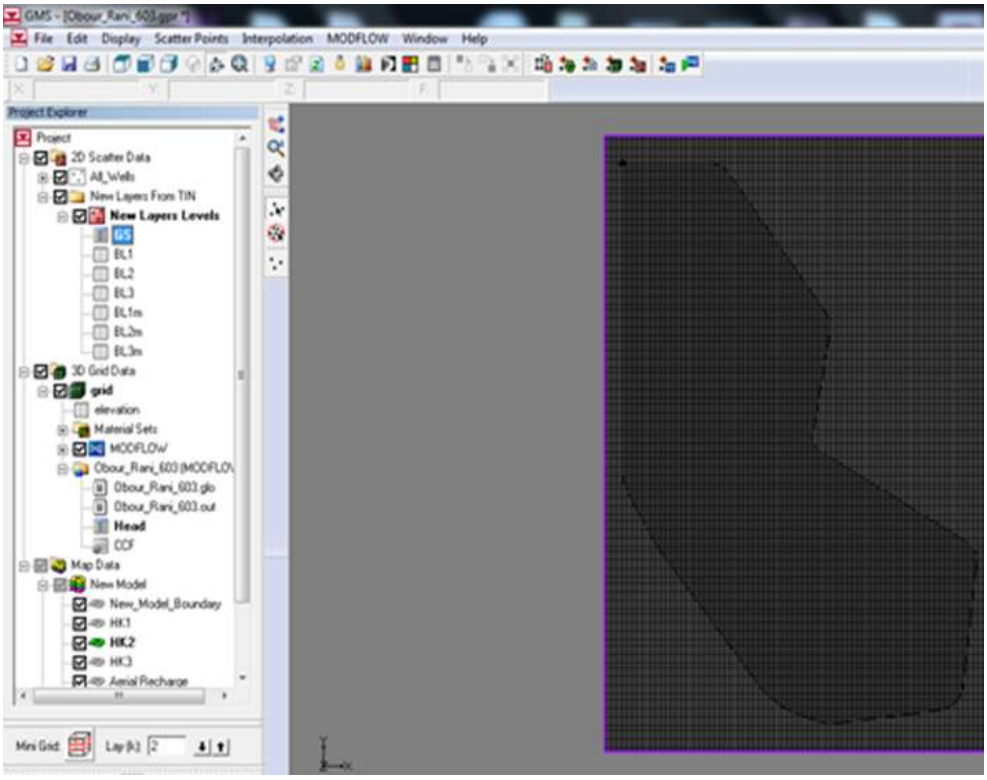

Figure 3. Plan view for the model grid

Numerical groundwater modeling

The groundwater flow model solves the groundwater flow equation using the finite difference method in which the groundwater flow system was divided into a grid of cells. For each cell, there is a single point called a node, at which head is calculated. MODFLOW (McDonald and Harbaugh, 1988). The main elements of the conceptual model are as follows:

- Geometry and the extension water bearing formation in the study area consist of two types of aquifers. The first aquifer is the quaternary aquifer (sandy aquifer) followed by clay layer followed by the bottom aquifer .
- Hydraulic parameters (Kh, Kv, S, porosity) of the aquifers .
- Introduce groundwater recharge over the area of study .
- Drainage surplus of irrigated lands with either surface water .
- Simulate the head boundary conditions according to the data of piezometric wells on the study area.

Input layers for the model

The input layers for the groundwater flow model area was divided into 2 types of layers input as follow.

- **Topography**
  The upper surface layer topography was extracted from the digital elevation model (DEM) of east delta topographic contour map then clipped it by (Quantum GIS) Software to get and extract the contour map of Obour city. The ground levels range between 30 m-173 m in obourcity.While in model study area of 6th and 7th districts .the ground levels ranges between 35 m-85 m.
- **Base of layers**
  The groundwater flow model area was divided into two types of soil which given three layers sand followed by clay followed by sand (in most conditions) The lithological data extracted from bore holes of each vertical drains constructed by the Consulting Engineering Center, Faculty of Engineering, Ain Shams University.
- By using these data no of lithological cross sections passing through the vertical drains in the area of 6th and 7th districts were produced by AutoCAD program.

Each cross section was changed to excel file, hence the data of these cross sections were summarized to form three base of layers (sand-clay-sand) then changed to grid files in surfer program to be exported as an input layers to be interpolated by MODFLOW. Figure 4 shows column cross section passing through the Modeled Area while Figure5 shows row cross section passing through the modeled area.

