Chapter five

Numerical Modeling of the Flow System in the study area

5.1. Introduction

Numerical simulation was developed to represent the flow system in the study area. The modeling of the groundwater flow and solute transport, in the study area, is carried out to understand the flow system and then to support the evaluation of the environmental risk for the water supply from wells related to potential contamination sources identified in the study area. Better understanding gained from numerical modeling will form the basis for recommendations that would improve the environmental management of the study area. The used methodology for the numerical simulations of the groundwater flow and solute transport can be summarized as follows:

- Develop a conceptual model of the flow system in the study area based on the collected and the reviewed data about the aquifer hydrogeological characteristics.

- Select a suitable simulator (numerical model) that has the capabilities required to achieve the objectives of the study.
- Input data to the simulator and construct the numerical model (slice surfaces, numerical grid, hydrogeologic parameters, and boundary conditions).
- Calibrate the model by trial and error using these parameters.
- Carry out a sensitivity analysis of the model to test the calibrated model parameters and to understand the flow system according to future changes in the study area.

- Define the groundwater flow patterns in three dimensions, estimate a mass balance of the water inflow and outflow in the system and identify the conditions that control flow in the system.
- Apply different management schemes on the model to study the impact of future development on the groundwater status in the studied area
- Asses the groundwater potential facing the future water resources scarcities.
- Use particle tracking to trace the pollutant travel in the groundwater.
- Use the findings from the numerical model to make recommendations that can improve the environmental management and protect the groundwater sources.

5.2. The Simulator

Visual MODFLOW Pro.V.4.2 was selected to simulate the study area as the most complete and user friendly, modeling environment for practical applications in three-dimensional groundwater flow and contaminant transport simulation. This software was developed by Waterloo Hydrogeologic Inc. Three numerical engines were selected from the various Visual MODFLOW engines:

(a) The MODFLOW-2000 engine to simulate groundwater flow under steady state conditions.

(b) The MODPATH engine to simulate particle tracking parting on the flow field obtained from MODFLOW.

(c) The MT3D v.1.5 engine to simulate three dimensional transient contaminant transport, including advection, dispersion and chemical reactions of contaminants in the groundwater system.

(a) MODFLOW is a computer program that numerically solves the three-dimensional groundwater flow equations for a porous medium by using the finite-difference method.

When the groundwater flow equation was combined with boundary and initial conditions, it describes transient three-dimensional groundwater flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions.

The groundwater flow model solves the groundwater flow equation using the finite-difference method in which the groundwater flow system was divided into a grid of cells. For each cell, there is a single point, called a node, at which head is calculated. *(McDonald and Harbaugh, 1988).*

(b) MODPATH is a particle tracking post-processing program designed to work with the U. S. Geological Survey's finite-difference groundwater-flow model, MODFLOW *(McDonald and Harbaugh, 1988)*. Output from steady-state or transient simulations is used in MODPATH to compute paths for imaginary particles of water moving through the simulated groundwater system. In addition to computing particle paths, MODPATH keeps track of the time of travel for particles moving through the system. By carefully defining the starting locations of particles, it is possible to perform a wide range of analyses, such as delineating capture and recharge areas or drawing flow nets.

The MODPATH particle tracking package consists of two separate computer programs:

(1) MODPATH, which calculates particle paths and travel times.
(2) MODPATH-PLOT, which takes numerical output from MODPATH and displays the results in a variety of graphical formats.

Both programs are written in standard FORTRAN-77 *(ANSI, 1978)*. MODPATH can be compiled and run on any computer that has a FORTRAN-77 compiler.

(c) MT3D is a transport model that can be used to simulate changes in concentration of single-species miscible contaminants in groundwater considering advection, dispersion and some simple chemical reactions, with various types of boundary conditions and external sources or sinks. The chemical reactions included in the model are equilibrium-controlled linear or non-linear sorption and first-order irreversible decay or biodegradation.

The MT3D transport model is intended to be used in conjunction with any block-centered finite difference flow model such as MODFLOW. It is based on the assumption that changes in the concentration field will not affect the flow field measurably. This allows the user to construct and calibrate a flow model independently. MT3D retrieves the hydraulic heads and the velocity components and sink/source terms saved by the flow model, automatically incorporating the specified hydrologic boundary conditions.

The numerical solution implemented in MT3D is a mixed Eulerian-Lagrangian method. The Lagrangian part of the method, used for solving the advection term, employs the forward tracking method of characteristics (MOC), the backward-tracking modified method of characteristics (MMOC), or a hybrid of these two methods. The Eulerian part of the method, used for solving the dispersion and chemical reaction terms, utilizes a conventional block-centered finite-difference method.

