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LOWERING GROUNDWATER IN THE ARCHAELOGICAL BABYLON CITY USING UNDERGROUND DAMS

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ABSTRACT

In this study a mathematical model used to simulate the groundwater lowering in the Ancient Babylon City, located 90 kilometres south of the capital Baghdad, Iraq. The solution proposed within this study is constructing of subground in addition to use 21 discharging wells with (45)m depth distributed around the study area, which covers about (11) km^2 Four scenarios are presented basing on the number and location of subground dams used. For each scenario, wells discharge and time of operation are varied and the results were analyzed. The results showed that installing of subground dam effects significantly groundwater elevations in the studied region and reduce time and efforts required to lower the Ancient Babylon City.

Keywords: Ancient Babylon City, Groundwater Lowering, Mathematical Model, Subground Dams, Visual MODFLOW2011.

1. INTRODUCTION

Management and controlling of groundwater levels is a complicated process requiring collaborate efforts from a number of specialists in geotechnical engineering, hydrogeology, hydrology, geochemistry, hydrochemistry,….etc. Ancient Babylon City is a city with a historic character of archaeological; the city suffers from high levels of groundwater which hinders antiquities exploration. To predominate this problem, the water table must reduce to the level of the bottom of the archaeological zone which expected to be about (14-16) m below ground surface.

Lowering groundwater levels in the Ancient Babylon using different dewatering scenarios and choosing the suitable dewatering scenario is the main target of this study. Ground layers in nature can be anisotropic and heterogenic where descriptive properties of aquifer such as conductivity, porosity and groundwater sources vary with location. Computer assisted mathematical modelling (Visual MODFLOW, 2011 Software) is used to include all these variations and simulate groundwater flow and also to predict the future behaviour of flow within the studied area under the proposed scenarios effect

Underground dams are structures working to prevent or impede the natural movement of groundwater. There are two basic types of underground dams, namely subground dams and sand storage dams. Construction of subground dam be below the ground level and impede groundwater movement, while water reserves in the sand storage dam within sediment accumulated by the dam itself. Subground dams usually constructed using clay, stone masonry, Plastic or tarred-felt sheets and concrete [1].

Groundwater flow models can be used to simulate water table changes with time under different situations. The present study used the three-dimensional finite difference software Visual MODFLOW, 2011 to simulate the groundwater flow for the suggested dewatering scenarios which mainly consist of subground dams and deep wells.

2. HISTORICAL BACKGROUND

The study conducted by (GDGSMI) is the first work on the Ancient Babylon City. It was carried out according to a request made by the State Organization for Antiquities to study the possibility of lowering ground water level; as a result that groundwater covers most of the old Babylonian remnants which obstructed the work of the archaeologists to discover the old city, A preliminary study was made to obtain information about the surface geology, lithology and the hydrogeological conditions of the area. The (GDGSMI) had concluded from this study that Shatt Al-Hilla River participates in raising the groundwater level about (4-5m)[2].

The Consulting Engineering Bureau, College of Engineering, Baghdad University (CEB), 2012 suggested a two-stage solution. The first step is the construction of cut-off curtain surrounding the site. They proposed that this may be implemented by curtain grouting. Three lines of grout holes were proposed for the strip along Shaat-Al-Hilla (Al-Hilla River). The central line was 45m deep and the two flank lines were 25m deep. The central line penetrated the lower medium sand and gravel confined aquifer and the two flank lines penetrated to the semi impermeable layer. The holes were staggered with spacing of 3m in each direction. A second set of grout holes was proposed along the inner side of Hawliya canal, so as to complete closure of the inner ring. This consisted of 25m deep holes, penetrating to the semi impermeable layer, with a spacing of 3m staggered along two lines 1.5m apart [3].

Ghodrati and Ghazaryan**,** examined the utilization process of exploiting underground water in a dried river bed, by using an underground dam constructed along the dessert borders, they also described the management plan of water stored in the underground dam's reservoir for preserving and developing the level of cultivation and horticultural lands, by using a mathematical model [4].

3. OBJECTIVES

The main objectives of this study are constructing a numerical groundwater flow model that can describe accurately the water table depths distribution under the Ancient Babylon Site in such way that reduces estimation uncertainties, suggesting a dewatering scenario for the Ancient Babylon Site such that water table brings down to a level that makes the archaeological investigations safe and evaluating the effect of subground dam on the overall regime of the system and also its effect on the groundwater dewatering process.

4. THEORITICAL DESCRIPTION

Mathematical model in groundwater problems usually consists of a set of partial differential equations that known as flow governing equations, a knowledge about system characteristics parameters, input variables, initial and/or boundary conditions is the first step to build a success mathematical model **Fig. (1),** successful model is that one describing the focusing phenomena accurately as it possible. Generally, mathematical model using a set of interrelated equations may interdependence logically to describe the disposition of the system and to clarify the relationship between variables and parameters [5].

