ORIGINAL ARTICLE

MANAGEMENT SCENARIOS FOR SEAWATER INTRUSION INTO UNCONFINED AQUIFER BETWEEN THE SIN AND ROUS RIVER-SYRIA

| Dimah Mohsen Mohamad [1*] | Sharif Badr Hayek [2] | and | Ali Mohamad Alasaad [3] |

[1] Tishreen University | department of Water Engineering and Irrigation | Lattakia | Syria |
[2] Tishreen University | department of Water Engineering and Irrigation | Lattakia | Syria |
[3] Tishreen University | department of Water Engineering and Irrigation | Lattakia | Syria |

| Received January 26, 2020 | | Accepted January 28, 2020 | | Published February 05, 2020 | | ID Article | Dimah-Ref.1-ajira260220 |

ABSTRACT

Background: The demand for fresh water in coastal areas increases due to the increase in economic activity, which requires an increase in the pumping of fresh groundwater to meet these needs. This causes low levels of groundwater and an imbalance in the hydrodynamic balance between fresh groundwater and sea water. **Objectives**: The research aims to build a numerical model for sea water intrusion in the research area using SEAWAT code in GMS program, and Develop a plan to invest available groundwater without depletion or salinization. **Methods:** The research was based on a monitoring network distributed in the study area consisting of 36 wells, where measurements (static depth of water level and electrical conductivity) continued during the period (October 2016 to September 2017). Chemical analyzes of some wells were also performed. We used the MODFLOW model to build a numerical model of groundwater movement, and SEAWAT model for studying the movement of salts in the research area. **Results**: This research finds that The salinity values increase from 400 mg/l to 8000 mg/l in the east and west, respectively, in calibration period. The application of two scenarios in the research area resulted in clarifying the effect of pumping from the proposed wells. **Conclusions:** The study reveals that the scenario of water resources investment without seawater intrusion was the scenario of drilling wells close to towns and at the same time distant on the seashore at a distance of no less than 700 meters.

Keywords: Salinity, SEAWAT, Model.

1. INTRODUCTION

The major reason for seawater intrusion is the investment of ground water exceeding the limit of natural equilibrium between fresh water and sea water that merged together in a coastal aquifer [1]. The intrusion occurred in two ways: one is the advancement of the salt water wedge at the bottom of the aquifer resulting from the density difference between salt water and fresh water. The other was the infiltration of salt water through the beach [2]. Investigations of seawater intrusion have been based on geophysical techniques, especially Time domain electromagnetic (TDEM) method, which is a quick and powerful tool for mapping the fresh/saline water interface, and for identifying salinity variation [3]. A mixture of hydrogeochemical methodology, isotopes, statistics, and GIS have also been used to investigate the causes of groundwater salinity [4]. As investigations of groundwater are costly and time consuming, mathematical modeling of seawater intrusion has emerged as an important tool for understanding the mechanism of groundwater flow and movement [5]. These models, will aid to project the behviour of coastal groundwater system with respect to the future environmental challenges and to evolve suitable measures to control the saltwater intrusion into coastal aquifers [6].

2. MATERIALS AND METHODS

2.1 Study site

The research area is located in the Syrian coast between the Rous river from the north and Sin river from the south, the Mediterranean borders it to the west, and Latakia-Tartous Highway from the east.

2.2 Numerical model

The hydrogeological conditions of the study area were represented using the numerical model SEAWAT (derived by Guo and Langevin in 2002), Which represents the density variable groundwater movement. This model was developed by combining the mathematical models MODFLOW and MT3DMS into one program to solve mathematical equations that describe the movement of groundwater and The equation of dissolved salts spread.

The equations that form the mathematical basis of representing the groundwater movement in coastal reservoirs include Darcy Law of the change in density Eq.(1), the differential equation of groundwater movement under the influence of the change in density Eq.(2), and finally the differential equation that represents the groundwater

movement and spread of total dissolved salts under the influence of the change in density Eq.(3).
Darcy Law of the change in density:

$$q_x = K_{fx}\left[\frac{\partial h_f}{\partial x}\right] \qquad (1)$$

$$q_y = K_{fy}\left[\frac{\partial h_f}{\partial y}\right] \qquad (1)$$

$$q_z = K_{fz}\left[\frac{\partial h_f}{\partial z} + \left(\frac{\rho-\rho_f}{\rho_f}\right)\right] \qquad (1)$$

q_x, q_y, q_z: are the qualitative discharge compounds; K_{fx}, K_{fy}, K_{fz}: are hydraulic conductivity compounds of freshwater; ρ: the density of water at a concentration greater than that of fresh water; ρ_f: density of fresh water; h_f: the equivalent hydraulic head of fresh water.

