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# Insights For Design of Discharge and Injection Wells using Visual MODFlOW in Coastal Aquifers

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## ABSTRACT

The population increase in Egypt and the supply limited freshwater resources of Egypt has driven the national policy in recent years to encourage investment in tourism, and establish touristic resorts in coastal areas. Desalination plants play a major role in closing the gap between supply and demand for the fresh water in coastal areas. An environmentally friendly and cost effective design for the brine disposal system is essential. The aim of this research is to develop charts for designing and managing the injection and discharge wells in coastal areas, minimizing the impact on ground water. A numerical modelling study was carried to simulate the ground water extraction and brine disposal using Visual MODFLOW three-dimensional groundwater flow and contaminant transport modelling application. Eighty different scenarios were tested by varying the brine injection rate, spacing between production and injection wells, initial concentration of the aquifer, concentration of the injection well, type of soil and screen location. The model results revealed that the lateral extent of the salt plume is directly proportional to the rate of injection. Moreover, the injection well should be deeper than the discharge well for achieving the optimal design for the injection and discharge wells. Also, the salt plume lateral extension is directly proportion to the hydraulic conductivity of the soil.

**Keywords:** Brine disposal, Injection well, Desalination, coastal aquifers, Visual MODFLOW, Groundwater.

# 1 INTRODUCTION

The population of Egypt increased from 23 million in 1955 to more than 94.8 million in 2017. The major part of Egypt water resources is limited to Egypt's share from the Nile waters due to the 1959 treaty between Egypt and Sudan. With a population expected to double in the next 50 years, Egypt is projected to reach a state of serious countrywide fresh water and energy shortage by 2025 (Stanleyand Clemente 2017). The water demand is increasing also due to the fast growing development in Egypt that required big movements of investments and people from the Nile Valley towards the east, to the Red Sea (Djebedjian et al 2005). Enlargement of Egypt and population activities outside the Nile Delta and Valley especially in tourisms and industry sectors necessitates the search for non-conventional water resources to be used in special purpose like tourism, industry and drinking. Under these conditions, desalination could be the challenge for Egypt to survive.

Desalination refers to the process of removing salts and other minerals from saline and brackish water to produce fresh water. Hence, many desalination stations have been established in many areas to feed its tourist compounds with fresh water for varying objectives and uses. However, the negative impact of desalination process is the brine disposal which is a real environmental problem that should be considered and studied before constructing a desalination plant. The simulation of groundwater flow and solute transport in coastal aquifers has been widely studied (Sindhu et al. 2012; Ganesan and Thayumanavan 2009; Kharmah and Almasri 2007).

The brine is commonly discharged into the sea or injected into a saline aquifer. The problem of disposing rejected brine into the sea that it may change seawater salinity leading to injuring plants and animals in the marine sanctuary (Williams and Feeney 2003). The environmental impacts of the disposal of gas production by-products waste water in deep aquifers were studied by (Ali et al. 2009). He assumed a single injection well with a rate of 220 $m^3$/day for 50 years, and he showed that the 10% relative contamination line will migrate vertically upward into the main water bearing formation for a distance of about 150 m while the lateral extent is about 1800 m.

Nassar and Ghanem(2008) assessed the behaviour of production and injection well fields of desalination plants through an experimental setup and computational simulation. They used a seepage tank with two well configurations to represent a 2-dimensional flow in the vertical plane experimentally. The results of their experiment were used to calibrate SEAWAT model and there was a great agreement between them. They found that the desalination plant in the long term is not acceptable if salinity increases at feeding water of desalination plant via discharge well due to brine disposal via injection well. Also, the results showed that the injection well will affect the salinity of the production well on the long run.

Ammar et al.(2012) presented a case study in central Sinai to evaluate two disposal options, evaporation ponds and the injection of rejected brine in deep geological units. The simulation of the evaporation pond showed that the effect of salinity on evaporation rates can result in an increase of pond area by about 140%. While, injecting the brine in the Upper Cretaceous aquifer unit around the desalination plant for a period of 25 years resulted in extending of the salinity plume 250 m around the injection well in the horizontal direction.

In this research, Visual MODFLOW (VMOD) is used to calibrate Nassar and Ghanem (2008) laboratory experiment, to simulate three-dimensional groundwater flow and contaminant transport. Then eighty scenarios were designed and simulated for groundwater extraction and rejected brine injection into subsurface aquifer in the coastal area. The aim of these scenarios is to create design charts and equations for designing and managing of production and injection well in coastal areas.

# 2 Visual MODFLOW Model

Visual MODFLOW (VMOD) is a software program developed by Waterloo Hydro geologic. The software is used to simulate three-dimensional groundwater flow and contaminant transport. It supports all of the most recent public domain of MODFLOW and MT3D for simulating groundwater flow and mass transport. Visual MODFLOW provides many numeric engines that perform the numeric calculations required to solve the finite difference scheme of groundwater flow and mass transport. SEAWAT is the numerical engine implemented in this study as it simulates three-dimensional, variable-density, transient groundwater flow in porous media. The governing equation for density-dependent groundwater flow model in terms of freshwater head, which is solved by MODFLOW routines in the SEAWAT code, derived by (Guo and Langevin 2002) is given by Eq. (1)

$$\frac{\partial}{\partial x}\left(\rho K_{fx}\left[\frac{\partial h_f}{\partial x}\right]\right)+\frac{\partial}{\partial y}\left(\rho K_{fy}\left[\frac{\partial h_f}{\partial y}\right]\right)+\frac{\partial}{\partial z}\left(\rho K_{fz}\left[\frac{\partial h_f}{\partial z}+\left(\frac{\rho-\rho_f}{\rho_f}\right)\right]\right)=\rho s_f\frac{\partial h_f}{\partial t}+\theta\frac{\partial \rho}{\partial C}\frac{\partial C}{\partial t}-\bar{\rho}q_s \quad (1)$$

Where $\rho$ is the fluid density, $K_{fx}$,$K_{fy}$ and $K_{fz}$ are freshwater hydraulic conductivity in the x, y and z direction, $h_f$ is the equivalent fresh water head, $\rho_f$ is the density of freshwater, $S_f$ is the fresh water specific storage, θ is the porosity, C is the concentration of solute mass per unit volume of fluid, $q_s$ is the volumetric flow rate of sources or sinks per unit volume of aquifer and t is time.