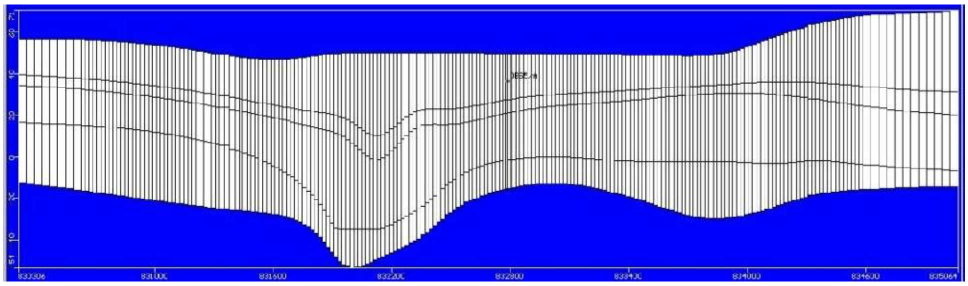

Figure 4. column cross section passing through the Modeled Area

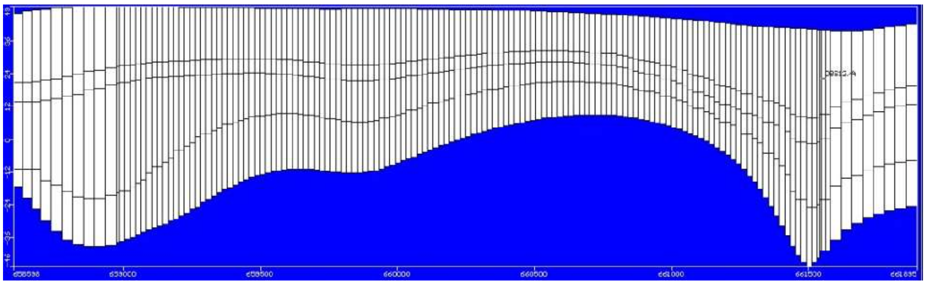

Figure 5. Row cross section passing through the Modeled Area

The boundary conditions

The boundary conditions in the created model are assigned in three types as head boundary condition, recharge areas and wall boundary condition to simulate the case of applying drains to the model .this boundary condition will be applied in the case of solution of water logging problem.

Model Calibration

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. This requires that field conditions at a site be properly characterized. Lack of proper site characterization may result in a model that is calibrated to a set of conditions which are not representative of actual field conditions. The calibration process typically involves calibrating to steady-state. With steady-state simulations, there are no observed changes in hydraulic head with time for the field conditions being modeled. These simulations are needed to narrow the range of variability in model input data since there are numerous choices of model input data values which may result in similar steady-state simulations.In the model of the study area the calibration process for the steady state condition was performed according to the initial groundwater levels map recorded from the data of the observation wells in the study area figure 6. Several runs are made by trial and error to adjust the final output groundwater levels map by changing the values of many parameters to the model (soil permeability, specific storativity and recharge values).

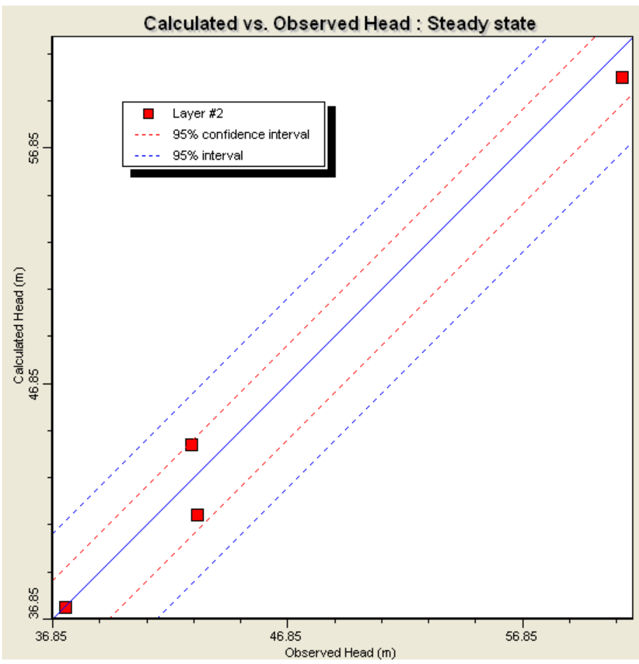

Figure 6.Calculated vs. observed piezometric levels results

To solve the problem of water logging and water mounding problems that appear in EL Obour city. Vertical drains is the proposed solution in this study. As shown in Figure 7:

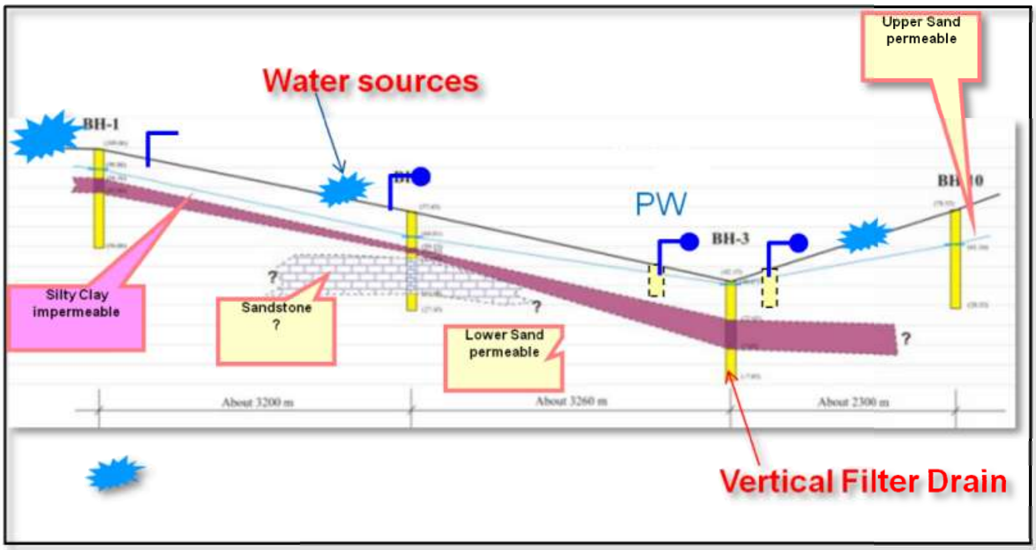

Figure 7. Alternative Solutions of the Water Mounding Problem after AbdElghany S.H., 2010)

The vertical drains wereapplied in the calibrated numerical model in 6th & 7th districts there are approximately 35 drains were applied in the field during the project. Necessary refinements for the model grids were done around each location of vertical drains to simulate the drain dimensions to be (0.6 m (diameter) * 35 (no. of drains), as shown in Figure 8.