The differential equation of groundwater movement under the influence of the change in density:

$$\frac{\partial}{\partial x}\left(\rho K_{fx}\left[\frac{\partial h_f}{\partial x}\right]\right) + \frac{\partial}{\partial y}\left(\rho K_{fy}\left[\frac{\partial h_f}{\partial y}\right]\right) + \frac{\partial}{\partial z}\left(\rho K_{fz}\left[\frac{\partial h_f}{\partial z} + \frac{\rho-\rho_f}{\rho_f}\right]\right) = \rho\, S_f\,\frac{\partial h_f}{\partial t} + \theta\,\frac{\partial \rho}{\partial C}\,\frac{\partial C}{\partial t} - \bar{\rho}\, q_s \qquad (2)$$

S_f: Storage coefficient; t: time; θ: porosity; c: dissolved salts Concentration; $\bar{\rho}$ The density of water that comes out of the well or the water that feeds the aquifer, q_s withdrawal or recharge rate for the volumes unit of the aquifer.

The differential equation of groundwater movement and spread of total dissolved salts under the influence of the change in density:

$$\frac{\partial}{\partial x}\left(D_{xx}\left[\frac{\partial C}{\partial x}\right]\right) + \frac{\partial}{\partial y}\left(D_{yy}\left[\frac{\partial C}{\partial y}\right]\right) + \left(D_{zz}\left[\frac{\partial C}{\partial z}\right]\right) - \frac{\partial}{\partial x}(v_x\, C) - \frac{\partial}{\partial y}(v_y\, C) - \frac{\partial}{\partial z}(v_z\, C) = \frac{\partial C}{\partial t} + \frac{q_s}{\theta}\, C_s \qquad (3)$$

D_{XX}, D_{YY}, D_{ZZ}: hydrodynamic dispersivity coefficient compounds; v_x, v_y, v_z: velocity compounds; c_s: concentration of dissolved salts in sources of withdrawal or recharge.

2.3 Boundary Conditions and the model building

The model domain should be divided into finite difference grid for simulation view, and The model network must go along with the geological structure boundaries, and comply with the hydrogeological conditions and boundary conditions of the region [7]. Regarding the research area, we have a rectangular grid; its dimensions are (20.920 x 5.173 km). It consists of 3000 cells of which 2031 cells are effective, with dimensions (209 x 172 m) per cell, so that the shape factor is 1.2.

Constant-head and constant-salinity boundaries were used to represent the boundary conditions of our model as shown in figure 1. The Constant-head was set to 0.0 m, and the constant intial condition of the salt concentration was fixed to 37 kg/m^3 at the sea boundary on the western side [8].

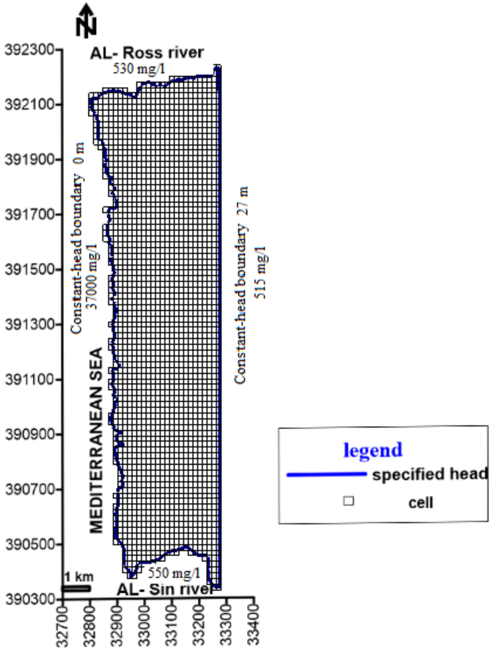

Figure 1: The figure presents Boundary Conditions of the research area.