The governing equation for solute-transport is given by Eq. (2):

$$\frac{\partial(\theta C)}{\partial t}=\nabla(\theta D.\nabla C)-\nabla(qC)\pm q_s C_s \quad (2)$$

Where:

D is the hydrodynamic dispersion coefficient tensor, q is specific discharge and

$C_s$ is the solute concentration of water entering from sources or sinks.

# 3 NUMERICAL MODEL CALIBRATION

The Numerical model in the current paper was calibrated with the experimental results conducted by (Nassarand Ghanem 2008) at Hydraulic Laboratory of Cairo University, Giza, Egypt. The experiment setup was a rectangular seepage tank with dimension of 1.42 m long, 0.1 m wide and 0.6 m high. An injection well is placed at the left part of the seepage tank of 10 cm width, with 0.05 m screen starting from 0.15 m above the base of the seepage tank. The constant head boundary is placed at the right part of the seepage tank with freshwater head 24.5 cm measured from the seepage tank bed. A constant head reservoir containing brine water of 39,400 ppm concentration is used to feed the injection well at a rate of 0.144 $m^3$/day.

## 3.1 Models domain

It consists of one row, 29 columns and five layers. Cells in column 1 are 0.02m horizontal by 0.05m vertical and cells in layer 1 are 0.05m horizontal by 0.2m vertical. The rest of the cells are 0.05 by 0.05m in size.

## 3.2 Initial and boundary conditions

Initial concentrations of model domain are set to be 800 mg/l and initial fresh water head are all set to be 0.245 m. Brine is applied in column one and layer two through a well with injection rate 0.144 $m^3$/dayand of concentration equal to 39400 mg/l.A constant fresh water head boundary is specified at column 29 and layer one equal to 0.245 m and of constant concentration equal to 800 mg/l.

## 3.3 Model parameters

The parameters used in this model are hydraulic conductivity, specific yield, porosity and coefficient of effective molecular diffusion. The assigned values for these parameters were set to be 83 m/day, 0.27, 0.3 and $8.53*10^{-8}$ $m^2$/min respectively.

## 3.4 Observation Points

Several observation points were constructed within the model domain as described in Table (1). The records obtained from head observation and concentration observation points are required during the calibration process of the mathematical model. Time steps were set to be 24 steps to represent both head and concentration values for six hours model run.

**Table 1. Observation points locations**

| Observation Point No. | Observation point type | X (cm) | Y (cm) | Z (cm) |
|---|---|---|---|---|
| HOB1 | Head | 19.5 | 5 | 7.5 |
| HOB2 | Head | 59.5 | 5 | 7.5 |
| COB3 | Salt conc. | 29.5 | 5 | 2.5 |
| COB4 | Salt conc. | 69.5 | 5 | 12.5 |
| COB5 | Salt conc. | 109.5 | 5 | 7.5 |

### 3.5 Results of calibration

The outputs of the model are illustrated in Figure (1) and Figure (2). Figure (1) shows a comparison between the results obtained from the VMOD and Nassar and Ghanem (2008) laboratory experiment for the concentration observation points COB3, COB4 and COB5. The correlation coefficient obtained from the model for these observation points was equal to 0.991, 0.995 and 0.981 respectively. While, Figure (2) shows a comparison between the results obtained from the VMOD and the Nassar and Ghanem (2008) laboratory experiment for the head observation points HOB1 and HOB2.The correlation coefficient obtained from the model for HOB1 equal to 0.901and for HOB2 equal to 0.835.

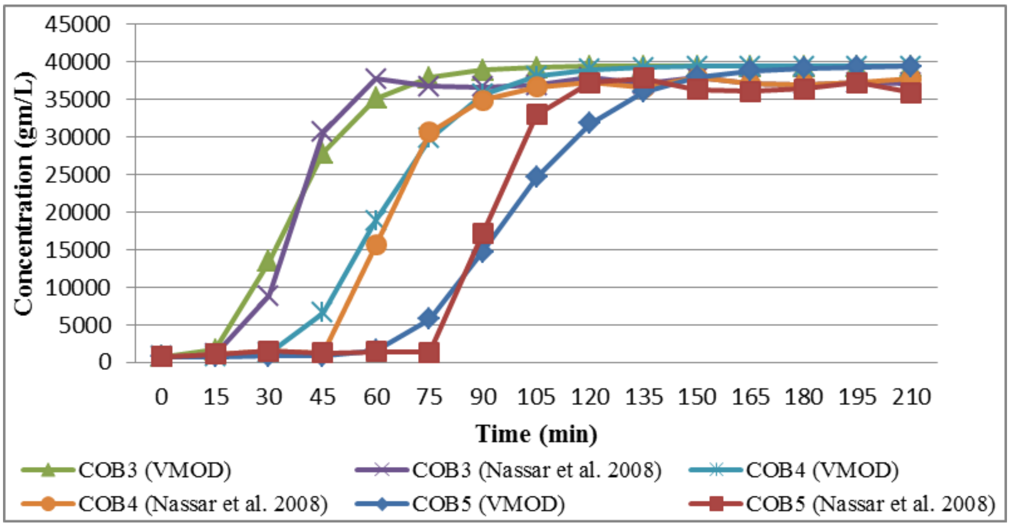


**Fig. 1. Comparison between results of Visual MODFLOW and Nassar and Ghanem (2008) laboratory experiment for COB3, COB4 and COB5**

