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LOWERING GROUNDWATER LEVELS IN MISHKHAB CITY BY GROUNDWATER MODELING

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ABSTRACT

Mishkhab city suffers from high groundwater level, which interferes with and hampers the process of any new construction of building .Another problem raised by groundwater is prevents declension water dismissal. Therefore dewatering is necessary for lowering the water table level, which was expected to be at a depth (7-10m) below ground surface. One of the most possible methods for dewatering without causing any effect to the remnants is by pumping deep well. The design considered in this study is a ringed well system surrounding the study area .A well field is containing (5) wells distributed in area about 3.8km^2, according to its hydrogeologic and hydraulic characteristics. Each well is assumed to penetrate a depth of (100m), and discharged at a rate of (16l/s). The numerical model uses the finite difference technique based on the continuity hypothesis and Darcy's law. The analytical model is theoretically based on the Hantush analysis of interfering drainage wells in a leaky confined aquifer with the Superposition and Image principles.

Numerical simulation is conducted with the aid of a computer program (package) called (Groundwater Modeling System, GMS) to simulate the steady and unsteady states of flow. Steady state simulation showed good agreement between the computed and observed head distribution during the calibration process. Unsteady state is observed during pumping when the well field system is operated. The outcome of such condition revealed the possibility of lowering the water table level in the Mishkhab city to the required depth after one year.

KEYWORDS: Groundwater Modeling, GMS, MODFLOW, Well, Groundwater, Water Table, Aquifer, Consolidation Settlement

INTRODUCTION

Groundwater constitutes an important component of many water resources such as water supply for domestic, agricultural, and industrial use. However, shallow groundwater level often represents a problematic state. It leads to soil salinity and alkalization and hence, to less or non productive state of land, in addition to its effect on buildings and constructions, because it can weaken soil stability and reduce bearing capacity.

The present research deals with a problem of shallow groundwater level in Mishkhab city in which groundwater is considered as a source of problems rather than a water resource. Mishkhab city is suffering from high groundwater level, which interferes with and hampers the process of any new construction of building .Another problem raised by groundwater is prevents declension water dismissal, solving such problems is very critical, and special and very urgent measures must be taken to protect old building in city from this disaster. Mishkhab city is located about 30 km to the south of the center of Najaf Governorate. Mishkhab city lies between longitude 44˚ 28′ 58″ - 44˚ 30′ E and latitudes 31˚ 48′ 55″- 31˚ 47′ 30" N, Figure (1). It is bounded from the east by Shatt Al-Mishkhab river, (a branch of the Euphrates river), and from the west by agricultural lands, while from the north and south by two artificial canal. The study area is about 3.8 km^2.

Figure 1: Satellite Image of Study Region

DEWATERING SYSTEMS

A dewatering system is to be designed in order to get the optimum quantity of water economically from a given geological formation .The choice of dewatering system depends upon topography, geological condition of the underlying strata , depth of groundwater table, climate and the quantity of water required, (Raghunath, 1982). Generally, groundwater dewatering can be accomplished in several ways. The methods which are currently in wide use are:

- Vertical drainage system.
- Horizontal drainage system.
- Well point system.
- Open drain.

To make a proper selection, adequate information on the above methods should be prepared including principles, advantages and disadvantages of each method.

Vertical Drainage System

The principle of vertical drainage is pumping water from the aquifer by a network of wells. This system is suitable for the large area with deep strata, which may be more permeable than that near the surface, (U.S. Army corps of engineer, 2001). There are two classes of wells used for drainage purposes, the water table or gravity well is located in an unconfined aquifer and removes water directly from the water bearing large. It may be either, a shallow or deep well, Figure (2.a).The other class is the artesian well that taps an aquifer containing water under pressure, Figure (2.b).