5.3. Conceptual Model and Input Data

The groundwater aquifer system of the study area was studied based on the geology and the hydrogeology of the study area to build the conceptual model. The Lower Pliocene clay represents an impermeable boundary for groundwater flow and contaminant transport. The geological context and hydrogeological context of the study area has been used to create the conceptual model which presents the main aquifer system in Girga locality.

(a) ***Geological context*:** The upper layer of the aquifer is a clay zone with an average thickness of 20 m vanishing towards the graded sand and gravel. The main aquifer is represented as two units; the upper Pleistocene age graded sand with intercalated clay lenses with an average thickness of 130 m, and the lower part, Plio-Pliestocene, of sandy gravel aquifer with an average thickness of 60 m.

(b) ***Hydrogeological context:*** the aquifer system is mainly recharged by the irrigation excess water infiltration and the River Nile is considered as the specified head boundary. Two types of production groundwater wells are applied; drinking water wells and private irrigation wells.

5.3.1. Model Layers

The aquifer system was divided into five modeling layers in the vertical direction to present the different lithology structures and productivities of the aquifer. These layers are classified into three main hydraulic groups which can be summarized as follows;

Group A:

This group includes the first layer which has an average thickness of 20m and it represents the silty clay layer which is deposited from the cultivated Nile flood plain vanishing towards the western boundary of the model.

Group B:

The group includes the second, third and fourth layers representing the pleiostoscene layer which consists of gravel, sand and clay. These layers lie in the highly productive aquifer. This group has an average thickness of 125m vanishing towards the edges. The third layer represents the average abstraction depths of the wells located at this area.

Group C:

The group represents the fifth layer which has an average thickness of 60 m. This layer represents the Holocene layer which consists of silty and sandy clay. This layer represents the moderate quaternary productive aquifer.

5.3.2. Boundary Conditions:

The boundary conditions imposed on the model were based on the initial piezometric head map and on the understanding of the hydrogeological conditions. Boundary conditions of the study area are described below. Figure (5.1) shows Boundary conditions of the model:

A. The Northern boundary of the model was represented as a specified head boundary of 58 m head above the mean sea level.

B. The Eastern boundary of the model was represented as a specified head boundary to simulate the River Nile with average water levels, which range between 59.8 m to 57.8 m above mean sea level. Within the study area, the River reach of Nile levels are lower than the groundwater levels.

The difference in water levels lets the River Nile act as a drain. This boundary condition will be just assigned to the first and second layers as the River Nile bed levels penetrates only up to the second layer. Taking into consideration, the difference in hydraulic properties between the semi confined layer and the River Nile bed.

C. The North Western boundary of the study area is represented by a no flow boundary as it represents the stream lines.

D. The Southern boundary of the study area is represented as a general head boundary

E. The South Western boundary of the study area is represented as a no flow boundary due to the presence of a natural fault.