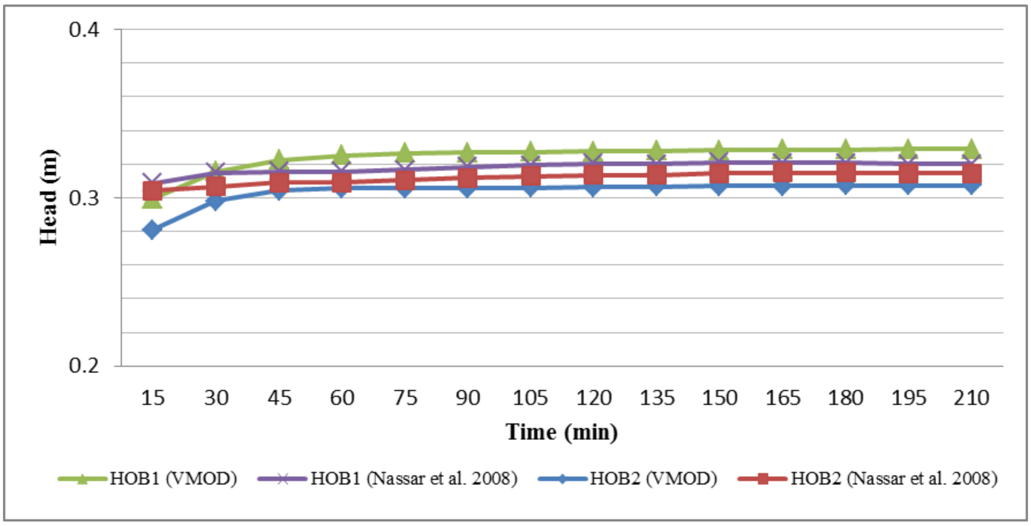


**Fig. 2. Comparison between results of Visual MODFLOW and Nassar and Ghanem (2008) laboratory experiment for HOB1 and HOB2**

# 4 NUMERICAL MODEL VERIFICATION

It is important to design a discharge system for brine disposal that respects the environment and predict the effect of brine disposal on the quality of water which obtained from discharge well in coastal areas. Eighty scenarios have been designed and simulated as discussed in following sections using Visual MODFLOW in order to develop charts for designing and managing of the injection and discharge well of a desalination plant in coastal areas.

## 4.1 Models domain

The flow domain dimension is 2500 m long, 1500 m wide and 150 m high. It consists of 75 rows, 125 columns and five layers as shown in Figure (3). Cells are 20m by 20m in the horizontal, and 20 m in the vertical.

## 4.2 Initial and boundary conditions

The initial concentration of model domain was set to be 40000 mg/l and the initial head was set at each layer according to Table (2). The east boundary of the model area (column 125) was the sea of concentration equal to 40000 mg/L and with constant head boundary as shown in Table (2). The groundwater level is at 50 m below ground surface and the aquifer thickness is 100 m. A general head boundary condition (GHB) was assigned along the outside edged of the model domain (column 1, row 1 and row 52) as shown in Table (2) and the conductance of the selected set of cells was assigned equal to 16 $m^2$/day.

**Table 2. Equivalent freshwater heads at each layer**

| Layer No. | Z (m) | $h_f$ (m) |
|---|---|---|
| 1 | 90 | 100.29 |
| 2 | 70 | 100.86 |
| 3 | 50 | 101.43 |
| 4 | 30 | 102 |
| 5 | 10 | 102.57 |

## 4.3 Model parameters

The parameters of the model are the specific yield, the soil porosity and the effective molecular diffusion with values 0.27, 0.32 and $1.228*10^{-4} m^2$/day respectively.

## 4.4 Wells and observation points

The discharge well is assigned at a fixed location 1020 m from sea, with a discharge rate ($Q_d$) equal to 1200 $m^3$/day and the injection well is located at spacing (S) from discharge well. The screen length of the injection well equal to 20m starting from 0 m above the base of the saline aquifer.

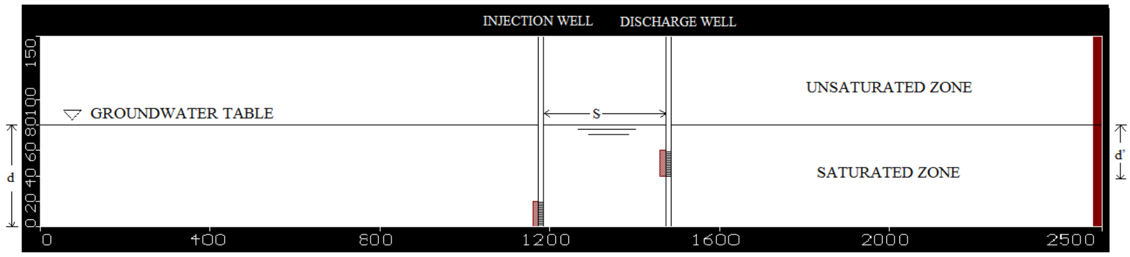


**Fig. 3. Numerical model showing vertical layout, (cross section for row 38)**

Where: d is the location of the screen of the injection well from the water table and d` is the location of discharge well screen from the water table.

## 4.5 Simulation of scenarios

Eighty (80) scenarios where examined all in all to cover the variability in different parameters, resulting from the permutations of six design parameters: the injection rate of injection well ($Q_i$), spacing between production and injection wells (S), initial concentration of the aquifer ($C_i$), concentration of the injection well ($C_{inj}$.), type of soil and screen location, as shown in Table 3. The studied scenarios expanded into five cases each consists of sixteen scenarios.

The first sixteen scenarios (Case 1)were designed by simulating the injection rate four times (600,660,720 and 780 m3/day) for four different spacing (100, 200, 300 and 400 m). While another sixteen scenarios (Case 2)were designed by simulating the concentration of injection rate four times (80000, 82500, 87500 and 97500 mg/l) for four well spacing (100, 200, 300 and 400 m). Also, another sixteen scenarios (Case 3) were designed by simulating four soil types using hydraulic conductivity (19, 26, 33 and 40) and four well spacing were simulated (100, 200, 300 and 400 m). Furthermore, sixteen scenarios (Case 4)were designed by simulating four screen locations of the discharge well where the screen was located at 0, 20, 40 and60 m from the base of the aquifer and four well spacing were simulated (100, 200, 300 and 400 m).Finally, sixteen scenarios (Case 5) were designed by simulating the initial concentration of the aquifer four times where (35000, 38000, 41000 and 44000mg/l) and four well spacing were simulated (100, 200, 300 and400 m).