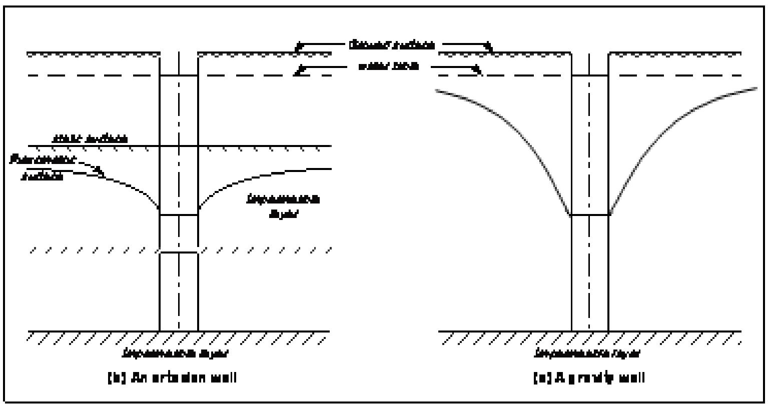

Figure 2: Vertical Drainage System (after Johnson, 1972)

Horizontal Drainage System

Subsurface horizontal drains such as shown in Figure (3) have been successfully used in draining large areas such as from lands and irrigated fields. It is buried out of sight, and a wide variety of materials is used include clay pipes in short sections, concrete pipes in various lengths, blankets of gravel laid in the soil, fibrous wood materials such as willow branches buried in the soil, covered stone drains, plastic pipes, and other materials which can be covered in the soil and which will remain intact for long periods of time.

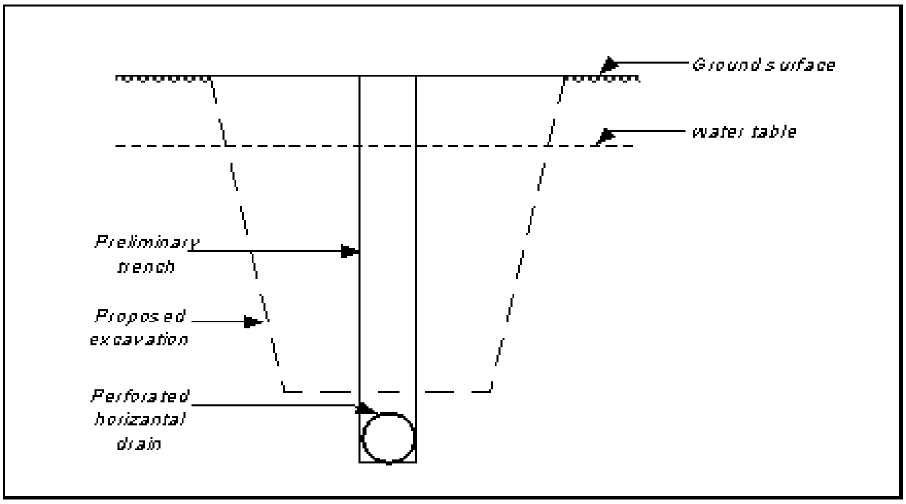

Figure 3: Horizontal Drainage System (After Johnson, 1972)

Well Point System

Well point systems are groups of closely spaced wells, usually connected to a header pipe or manifold and pumped by suction lift, (Johnson, 1972).

Well point system may be used for water supply or for dewatering. For a water supply system, it is important to space the individual wells so that their areas of influence overlap only slightly. In contrast, the areas of influence in a dewatering system must overlap extensively in order to lower the water table over the desired area. Well points in a dewatering system are usually spaced from 0.65 to 1.6 m depending upon the permeability of the saturated layer, the depth of which the water table must be lowered and the depth to which the well points can be installed Figure (4).

