Effect of Subground Dam Properties on the Groundwater Lowering Strategy in the Ancient Babylon City

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Abstract
A three dimensional finite difference model have been applied to simulate the groundwater system using a well-known computer code called Visual MODFLOW. Twenty-one wells of 1500m^3/sec with two subground dams proposed to construct at the east and west of the Ancient Babylon City have been proposed to lower water table elevation. The study concerns the effect of subground dam's properties (subground dam thickness and hydraulic conductivity) on the groundwater lowering in the Ancient Babylon City. According to results, subground dams installation in the studied region provides flexibility in the decision of groundwater lowering strategy where it found that there is a range of dam thickness- hydraulic conductivity combination can result suitable groundwater elevations for safe archaeological exploration.

Keywords: hydraulic conductivity, Groundwater lowering, dam thickness, Subground dams, Visual MODFLOW

1. Introduction

Underground dam is a facility that constructed underground and almost perpendicular to groundwater flow direction for various purposes such as groundwater reservation, impeding natural movement to specified region and to prevent the progression of hazardous wastes into an aquifer. There are two basic types of underground dams, namely subground dams and sand storage dams.

The material used in subground dam constructing is one of the most important factors in its construction, not only because the material will be installed underground, but also because it must successfully address there major problems. Although one material rarely possesses the properties needed to fulfill all requirements, cement grouting, sheet piling, puddled clay, emulsified asphalt, silica gel, calcium acrylate, plastics and Montana wax, singly or in combination, may be adequate (Basri, 2003).

Hussein, 2015 examined four dewatering scenarios for a real case study, namely, Babylon Ancient City, Iraq and recommended a scenario that used 21 wells of 1500m^3/sec discharge with two subground dams proposed to construct at the east and west of the studied region. Present study used this scenario to investigate the effect of subground dam material hydraulic conductivity and dam thickness on the efficiency of subground dam in groundwater lowering. Three-dimensional finite difference groundwater flow model used with the aid of Visual MODFLOW software.

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. 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 (Clarke, 1973).

2. Historical Background

The construction of underground (subground or subsurface also called) dams for the purpose of storage of groundwater was not the way modern. Groundwater dams were constructed on Sardinia in Roman times and damming of ground water was practiced by ancient civilizations in North Africa. More recently, various small-scale groundwater damming techniques have been developed and applied in many parts of the world, notably in South and East Africa and in India (Hansson & Nilsson, 1986).

The most comprehensive information about groundwater dams is given in (Nilsson, 1988), which consists of most detailed concept including literature review. As it is mentioned in(Nilsson, 1988); there are several groundwater dams in the world including Europe, Africa, Asia and America. The use and usefulness of the underground dams as a means of sustainable development, and their performance in the management of groundwater resources were analysed with the help of two example studies by Yilmaz, 2003. In the first example a hypothetical idealized aquifer is considered, while in the second one, a real aquifer is selected. Ishida et al., 2011 reviewed the basics about underground dams, the construction of underground dams around the world, and the problems involved in the sustainable use of groundwater. According to their review of the construction of underground dams, the scale of underground dam projects had been grown. Some problems with underground dams reported in the past, i.e., sedimentation, flooding, collapse, and salination, occurred because of human error, as well as the immaturity and complexity of geological features. A 3-D finite element (FE) numerical model was used to analyse structurally a proposed subsurface concrete dam to serve as a strategic water supply storage for the Holy city of Makkah, Saudi Arabia by Khairy et al., 2011, while Fakharinia et al., 2012 investigated of subsurface dam construction and its effects on water table height in consumption location and interception of nitrate transport. Therefore the Shahrekord aquifer model was simulated by MODFLOW and MT3D models. Mobarakabadi, 2012 used AHP method in order to provide a model for optimal location of subsurface dam, Khomein city in Markazi Province, Iran was studied. Ghodrati and Ghazaryan, 2013 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.

3. Results and Discussion

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), study area is about (11 km²), as shown in figure-1and figure-2

Figure 1: Location of studied region

Figure 2: Ancient Babylon City

A general form of the governing equation for an aquifer is **Eq. (1)**

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

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.