**Table (3): Simulated scenarios used in verification**

| Case (1) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Scenarios | Initial conc. of aquifer (mg/l) | Injection Conc. (mg/l) | $Q_d$ ($m^3$/day) | $Q_i$ ($m^3$/day) | S (m) | K (m/day) | d̀/d |
| 1, 2, 3& 4 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 5, 6, 7& 8 | 40000 | 80000 | 1200 | 660 | 100, 200, 300, 400 | 33 | 0.6 |
| 9, 10, 11 & 12 | 40000 | 80000 | 1200 | 720 | 100, 200, 300, 400 | 33 | 0.6 |
| 13, 14, 15 & 16 | 40000 | 80000 | 1200 | 780 | 100, 200, 300, 400 | 33 | 0.6 |
| Case (2) | | | | | | | |
| Scenarios | Initial conc. of aquifer (mg/l) | Injection Conc. (mg/l) | $Q_d$ ($m^3$/day) | $Q_i$ ($m^3$/day) | S (m) | K (m/day) | d̀/d |
| 17, 18, 19 & 20 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 21, 22, 23 & 24 | 40000 | 82500 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 25, 26, 27 & 28 | 40000 | 87500 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 29, 30, 31 & 32 | 40000 | 97500 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| Case (3) | | | | | | | |
| Scenarios | Initial conc. of aquifer (mg/l) | Injection Conc. (mg/l) | $Q_d$ ($m^3$/day) | $Q_i$ ($m^3$/day) | S (m) | K (m/day) | d̀/d |
| 33, 34, 35 & 36 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 19 | 0.6 |
| 37, 38, 39 & 40 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 26 | 0.6 |
| 41, 42, 43 & 44 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 45, 46, 47 & 48 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 40 | 0.6 |
| Case (4) | | | | | | | |
| Scenarios | Initial conc. of aquifer (mg/l) | Injection Conc. (mg/l) | $Q_d$ ($m^3$/day) | $Q_i$ ($m^3$/day) | S (m) | K (m/day) | d̀/d |
| 49, 50, 51& 52 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 1 |
| 53, 54, 55 & 56 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.8 |
| 57, 58, 59 & 60 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 61, 62, 63 & 64 | 40000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.4 |
| Case (5) | | | | | | | |
| Scenarios | Initial conc. of aquifer (mg/l) | Injection Conc. (mg/l) | $Q_d$ ($m^3$/day) | $Q_i$ ($m^3$/day) | S (m) | K (m/day) | d̀/d |
| 65, 66, 67& 68 | 35000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 69, 70, 71& 72 | 38000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 73, 74, 75&76 | 41000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |
| 77,78,79&80 | 44000 | 80000 | 1200 | 600 | 100, 200, 300, 400 | 33 | 0.6 |

*Time steps were set to be 10 steps to represent both head and concentration values for ten years model run.

## 4.6 Results and Discussion

The results of the simulated scenarios after 10 years are illustrated in Figures 4, Figure 5, Figure 6, Figure 7 and Figure 8.

Figure (4-A) is a design chart that has been developed by four design parameters, relative salt concentration, injection rates ($Q_i$), wells spacing (S), and simulation period (T). The Relative Salt Concentration at production well (RSC) is given by Eq. (3):

$$RSC = \left(\frac{C_c - C_i}{C_i}\right) * 100 \qquad (3)$$

Where: $C_c$ is the calculated concentration from Visual Modflow model $C_i$ is the initial concentration and RSC is the relative salt concentration.

Figure (4-A) shows that RSC is directly proportion to injection rate and inversely proportion to spacing, it means that as spacing increase by 300% the RSC decrease by 67% at rate of injection equal 780 $m^3$/day but we have to take into consideration the available area for constructing the desalination plant and the cost of construction.

Figure (4-B) represents the relative salt concentration for different injection concentration over time. The figure shows also that the injection concentration has a slight effect on the relative concentration. Figure (5-A) represents the relative salt concentration for different hydraulic conductivity over time. It illustrates that the hydraulic conductivity has great impact in small spacing between the two wells but with large spacing the effect of hydraulic conductivity is negligible. For same spacing and hydraulic conductivity the relative concentration increases by the time. Figure (4-B) and Figure (5-A) are the output of Visual Modflow simulations and can be used as design charts for evaluating the impact of changing each of injection concentration ($C_{inj.}$) and hydraulic conductivity (K) on the RSC respectively. These charts can be used as a design aid for selecting the most suitable injection rate and spacing between injection and discharge wells according to soil type to avoid the negative impact of brine disposal on the ground water. Also, it can be used in predicting the effect of brine disposal on the groundwater quality after 10 years.

Figure (5-B) is the design chart that has been developed by four design parameters, relative salt concentration (RSC), screen location (d`), wells spacing (S), and simulation period (T). This figure shows that the injection well screen should be deeper than the discharge well screen to obtain less salt concentration of water from the discharge well. The RSC after 10 years of simulation became 9.85% when the screens were at the same level at spacing equal 400m while it decreased to 1.26% when the screen of the injection well became deeper than discharge well by 60%.Figure (5-C) is the design chart that has been developed by four design parameters, relative salt concentration (RSC), initial concentration of the aquifer, wells spacing (S), and simulation period (T).It illustrates that the initial concentration of the aquifer has a higher effect on the relative salt concentration as long as it is small and its effect decrease as its value increase. For same spacing and initial concentration of the aquifer the relative concentration increases by the time.

Figure (6) represents the shape of the salt plume that develops around the injection well, for rate of injection equal 600, 660, 720 and 780 $m^3$/day the lateral extend of the salt plume were 918.7 , 947.2, 975.6 and 998 m respectively from the beginning to the end of salinity contour line 41000 mg/l after 10 years of simulation. It also shows that the salt plume migrates downward due to the high density of the injected brine into the aquifer.

Figure (7) represents the shape of the saltplume that develops around the injection well after 10 years of simulation. When the value of the hydraulic conductivity (K) increased by 110.5 % the lateral extend of the salt plume increased by 18.44 %.

Figure (8) represents the shape of the salt plume that develops around the injection well after 10 years of simulation. When the value of the Injection concentration ($C_{inj.}$) increased by 21.875 % the lateral extend of the salt plume increased by about 10 %.