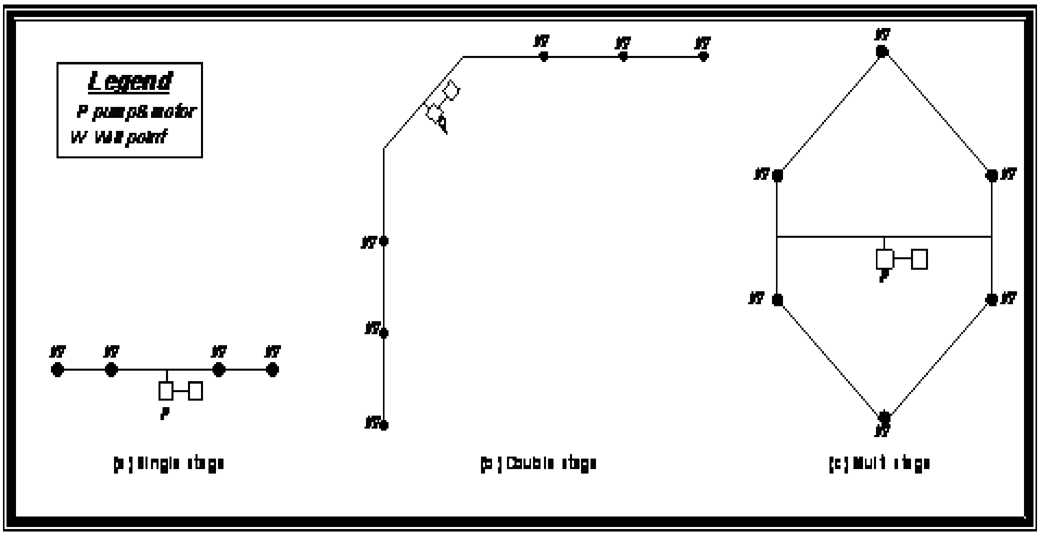

Figure 4: General Forms of Well Point System (after Johnson, 1972)

Open Drain

Open drains are widely used for surface and sub surface drainage. They are used as individual field drains and main drains, (U.S Army corps of engineer, 2001). The most efficient channel is the one that will have the maximum capacity for a given slope and cross-sectional area. The most efficient cross section is the one with the smallest wetted perimeter. For earth channels, Trapezoidal cross sections are used. Half hexagon has the smallest perimeter and has the must efficient cross section, Figure (5).

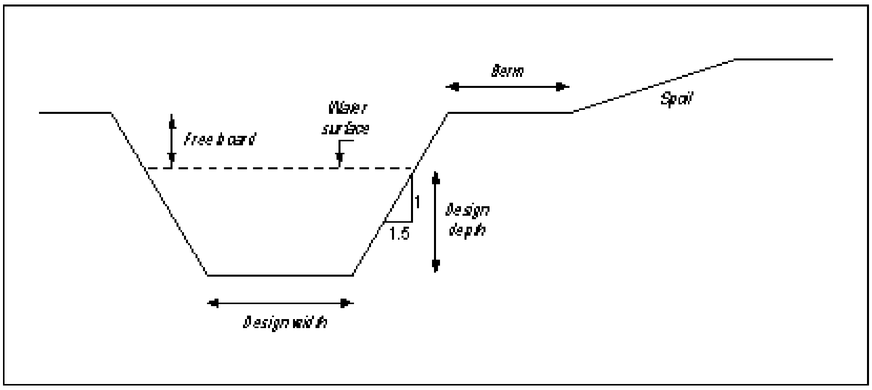

Figure 5: General Form of an Open Drain (after Luthin, 1978)

The above detailed discussions and presentations of the various dewatering systems led to conclude that the vertical drainage system is considered the only system suitable for the study area. Pumping should be performed by the deep wells in order to provide a slow dewatering rate and hence, to avoid any settlement that may take place.

NUMERICAL MODEL BY FINITE DIFFERENCE TECHNIQUE

Finite difference equations can be derived in two ways; i.e., from the physical stand point involving Darcy's law and the principle of conservation of mass, or by conventional mathematical treatments, substituting the finite difference approximations for the derivatives of governing equation . Both derivational routes lead to the same result.