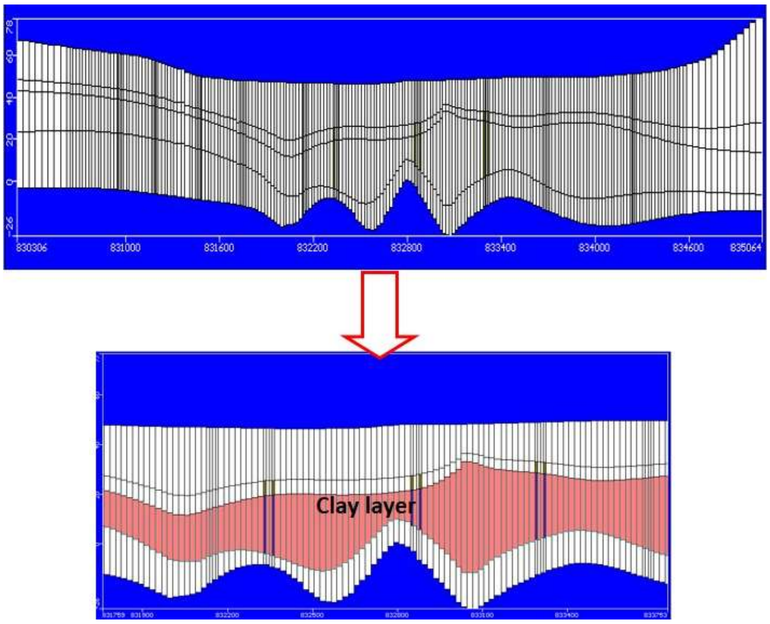

Figure 8. Vertical cross section passing through the number of drains penetrating the model layers

Representation of Problem

LPF package was used as an alternative to the BCF and HUF packages which is similar to the "true layer" option used with the BCF package in version 3.1. With MODFLOW 2000, the layer elevations (top and bottom) are defined as input to the Global Process (using the Global Options dialog), regardless of which flow package is being used. With the LPF package, the user defines the horizontal and vertical hydraulic conductivity for each layer.

MODFLOW then computes the cell by cell conductance using the *K* values and the layer geometry .Other noteworthy features include the ability to enter horizontal anisotropy values on a cell by cell basis. There is also an option to specify vertical anisotropy factors rather than vertical hydraulic conductivity values. This option is particularly useful when performing automated parameter estimation since it ties the *Kv* to *Kh* and eliminates the need to define *Kv* as an independent parameter.

Proposed Scenarios

The vertical drainage wells were represented by large vertical hydraulic conductivities with respect to the horizontal conductivities.The different ratios were proposed for the wells in the 6^{th} and 7th districtsin Al Obour City as shown in Table (1).

Table 1. Proposed scenarios that applied to the model

Scenario No.	Percentage of Kh/kv	Kh
1	Kh/kv=1	Kh=200
2	Kh/kv=.5	Kh=200
3	Kh/kv=0.2	Kh=200
4	Kh/kv=0.1	Kh=200
5	Kh/kv=0.05	Kh=200

Vertical hydraulic conductivity

The LPF package has the option to enter vertical hydraulic conductivity values as either actual hydraulic conductivity values or as anisotropy factors dependent on horizontal hydraulic conductivity. Vertical anisotropy (VA)is the ratio of horizontal to vertical hydraulic conductivity. In this case, the horizontal conductivity (HK) is divided bythe vertical anisotropy ratio(VA) to obtain vertical hydraulic conductivity (VK), and values of VA typically are less than or equal to 1.0." These options are only available for multi-layer models.

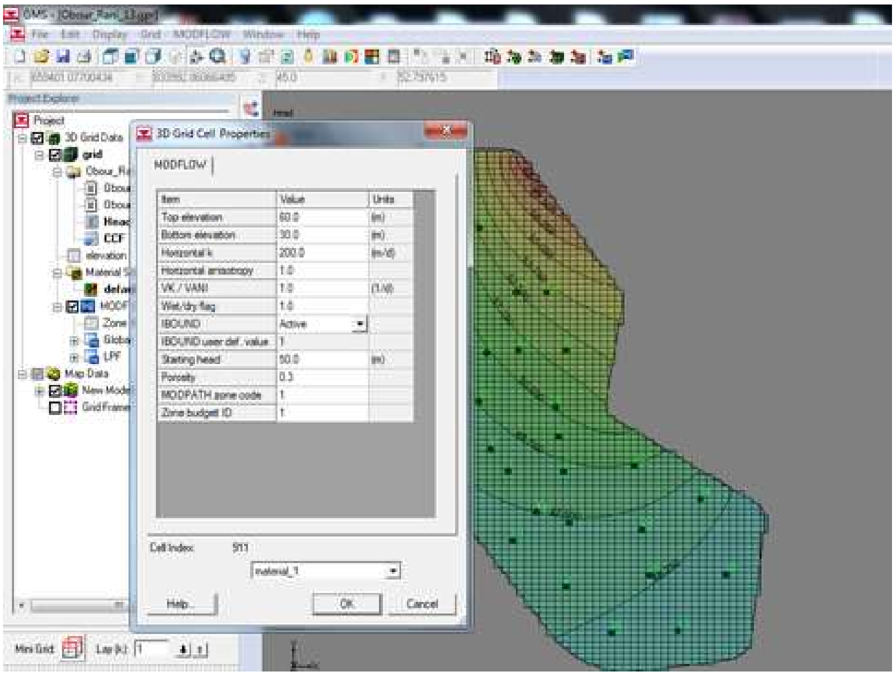

Figure 9. The first scenario (KH/KV=1)

RESULTS AND ANALYSIS

Figure 10 (A,B) represents the output of modflow of direction of flow towards the drain inlet and its outlet direction in plan view; Figure 11 shows the direction of flow towards the drain inlet and its outlet direction in cross section. From the previous results, It was concluded that the ratio of kh/kvshould not be less than 0.1, because after this ratio (kh/kv=0.1) there is no drop in the water level.