The constant head and concentration boundary condition on the eastern side is derived from the hydrodynamic network and field measurements of the research area. The Rous river borders the research area to the north, and the Sin river borders it to the south, and they represent a boundary condition with a known head (Constant-head boundary), related to the depth of water in the two rivers during the selected simulation period, and the constant salt concentration is 530 mg/l in Rous river while has the value of 550 mg/l in Sin river.

The Recharge package, designed to simulate natural groundwater recharge to the groundwater system, was created using precipitation data in November 2016, as well as flow and transport modeling requires as input a regular grid of hydraulic conductivity values; because exhaustive sampling of the permeability field is not realistically possible [9]. We also input porosity and dispersivity as important parameter for reproducing a steady-state distribution of hydraulic head, salinity, and flow in the transition zone between fresh water and salt water in a coastal aquifer system [10].

2.4 Model Calibration: Calibration of the ground water flow model is done by varying the hydrogeologic parameters (Within limits not to exceed 5-10%) for till a reasonable good match between the observed and calculated heads are obtained [11]. The model Calibration required operating it more than 500 times, until reaching the best model representing the groundwater system in the research area as shown in figure 2; where all head differences between the calculated and measured values ranged between (0.008-0.25 m), while differences in salt concentration ranged between (4-49 mg/l).

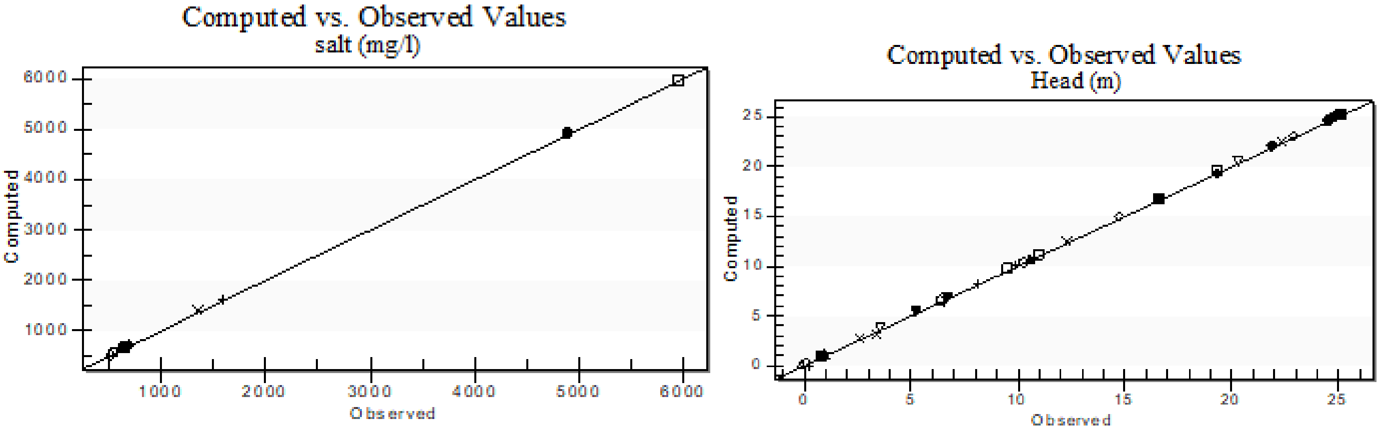

Figure 2: The figure presents computed versus observed head and salt of the research area model.

3. RESULTS

Calculated concentrations after running SEAWAT transport model shows that the salinity increases from east corresponding to 400 mg/l to exceed 8000 mg/l at the west direction, the salinity values near the two rivers are lower than those in the middle of the research area as shown in figure 3, and summary of water balance is shown in table 1.