A general form of the governing equation for the aquifer is:

$$\frac{\partial}{\partial x}\left(k_x h\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y h\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z h\frac{\partial h}{\partial z}\right)-W=Sc\frac{\partial h}{\partial t} \qquad -----(1)$$

where;

x, y, z : Cartesian coordinates, (L) along the hydraulic conductivity axes

kx, ky, kz ,(L/T) .

h : Head of groundwater pressure, (L).

W: Flux per unit volume, it represents quantities discharged (or recharged) to (or from) the aquifer, (L3/T).

Sc :Specific storage for the porous medium (dimensionless).

t : Time (T).

Sc, k_x, k_y and k_z can be function of space, while W and h are functions of space and time .

COMPUTER MODELING OF GROUNDWATER FLOW

The use of digital computers in ground water resource evaluation has grown rapidly within the past few years. Computer programs are now widely available that allow solution of large sets of simultaneous equations that are involved in studying case and effect relationships in heterogeneous aquifer systems with a wide variety of boundary conditions. The digital computer programs can deals with problems of much greater complexity than is practical with electric analog or analytical methods. However, digital computers will not cause analytical methods or electric analog simulators to become obsolete. Used in conjunction with other tools available to the hydrologist, digital computers can greatly improve the analysis of groundwater problems.

Discussion of the digital techniques includes the necessary mathematical background, documented program listings, and field applications. Selecting the appropriate program for a modeling job involves matching modeling needs with the capabilities and controls of available programs. There are numerous programmers for use in groundwater modeling. The modular one is provided by the United States Geological Survey (Department of Defense, 1998), named as Groundwater Modeling System (GMS), which provides a comprehensive graphical environment for numerical modeling, tools for site characterization, model conceptualization mesh and grid generation, and geostatistics. Several types of numerical codes are supported by GMS.

A GMS package has been used in the present study because:

It has numerical features necessary to model the study area.

It is well documented and widely used.

It is available through the public domain.

A graphical interface to the groundwater model MODFLOW is provided in GMS. MODFLOW is a qusi three dimensional, cell centered, finite difference, saturated flow model, which can perform both steady state and transient analysis and has a wide variety of boundary conditions and input option. GMS supports MODFLOW as a pre – and post– processor. The input data for MODFLOW are generated by GMS and saved to a set of files. These files are then read by MODFLOW when MODFLOW is executed. The output from MODFLOW is then imported to GMS for post – processing.

MODFLOW views a quasi three dimensional system as sequence of layers. The horizontal grid is generated in the usable way by specifying grid dimensions in the X and Y directions. As with all finite difference grids, the horizontal grid must be the same for each layer.

The approach of modeling the aquifer included two major steps:

Developing the steady state model.

Developing the transient model.

Further, third major step is assembling the data sets and running the model for predictive runs. At first the steady state model is developed because steady state models are often much easier to calibrate than transient models and results of the steady state model can easily be used as a starting point in the transient model.

DESIGN OF WELL FIELD FOR THE MISHKHAB SITE

Well field is defined as a group of wells operating in a given area. The overriding objectives in well field design are, the attainment of the highest yield possible with minimum drawdown in pumping wells, minimizing environmental effects, minimizing siltation, reasonable short and long term costs, (U. S Army corps of engineer, 1999),

Good well field design aims to ensure an optimum combination of performance and long service life at a reasonable cost.

The design should address the followings:

- Design of production wells (size of the well and the screen, selection of a suitable pump, well efficiency, and the optimum discharge of the well)
- Required number of wells and their distributions, and
- Economic considerations of drainage by pumped wells.

Using pump characteristic curves with estimated discharge (16 l/s), the efficiency of the pump was found to be 70 percent. Thus the brake horse power, B.h.P was found to be, approximately 3 kw. Figure.

- shows representation of designed well section in the study area.

