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Hydrodynamic Salts Isolation Model in The Delta of Wadi El Arish, North Sinai, Egypt

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ABSTRACT

An encroachment of sea water due to over pumping in the Delta of Wadi El Arish area had led to an increase in the zones of salts plume in the Quaternary aquifer. The present study aims to construct a model of hydrodynamic salts isolation for groundwater aquifer cleanup to a specified level until a balance is reached. The obtained results give rise to the Retardation factor (1.45) of the Quaternary aquifer in the studied area. The study indicates that the stored volumes of water in pores varies from less than $0.1x10^6$ m^3 to $3x10^6$ m^3 for each cell of the model grid in the studied area. The number of pore volumes ranges from one to two pore volumes for each cell of the model grid. The longest time for displacement of single pore volume reaches 10 years. The time for cleanup of the groundwater in the aquifer to a specified level varies from less than 2000 days to about 7000 days. Numbers of capture zones are detected in the studied area as a result of the application of the hydrodynamic salts isolation model.

Introduction

Groundwater contamination in the world has become an increasingly prevalent problem. Hydrodynamic controls can be used to isolate the zone of contaminated groundwater by modifying the local flow regime through the strategic placement of pumping and injection wells. Pump-and-Treat is one of the most common methods for remediation of groundwater contamination. Pump-and-Treat remediation strategies involve pumping of salted groundwater to the surface using a series of extraction wells, treating the groundwater to remove the salts and then re-injecting the fresh water in subsurface. Pump-and-Treat systems are frequently designed to hydraulically control the movement of salted groundwater in order to prevent continued expansion of salted zone. Treatment of salted groundwater reduces salts concentration in groundwater to below cleanup standards. This remediation technique is commonly referred to as hydrodynamic salts isolation. The present work is concerned with the application of a mathematical model in order to remediate the Quaternary groundwater aquifer in the Delta of Wadi El Arish. Two constructed models are applied including; hydraulic flow model and hydrodynamic salts transport model with a complete interaction between them. The studied area is located in the northeastern coast of Sinai Peninsula (**Fig. 1**).

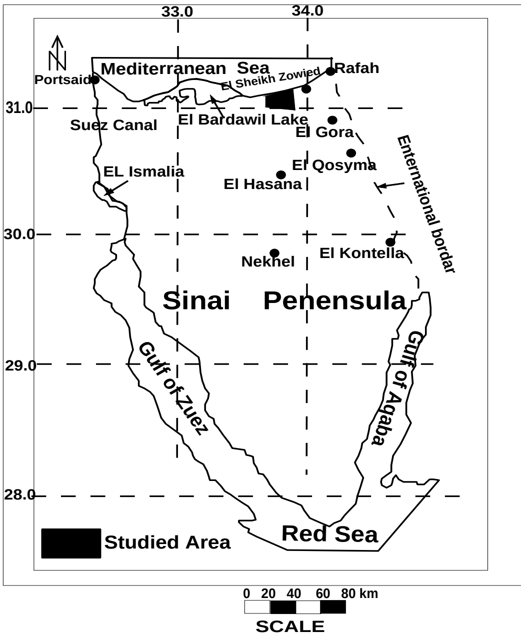

Figure (1): Location map of the Delta of Wadi El Arish, North Sinai, Egypt (after [1]).

It occupies an area of about 192.2 km^2. It is dominated by an arid climate with an annual rainfall intensity of 150 mm/year. The groundwater aquifer is subjected to over pumping of the groundwater for domestic and agricultural uses. Over exploitation of groundwater in the studied area had led to continuous quantitative and qualitative deterioration.

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Hydrogeological Background

The Water-bearing Formation in the Delta of Wadi El Arish area represents a complex system consists of Three water bearing rock units **(Fig. 2)**.

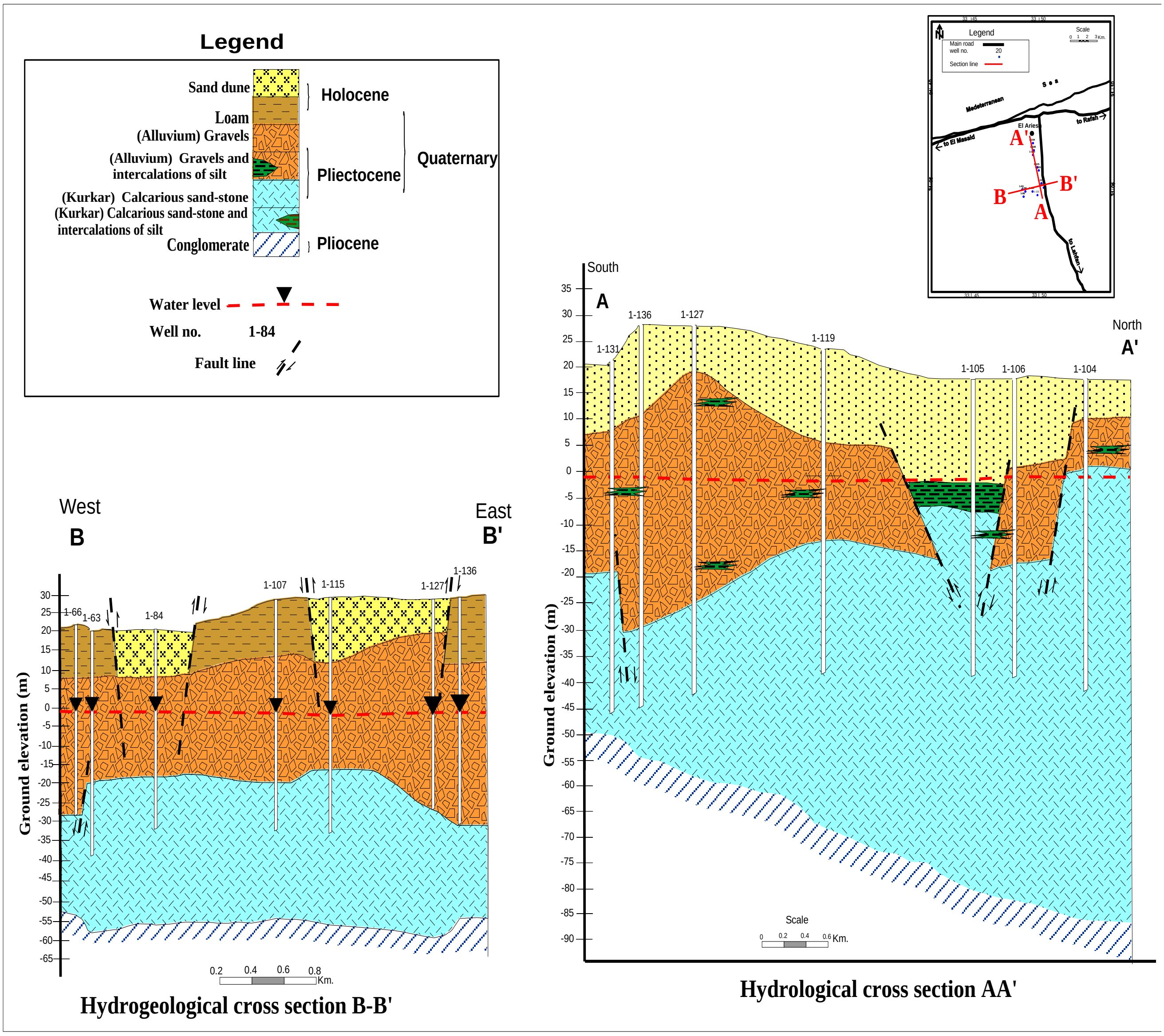
They are hydraulically connected and forming one hydrogeological aquifer system. They are defined from top to base as follows:

1- Sand dunes (Holocene deposits.)
2- Alluvial deposits, which are mainly composed of quartz sand, gravel, fine calcareous silt and clay (Pleistocene deposits).
3- Complex calcareous sandstone (Kurkar), which dominates the whole coastal zone and inland southward to about 13 km from the coastline (Pleistocene rock unit).