Optimization of vertical drainage wells number

In order to select the optimum number of wells, five different scenarios have been applied with various numbers of wells to choose the best economic solution. Number of wells in each scenario are changed. The optimum number for the drainage wells is select so as to be the minimum number after which the groundwater levelsdo not change significantly. A number of 35 wells distributed over the modeled Area of the 6th& 7th districts, then started to reduce the number of wells and see the effect of this issue on the water level (35, 30, 27, 24, and 20 wells).

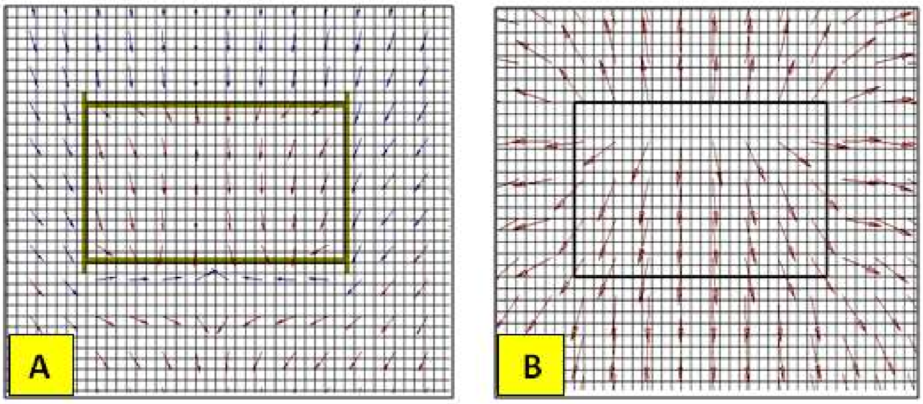

Figure 10. Direction of flow towards the drain inlet (A) and from outlet (B) in plan view

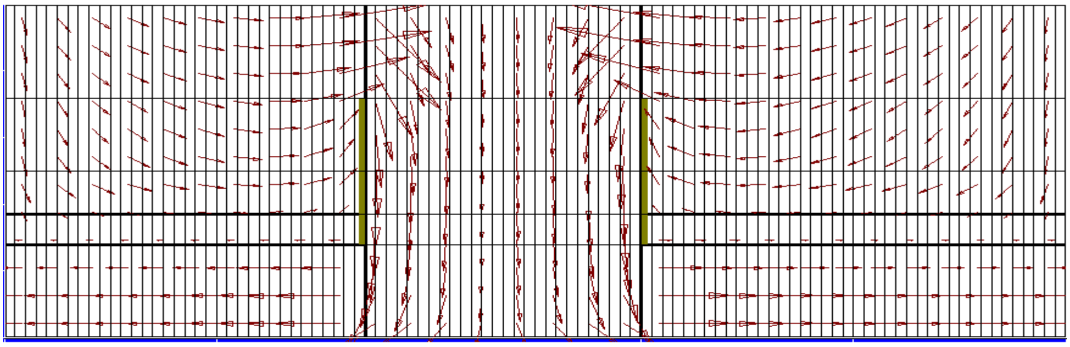

Figure 11. Direction of flow towards the drain inlet and its outlet direction in cross section

Table 2: Water levels change for the different scenarios for some drains applied in the study area of the 6th& 7th districts

Well No.	X	Y	Observed	Calculated after applying Drain				
				0.05	0.1	0.2	0.5	1
6	659964.357	832646.372	50.115021	49.892092	49.892874	49.906874	49.937683	49.942947
7	659151.297	832898.499	48.611343	48.320435	48.320621	48.33851	48.358982	48.36099
9	659431.888	833054.81	49.886845	49.269276	49.276764	49.306304	49.339218	49.341576
10	659378.302	834002.624	52.809631	48.260666	48.26152	48.274705	48.292843	48.338299
11	659569.429	833504.165	52.151283	50.347779	50.358241	50.367925	50.397469	50.482342
12	659893.029	833514.345	53.279602	52.304901	52.305433	52.314423	52.32687	52.359699
14	659674.793	833346.832	51.797607	50.782184	50.784543	50.791963	50.828037	50.835911
15	659659.505	833515.565	52.25893	50.671054	50.675153	50.683781	50.719265	50.790913
20	660067.204	831772.155	47.502953	47.286648	47.292712	47.303712	47.362244	47.361629
24	660626.489	831716.465	47.061337	46.82045	46.821512	46.845432	46.87012	46.884632