(A)

(B)

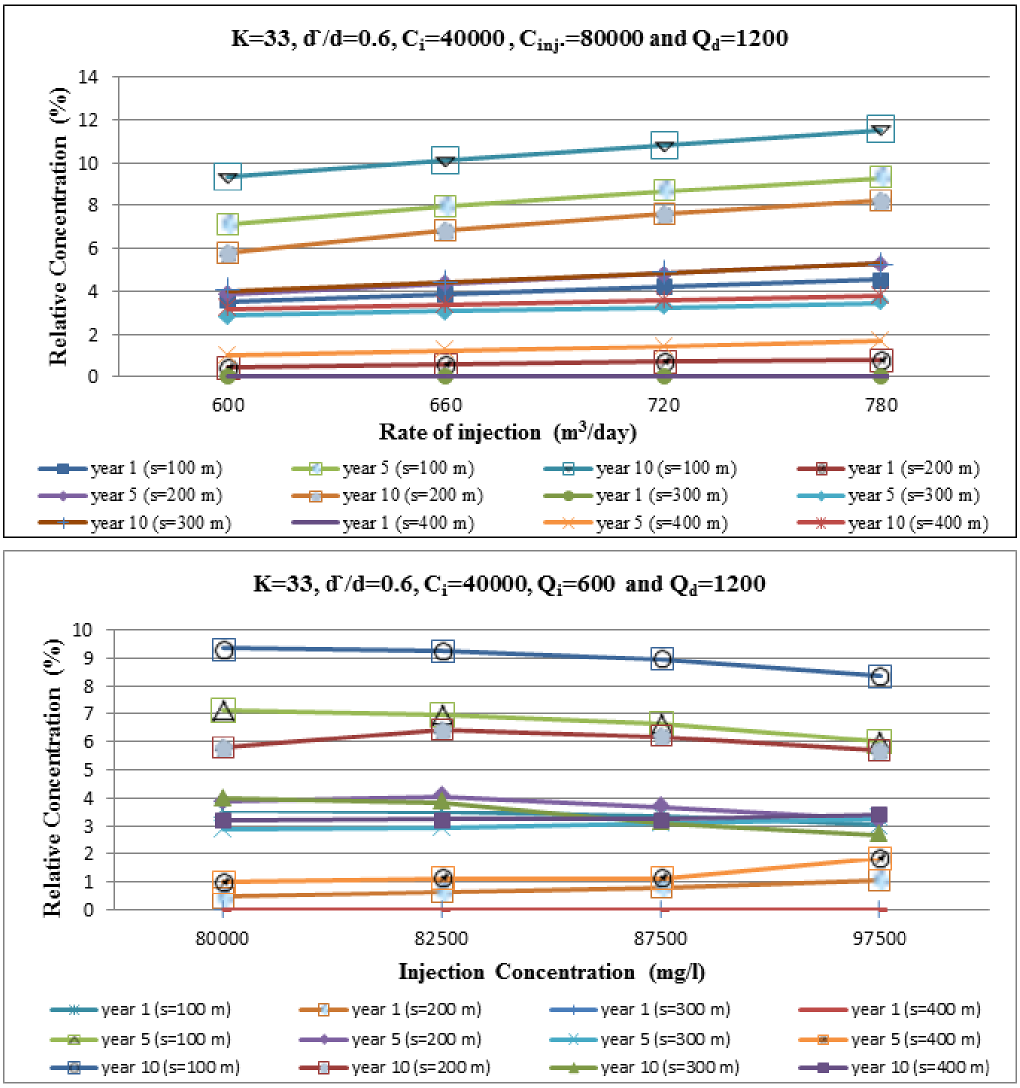


**Fig. 4. Relative salt concentration at discharge well after 10 years simulation period for Scenario A and B**

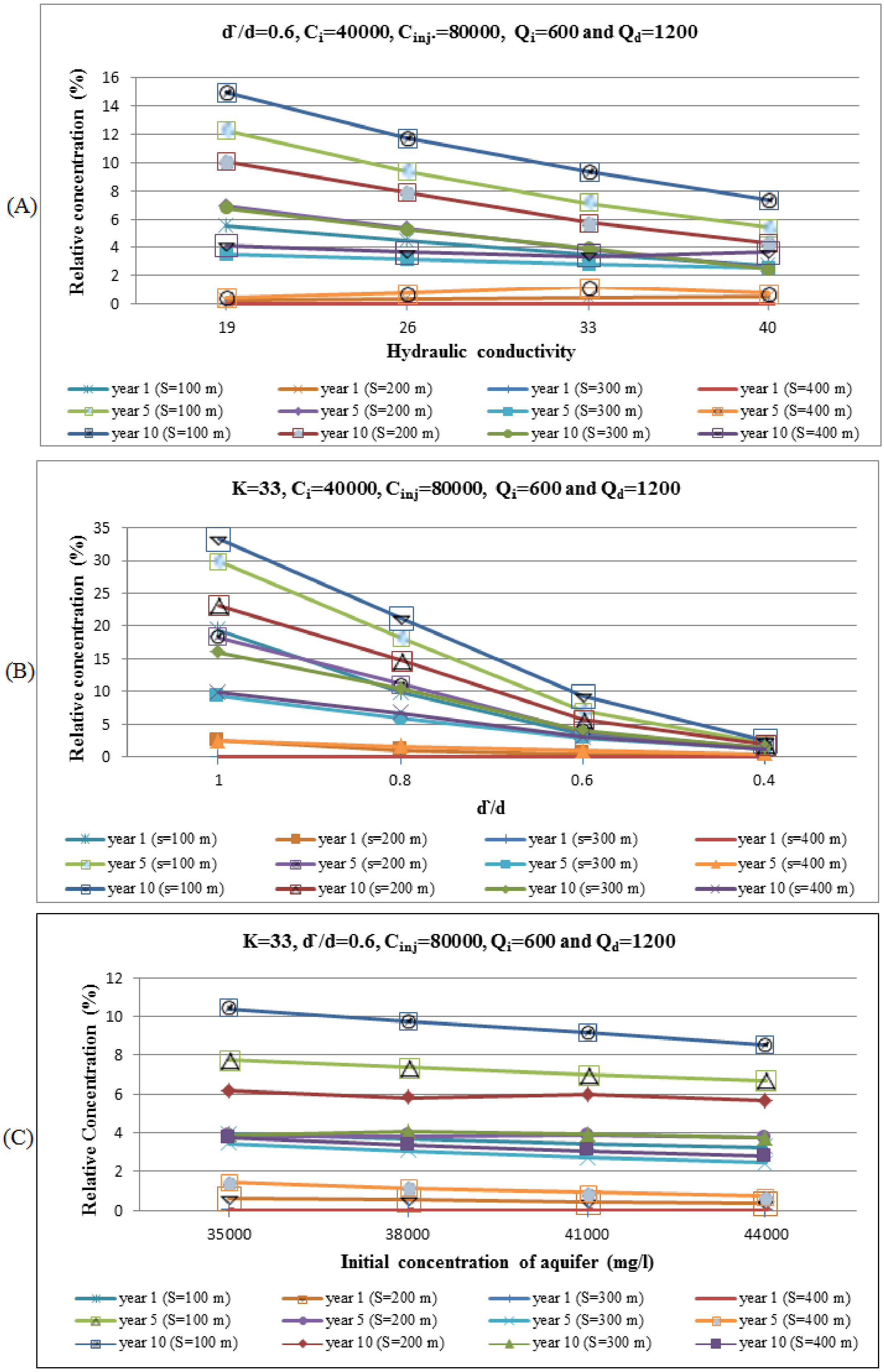


**Fig. 5. Relative salt concentration at discharge well after 10 years simulation period