The groundwater flows generally from South at Lahfan fault to North towards the Mediterranean Sea and from East at Wadi El Maazer to West **(Fig. 3)**. The hydrogeological boundary conditions are considered as follows **(Fig. 4)**:

1- A constant head boundary at northern direction (Mediterranean Sea).
2- A permeable fault (Lahfan fault) at South and southeastern direction.
3- Changing in head pressure boundary in the West and northwestern directions.
4- Changing in head pressure boundary in the East and northeastern directions.
5- The Quaternary aquifer is underlined by impermeable Pliocene bed.

The water salinity (TDS) of the Quaternary aquifer ranges from 2.3 kg/m^3 to 6 kg/m^3 [2]. **Fig. (5)**, represents the groundwater-sea water interface in the studied area [2].



Hydrogeological cross section B-B'

Hydrological cross section AA'

Figure (2): Hydrogeological cross sections for the Quaternary aquifer in Delta of Wadi El Arish, North East of Sinai, Egypt (after [2]).

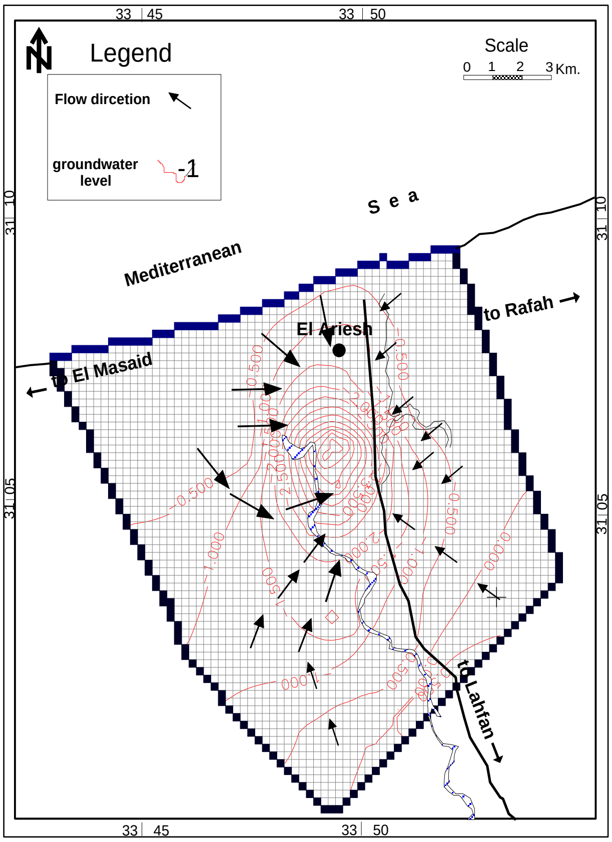


Figure (3): Groundwater level contour map, Delta of Wadi El Arish, North Sinai, Egypt (after [2]).

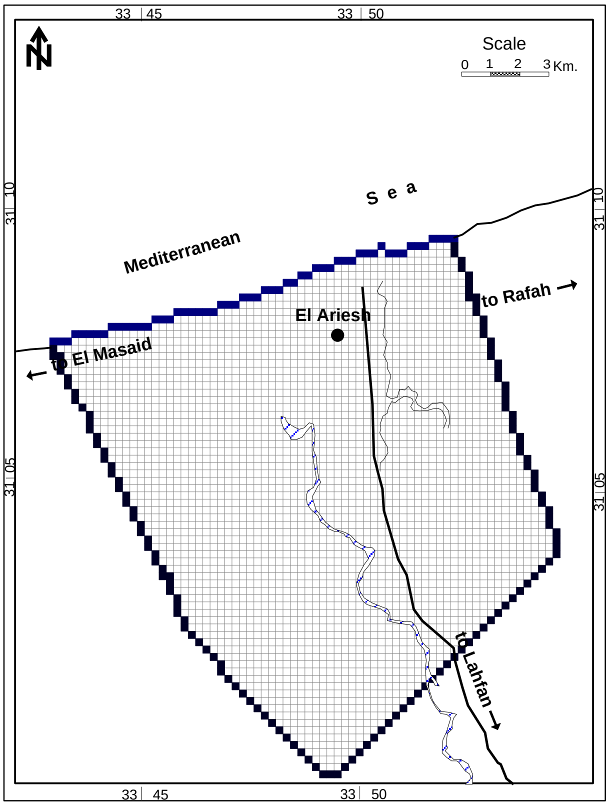


Figure (4): Boundary conditions, Delta of Wadi El Arish, North Sinai, Egypt (after [2]).

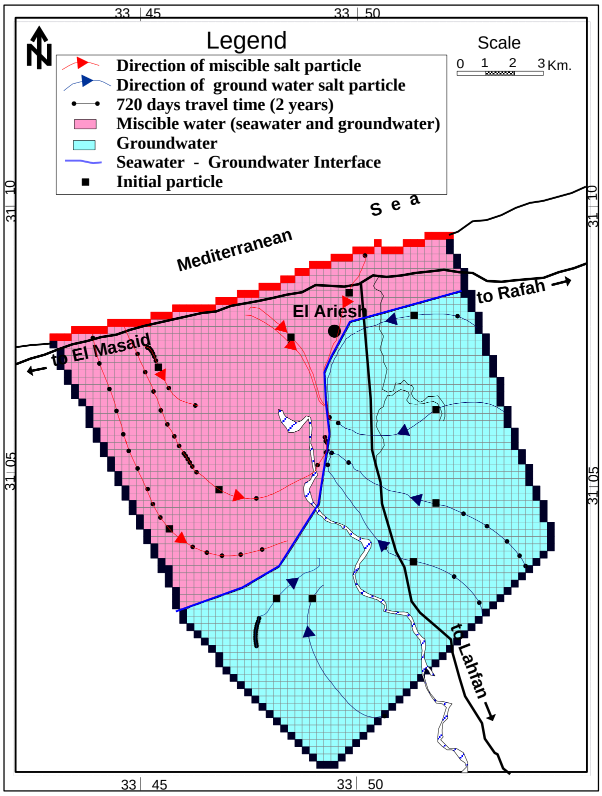


Figure (5): Delineation of seawater-groundwater interface and travel time of salts particle at different location for the Quaternary aquifer in the Delta of Wadi El Arish, North Sinai, Egypt (after [1]).

Models Description

A detailed description of the applied models in the previous studies are presented as follows:

1- Hydraulic flow model [2]. The hydraulic flow model in the Delta of Wadi El Arish area was constructed by [2] applying the available data at that time. It uses MODFLOW program (version 5) for Windows [3]. The model was designed for an area of about 192.2 km^2 and the network was defined as regular square cells with cell dimension 250m x 250m. It was constructed by considering the above-mentioned boundary conditions and representing one complex formation of groundwater system. The Pliocene formation is considered as an underlying impervious layer. The aquifer is recharged by the following different sources as reported by [2]:

  a. Direct precipitation (rainfall) on the coast with an intensity of 150 mm /year. Volume of water precipitated along an area of 192.2 Km^2 reaches 28.830 $(10)^6$m^3/year = 0.079$(10)^6$ m^3/day.

  b. Vertical leakage of groundwater from deep Cretaceous Formation along Lahfan fault system in the Southern area with a rate of 20000 m3/day as well as a subsurface flow through Wadi El Maazar in the eastern area.