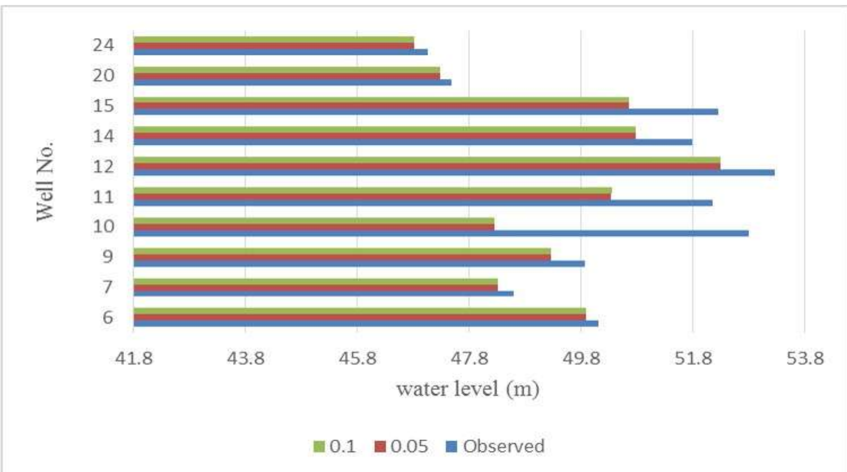

Figure 12.The water levels change for the different scenarios

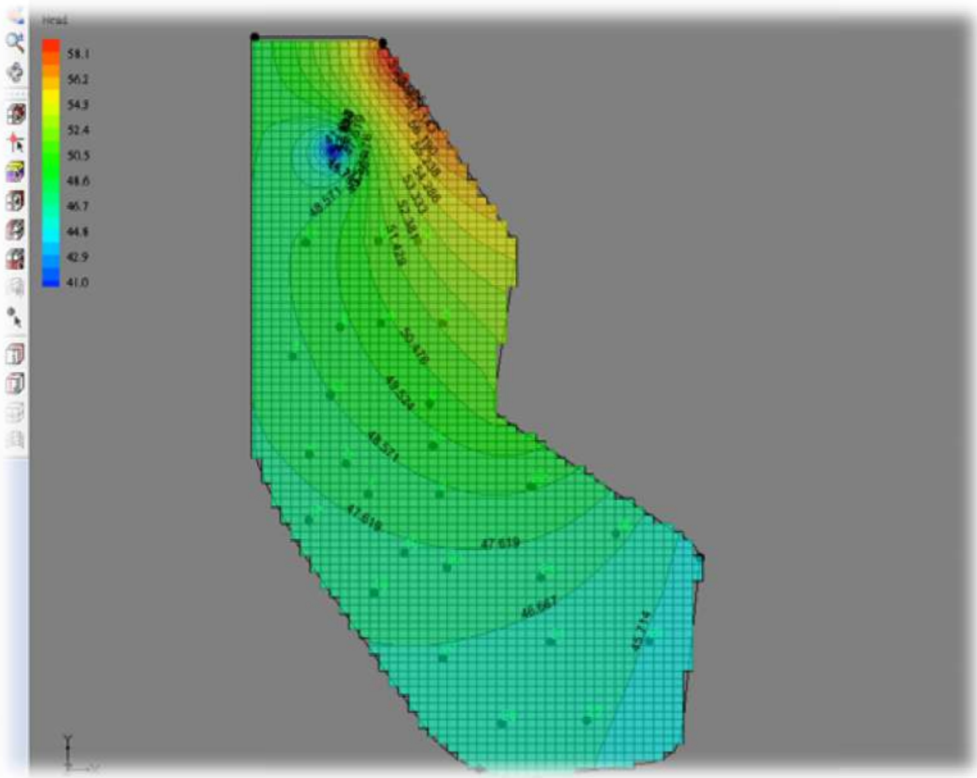

Figure 13. The head difference contour map in case of (kh=200&kh/kv=0.1)