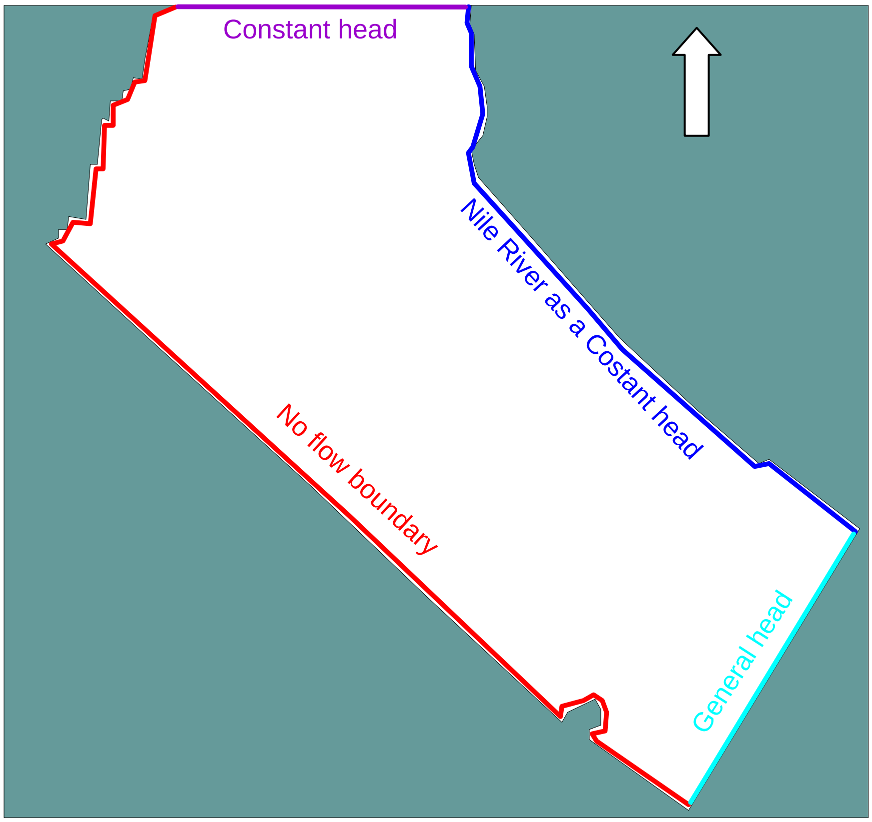


Figure (5.1) Boundary conditions of the model

5.3.3. Model Grid:

Dimensions of the study area model are 40125 m × 37500 m, and by assigning an average grid element size of 250 m ×250 m, the number of rows and columns are 152 and 162, respectively, Figure (5.2).

The three dimensional grid was constructed by generating three digitized surfaces using Surfer package software v.8 .The digitized surfaces are topographic surface, piezometric heads and base of aquifer. A grid file for each surface is produced and imported to the model input.