Four arbitrary points have been chosen randomly to check the effect of dam properties on the behaviour of groundwater elevations in the studied region, points coordinates are P1 (1700, 2000), P2 (2100, 3000), P3 (2400, 1100) and P4 (800, 1400). Figures 3 to 6 show the effect of subground dam thickness on groundwater behavior in the studied area, the model have been applied with well discharge =1500 m^3/sec, run time=300days, dam permeability=0.0000025 m/sec and dam thickness varies between (1-8m). Figure-7 shows a comparison between results in the arbitrary points. The results reveal that groundwater elevations in the studied region are sensitive to dam thickness variation.

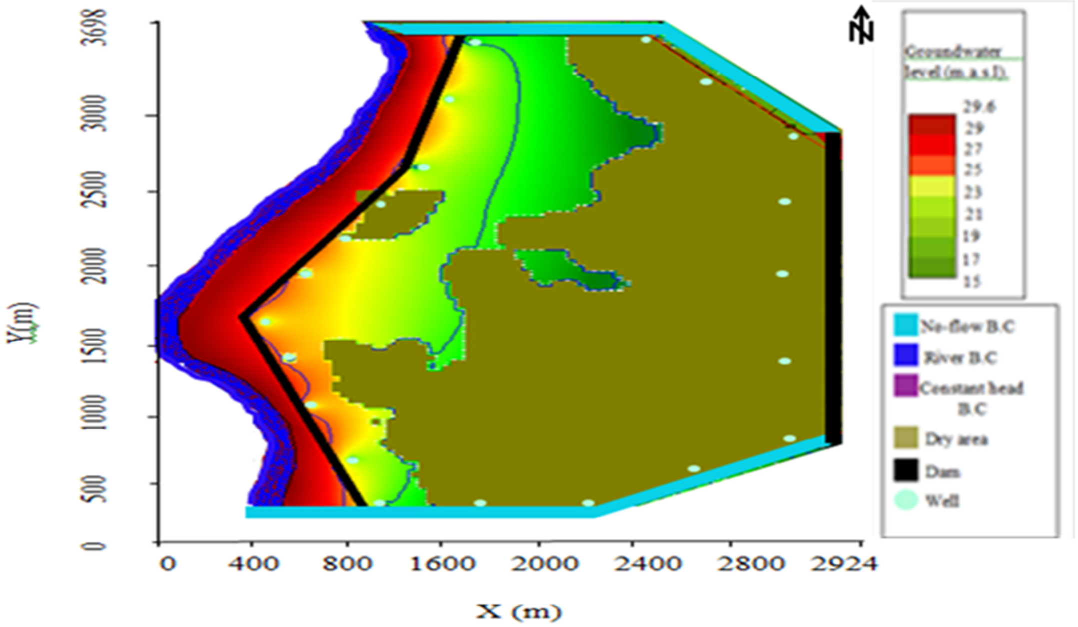

Figure 3: Water table elevation in studied region with t_d=(1-2) m and k_d=2.5x10^{-6}m/sec