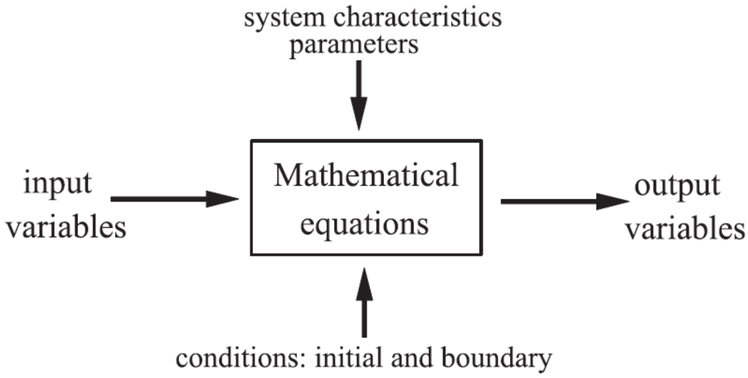


Figure (1): Mathematical model components

Finite difference equations can be derived in two ways; i.e., from the physical stand point involving Darcy's law and the principle of mass transfer, 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 an aquifer is **Eq. (1)**

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

Where x, y, z:Cartesian Coordinates, k_x, k_y, k_z: Hydraulic conductivity along axes (L/T), h:Head of groundwater pressure, (L), W: Flux per unit volume, it represents quantities discharged (or recharged) to (or from) the aquifer, (L^3/T), Sc:Specific storage of the porous medium, (dimensionless), t: Time (T), Sc, k_x, k_y and k_z are functions of space, while w and h are functions of space and time.

The finite difference method replaces the partial differential equation of flow, **Eq. (1)**, by a set of difference equations in discretized space and time. The two dimensional areal and quasi-three dimensional model depends on the perspective of the aquifer; while two dimensional profile and full three dimensional models flow system, [6].

Beside the governing equation and initial conditions, mathematical models consist of boundary conditions. These conditions are mathematical statements at the boundary of the problem domain. In model design, the process of selecting the right boundary condition considered the most important and critical stride, as a wrong boundary may lead to serious errors in the results. Boundary conditions can be divided into three types: Dirichlet condition, Neumann condition and Cauchy condition [7, 8].

5. STUDY AREA

Babylon City located about (90km) to the south of the capital Baghdad and about (10km) to the north of Hilla City. Babylon City lies on both banks of Shatt al-Hilla (al-Hilla River) between longitude (44° 20´ – 44° 35´E) and latitude (32° 25´ – 32° 35´N). The main archaeological site is bounded from the west by Shatt al-Hilla, a branch of the Euphrates River, and an artificial canal called Babil (Babylon) canal passed through the studied region. Two artificial lakes connected by al-Hawliyah (circumferential) Canal enclose the main part of Babylon. The study area is about (11 km²), which is suggested according to the expected area that imminently planned to be investigated, **Fig. (2)**

Figure (2): Ancient Babylon City location

6. MODEL APPLICATION

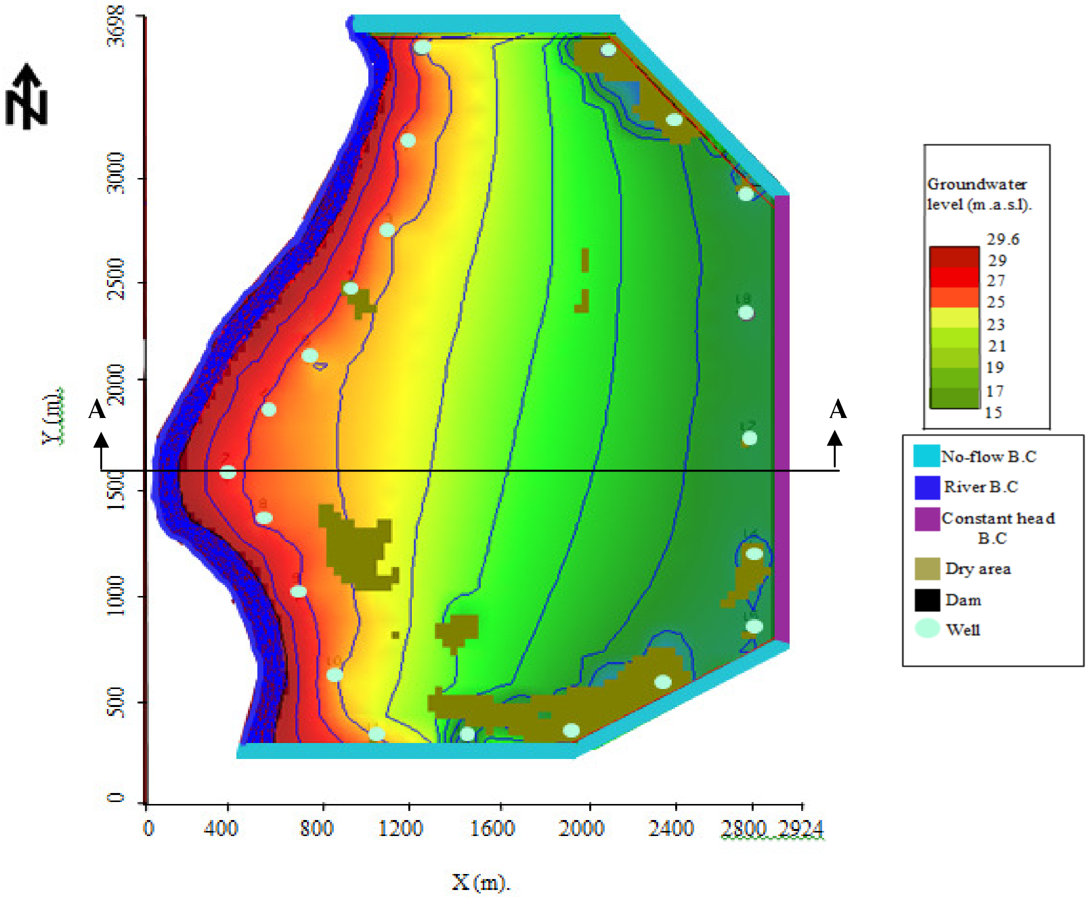
Four scenarios are discussed within this study as proposed solutions to lower the groundwater level in the study area. For all scenarios, location of wells, location of subground dam and the number of wells were decided previously by trial and error. Subground dam thickness is (6-8)m and dam hydraulic conductivity is $2.5x10^{-6}$ m/sec. Twenty one wells, placed around the site, have been used in the first scenario. Subground dam (45 m depth) at the west of the studied region in addition to 21 wells around the study area have been used in the second scenario. One subground dam (45 m depth) at the east with 21 wells have been used in the third scenario. Two subground dams (45 m depth) at east and west sides have been added to the 21 wells in the fourth scenario.