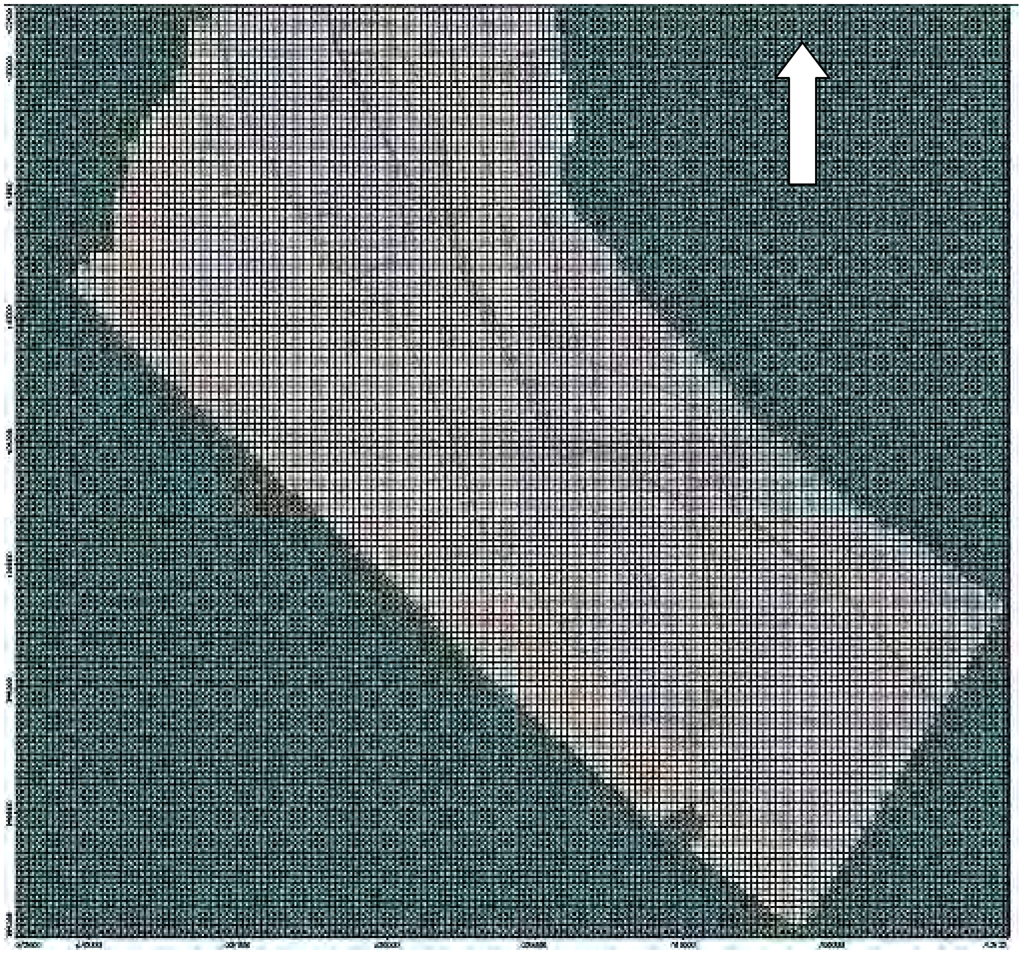


Figure (5.2) shows the Model Grid

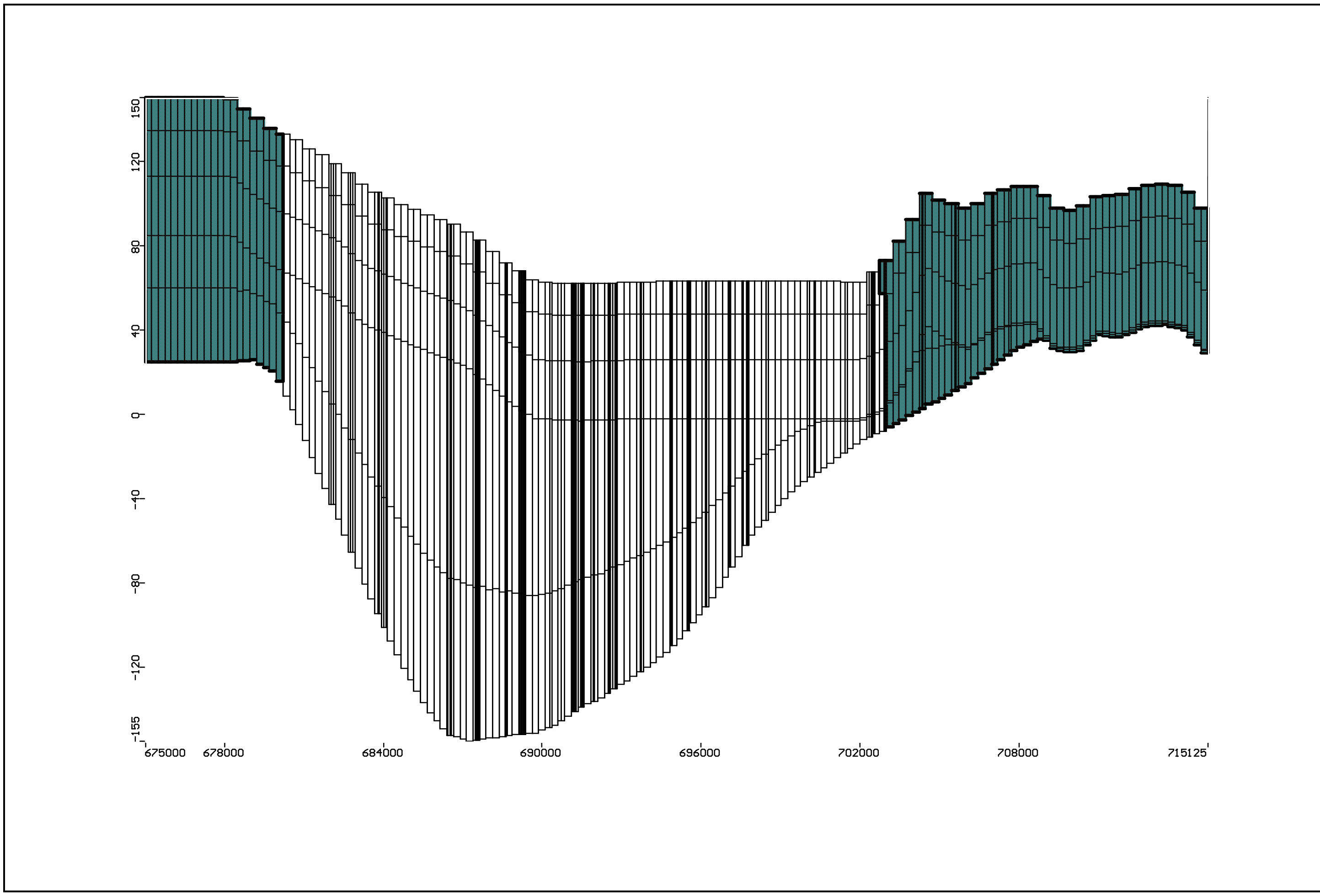


Figure (5.3) Cross section for the model grid

5.3.4. Model Hydrogeological and Hydraulic parameters inputs:

The base aquifer level Figure (5.5) is produced by subtracting the aquifer thickness contour (based on the hydrogeological map) from the topographic contour map, Figure (5.4), because the thickness of the aquifer in the reclaimed desert area was not well known.

The initial hydrogeological properties of the model area are used as input data based on previous studies and the aquifer pumping test analysis. The specific storage is taken as 0.0001 [1/m], specific yield is 0.2 and total porosity is 0.25.