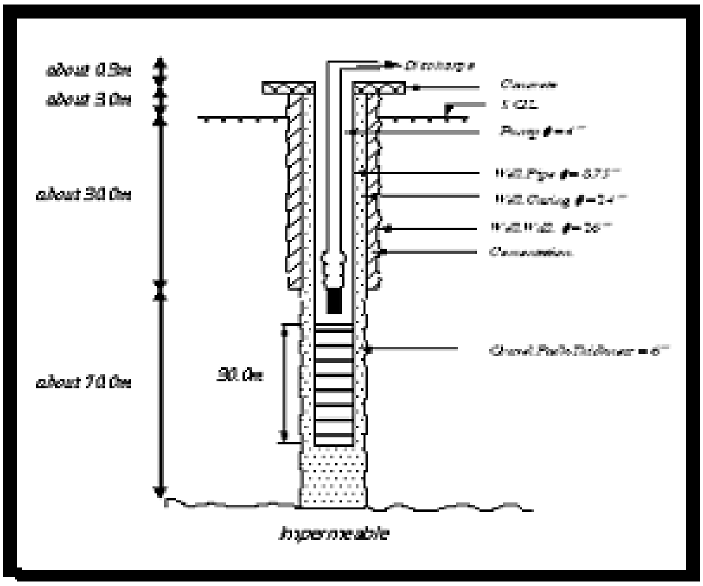

Figure 6: Designed Well Section

ECONOMIC CONSIDERATION OF DRAINAGE WELLS

The cost analysis of pumping wells includes initial construction costs, operation and maintenance costs, the power installation, and the cost of connecting pipeline between the wells, all of these components may be expressed as an annual cost per unit length of intervening distance.

Excluding the constant cost of lifting the water against the head developed in each well when it is operating alone, the yearly cost of operating a well field may be considered as an average cost value over a year as expressed by Hantush (1964)

$$C = C'm\delta + C''\sum_{n=1}^{N} Q_n \int_0^{t_0} S_n dt \qquad -----(2)$$

where;

C : total yearly cost of operation as affected by well interferences.

C': capitalized cost per unit length of pipe line for maintenance, depreciation, original cost of pipe line, etc.

C″: cost to raise a unit volume of water a unit height, consisting largely of power charges, but also properly including some additional charges on the equipment.

Sn: total drawdown in the nth well caused by pumping all the other wells (L)

mδ: length of connecting pipelines between wells and the power installation (L)

N: number of wells in operation.

Qn: discharge of nth well (L3/T).

t0: period of continuous pumping (T).

m: distance between any two wells (L).

All parameters of Eq. (2) are prepared in order to estimate the yearly operation cost, which found to be about (30000$).

The construction and power installation costs are calculated according to current prices, were found to be about (33000$) for each well. The construction costs are (165000$) for (5) wells. So, the total cost of the well field (during one year operation) is about (150000$).

APPLICATION OF THE MODELS AND THE RESULTS

The model domain was divided into (36) rows and (18) columns, making a total (648) cells and covering an area of approximately (3.8 km2). All the cells have uniform lateral dimensions of (77 m) along rows (ΔX) by (77 m) along columns (ΔY), Figure (7). This cell size was chosen to be small enough to reflect the density of input data and the desired output detail and large enough for the model to be manageable. Cell thickness depended on the elevation of the contact between the bottom of layer and free water surface, which usually equal to (100m) in all cells.