Scenario -1: Due to scenario-1, constant head boundary condition equal to 15 m.a.s.l, the lowest possible elevation greater than top of impermeable layer, at the east boundary of the region. Results of this scenario shows that using wells of (1500 m³/day) discharge without subground dam to lower the water table not give an acceptable lowering (the required 14-16 m or more lowering) during the 300 day time simulation, as shown in **Fig. (3)**.

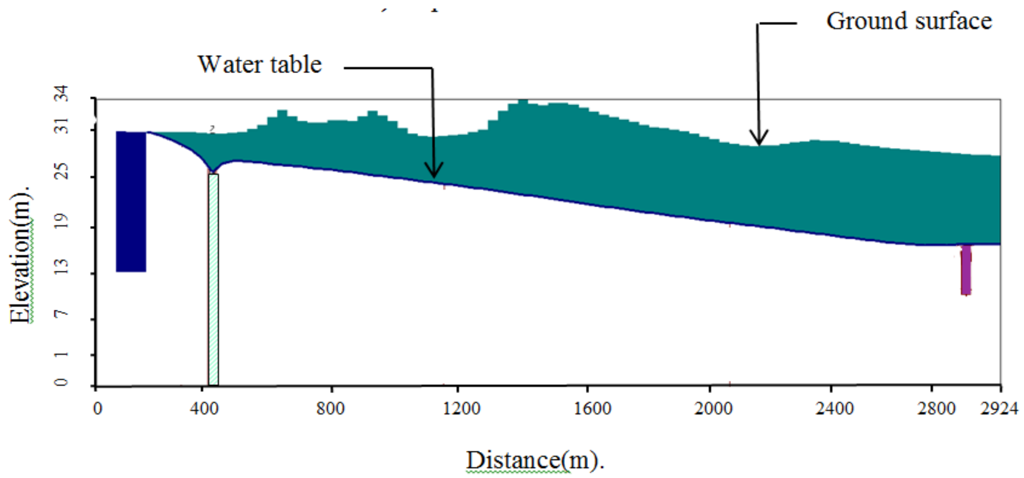
Scenario -2:_Fig. (4) Shows the results of scenario-2 using 15m.a.s.l boundary condition at east side of studied region, Q=1500 m³/day for each well and simulation time =300 day. The results reveals that scenario-2 produce a better water table lowering than scenario-1 as it clear that dry regions covered a greater area compared with that resulted from scenario-1. Although, groundwater levels are still shallow and do not accommodate the requirement of future investigations in the Archaeological Site of Babylon.

Scenario-3: The results of this scenario are as shown in **Fig. (5),** the results demonstrate clearly the benefit of subground dam installation on groundwater levels. Dry regions increase at east side of studied region compared with scenario-1 and scenario-2 (approximately about one-half of studied region). Groundwater levels are rarely increased at the west side (river side) in comparison with scenario-2 results. This scenario gives an acceptable groundwater elevation at region near the subground dam where the elevations faraway the dam also still out of the archaeological investigation requirement as the water table is shallow especially for regions near Shatt Al-Hilla banks.

Scenario -4: From results of this scenario (two dams located at west and east sides of the studied region), it can be concluded that groundwater elevations are of acceptable values for archaeological investigations requirements. With the increasing of wells discharge, dry regions begin to appear at the east subground dam and progressed gradually toward west subground dam; dry regions approximately covered the whole studied area at well discharge equal to 1500 m³/day. **Fig. (6).**