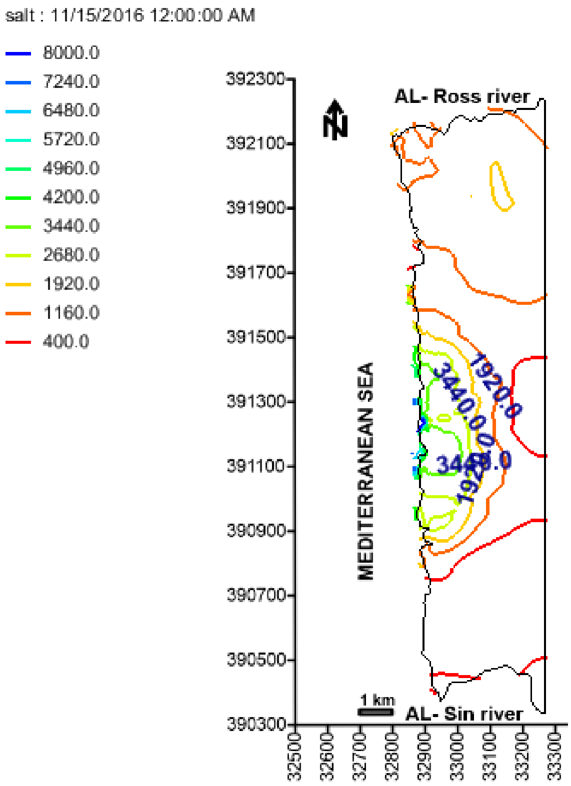

Figure 3: The figure presents salt concentration under steady-state condition.

Table 1: The table presents summary of water balance in the research area for steady-state condition.

Sources/Sinks	**Flow in (m^3/day)**	**Flow out (m^3/day)**
Constant Head	20332	-24044
Wells	0	-9600
Recharge	13312	0
Total	33644	-33644

We tested two scenarios for managing the groundwater resources in the research area. In the first scenario, we proposed drilling 8 wells in the northwestern part, and 9 wells in the western part near the beach, and 10 wells in the southwestern part (in addition to the private wells), With a distance between the wells 200-500 m within each group, and from the beach about 100-300 m, due to the expected need for these water resources in agriculture and tourism, with a discharge of 150 m^3/day. This led to a decrease of groundwater levels about 1-5 m as shown in figure 4, and there was a seawater intrusion in that region until 500-700 m. This applied scenario caused an increasing in the salinity values of the ground water, especially to those wells which reside near the sea. The salinity value of well (3) increased from 1608 mg/l to become 3445 mg/l as shown in figure 4.