for Scenario A, B andC**

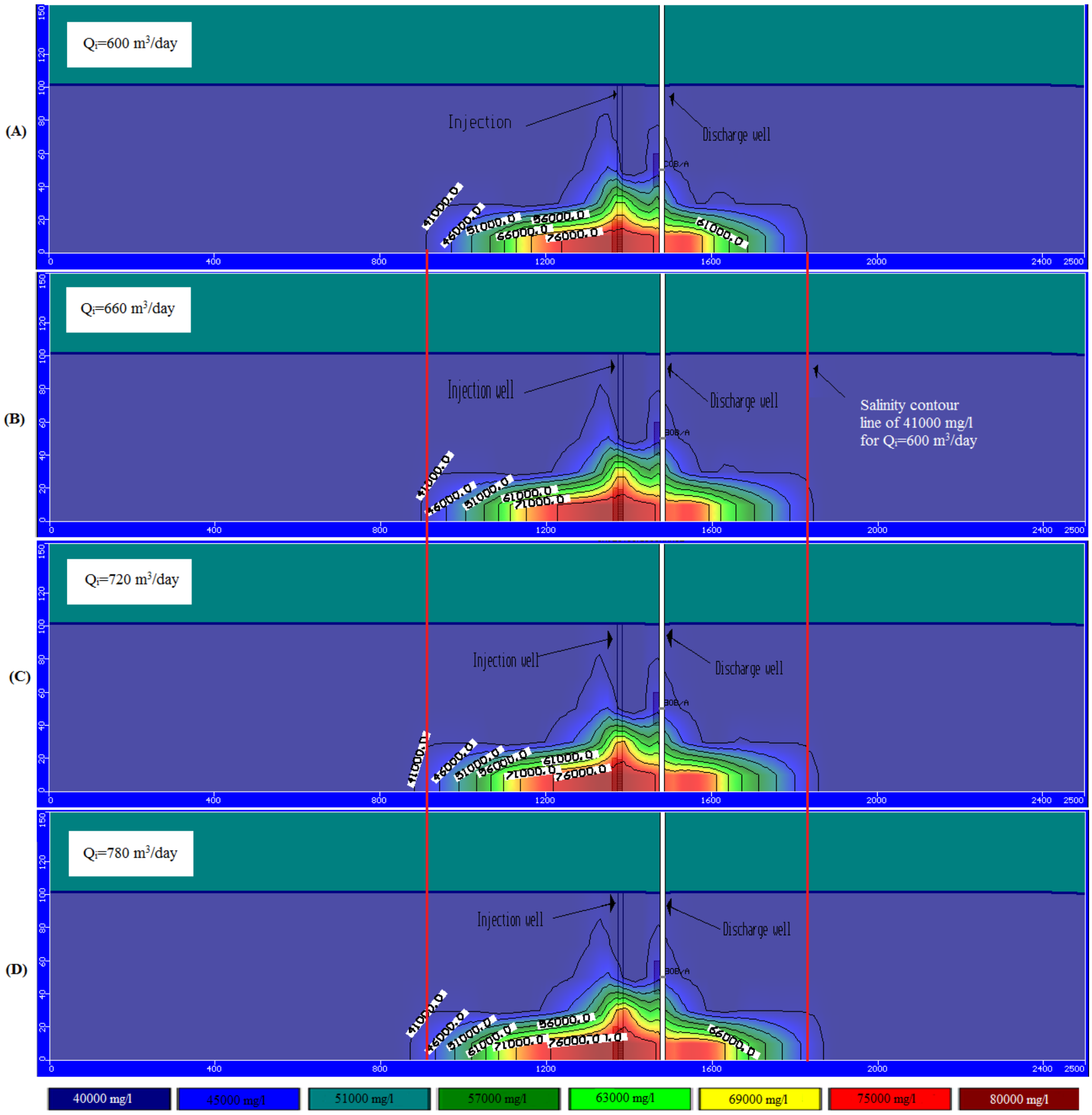


**Fig. 6. Salt concentration distributions along x–z vertical plane after 10 years of simulation for Scenario (A) and different injection rates (a) 600 m3/day, (b) 660 m3/day , (c)720 m3/day and (d) 780 m3/day (for S = 100 m).**