The groundwater is pumped out from 235 wells tapping the Quaternary aquifer with a rate of 45000m^3/day in the winter season, changes to about 90000m^3/day in the summer season. The model is calibrated for transient state according to a field survey data that was carried out in the year 2005. The model was calibrated, where the values of the horizontal hydraulic conductivity of the complex system were defined for each cell. These values from 10m/day in the western area to 80m/day in the eastern area. While the diffusivity coefficient varies from 700m^2/day in the western area to 30000m^2/day in the eastern area.

The results of the hydraulic flow model indicate that the studied area is subjected to an increase in pumping along the coastal line and the inland area. The above results reflect a drop in the groundwater level ranges from 1m to 5m after ten years prediction. The lowering in the groundwater level had led to seawater encroachment in the studied area and deterioration of the fresh groundwater resources.

2- Hydrodynamic salts dispersivity model [1]. The model aims to define the areas of advection, dispersion and diffusion. The longitudinal dispersivity is estimated as 25.6 m, while the effective molecular diffusion is calculated as 6.048 x 10^{-5} m/day. The obtained results indicate that the effective porosity varies from 0.02 to 0.3. The result of such model indicates that the retarded velocity of the Quaternary aquifer varies from less than 0.003 m/day to 2 m/day. The study is referred to the mechanical dispersion coefficient that ranges from about less than 5 m^2/day to about more than 120 m^2/day. Different variations of the hydrodynamic salts dispersivities are investigated, where the values of Peclet number ranges from 0.4 to more than 40. The travel times of dissolved salt particles from recharge areas to discharge areas are changed from about 2 years to 28 years. Slow and fast chemical reactions are detected. The model expressed seawater-fresh groundwater interface and travel time variation of miscible and groundwater salt particle for the Quaternary aquifer in the Delta of Wadi El Arish area.

The Current Model

The current innovated model is the hydrodynamic salts isolation model. It is applied in the present study depending on the application of the previous two models; the hydraulic flow model and hydrodynamic salts dispersivity model. The current model is applied using the interaction of three programs; three-dimensional hydraulic MODFLOW, three-dimensional contaminant transport model MT3D and three-dimensional particle tracking program PM-PATH. Such programs are adopted by [3]. The current model is represented by a network of regular cells of the same dimensions in the hydraulic flow model. Such model covers the area occupying about 192.2 square kilometers and the network was defined as regular square cells with cell dimensions of 250m x 250m. The grid Peclet number (Pe) of regular cells is 9.8. This Peclet number is acceptable to avoid numerical dispersion. The acceptable solution may be obtained with a grid (Pe) as high as 10 [4]. The current model was run depending on the hydrological and hydrochemical data as discussed in the previous models. Twelve stress periods have been taken with 30 days for each in the transient simulation. The model is running daily with 30 days time step and one transport step size.

Cleanup Time

The time required to achieve the cleanup standard of groundwater under various remedial alternatives is obtained by estimation of time required for one pore volume of clean water to flush through the area and multiplying this by the required number of pore volumes [5]. The time required for displacement of one pore volume through the studied area was estimated through the three-dimensional particle tracking program PMPATH, numerous particles were initiated within and along the upstream of the studied area the longest calculated time was taken as the time required of displacement of one pore volume. The pore volume is the volume of pore space. In the studied area, the longest calculated time is calculated as 10 years [1]. The number of pore volume (Npv) required to reduce the initial dissolved concentration (Ci) to cleanup standard or target concentration (Cs) is given by the following equation [5]:

$$\mathrm{Npv} = -R \ln \frac{Cs}{Ci} \quad \text{-------------------------} \quad (1)$$

The cleanup standard or target concentration (Cs) is assumed to be 1.5 Kg/m^3, while the initial dissolved concentration (Ci) is adopted by [1], see **Fig. (6)**. The dissolved salts concentration of the Quaternary aquifer varies from about 5 kg/m^3 and 6 kg/m^3 in the northern and eastern areas, respectively, to 2.3 Kg/m^3 in the southern area of the studied zone.

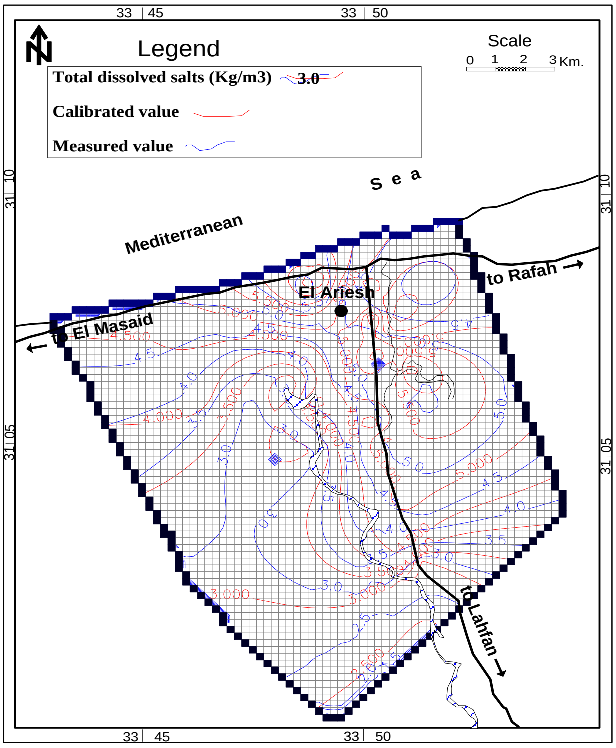


Figure (6): Calibrated total dissolved salts (kg/m^3), March 2006, for the Quaternary aquifer in Delta of Wadi El Arish, North Sinai, Egypt (after [1]).

The retardation factor (R) includes all of the interactions between the chemical species and the solid surfaces of porous media. These interactions tend to retard the migration of chemical relative to the water and delay its arrival down gradient. The locations of the reactive and nonreactive salts plume relative to the source area are compared and the retardation factor is calculated as follows [6]:

$$R = \frac{\text{Distance from source of nonreactive plume}}{\text{Distance from source of reactive plume}} \quad ----------- \quad (2)$$

Retardation can be also estimated using temporal data as follows:

$$R = \frac{\text{Time for reactive chemical to reach a given point}}{\text{Time for nonreactive chemical to reach a given point}} \quad --------- \quad (3)$$

According to [5], the retardation factor can be interpreted as a ratio of the breakthrough time at outflow face for the sorping tracer, to that for a nonsorping tracer **(Fig.7 (A))**. In the field situation, the retardation factor can be interpreted as the observed distance traveled by the front of the nonsorping solute plume to that of the sorping solute plume **(Fig.7(B))**. From the above discussion, the retardation factor in the studied area is estimated from the hydrodynamic salt dispersivity map **(Fig.8)** as follows:

1- Retardation factor in the middle area:

$$R = \frac{AC}{BC} = \frac{12500\ \text{m}}{7750\ \text{m}} = 1.6 \quad -------------------- \quad (4)$$

2- Retardation factor in the eastern area:

$$R = \frac{DF}{EF} = \frac{7500\ \text{m}}{5250\ \text{m}} = 1.4 \quad -------------------- \quad (5)$$

3- Retardation factor in the northern area:

$$R = \frac{GL}{LK} = \frac{9500\ \text{m}}{7250\ \text{m}} = 1.3 \quad -------------------- \quad (6)$$

4- Retardation factor in the southern area:

$$R = \frac{MO}{MN} = \frac{8500\ \text{m}}{5650\ \text{m}} = 1.5 \quad -------------------- \quad (7)$$

The average retardation factor in the studied area reaches 1.45. In the contaminant transport, one of the advection and dispersion is mostly common than the other depending on the retardation factor. If the retardation factor is equal to 1, then the advection is mostly common. While, if the retardation factor exceeds 1, the dispersion is the most common. In the current model, the dispersion is the most common in the studied area.