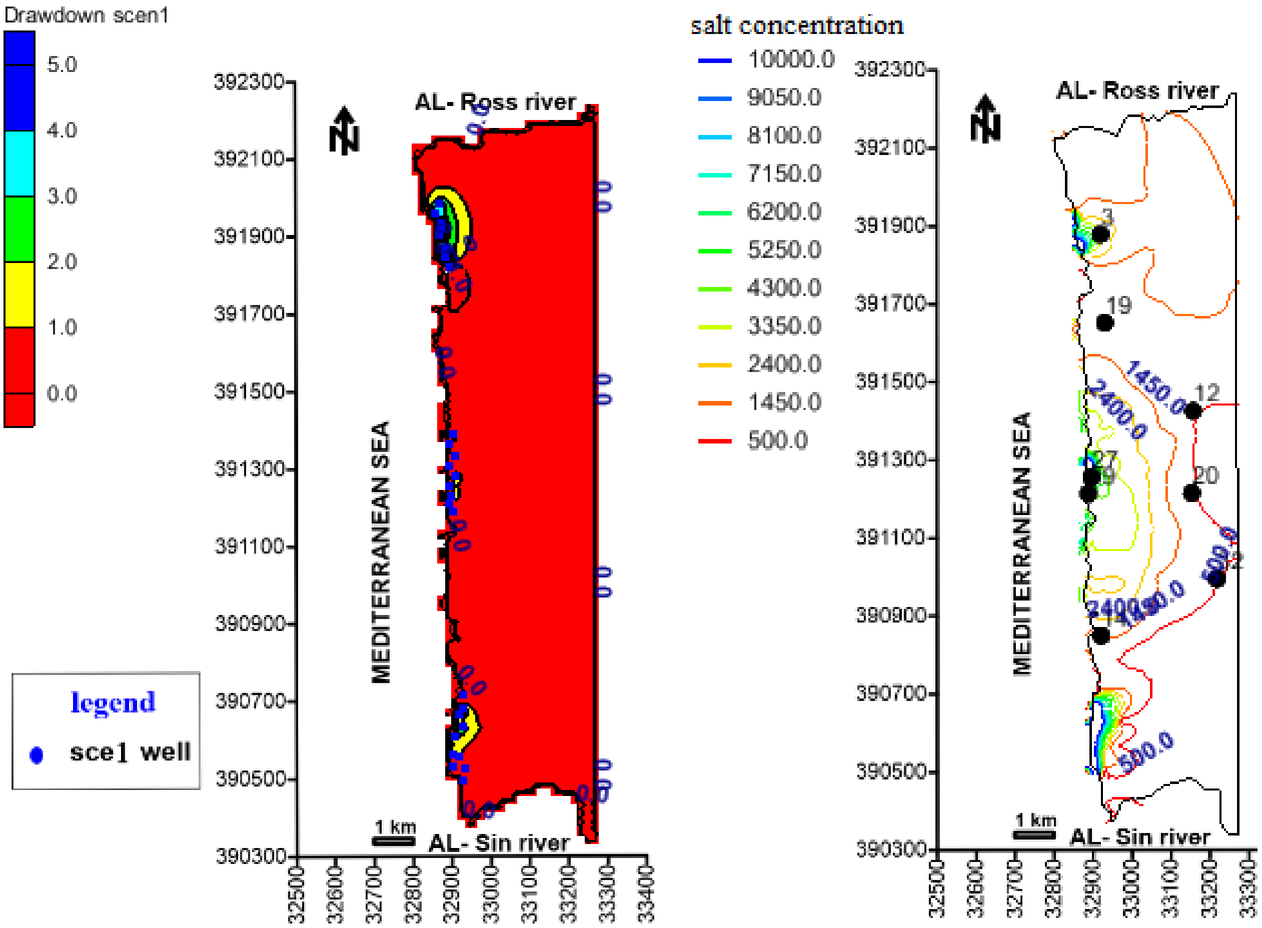

Figure 4: The figure presents drawdown values and salt concentration in the research area according to the first scenario.

In the second scenario, the extraction of existing wells in the research area is the same as the intial condition, but three groups of wells (distributed as shown in figure 5) are proposed as a solution to confront the population demand in the study area towns, and each group consists of four wells; with an average discharge of 100 m^3/day. Results of this scenario show that the maximum water level decline reaches 1m without seawater intrusion, and salinity showed moderate values for observation wells ranged between 523-1600 mg/l except wells 27 and 29 located within 300 m from the seaside as shown in figure 5. The salinity value of well (3) remains the same as in the calibration model (1608 mg/l).