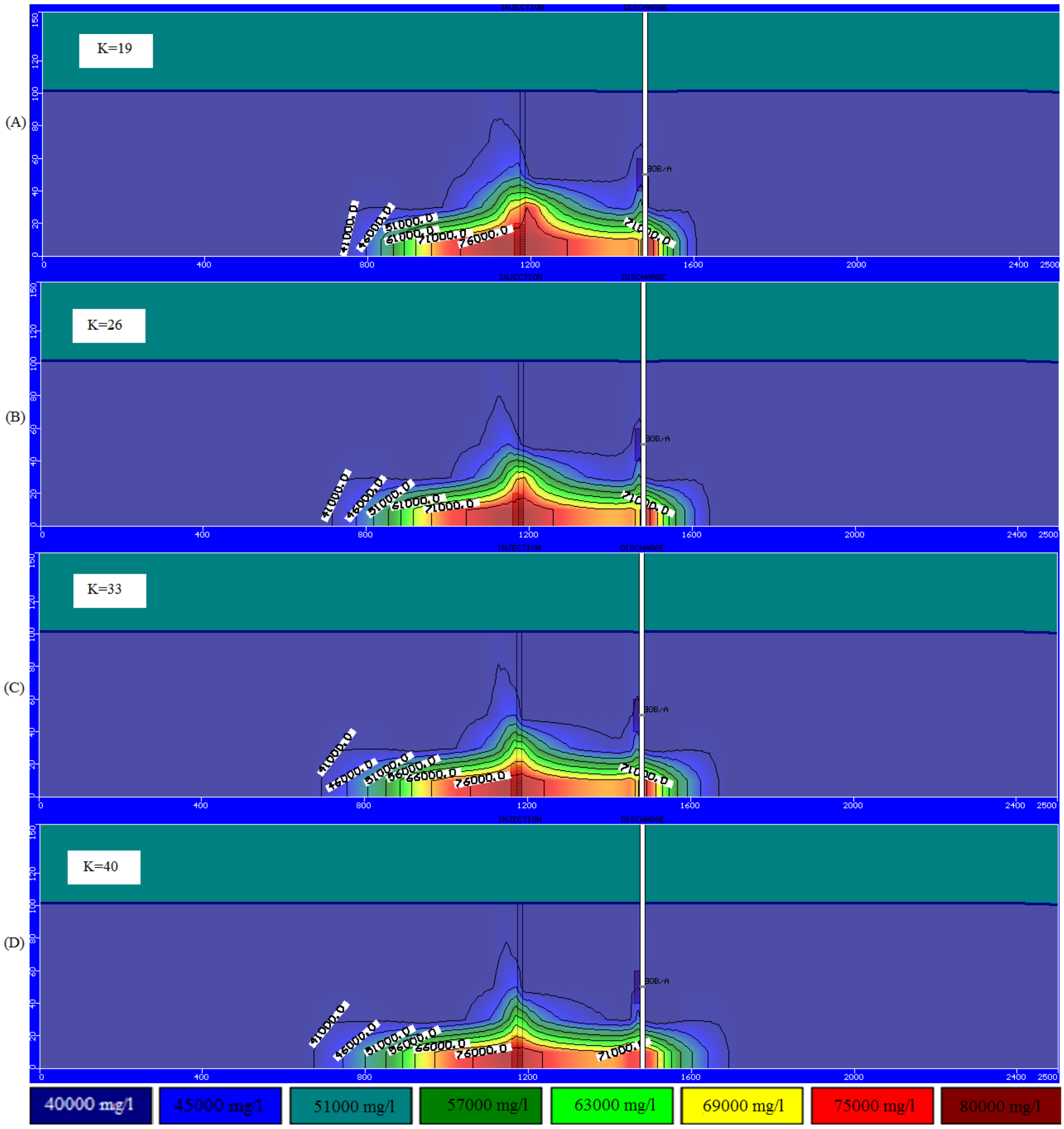


**Fig. 7. Salt concentration distributions along x–z vertical plane after 10 years for scenario (C) and different hydraulic conductivity (a) 19, (b) 26, (c)33 and (d) 40 for S=300 m**