The distances AC, DF, GL and MO represent the distances traveled by the front of nonsorping salts plume, while the distances BC, EF, KL and NO represent the distances traveled by sorping salts plume. The mechanism of chemical processes that occur in the studied Quaternary aquifer reflect that, salts plume are removed from the water and immobilized in or on the solid matrix of the porous medium by electrostatic forces, which referred to sorption process. The opposite process occurs, where the salt particles are detached from the solid matrix and reenter the dissolved phase which is referred to desorption. Sorption includes adsorption and absorption processes. Adsorption refers to adherence of chemical species primarily on the surface of the porous matrix, while absorption refers to more or less uniform penetration of chemical species into the solid grain.

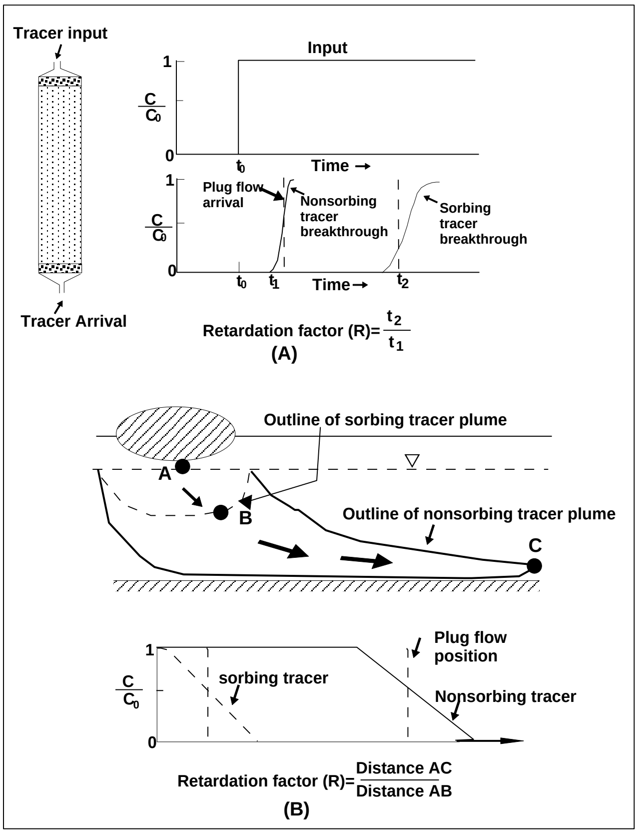


Figure (7): Schematic illustration of the retardation concept: **(A)** the ideal laboratory case and **(B)** a hypothetical field case (modified from [7]).

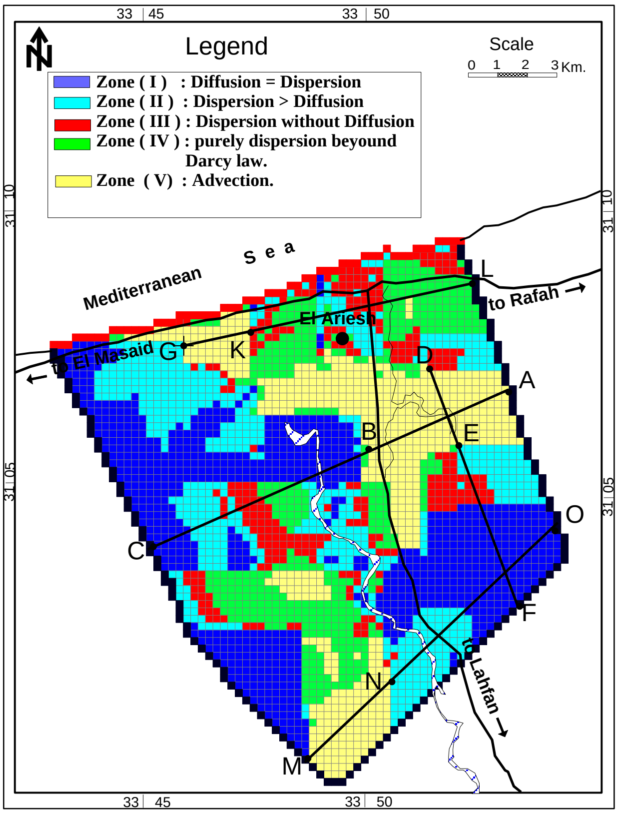


Figure (8): The hydrodynamic salts dispersivities and advective zones in the Quaternary aquifer in Delta of Wadi El Arish, North Sinai, Egypt (after [1]).

The volume of pore space reflects the volume of water in pore space and it can be calculated from the following equation [5]

$$\text{Volume of water} = \theta \times A \times L \quad \text{--------- (8)}$$

Where:

θ : Effective porosity

A: Cross-sectional area

L: Aquifer thickness

The effective porosity is calculated from the hydrodynamic salts dispersivity model **[1]**, while the thickness of the Quaternary aquifer is calculated from the hydraulic flow model [2]. **Fig. (9)** represents the volume of water in pores for the Quaternary aquifer in the studied area. It varies from less than 0.1 x 10^6 m^3 to 3 x 10^6 m^3 for each cell of the model grid in the studied area. The calculated total volume of water in pores in the studied area is 2700 million cubic meters. The current model used three–dimensional particle tracking PMPATH in conjunction with three-dimensional flow simulation MODFLOW to calculate the time required for single pore volume and to verify full capture of salts plume in groundwater by remedial installations.

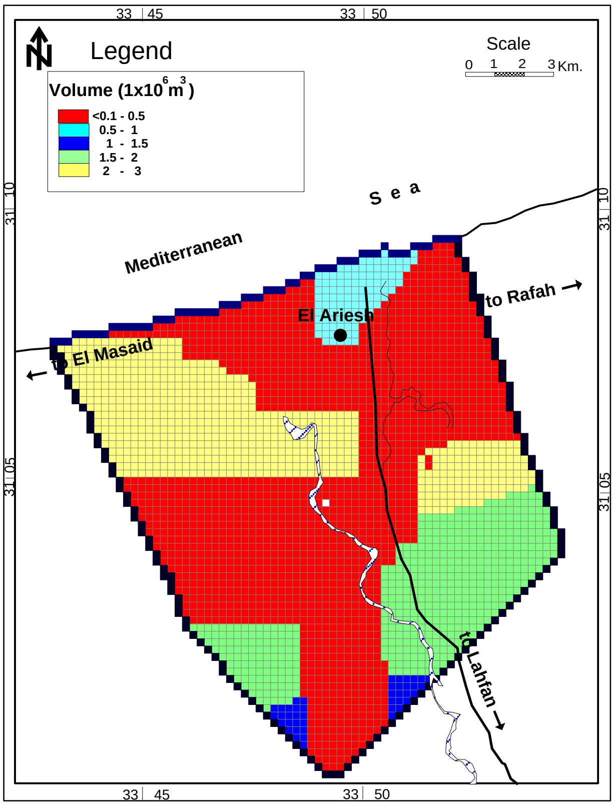


Figure (9): Volume of water in pore space for the Quaternary aquifer in Delta of Wadi El Arish, North Sinai, Egypt.

Fig. (10) represents the number of pore volume (Npv) required for groundwater cleanup to a specified level in the studied area. It varies from one pore volume to two pore volumes for each cell of the model grid. This indicates low efficiency of groundwater in the studied area. The full replacement of single pore volume in all parts of the studied Quaternary aquifer would require 10 years [1]. **Fig. (11)** represents the groundwater cleanup time of the Quaternary aquifer in the studied area. It varies from about 2000 days in the southern area to about 7000 days in the northern area for each cell in the model grid. From the above results, it can be concluded that, the remedial technique such as Pump-and- Treat system for groundwater cleanup needs more time in the northern area than in the Southern area.