The hydraulic conductivity of the clay layer, in the model area, ranges from 0.1 to 0.2 m/day for the horizontal direction and 0.01 to 0.02 m/day in the vertical direction. For, pleiostoscene, the mixed gravel, sand and clay zones, K_x and K_y are between 60 and 80 m/day, K_z from 6 to 8 m/day. The Plio-Pleistocene zones have the vertical conductivity in the range of 2-4 m/day and the horizontal one in the range of 20 to 40 m/day.

The initial recharge values for the model area inputs were calculated depending on the soil nature and the intensity of the cultivation, with the help of the previous studies in the region. The recharge, in the old traditional lands, ranges between 0.5 and 0.8 mm/day. For the reclaimed lands, the recharge varies between 0.4 to 1 mm/day. For the uncultivated dessert fringes the recharge was applied as 0.08 mm/day.

Figure (5.4) Topography contour map for the studied area

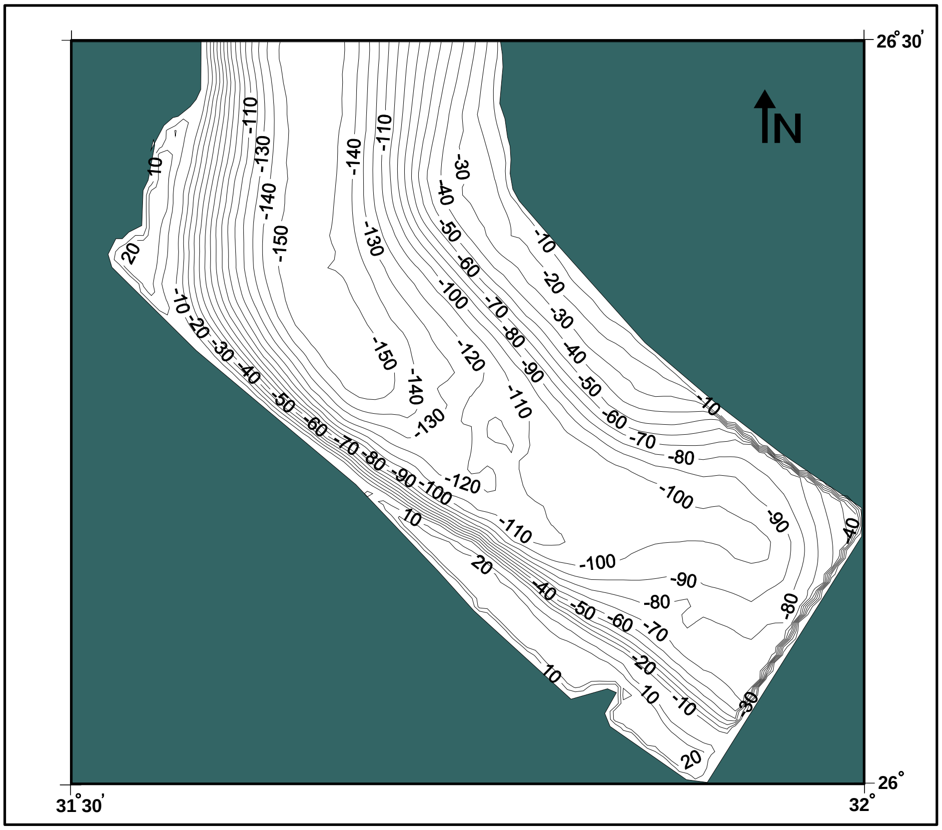


Figure (5.5) contour map for the aquifer base for the studied area

5.4. Sensitivity Analysis:

The purpose of the sensitivity analysis is to quantify the uncertainty in the calibrated model caused by uncertainty in the estimates of aquifer parameters, stresses and boundary conditions. A sensitivity analysis is an essential step in all modeling application.

During sensitivity analysis, calibrated values for hydraulic conductivity, storage parameters, recharge and boundary conditions are systematically changed. The magnitude of change in heads from the calibrated solution is a measure of the sensitivity of the solution to that particular parameter. The results of the sensitivity analysis are reported as the effect of the parameter change on the average measure of error selected as the calibration criterion. Ideally, the effect on the special distribution of head residuals is also examined.

The results of the sensitivity analysis indicate that the relationship between recharge rate and the piezometric head is almost linearly proportional. Increasing the recharge rate led to increase the piezometric heads and vice versa. For the relation between the hydraulic conductivity and the piezometric heads is almost inversely linear. Increasing the hydraulic conductivity led to decrease in the piezometric head and vice versa. In general, the model is more sensitive to the recharge rate than the hydraulic conductive. The result of the sensitivity analysis for the recharge rate and hydraulic conductivity is shown in Figure (5.6).