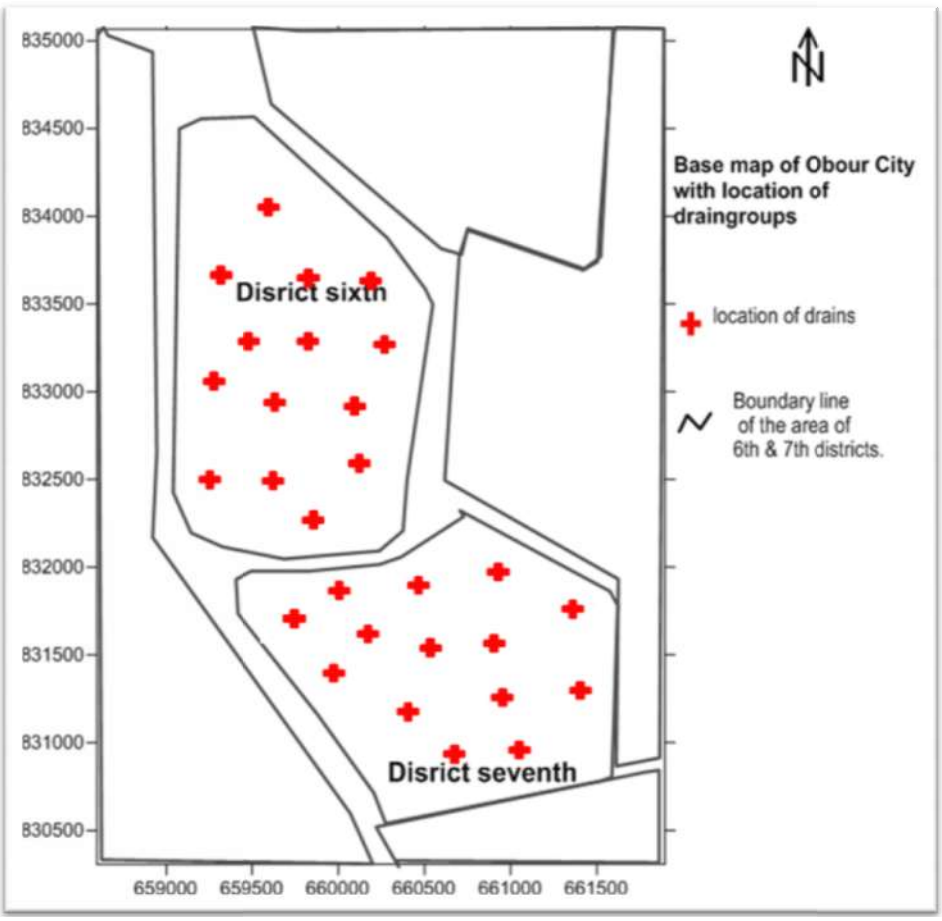

Figure 14. Location map of drains in 6th and 7th Districts on base map

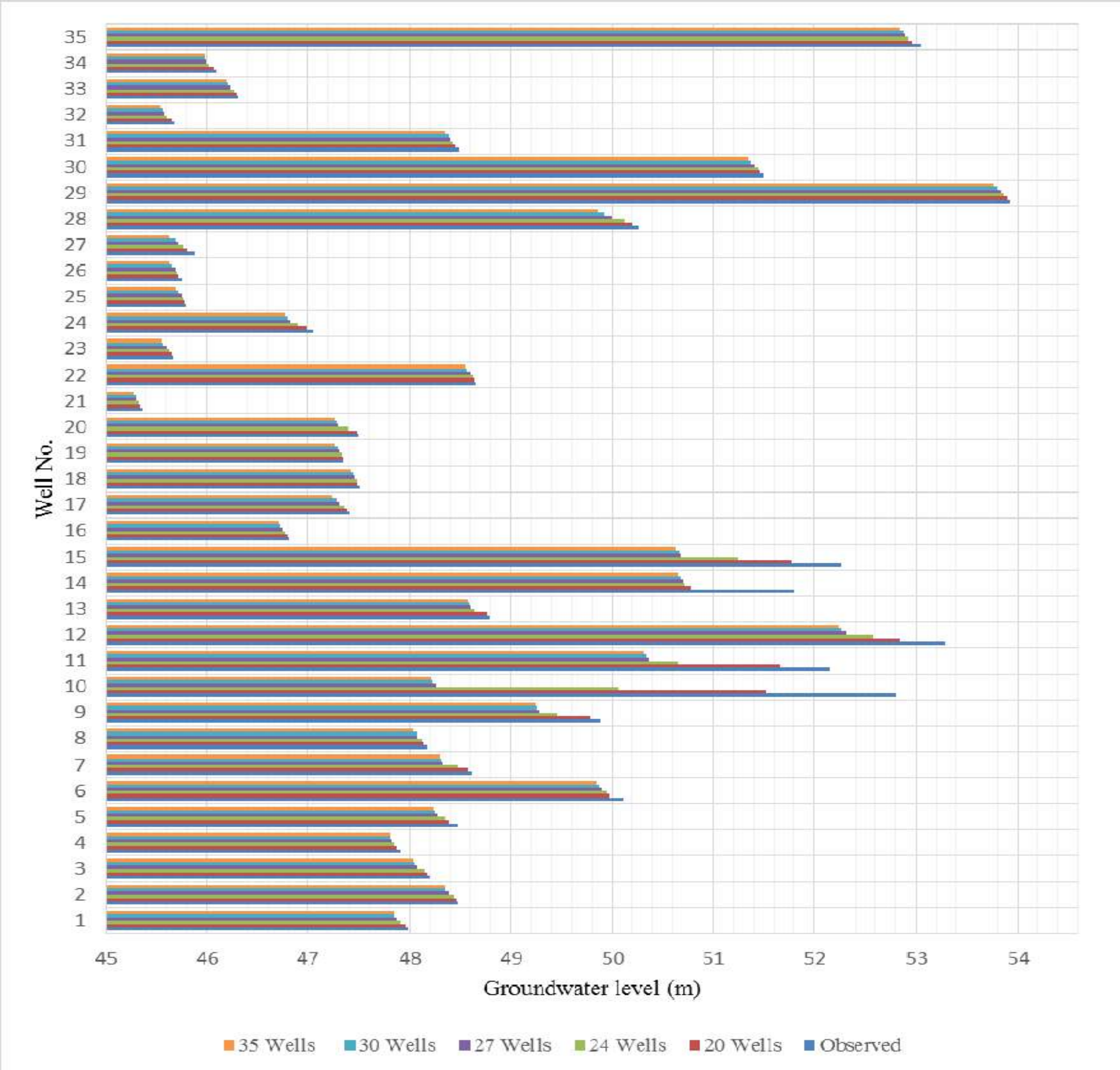

Figure 15. Groundwater head changes after applying dewatering solution of vertical drains with different numbers