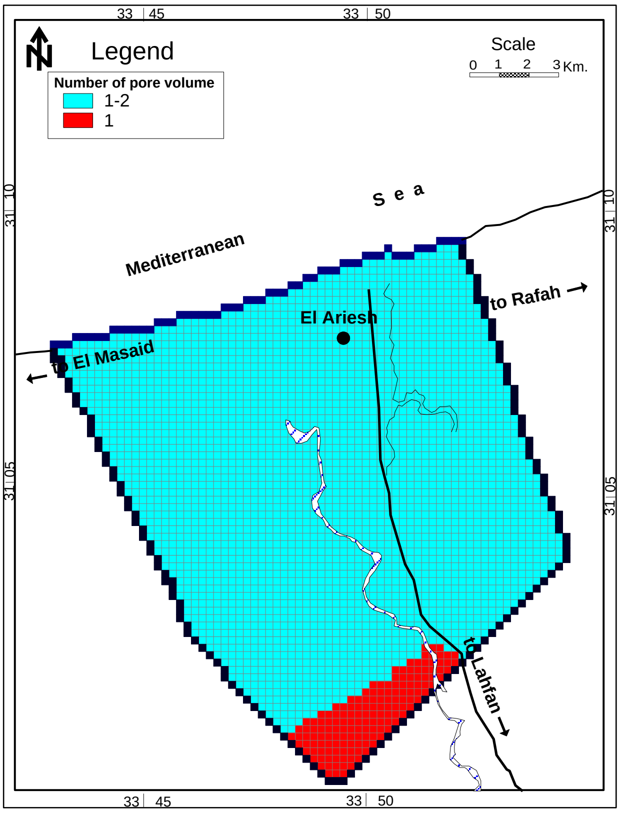


Figure (10): Number of pore volume required for groundwater cleanup to a specified level in the Quaternary aquifer in Delta of Wadi El Arish, North Sinai, Egypt.

Hydrodynamic Isolation System

Hydrodynamic isolation systems vary in complexity and effectiveness. The simplest system involves a single pumping well located at either the leading edge or centroid of the salts plume. Isolation systems grow in complexity as more pumping and injection wells are employed in a variety of configurations to maximize the systems effectiveness. The objective of the hydrodynamic isolation technique is to modify the groundwater flow pattern to contain salt plume within the capture zone of the wells. The capture zone of a well or a system of wells is defined as the area contributing flow to the well [8]. The shape of the capture zone depends on the average linear groundwater velocity, the quantity of water being pumped from the aquifer or injected into the aquifer and the distribution of hydraulic conductivity. As the groundwater velocity increases, the width of the capture zone decreases for a given pumping or injection rates.

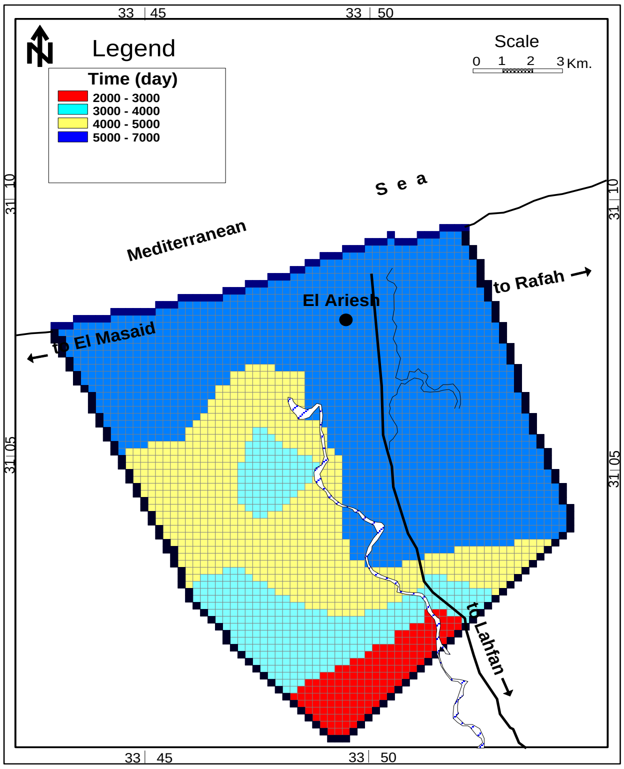


Figure (11): Groundwater cleanup time for the Quaternary aquifer in Delta of Wadi El Arish, North Sinai, Egypt

The groundwater velocity will be faster at the center of the capture zone than at the edges. It plays an important role in the protection of groundwater supply wells. Isolation wells are useful, where they effectively prevent any further advection of contaminant down gradient [9]. **Fig. (12)** represents the schematic illustration of the double cell hydraulic isolation system. The technique represents two injection wells located in the upstream side and two pumping wells located in the downstream side. The groundwater is pumped to the treatment station to remove the salts and reproduce pure water to be injected in the injection wells.

The capture zone of a well depends on the pumping rate and aquifer conditions. However, by using more wells, the well spacing becomes an important parameter as well as the pumping rate. The greater the pumping rate, the larger the capture zone, and the closer the wells are placed, the better the chance of complete plume capture. [10] represents an investigation of various pumping and injection well patterns to remediate contaminant plume **(Fig. 13)**. The key hydrogeologic variables which control the rate of cleanup are; well locations, pumping rates, injection rates, transmissivity, dispersivity and hydraulic gradient of the aquifer. The three spot, doublet and double cell well patterns are effective under low hydraulic gradient conditions. Three spot patterns showed the best performance under high hydraulic gradient. Cleanup time was found to be inversely related to the pumping rate. Injected water directly into an aquifer system by means of wells are similar to normal producing well. Injected water must be of high-quality standard. Suspended materials should less than 1 p.p.m. [11]. The high cost of injection well and water treatment usually restrict this form of recharge to a particular project such as the creation of seawater barriers. The injected water has been very successful in retarding the seawater encroachment into a costal aquifer.

The average cost per mega liter (1000 m^3) of artificially recharged water, including interest, redemption and operation reaches about $US 4.00 [11]. Accordingly, an aquifer area of one kilometer needs 4000m^3 / day of injected water for groundwater cleanup. One kilometer of the aquifer costs about $US 5760 / year for injected a volume of water of about 1.5 x 10^6 m^3. The coasts of the treatment station and well drilling are not included in the total account.

The hydrodynamic isolation system is modeled for the Quaternary aquifer in the Delta of Wadi El Arish. Different well patterns as mentioned are applied where 37 injection wells are suggested in the studied area in conjunction with pumping wells. Two scenarios are concerned in the current model.