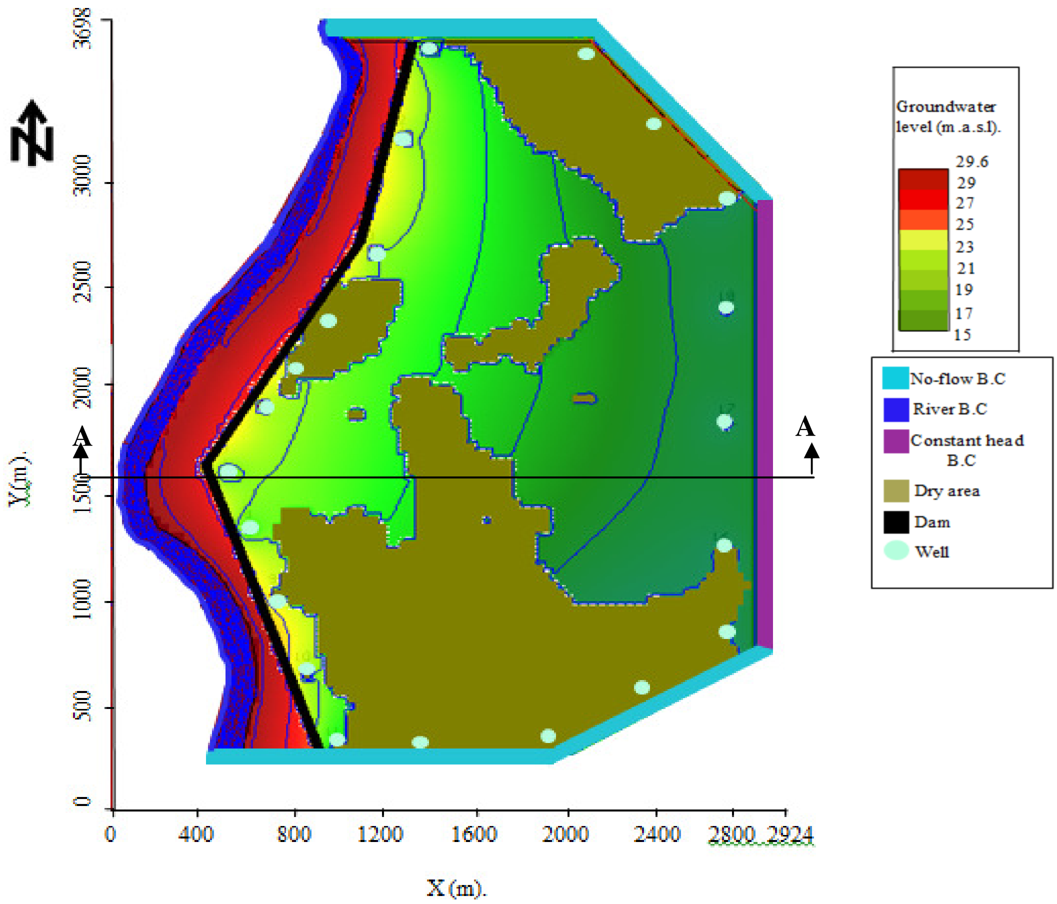


a) Top view of water table

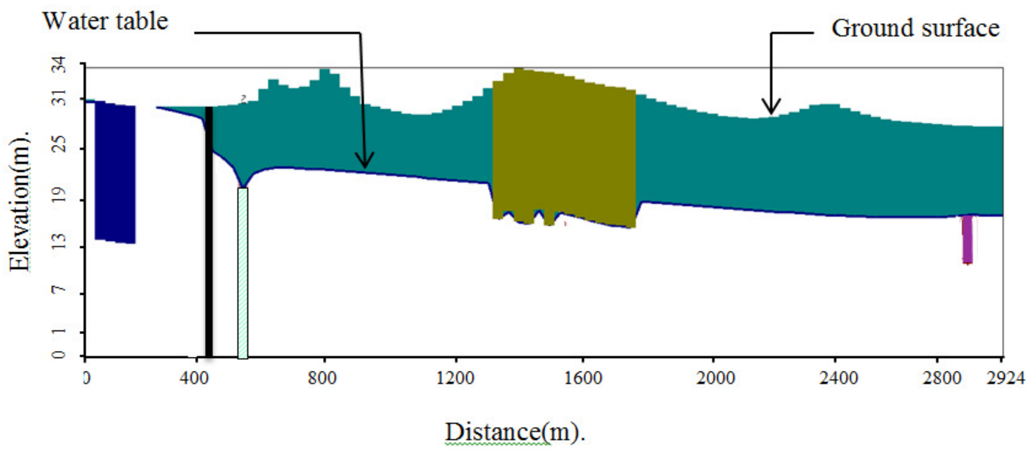


b) Section A-A

Figure (3): Water table elevation of scenario -1 (Q=1500 m³/day, t=300 day).