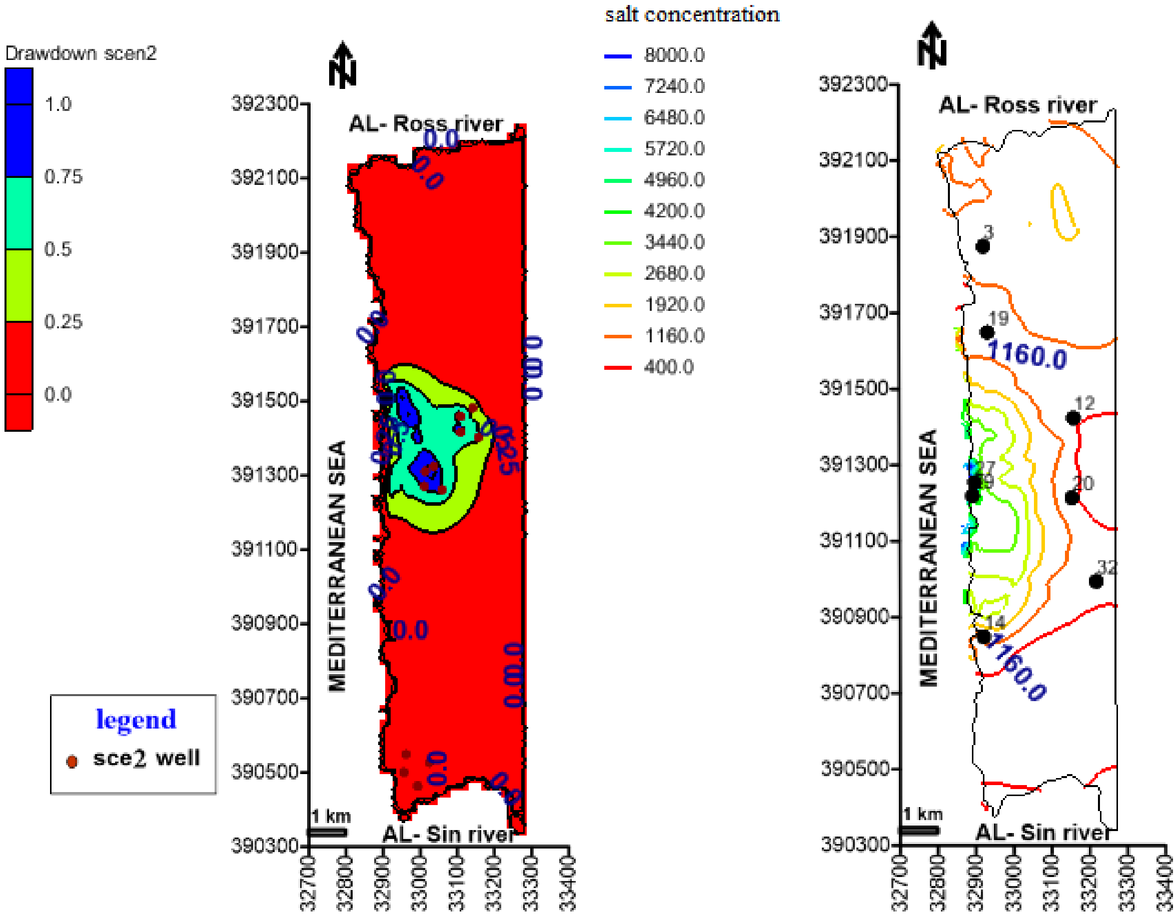

Figure 5: The figure presents drawdown values and salt concentration in the research area according to the second scenario.

4. DISCUSSION

The results from two scenarios of flow and solute transport simulation; that are illustrated before, indicate that the second scenario gives an acceptable solution to access for more discharge from the groundwater reservoir with intermediate results.

In the first scenario the maximum drawdown occurred at value 5m, which cause an increase of seawater flow to the region up to 859 m^3/day; that is, the operation of this scenario causes depletion of the groundwater reservoir, and a decrease in the levels of groundwater below sea level, such as the area of well 27 in which the concentration of salts reaches 10228 mg/l, therefore it is necessary to avoid the application of this scenario in this Region. while the maximum salinity recorded in the existing wells was equal to 10228 mg/l, but after drilling 12 wells according to the second scenario with total discharge in the region reach 10800 m^3/day without increasing the pumping rate from existing wells, intermediate results between calibration model and first scenario were detected; the maximum drawdown was 1m within a range of no more than 1 km^2 around the well. As the presence of a recharge for groundwater flow despite the increase in the rate of investment leads to an increase in the rate of flow [12]. This increase into the area is 525 m^3/day, and thus stability in levels and the concentration of salts, so the second scenario is considered a proper solution to obtain for more quantity of water from groundwater reservoir with intermediate values for salinity [13]. With the necessity of reducing investment rates in the areas adjacent to the seashore by a distance of no less than 300m, especially in the areas adjacent to Wells 27 and 29, with the aim of avoiding low levels of groundwater and a backward movement from the sea towards land.

5. CONCLUSION

In the research area, there are suitable geological and hydraulic conditions for seawater intrusion with fresh water, especially in areas near the beach up to 300 m, where an increase in pumping from wells near the sea shore leads to a wedge of seawater to 500-700 m in the aquifer. The scenario of drilling 12 wells divided into three groups represents a suitable solution to cover the future water needs for auxiliary irrigation in the research area, where 10800 m^3/day can be invested without progress of the seawater wedge, and the maximum drop reached 1 m.

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Cite this article: Dimah, Mohsen Mohamad, Sharif Badr Hayek, and Ali Mohamad Alasaad. MANAGEMENT SCENARIOS FOR SEA WATER INTRUSION INTO UNCONFINED AQUIFER BETWEEN THE SIN AND ROUS RIVER**.** *Am. J. innov. res. appl. sci.* 2020; 10(3): 106-111.