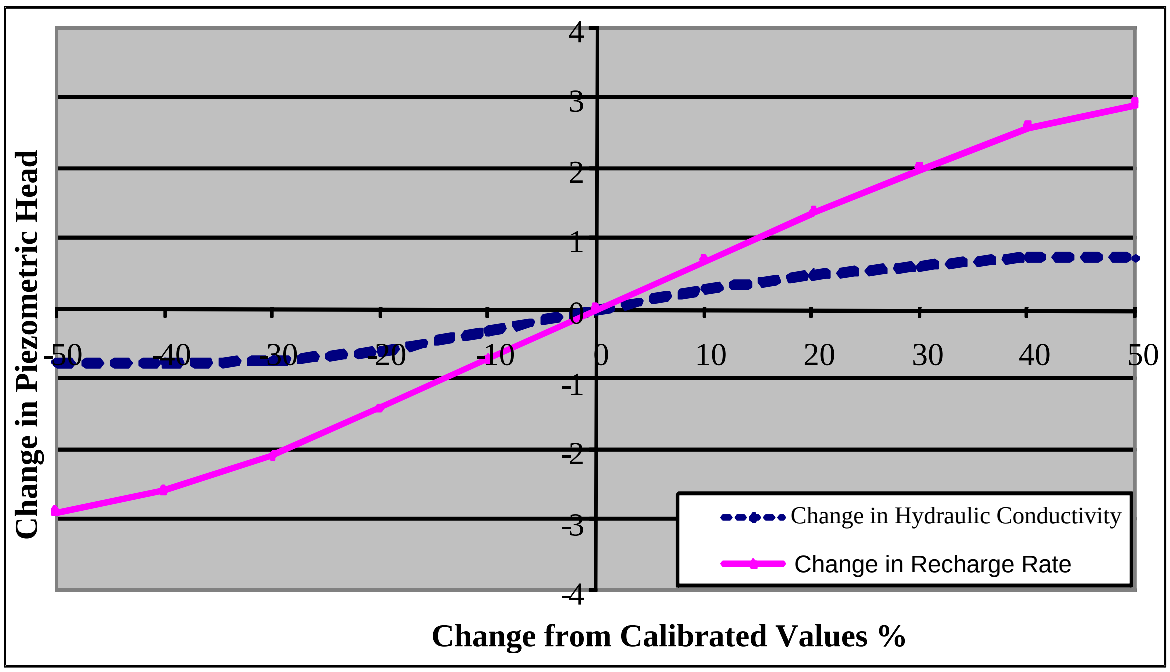


Figure (5.6) Results of the sensitivity analysis for recharge rate and hydraulic conductivity

5.5. Model Calibration:

Before the model can perform its tasks in predicting the response of the system to any future activities, it must be calibrated. Calibration of the flow model refers to a demonstration that the model is capable of producing field measured heads and flow, which are the calibrated values. The model calibration is performed through several trials by changing the hydraulic conductivity and the recharge values. The calibration target, of the model, is to minimize the difference between the calculated and the measured heads. The permissible difference was only 10% of the difference between the maximum and minimum head values. In this case model, the permissible Root Mean Square was 0.27 m.

The calibration process has been done in two phases to assure its accuracy.

- **First phase (steady state calibration):**

The model is constructed with the initial data from the hydro geological map of Girga published at 1990 by the Research Institute for Groundwater (RIGW) and calibrated with a steady state flow.