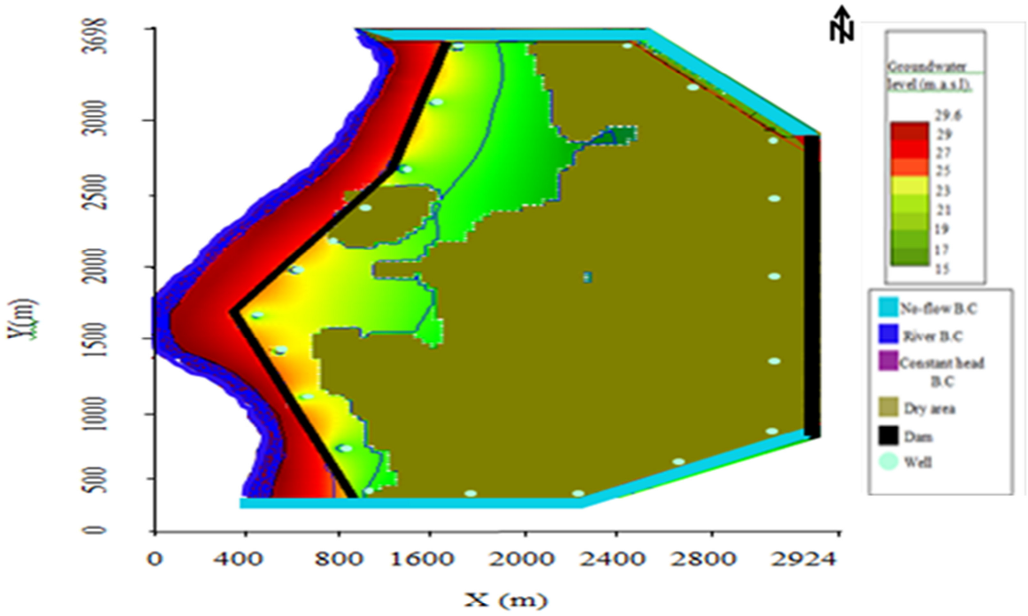

Figure 4: Water table elevation in studied region with t_d= (3-4) m and k_d=2.5x10^{-6}m/sec

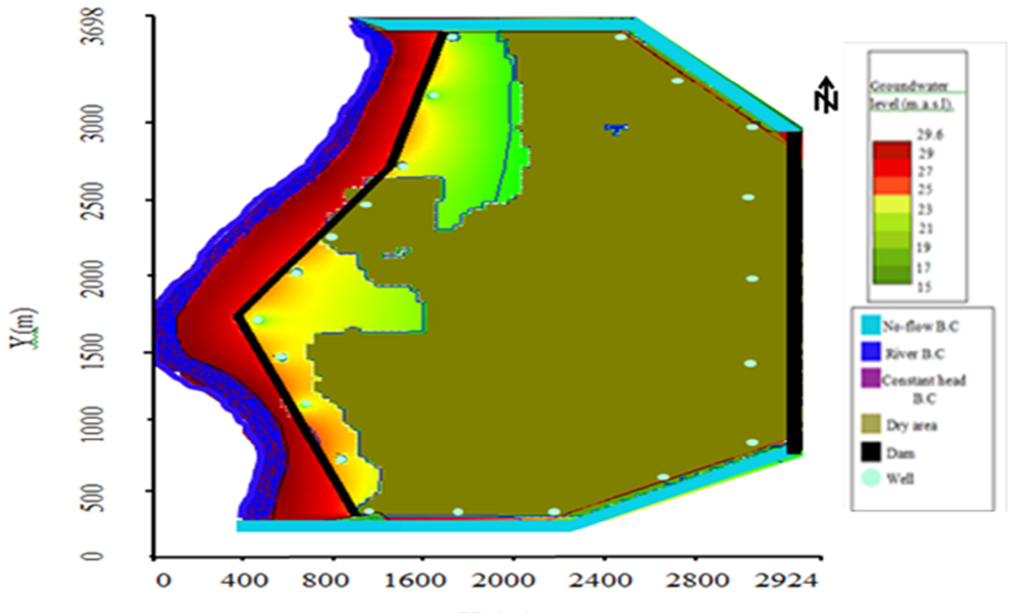

Figure 5: Water table elevation in studied region with t_d= (4-6) m and $k_d=2.5\times10^{-5}$m/sec