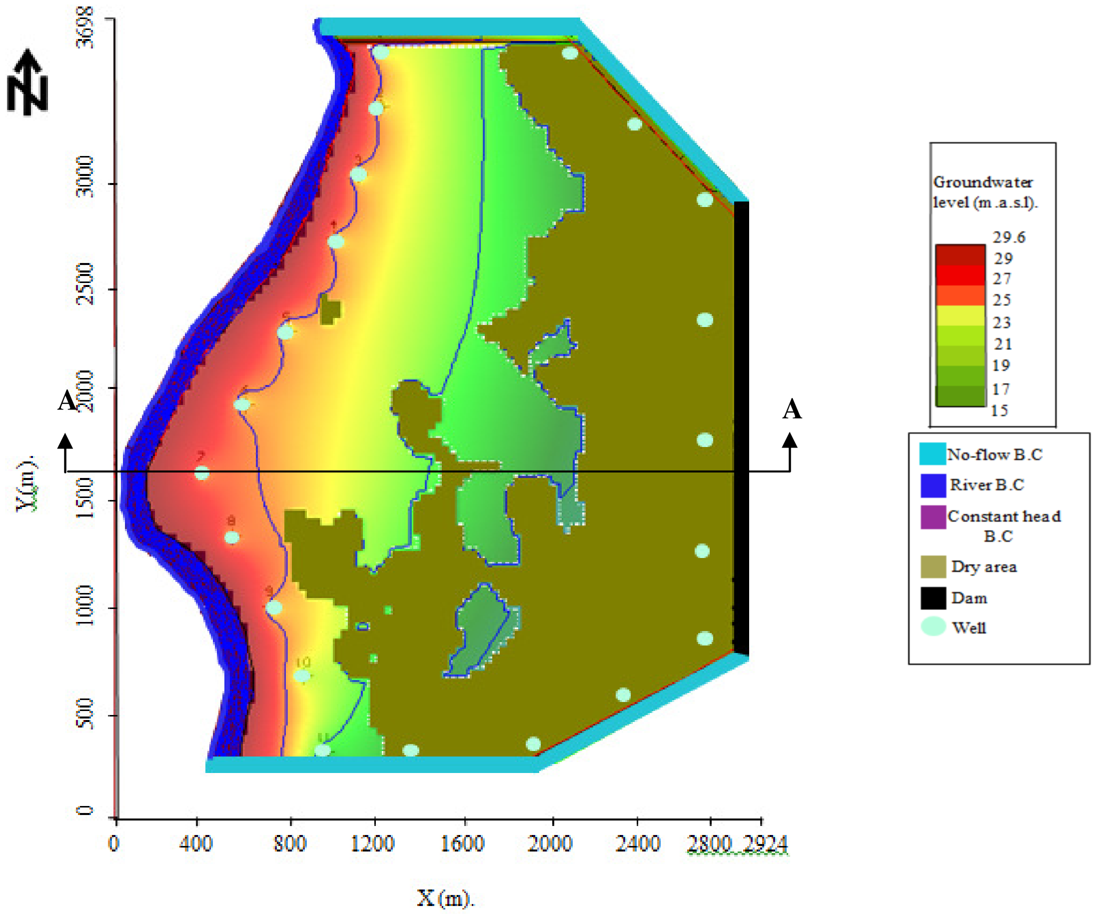


a) Top view of water table

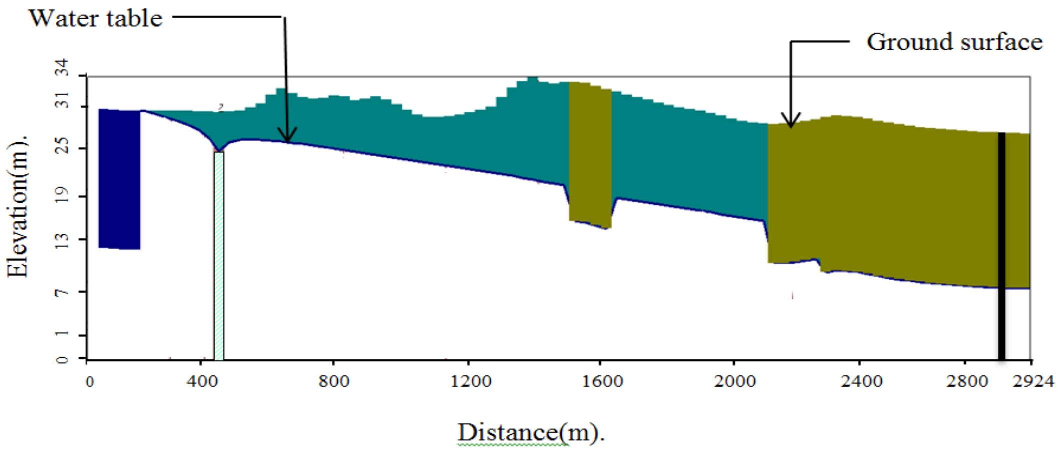


b) Section A-A

Figure (4): Water table elevations of scenario -2 (Q=1500 m³/day, t=300day)