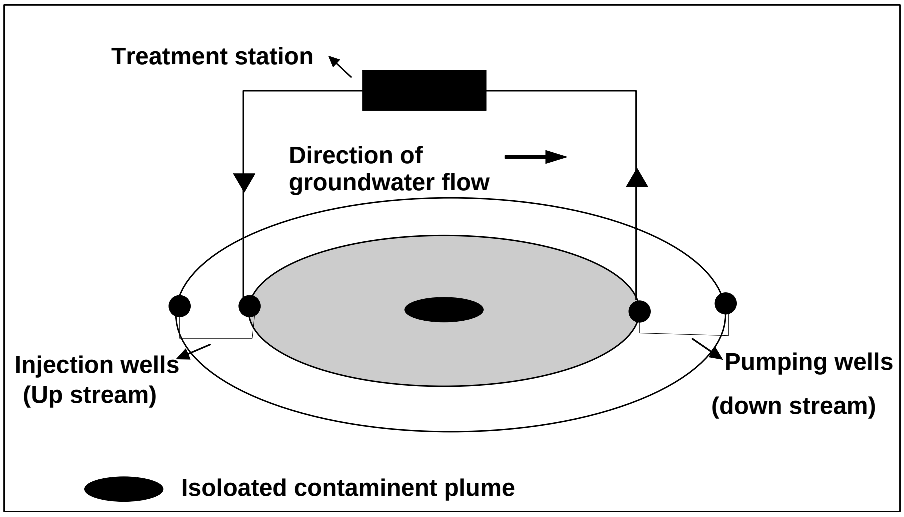


Figure (12): Schematic illustration of double-cell hydraulic isolation system

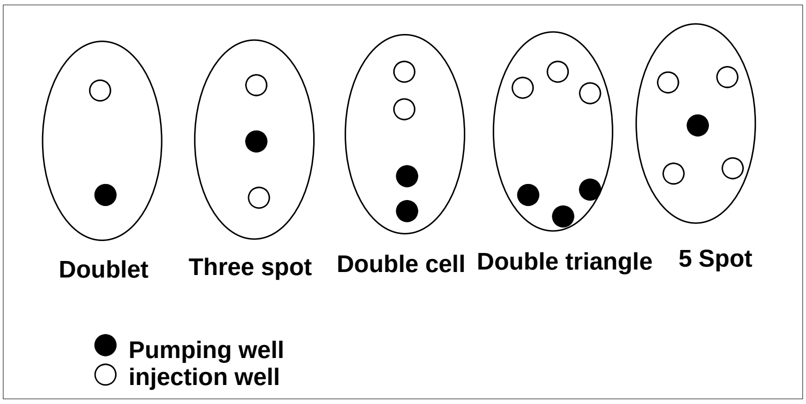


Figure (13): Different pumping and injection well patterns used in the hydrodynamic isolation system (After [10])

The first scenario: A Suggested injection rate for each well to be5000m^3/day. Pure fresh water is injected for each well with a constant salinity concentration TDS of 0.050 kg/m^3. The model is running daily with 12 stress periods of 30 days per each and 30 days time step with one transport step size for each stress period. The model is running in the transient time for 5 years. All pumping wells in the studied area were operated regularly during the simulation. The result of model simulation detects many capture zones in the studied area. Eight capture zones are selected for the present analysis **(Fig. 14)**.

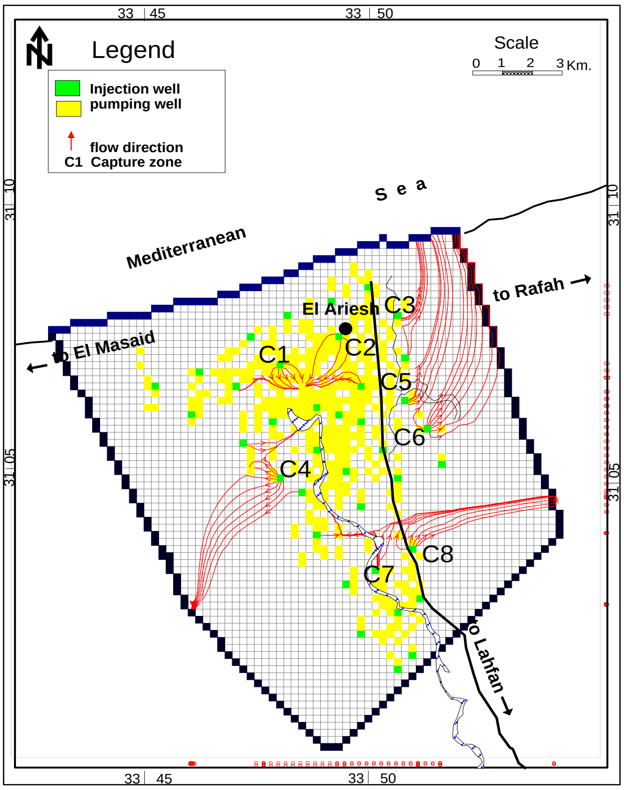


Figure (14): Different capture zones for the Quaternary aquifer in Delta of Wadi El Arish, North Sinai, Egypt

Breakthrough curves and groundwater plots are adopted for each capture zone **(Fig. 15)**. The breakthrough curve is a concentration-time curve. Also, it can be a concentration-distance curve in another job. It reflects the effect of physical and chemical processes on the salts transport (Advection, diffusion, dispersion, sorption and desorption). The concentration-time curve for model cells demonstrates the simulated changes concentration over time clearly. **Fig. (15)** illustrates two stages on remediation of the salted aquifer during the model simulation. In first stage, there is a rapid removal of salts mass. The second represents the diffusion-controlled period as the concentration has attained as an Ymptotic shape.

The rapid decline in the concentration of salts in the water represents the removal of salted water contained in the pores of the Quaternary aquifer. When the larger pores are being flushed, the drop in the concentration will be rapid. As the smaller pores are being flushed, the rate at which the concentration decline will decrease. From such curves and plots, the following are deduced **(Fig. 15)**:

At capture zone (**C1**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 4kg/m^3 to 2.7kg/m^3 associated with an increase in the groundwater level from -1.5m to 1.5m and decreases to -0.25m due to the interaction of cone of depressions. The groundwater cleanup time will be one year of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 68% of the actual concentration.

At capture zone (**C2**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 5kg/m^3 to 3.5kg/m^3 associated with an increase in the groundwater level from 1.5m to 3m and decreases to 1m due to the interaction of cone of depression. The groundwater cleanup time will be two years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 40% of the actual concentration.

At capture zone (**C3**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 4.25kg/m^3 to 3kg/m^3 associated with an increase in the groundwater level from -0.5m to 1m. The groundwater cleanup time will be two years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 70% of the actual concentration.