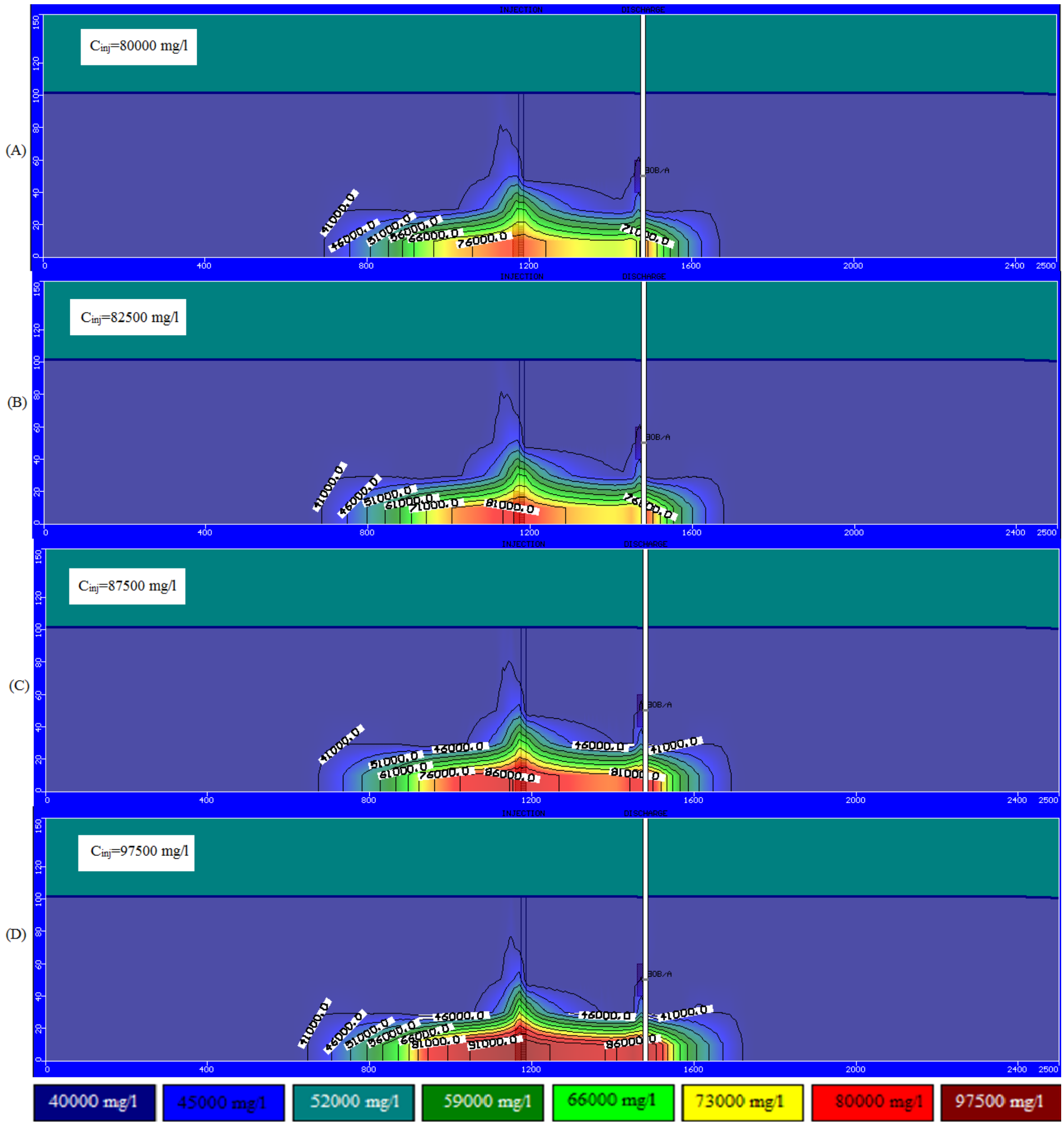


**Fig. 8. Salt concentration distributions along x–z vertical plane after 10 years for scenario (B)and different concentration of injection (a) 80000, (b) 82500, (c)87500 and (d) 97500 mg/l for S=300 m**

**The Datafit 9 program has been employed in the following cases:**

Case1,determining the mathematical relationship between the dependent variable Calculated Concentration and independent variables ($C_i$, $C_{inj}$, T, $Q_d$, $Q_i$, S, K and d`/d).While Case 2, determining mathematical relationship between the dependent variable Calculated Concentration and independent variables ($C_i$, $C_{inj}$, T, $Q_d$, $Q_i$, S and K) where d`/d was set to be 0.6 as a constant value. Nonlinear Regression Analysis was carried out resulting in 3 equations in each case as shown in Table (4).Equation1 gives the highest coefficient of multiple determination ($R^2$) to predicate the Calculated Concentration from the discharge well for the first case and Equation 4 for the second case.

Table 4: Regression Analysis

| No. | Equation | a | b | c | d | e | f | g | h | i | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Case 1 | | | | | | | | | | | |
| 1 | $C_c = exp(a*C_i+b*C_{inj}+c*T+d*Q_d+e*Q_i+f*S+g*K+h*d`/d+i)$ | 2.46E-05 | -2.00E-07 | 5.88E-03 | -1.00E+09 | 1.37E-05 | -2.23E-04 | -1.27E-03 | 0.221879 | 1.22E+12 | 0.856 |
| 2 | $C_c = a*C_i+b*C_{inj}+c*T+d*Q_d+e*Q_i+f*S+g*K+h*d`/d+i$ | 1.01251 | -0.01158 | 241.929 | -5.50E+13 | 0.11328 | -9.02731 | -48.8444 | 9085.554 | 6.64E+16 | 0.846 |
| 3 | $C_c = a*C_i+b*C_{inj}+c*T+d*Q_d+e*Q_i+f*S+g*K+h*d`/d$ | 1.01258 | -1.16E-02 | 242.007 | -0.87018 | 0.10424 | -9.03012 | -48.9656 | 9097.199 | 0 | 0.846 |
| Case 2 | | | | | | | | | | | |
| 4 | $C_c = exp(a*C_i+b*C_{inj}+c*T+d*Q_d+e*Q_i+f*S+g*K+h)$ | 2.46E-05 | -2.34E-08 | 5.21E-03 | -6.40E+07 | 3.64E-05 | -1.86E-04 | -1.39E-03 | 7.71E+10 | 0 | 0.95 |
| 5 | $C_c = a*C_i+b*C_{inj}+c*T+d*Q_d+e*Q_i+f*S+g*K+h$ | 1.00795 | -3.77E-03 | 215.511 | -5.30E+12 | 1.11198 | -7.59336 | -53.9849 | 6.31E+15 | 0 | 0.95 |
| 6 | $C_c= a*C_i+b*C_{inj}+c*T+d*Q_d+e*Q_i+f*S+g*K$ | 1.008 | -3.78E-03 | 215.514 | 2.671825 | 1.11306 | -7.59495 | -53.9825 | 0 | 0 | 0.95 |

# 5 CONCLUSIONS

This work studies the effect of brine disposal through injection well on the quality of groundwater. Eighty scenarios were designed and simulated using Visual Modflow by changing six design parameters, namely pumping rate of injection well ($Q_i$), spacing between production and injection wells (S), initial concentration of the aquifer ($C_i$), concentration of injection well ($C_{inj.}$), type of soil and screen location. The model outputs revealed that the salt plume developed around the injection well migrates downward due to the high density and its lateral extent increases by increasing the rate of injection. The salt plume lateral extension is particularly sensitive to hydraulic conductivity, as after 10 years of simulation when injection and discharge wells are 300 m apart from each other the lateral extend of the salty plume increased from 859.2 to 1017.7 m by changing the hydraulic conductivity (K) from 19 to 40 respectively.

Also the optimal design of discharge and injection wells is achieved by constructing the injection well deeper than the discharge well, when the screens of injection and discharge wells were at the same level at spacing equal 400 m the RSC after 10 years of simulation became 9.85% while it decreased to 1.26% when the screen of the injection well became deeper than the discharge well by 60%. The simulation also concluded that the relative salt concentration is inversely proportion to the spacing between injection and discharge wells as after 10 years of simulation when the spacing between wells increased from 100 to 400 m at rate of injection equal 600 $m^3$/day the relative salt concentration decreased by 63.9 %. But the relative salt concentration is directly proportion to the rate of injection as after 10 years of simulation at spacing between wells equal 100 m when the injection rate increased from 600 to 780 $m^3$/day the relative salt concentration increased by about 23 %.Finally, these results can be used as a guide during the construction of new costal desalination plants and also in predicting the future impact of brine disposal on ground water.

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