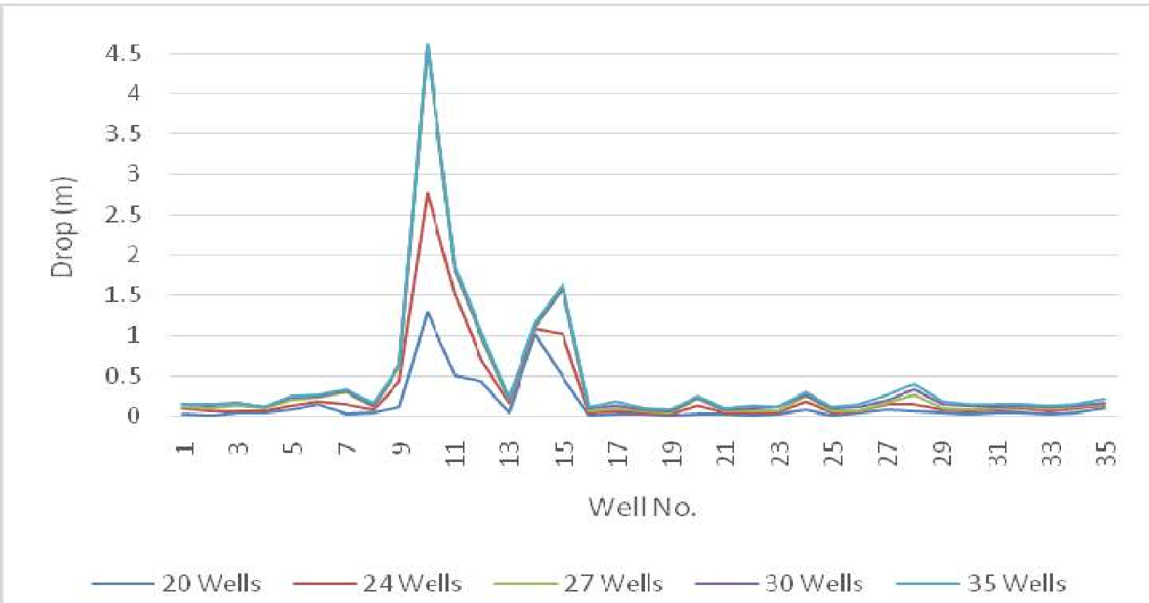

Figure 16. The difference in drop of water levels due to applying (20, 24, 27, 30& 35 wells)

The optimum number is that less number of wells gives us a suitable drop in water levels, where the level after that start to be the same. Results are listed in table (3) and figure 15 as follow:

From the previous results, it was noticedthat when the number of wells more than27 wells, the drop in the water levels increases but the ratio of drop less than5%, which means that increasing the number of wells more than 27 wells does not affect the drop in water level significantly.

Table 3. Comparison between calculated and observed water levels due to the applying (20, 24, 27, 30& 35 wells)

Well No.	X	Y	Observed	Calculated after applying Drain KH=200&KH/KV=0.1				
				20 Wells	24 Wells	27 Wells	30 Wells	35 Wells
1	659598.327	832162.699	47.982433	47.955941	47.902565	47.866812	47.850165	47.843942
2	660023.659	832161.065	48.480545	48.466527	48.433816	48.389359	48.359346	48.34921
3	659467.446	832326.128	48.202473	48.170694	48.151972	48.070478	48.051663	48.043258
4	659249.426	832374.73	47.907085	47.866173	47.849446	47.822104	47.810837	47.80563
5	660042.6241	833075.9972	48.473312	48.393554	48.359146	48.271028	48.258941	48.23974
6	659964.357	832646.372	50.115021	49.973253	49.943825	49.892874	49.876428	49.85645
7	659151.297	832898.499	48.611343	48.584697	48.483642	48.320621	48.305941	48.293347
8	659984.3017	832421.0947	48.179955	48.137968	48.116337	48.071086	48.068163	48.036691
9	659431.888	833054.81	49.886845	49.784627	49.461853	49.276764	49.255391	49.249314
10	659378.302	834002.624	52.809631	51.519726	50.059376	48.26152	48.22115	48.205569
11	659226.1096	833504.165	52.151283	51.654993	50.651935	50.358241	50.3391	50.31193
12	659893.029	833514.345	53.279602	52.846337	52.583941	52.305433	52.264672	52.23644
13	659373.921	832691.629	48.797195	48.757442	48.638221	48.60178	48.596374	48.580112
14	659674.793	833075.9972	51.797607	50.776318	50.720693	50.704543	50.67935	50.648916
15	659659.505	833515.565	52.25893	51.769915	51.249334	50.675153	50.668913	50.635623
16	661072.372	831951.478	46.812119	46.803984	46.781568	46.751691	46.732813	46.712889
17	659245.524	832022.462	47.404022	47.380935	47.351699	47.310187	47.285469	47.239833
18	659814.572	831849.092	47.507725	47.491278	47.476193	47.454212	47.446382	47.42145
19	659634.3669	831635.2116	47.343746	47.338221	47.328641	47.30291	47.293151	47.278189
20	660067.204	831772.155	47.502953	47.482364	47.391675	47.292712	47.287132	47.261364
21	660684.1713	831373.2506	45.370571	45.349377	45.336915	45.30508	45.300052	45.283911
22	660567.5263	832202.7938	48.651745	48.638446	48.619723	48.60103	48.573942	48.542347
23	661269.147	831379.866	45.669296	45.649371	45.629723	45.60731	45.573997	45.562536
24	660626.489	831716.465	47.061337	46.991683	46.900594	46.821512	46.802365	46.775281
25	660898.612	830953.49	45.801083	45.791342	45.767755	45.746444	45.712883	45.70085
26	660392.5589	830936.649	45.753006	45.719349	45.706697	45.690055	45.65842	45.62469
27	660042.6241	831285.9303	45.885773	45.803284	45.759348	45.72215	45.69632	45.626725
28	659226.1096	834298.4818	50.254684	50.20321	50.121691	49.99559	49.921794	49.85976
29	660159.2691	833512.5988	53.930894	53.897404	53.863974	53.836725	53.796725	53.757968
30	660159.2691	832901.3565	51.496464	51.465966	51.446836	51.413559	51.376836	51.357176
31	659051.1422	833294.298	48.491024	48.453211	48.423271	48.400903	48.388851	48.355432
32	661325.7184	831023.9693	45.685076	45.64927	45.603245	45.582151	45.568324	45.550076
33	661034.1061	831591.5515	46.315821	46.295817	46.272001	46.231001	46.218543	46.205817
34	660742.4937	831198.61	46.104984	46.073022	46.020654	46.001231	45.992111	45.975022
35	660275.914	833250.6378	53.045151	52.946604	52.923214	52.900321	52.886604	52.85004