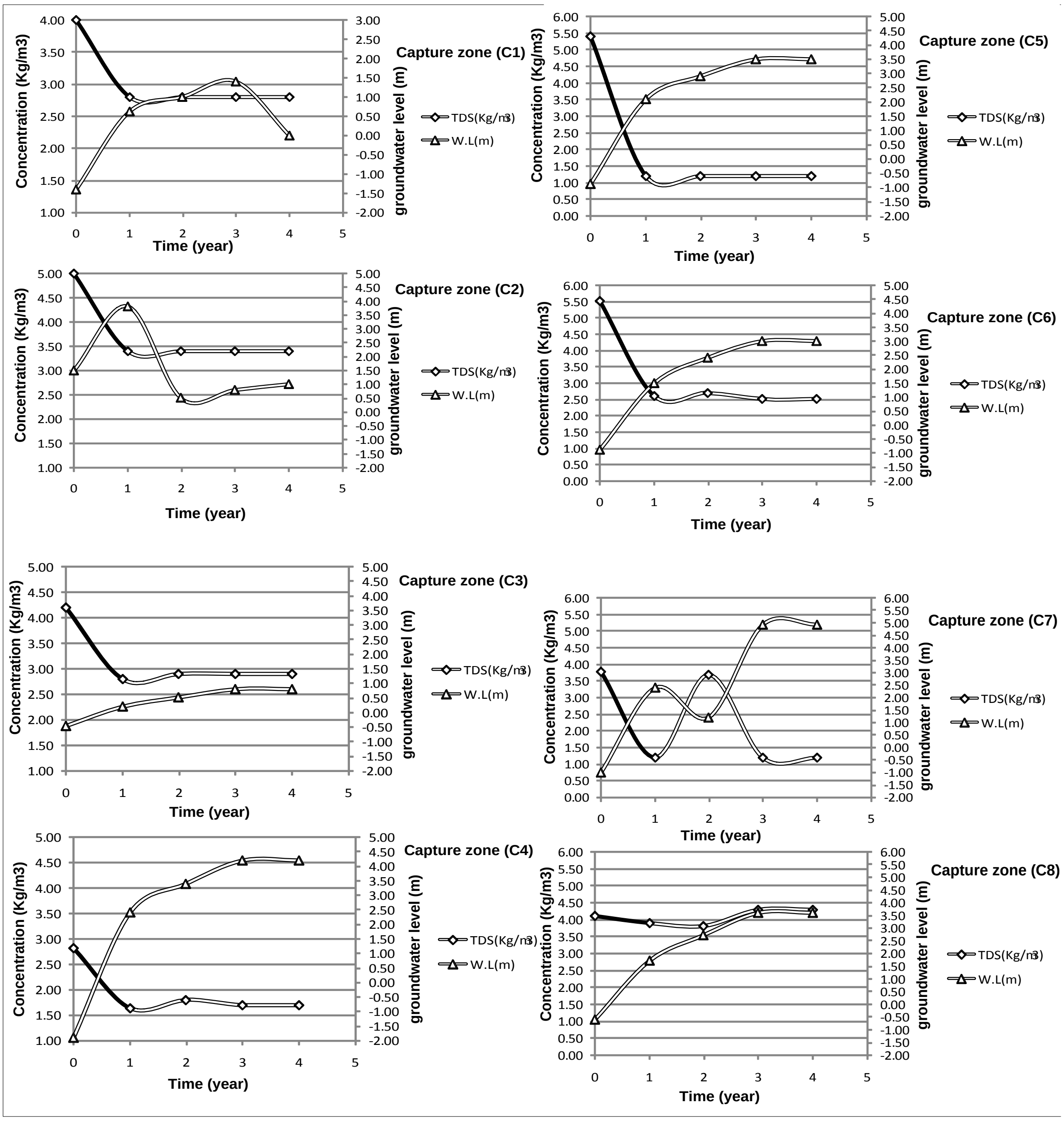


Fig 15: Breakthrough curves and groundwater plots at each capture zone for the Quaternary aquifer in the Delta of Wadi El Arish, North Sinai, Egypt

At capture zone (**C4**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 3.75kg/m^3 to 1.75kg/m^3 associated with an increase in the groundwater level from -2m to 4m. The groundwater cleanup time will be three years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 47% of the actual concentration.

At capture zone (**C5**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 5.5kg/m^3 to 1.25kg/m^3 associated with increase in the groundwater level from -1m to 3.5m. The groundwater cleanup time will be three years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 23% of the actual concentration.

At capture zone (**C6**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 5.5kg/m^3 to 2.5kg/m^3 associated with an increase in the groundwater level from -1m to 3m. The groundwater cleanup time will be three years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 45% of the actual concentration.

At capture zone (**C7**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 4kg/m^3 to 1kg/m^3 associated with an increase in the groundwater level from -1.5m to 4.75m. The groundwater cleanup time will be four years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 25% of the actual concentration. Large amounts of salts mass are retained near to the injection well as observed during the model simulation, where the salt plume fails to represent rapid, anomalous spreading.

At capture zone (C8): The result of model simulation indicates an expected decrease in the concentration of salts mass from 4kg/m^3 to 3.75kg/m^3 associated with an increase in the groundwater level from -0.5m to 3.5m. The groundwater cleanup time will be four years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 93% of the actual concentration. Large amounts of salts mass are retained near to the injection well as observed during the model simulation, where the salt plume fails to represent rapid, anomalous spreading.

***The second scenario*:** The suggested injection rate for each well is 2500m^3/day. Pure fresh water is injected for each well with constant salinity concentration (TDS) 0.050 kg/m^3. The model is running daily with 12 stress periods of 30 day per each and 30 days time step with one transport step size for each stress period. The model is running in the transient time for 5 years. All pumping wells in the studied area are operated regularly during the simulation. The result of model simulation detects many capture zones in the studied area. Eight capture zones are selected for the present analyses **(Fig. 16)**. Breakthrough curves and groundwater plots are delineated at each capture zone. **Fig. (17)** illustrates two stages on remediation of salted aquifer during the model simulation. In stage one; there is a rapid removal of salts mass. Stage two represents the diffusion-controlled period as the concentration has attained as an Ymptotic shape. The rapid decline in the concentration of salts in the water represents the removal of salted water contained in the pores of the Quaternary aquifer. When the larger pores are being flushed, the drop in the concentration will be rapid. As the smaller pores are being flushed, the rate at which the concentration decline will decrease. From such curves and plots, the following are deduced **(Fig. 17)**:

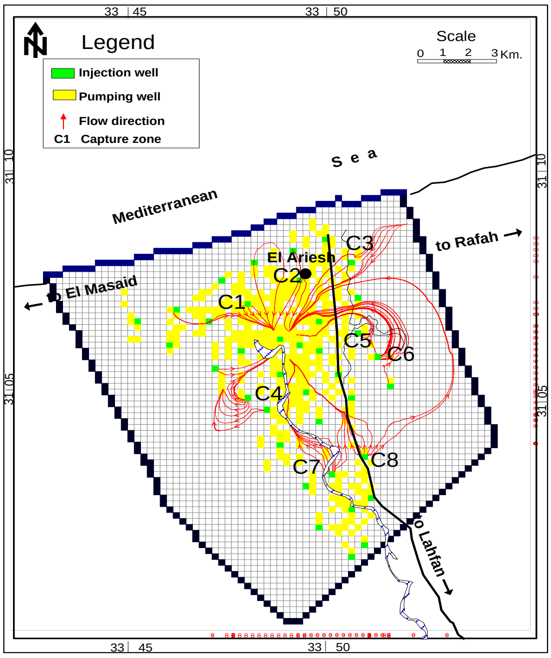


Figure (16): Different capture zones for the Quaternary aquifer in the Delta of Wadi El Arish, North Sinai, Egypt

At capture zone (C1): The result of model simulation indicates an expected decrease in the concentration of salts mass from 4kg/m^3 to 3.5kg/m^3 associated with an increase in the groundwater level from -1.5m to -1.25m and decrease to -1.75m due to the interaction of cone of depression from the surrounding wells. The groundwater cleanup time will be two years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 88% of the actual concentration. Large amounts of salts mass are retained near to the injection well as observed during the model simulation, where the salt plume fails to represent rapid, anomalous spreading.

At capture zone (C2): The result of model simulation indicates an expected decrease in the concentration of salts mass from 5kg/m^3 to 4kg/m^3 associated with an increase in the groundwater level from -1.5m to -0.75m. The groundwater cleanup time will be four years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 80% of the actual concentration.

At capture zone (C3): The result of model simulation indicates an expected decrease in the concentration of salts mass from 4kg/m^3 to 0.5kg/m^3 associated with an increase in the groundwater level from -0.5m to -0.4m. The groundwater cleanup time will be three years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 12% of the actual concentration.

At capture zone (C4): The result of model simulation indicates an expected decrease in the concentration of salts mass from 3kg/m^3 to 2kg/m^3 associated with an increase in the groundwater level from -2m to 0.25m. The groundwater cleanup time will be two years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 67% of the actual concentration.

At capture zone (C5): The result of model simulation indicates an expected decrease in the concentration of salts mass from 5.5kg/m^3 to 2.5kg/m^3 associated with an decrease in the groundwater level from 0.75m to 0.25m and increase to 0.7m after four year of injection. The groundwater cleanup time will be one year of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 45% of the actual concentration. Small amounts of salts mass are retained near to the injection well as observed during the model simulation, where the salt plume fails to represent rapid, anomalous spreading.

At capture zone (C6): The result of model simulation indicates an expected decrease in the concentration of salts mass from 5.5kg/m^3 to 0.0kg/m^3 associated with an increase in the groundwater level from -1m to 0.75m. The groundwater cleanup time will be four years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 0% of the actual concentration.