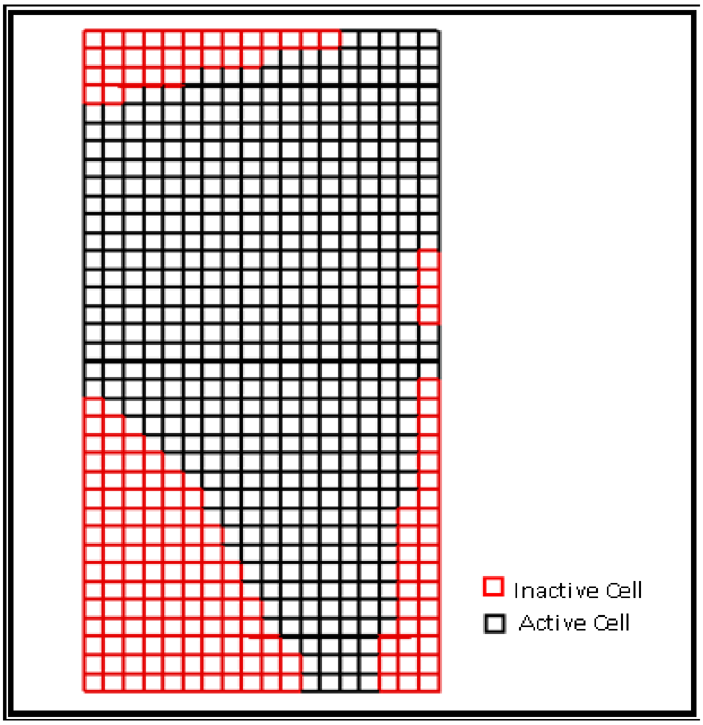

Figure 7: Grid Design for Study Area

MODEL BOUNDARIES AND INITIAL CONDITIONS

Using the map of the ground water flow pattern, the eastern end of the studied area is bounded by Shatt Al-Mishkhab River, therefore it was considered as head dependent boundary allowing inflow to the model region as proportional to head difference between the water surface in the river and the water table. The northwestern and southeastern parts of the basin bounded by the two canals. These parts were identified as constant head cells. Constant head cells were define. Other parts of the upper aquifer simulated as specified head boundaries (hydraulic boundaries) by setting the head at these boundary nodes equal to known head values, Figure (7).

Concerning the western boundary was defined as constant head boundary.

It should be maintained that the numerical model in the study area was considered upper and lower limits for the system. The upper limit is the water table in the unconfined aquifer and the lower limit is the impervious layer, which is the bottom of the aquifer. All nodes outside the boundary of the modeled region are assigned fixed head nodes (inactive cells). The internal cells were considered variable head cells. The initial condition in the steady state is the head distribution within the model area at initial time (t = 0). The initial heads were considered as the initial condition for the steady state calibration.

UNSTEADY STATE SIMULATION

Unsteady flow occurs during pumping. Therefore the dimensions of time and change in ground water storage must be incorporated. A system of 5 wells is assumed to be installed, Figure (8), each well is suggested to be discharging at an average rate of (16 l/s).

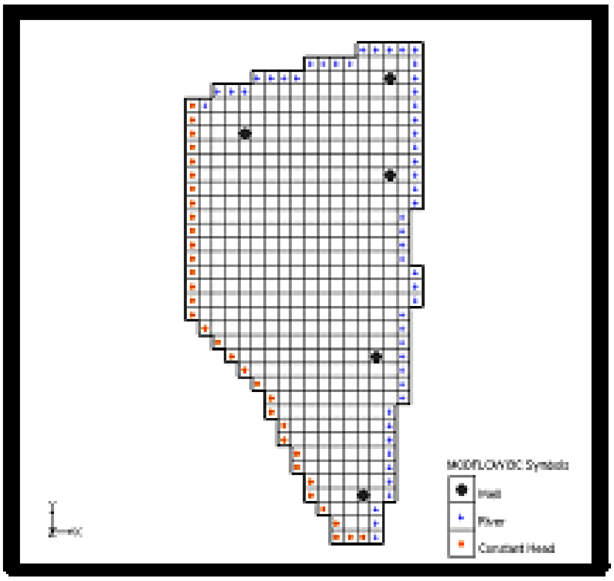

Figure 8: Boundary Assignments for the Aquifer

The simulation included recharge rate from Shatt Al-Mishkhab River and the artificial river which is distributed in each grid block .This rate will increase with increasing difference between the rivers and aquifer heads because of declining water table in the aquifer due to pumping. The accuracy of the results usually decreases with the simulation period. In the present work, the model has not been verified with observed aquifer response to production. Therefore, simulation results over a period longer than a year will have a lower accuracy in comparison with short periods. The simulation period was divided into fourteen non uniform time steps .The length of the first time step was (10.14) days, which increases in geometric fashion by a multiplication factor of (1.2) within each stress period.