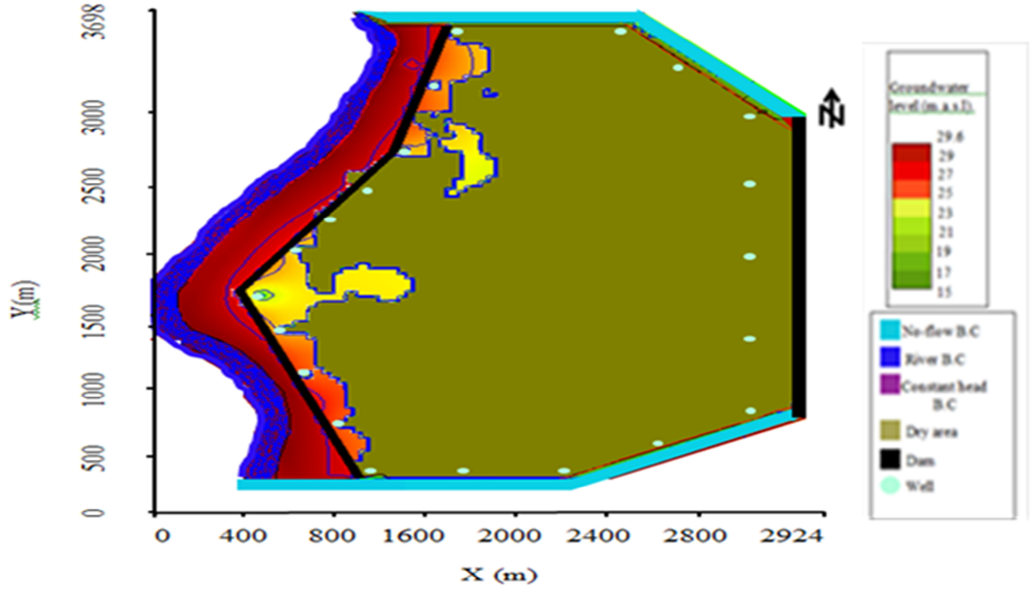

Figure 6: Water table elevation in studied region with t_d= (6-8) m and $k_d=2.5\times10^{-5}$m/sec

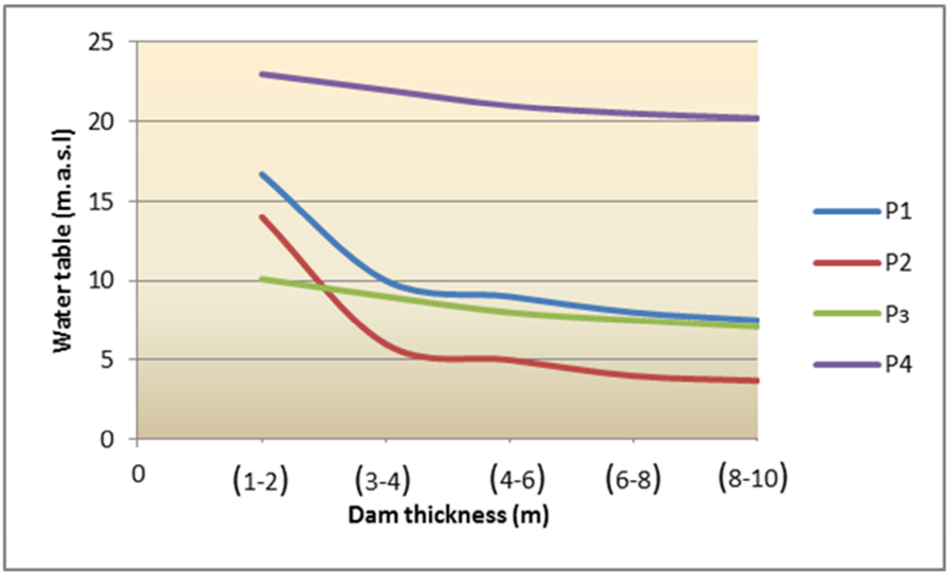

Figure 7: Water table VS. Dam thickness in the four arbitrary points

The choices for the material should be given considering economic factors, labour conditions, level of maintenance etc. for the site specific conditions. Dam hydraulic conductivity is a major factor that affects the ground water elevations. Figures 8 to 11 show the variation of water elevations with variation of dam's hydraulic conductivity, four values are examined within this study $1x10^{-6}$, $2.5x10^{-6}$, $5x10^{-7}$ and $1x10^{-9}$m/sec. Figure-12 show the relation between water elevation and hydraulic conductivity with various dam thicknesses in the arbitrary points. It can be seen that minimum effective hydraulic conductivity is about $5x10^{-7}$ and decreasing hydraulic conductivity below this value is of negligible effect on results. Furthermore, increasing of dam thickness above (4-6)m for dam conductivity greater than $2.5x10^{-6}$ is slightly affected the results.