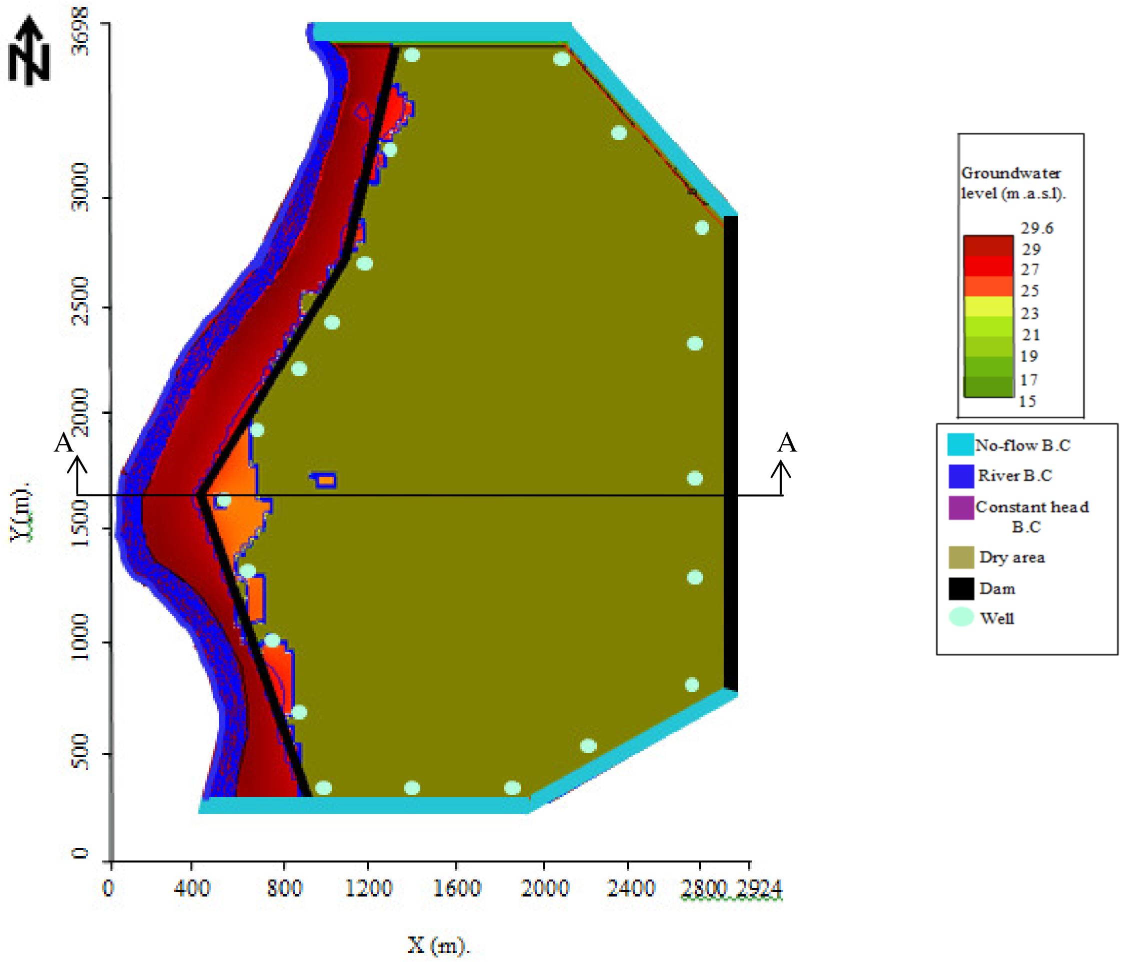


a) Top view of water table

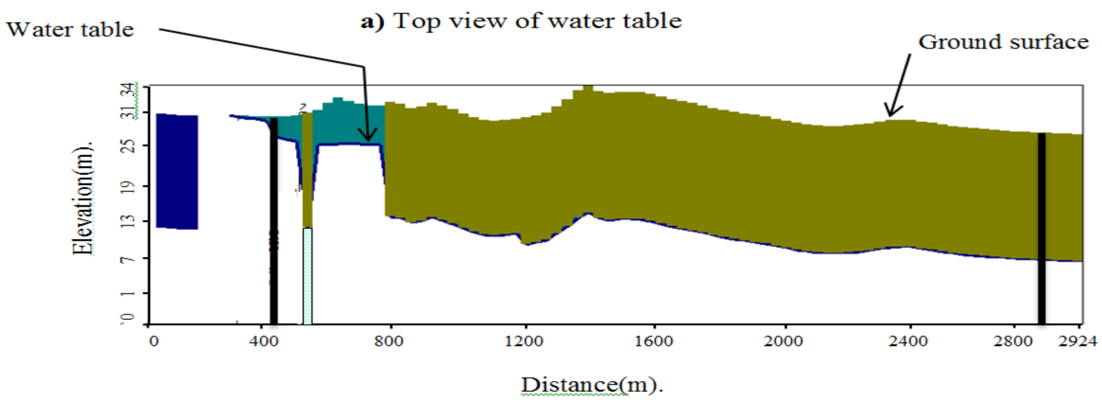


b) Section A-A

Figure (5): Water table elevations of scenario -3 (Q=1500 m³/day, t=300day)



a) Top view of water table



b) Section A-A

Figure (6): Water table elevations of scenario -4 (Q=1500 m³/day, t=300day)

Four arbitrary points are chosen randomly to check the effect of running time and wells discharge on the behaviour of groundwater elevations in the studied region of Babylon site, points coordinates are P1 (1700, 2000), P2 (2100, 3000), P3 (2400, 1100) and P4 (800, 1400). Figs. 7 to 10 show the relation between discharge and water table at different running times. Results revealed that running time do not highly effected results while wells discharge significantly affects the result.

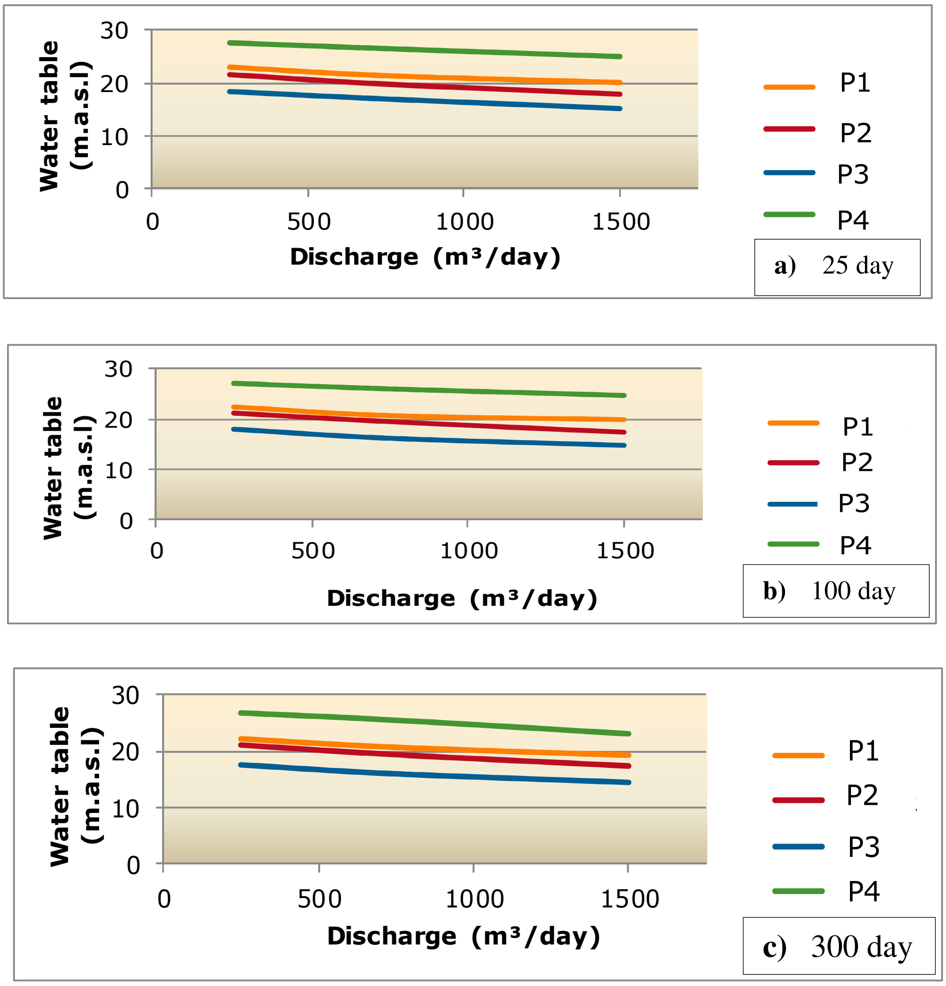
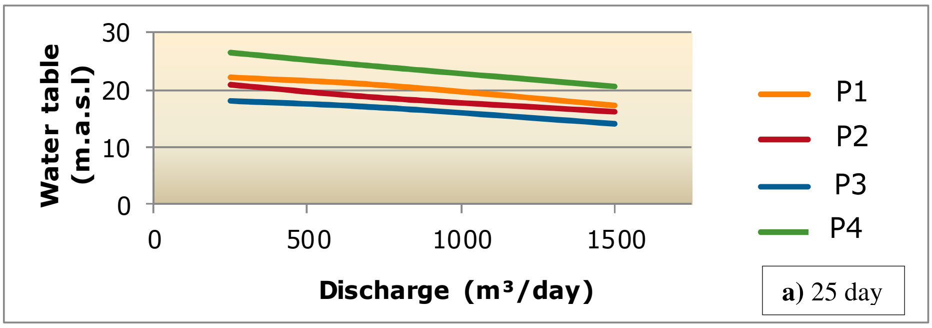