For pump maintenance, and other operating facilities, it is suggested to operate the wells at a rate of 75 percent of their efficiency, while keeping total discharge constant.Distribution of the wells was selected after several iterations of changing in order to get the optimum drawdown. It was found that most wells were located near the recharge boundaries, as shown in figures. (9,10,11, and 12).

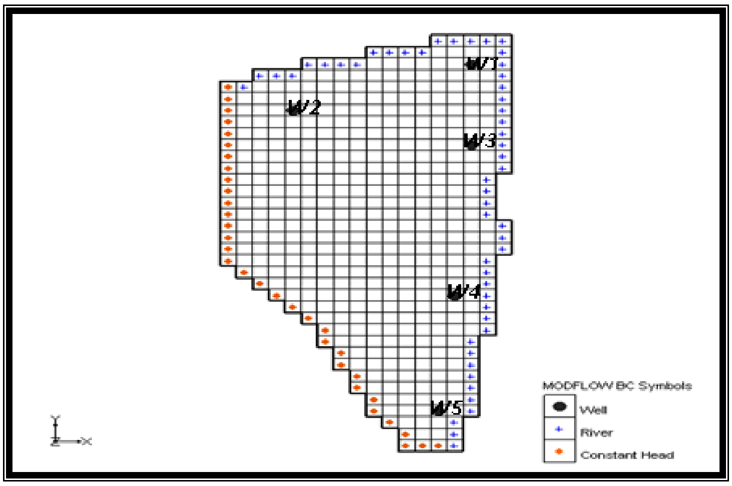

Figure 9: Drawdown after Four Year

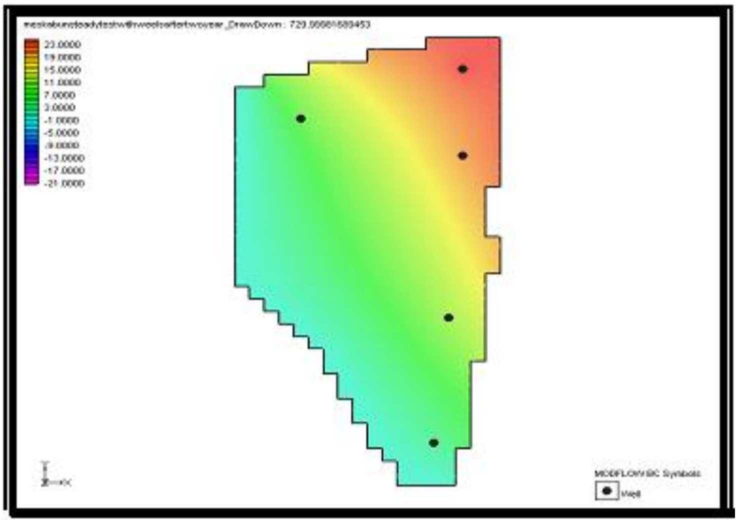

Figure 10: Drawdown after Four Year

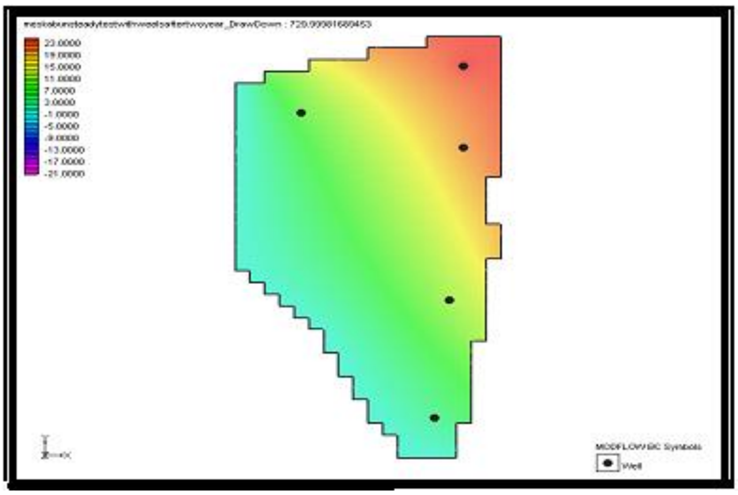

Figure 11: Drawdown after Four Year

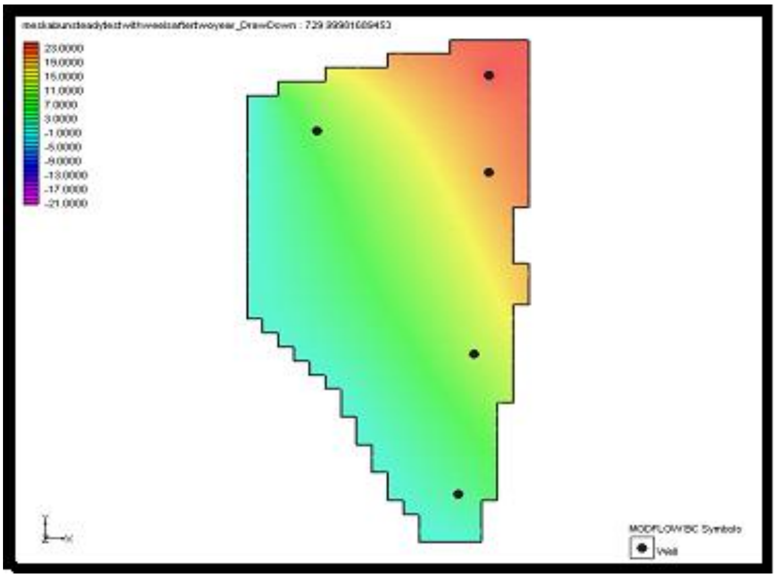

Figure 12: Drawdown after Two Year

EFFECT OF LOWERING GROUNDWATER TABLE ON SETTLEMENT

When stress is applied to soil, and the void are filled with air alone , compression of soil occurs rabidly because air is compressible and can escape easily from the voids. Such compression is usually known as a "compaction".

In saturated soil mass having it's voids filled with in compressible water, decrease in volume. Compression can take place when water is expelled out the voids, such a compression resulting from along term static. Load and the consequent from water is termed as "Consolidation.

The final equation to calculate the consolidation seteelment is:

$$Sc_t = Ut\left(\frac{H_o.Cc}{1+e_o}\log\frac{\sigma_f^{'}}{\sigma_o^{'}}\right) \qquad ----(3)$$

CONCLUSIONS

From the information collected during this study, and from the analysis of results, the following conclusions are drawn:

- The groundwater level in Mishkhab city can be lowered to the required levels to coincide with the base of the remnants by means of forty five wells located on a ring spreading with a considerable density of these wells along Shatt Al- Mishkhab water course, since it is considered as the main recharging source.
- The numerical solution indicates that water level at the middle of the study area i.e. at AL- Mishkhab city can be lowered to about 16 m from its present level after the steady state condition is reached within a period of 250 days.
- The well fields designed by the previous studies aimed to lower the water table within a range of (6-7 m) as a maximum dewatering level, as this level will help in the excavation of the second old Mishkhab city only keeping the first oldest city buried to depth of about 16m below the ground surface. Therefore these studies would help to solve the problem only partially and not completely. In addition to that direct pumping from the upper aquifer will lead to rapid lowering of groundwater level, which may result in causing subsidence in the area and that in turn will obstruct the excavation efforts.

- The present study aimed to solve the problem completely without any affect to the remnants by slow dewatering process.

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