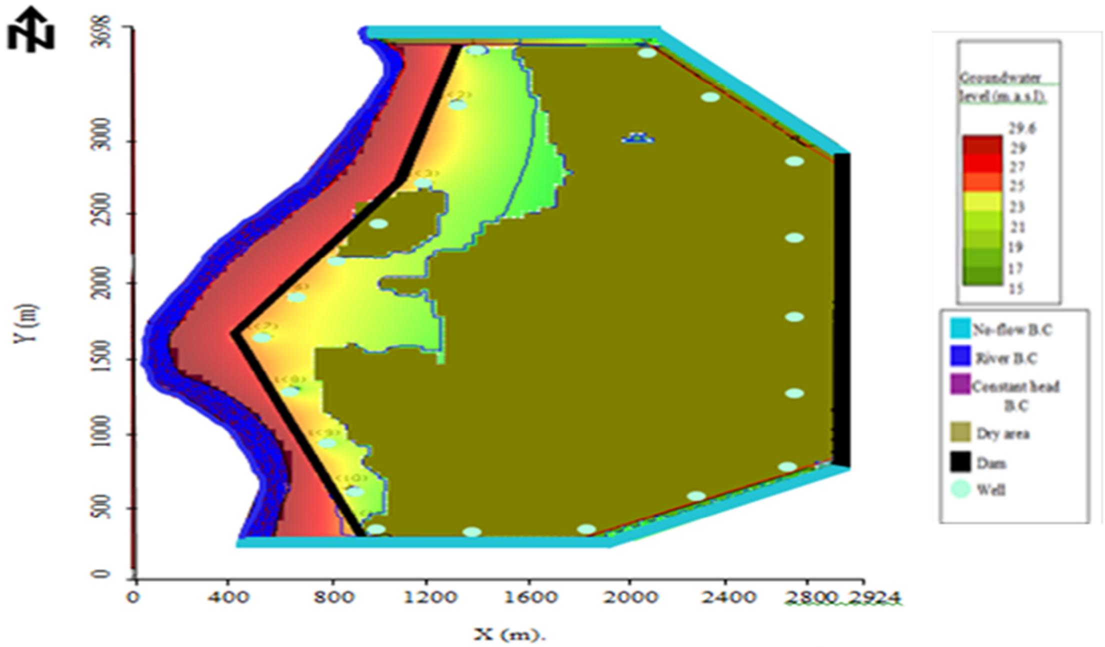

Figure 8: Water table elevation of studied region using ($k_d=10^{-5}$ m/sec and t_d=8-10 m)

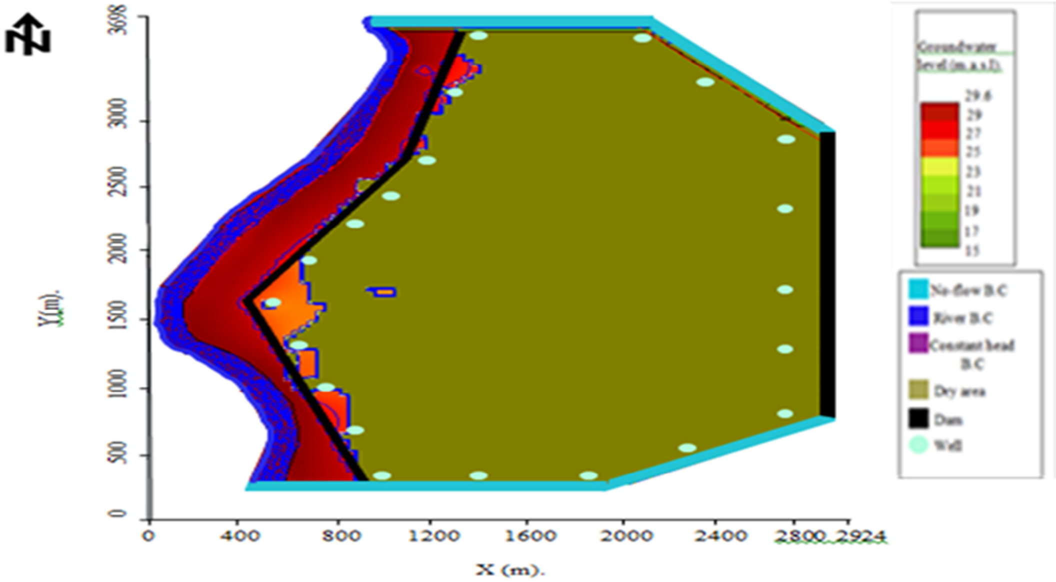

Figure 9: Water table elevation of studied region using (k_{δ}=2.5x10^{-5} m/sec and t_{δ}=8-10 m)