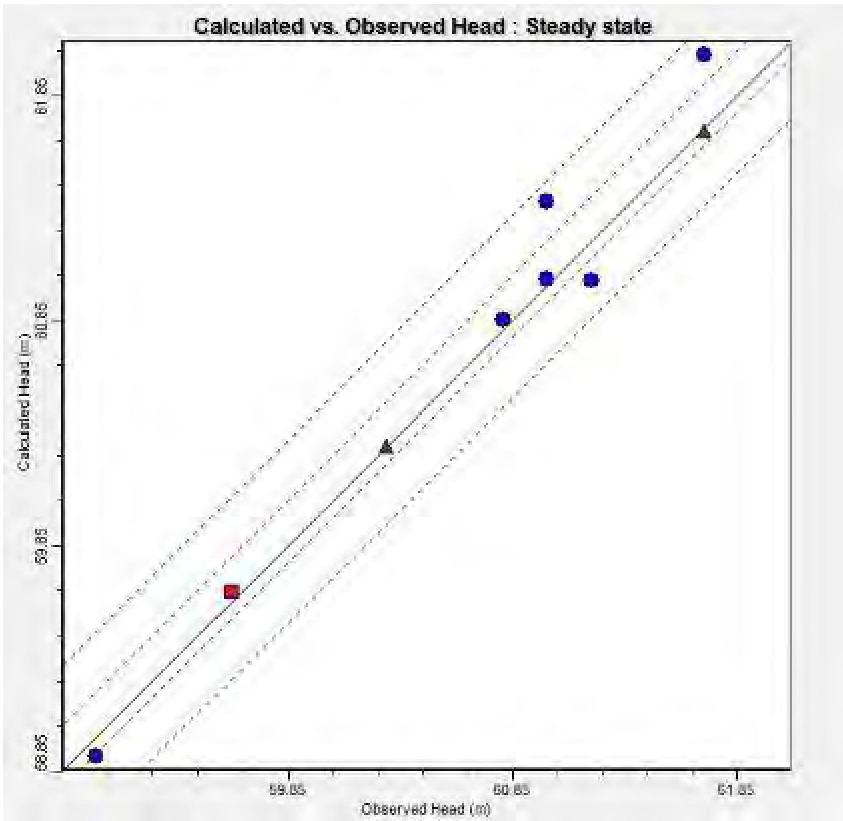
The final steady state calibration values for the hydraulic conductivity are as shown in Table (5.1).

Table (5.1) Hydraulic conductivity of the different layers in the study area

	Kx m/day	**Ky m/day**	**Kz m/day**
Clay zones	0.2	0.2	0.04
Silty and sandy clay zones	60	60	6
Gravel, sand and clay zones	60	60	6
Pleistocene-Highly productive aquifer	80	80	8
Holocene-Moderate productive aquifer	35	35	3.5

And the final recharge values for the model calibration are 0.6 mm/day for old lands, 0.4 mm/day for new reclaimed lands and 0.08 for the desserts fringes.

Fig (5.7) shows the calculated heads versus the observed ones and the R.M.S error for the final calibration run. Table (5.2) shows the observed versus calculated heads at the observation wells.



Standard error of the estimate =0.06m

Root Mean Square =0.18m

Correlation Coefficient=0.986

Figure (5.7) Calculated verses observed heads, Phase one of calibration

Table (5.2) Observed and calculated head difference of first phase.

Observation well	Observed head (m)	Calculated head (m)	Difference
V80'	60.29	60.29	0
7B	59	58.92	0.08
V82	61.70	62.03	-0.33
V81'	61.70	61.69	0.01
V81	60.81	60.85	-0.04
V77'	59.60	59.64	-0.04
V78	59	58.92	0.08
V79	61	61.03	-0.03
02	61	61.38	-0.38