At capture zone (**C7**): The result of model simulation indicates an expected decrease in the concentration of salt

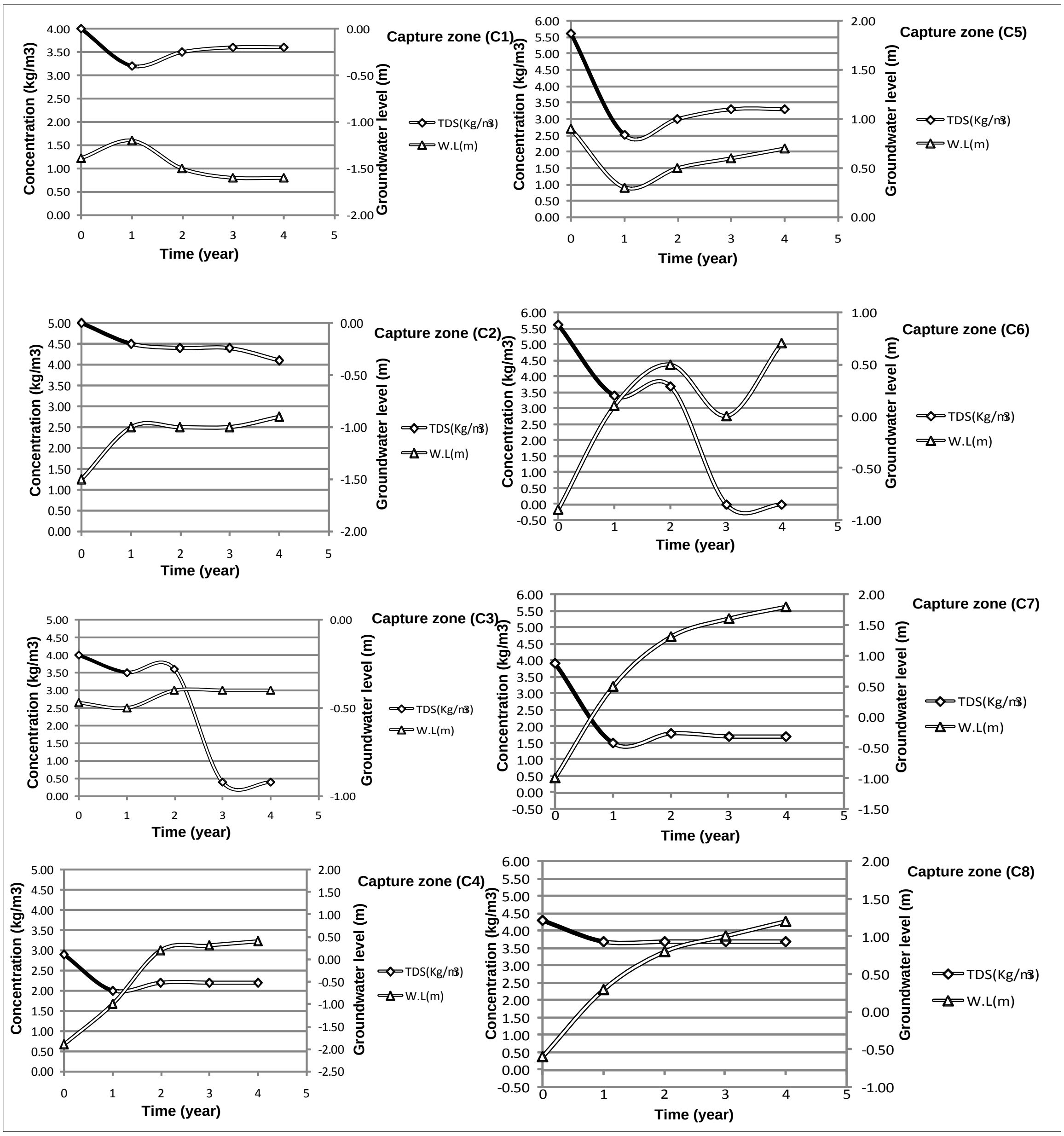


Fig 17: Breakthrough curves and groundwater plots at each capture zone for the Quaternary aquifer in the Delta of Wadi El Arish, North Sinai, Egypt

mass from 4kg/m^3 to 1.75kg/m^3 associated with an increase in the groundwater level from -1m to 1.25m. The groundwater cleanup time will be two years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 44% of the actual concentration.

At capture zone (**C8**): The result of model simulation indicates an expected decrease in the concentration of salts mass from 4.5kg/m^3 to 3.5kg/m^3 associated with an increase in the groundwater level from -0.75m to 0.75m. The groundwater cleanup time will be two years of injection, where the desorption process took place. The remaining salts mass on the solid matrix (residual) will be 78% of the actual concentration. Large amounts of salts mass are retained near to the injection well as observed during the model simulation, where the salt plume fails to represent rapid, anomalous spreading.

Fig. (18) illustrates the groundwater level contour map after cleanup of the Quaternary aquifer in the studied area.

The detected capture zones of the two scenarios refer to the following points:

1- The reported simulated salt plumes are expected to decrease more in the studied area than the actual state.

2- The plumes of the dissolved salts should move in the direction of groundwater flow.

3- Such remedial technique is not be able to remove all terraces of salts plume.

4- In existing of the treatment station in the field, the capture zone plume will be decreased in its salinity concentration more and more than the actual concentration and the remaining salts plume concentration will be lowered to reaches 25 % as tested on the other area by [12] and copyright in [6].

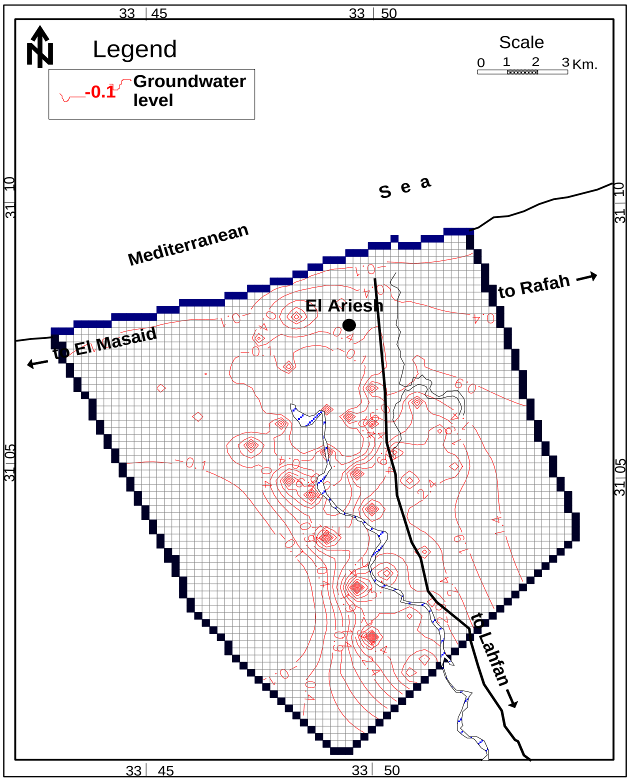


Figure (18): Groundwater level contour map after cleanup of the Quaternary aquifer in the Delta of Wadi El Arish, North Sinai, Egypt

Recommendations

The obtained results of the current study give rise to the following recommendations:

1- The technique of hydrodynamic isolation system should be applied using the first scenario.

2- Certain chemical solvents should be added to the injected pure water by wells in order to remove the concentrated salts mass on the solid matrix.

3- The hydrodynamic salts isolation model can be applied in the coastal areas of the Mediterranean Sea, the Red Sea and in the Arab Gulf where the aquifer is subjected to sea water intrusion. It can be applied in the other coastal areas in the world and in the inland areas for the aquifers having high saline groundwater, the model can be applied under certain conditions concerning the hydrogeological parameters.

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