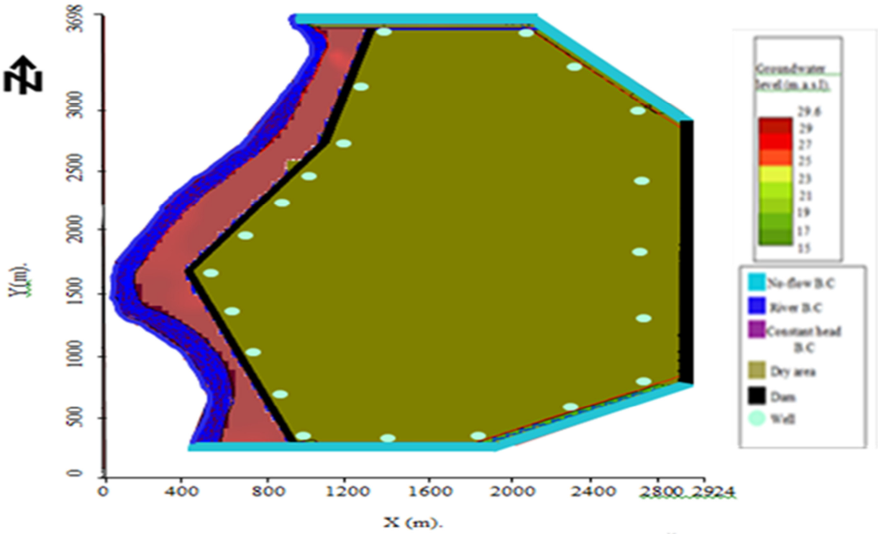

Figure 10: Water table elevation of studied region using (k_{δ}=5x10^{-7} m/sec and t_{δ}=8-10 m)

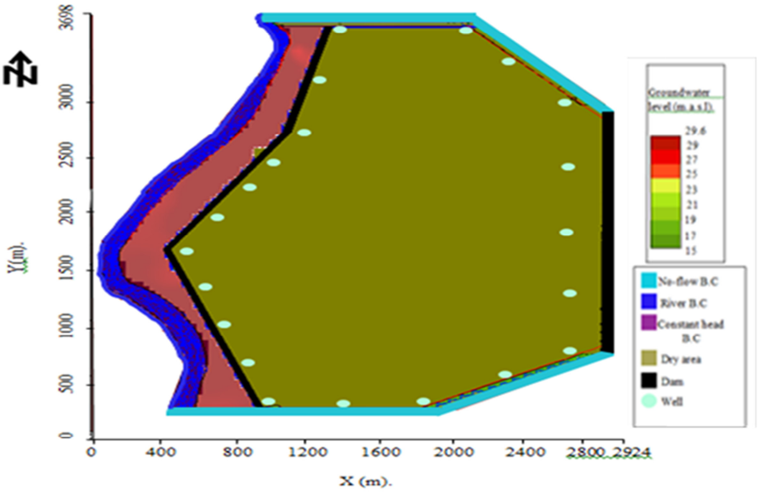

Figure 11: Water table elevation of studied region using (k_{δ}=10^{-9}m/sec and t_{δ}=8-10 m)