Figure (7): Discharge -Water table relationship for various running time in scenario -1



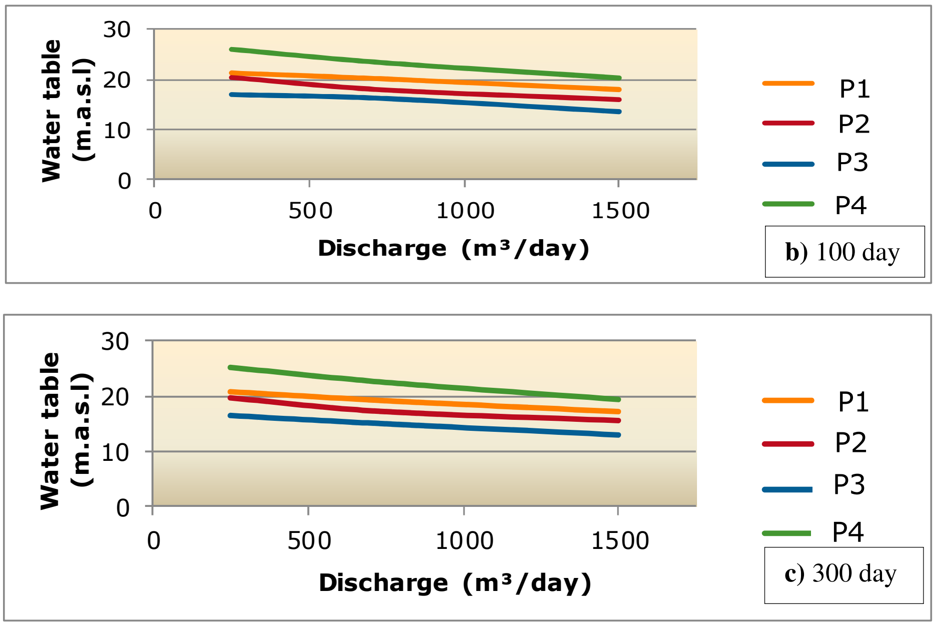


Figure (8): Discharge -Water table relationship for various running time in scenario -2