Conclusions

According to the all results it was found that

- It is economic solution and uniform distribution of wells number and location.
- When the number of wells ismore than 27 wells, it was found that the difference in water levels is unnoticeable (significantly) that the rate of decline in the water levels less than 5%.

- When the number of wellsisless than 27 wells, it was found the efficiency of wells in reducing the water level is incompetent, so 27 wells is consideredthe optimum solution and recommended to be implemented in this area.
- It was seen that theanisotropy ratio of kh/kv must not less than 0.1, after this ratio (kh/kv=0.1)there is no drop in the water level.
- The reduction of water by using vertical drainage wells is slowly and continuously, therefore there is no chance forland subsidence.

Recommendations

The present study recommended the following:

- Studying the proposed numerical model (GMS MODFLOW) in small areas and studying the optimum distribution for the drainage wells.
- Establishing a monitoring system to record the groundwater levels depletion in the study area under control .
- Investigating other locations for drains in the study area to be less vulnerable to sedimentation occurrence.
- Enhancing the efficiency of the vertical drains by following up a regular maintenance.
- Control the sources of excess water from sewage drainage systems, green areas water supply networks to maintain the proposed solutions.

REFERENCES

Abbera, T. 1983. "Finite element analysis of square aquifers containing pumped wells and comparison with finite difference method" Nordic, Hydrology, Vol.14, pp.85-92.

Bair E. S. and O`Donnell T. P. July-August 1983. "Use of Numerical Modeling in the Design and Licensing of Dewatering and Depressurizing Systems" Groundwater Vol. 21, No. 4.

Buss, J. 1987. "Unterstromung von deichen" Unpublished Ph.D. Thesis, Leichweiss-Institute fur Wasserbautechnishen UniversitatBraunschweig.

Chen, J. C., Jan, C. D. and Lee, M. S. 2008. "Reliability analysis of design discharge for mountainous gully flow" J. Hydraulic Res., 46, 835– 838.

Choi, E.C. 1978. "A finite element study of steady state flow in an unconfined aquifer resting on a slopin bed" Water Res. Res., Vol.14, No.3, pp.391-394.

Connorton, B. J. and Reed, N. R."A numerical model for the prediction of long term well yield in an unconfined Chalk aquifer" quart. F. Enggrg, geol., 11: 127-138.

Faucent C. R. and Mercer J. W., 1980. "Groundwater Modeling: Mathematical Models" Groundwater v.18, no.3, pp212-227.

France P.W. 1974. "Finite element analysis of three-dimensional of groundwater flow problems" Journal of Hydrology, Vol.21, pp.381-398.

France, P.W. 1980. "A simple technique for the analysis of free surface flow problem" Water Resource Research, pp.5.20-5.27.

Gupta, S.K., Cole C.R. and Pinder, G.F., 1984. "A finite element three-dimensional groundwater (FE3DGW) model for a multi aquifer system" Water Res. Res., Vol.20, No.5, pp.553-563.

Hassan, A. 1988. "Hydrology of wadis in arid regions with application to quality models" Unpublished Ph.D., Ain shams Univ., Cairo, Egypt.

Huyakorn, P.S. 1986. "Technique for making finite elements competitive in modeling three-dimensional flow and transport" Water Res. Res., Vol.22, No.2, pp.187-197.

JavadDavoodi, S. M. and Mojtaba S. 2015. "Optimum Dewatering Network Design Using Firefly Optimization Algorithm"World Academy of Science, Engineering and TechnologyEnvironmental and Ecological Engineering Vol:2, No:3.

Jiang, S., Kong, X., Ye H., Zhou, N. 2013. "Groundwater dewatering optimization in the Shengli no. 1 open-pit coalmine, Inner Mongolia, China"Environmental Earth SciencesMay 2013, Volume 69, Issue 1, pp 187-196

McDonald, M.G. and Harbaugh, A.W. 1988. A modular, threedimensional, finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 6, Chap. A1, 586 p.

National Research Council, 2000."Investigating groundwater systems on regional and national scales" Washington, DC, National Academy Press, 143 p.

Neuman, S.P., Preller, C. and Narasimhan, T.N. 1982."Adaptive explicit-implicit quasi three-dimensional finite element model of flow and aubsidence in multiaquifer system" Water Res. Res., 18(5), pp.1551-1561.

Powrie1 W. and RobertsT. O. L. 1990. "Field trial of an ejector well dewatering system at Conwy, North Wales"Quarterly Journal of Engineering Geology and Hydrogeology, 23, 169-185.

Tullio, T. 1989. "A semiautomatic mesh generation algorithm for three-dimensional groundwater tetrahedral finite element model" Water Resource Research, Vol.25, No.3, pp.573-576.

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