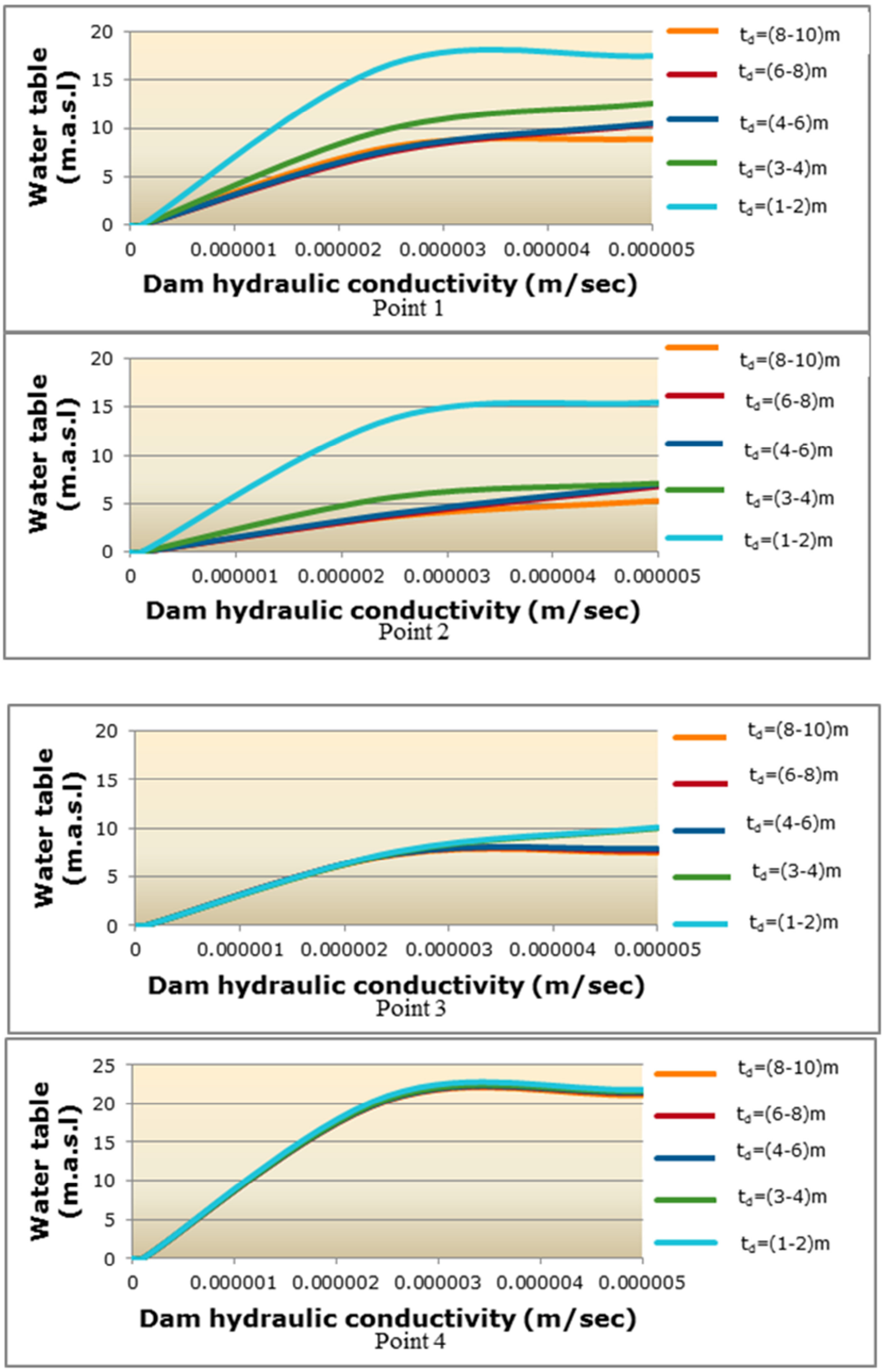

Figure 12: Water table VS. Dam hydraulic conductivity with various dam thicknesses in the four

7. Conclusions

Depending on subground dam material used and its thickness, there are several visible solutions for groundwater rising problem which reaches sometimes to dry the aquifer of the studied area completely, so the designer has a flexibility to choose any of the alternatives given in this study depending on material availability, subground construction cost and the amount of groundwater elevation preferred to lower. Results of this study demonstrated that dam thickness is significantly affected groundwater elevations especially with high permeability subground dams and have less effect with those of low permeability. The results also revealed that decreasing subground dam permeability below ($5x10^{-7}$ m/sec) is not valuable in water table lowering of the Ancient Babylon City and the maximum effective value of subground dam permeability is about ($3x10^{-6}$ m/sec).Also, increasing dam thickness above (4-6) m with dam conductivity greater than $2.5x10^{-6}$ m/sec is of negligible effect on water elevations in the studied region.

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Appendix 1: Symbols

t [sec] : Time
p_1, p_2, p_3 and p_4 [-]: Arbitrary points
t_d : [m]: Subground dam thickness
k_d [m/sec]: Subground dam hydraulic conductivity
ky, kz and kz [m/sec]: Hydraulic conductivity along axes
h [m]: Head of groundwater pressure
W [m^3/sec]: Flux per unit volume, it represents quantities discharged (or recharged) to (or from) the aquifer
Sc [Dimensionless]: Specific storage of the porous medium

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