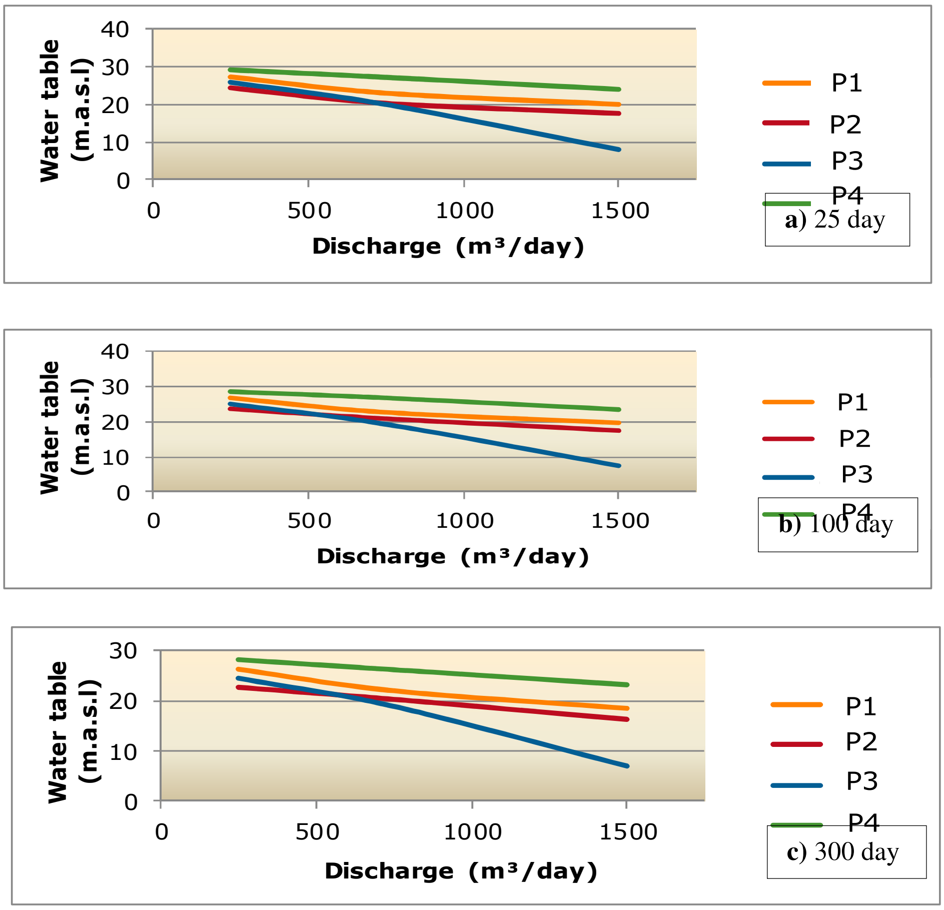


Figure (9): Discharge -Water table relationship for various running time in scenario -3

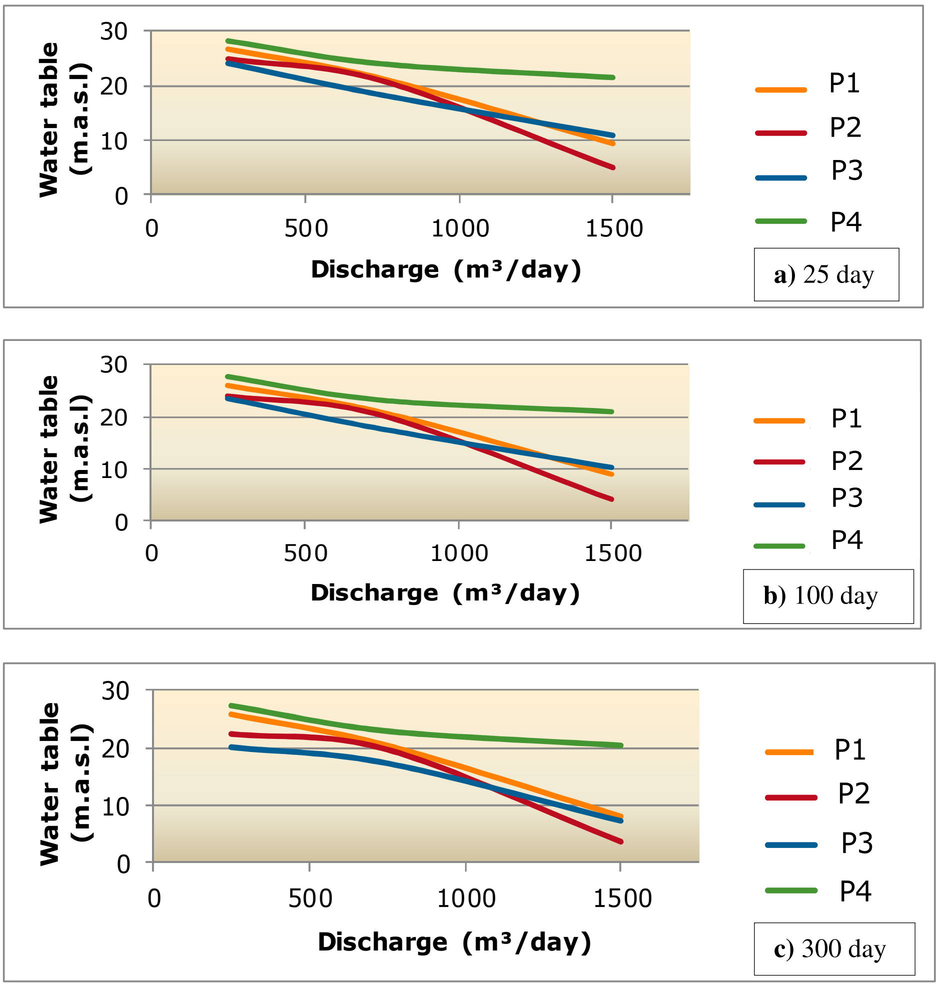


Figure (10): Discharge -Water table relationship for various running time in scenario -4

Four arbitrary points are chosen randomly to check the effect of running time and wells discharge on the behaviour of groundwater elevations in the studied region of Babylon site, points coordinates are P1 (1700, 2000), P2 (2100, 3000), P3 (2400, 1100) and P4 (800, 1400). **Figs. 7 to 10** show the relation between discharge and water table at different running times. Results revealed that running time do not highly effected results while wells discharge significantly affects the result.

7. CONCLUSIONS

1. Research results affirmed that three dimensional numerical modeling using Visual MODFLOW software could be used to quantitatively simulate of groundwater management.
2. The study revealed that using wells system alone without cutting groundwater sources would not be sufficient to control the rise in groundwater elevations in Babylon Archaeological Site because of site nature limitations. Furthermore, using of subground dams without well system is of negligible effect on groundwater elevations in the site.
3. Using of one subground dam as that done in scenario-2 and scenario-3 is not highly affected the groundwater elevations because of the studied region works as a sink for a source either coming from east neighbouring regions in scenario-2 or Shatt Al-Hilla in scenario-3.

4. Different proposed scenarios have been simulated and compared within the present study, scenario-4 (21 wells system with two subground dams) seems to be more efficient in groundwater lowering of the studied region compared with other scenarios.

8. RECOMMENDATIONS

1. A Geotechnical study may be beneficial to investigate the expected subsidence that will occur in the Babylon Ancient Site due to well pumping.
2. Studying the effect of Shatt Al-Hilla lining and other feasible solutions for the problem of groundwater rise such as excavating a ditch around Babylon Ancient Site.

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