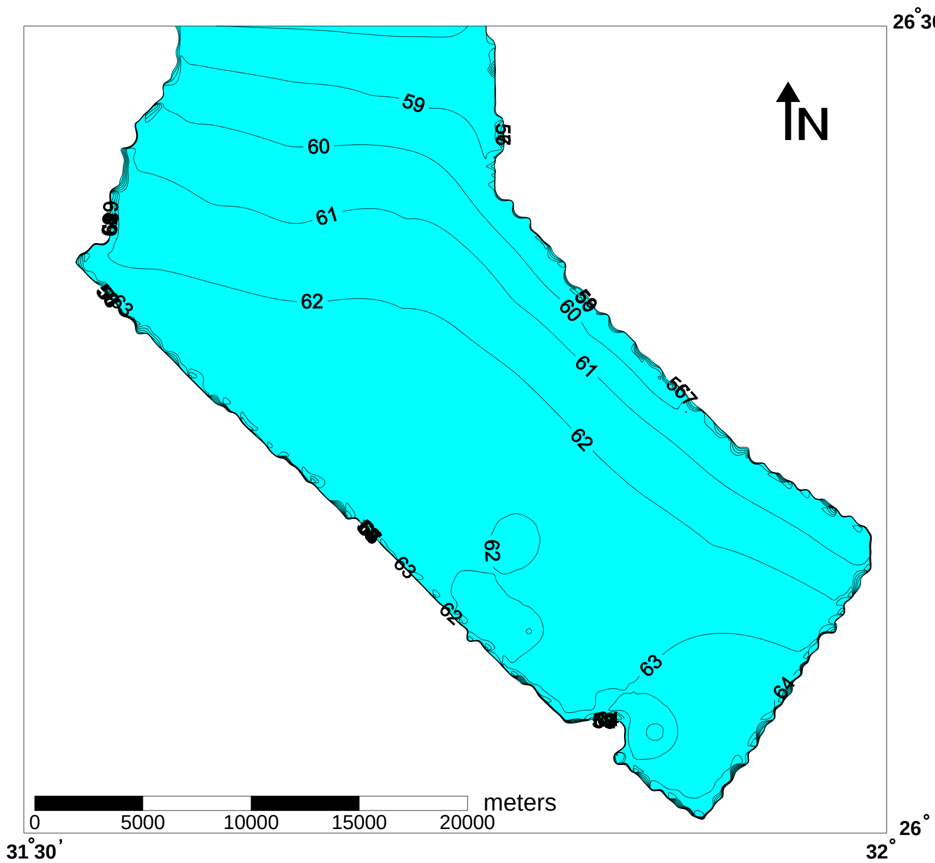


Figure (5.8) observed piezometric contour map of the Quaternary aquifer in Girga region, 1990.

- **Second phase:**

The model was updated by the new abstractions and recharge values until the year of 2007. Then, the model was run for a transient state flow covering the period from 1990 through. New piezometric heads are generated. By comparing the new calculated heads in 2007 by the measured values from the field, the model was proven to be working satisfactory. The recharge values were increased according to the increase of cultivation in some areas and reclaimed new ones (Tables (5.3)). The final recharge values that was supplied to the model in, the transient state case, are as follows:

Table (5.3) Recharge values for transient state, (Second Phase).

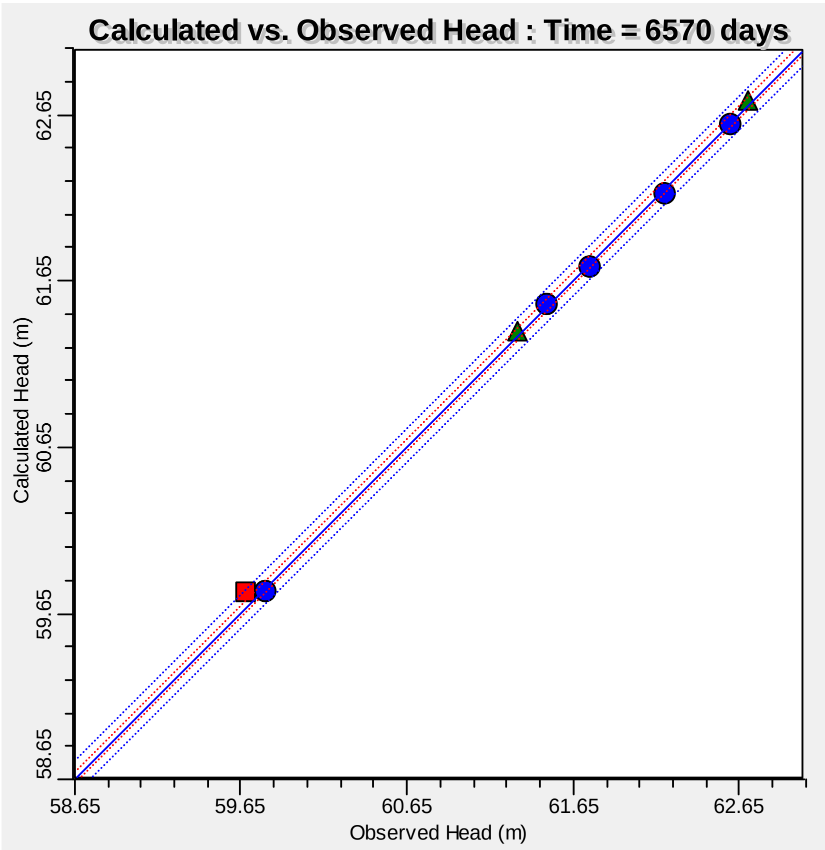
Zone	1990-1999	1999-2007
Old lands	0.6 mm/day	0.68 mm/day
New reclaimed lands	0.4 mm/day	0.66 mm/day
Dessert fringes	0.08 mm/day	0.08 mm/day

The table (5.4) shows the observed versus calculated heads at the observation wells.

Table (5.4) Observed and calculated head difference of second Phase.

Observation well	Observed head level (m)	Calculated head level (m)	Difference (m)
V80'	61.31	61.35	-0.04
7B	62.2	62.17	0.03
V82	62.6	62.59	0.01
V81'	62.70	62.73	-0.03
V81	61.75	61.73	0.02
V77'	59.68	59.78	-0.1
V78	59.8	59.77	0.03
V79	61.5	61.51	-0.01

Fig (5.9) shows the calculated heads versus the observed ones and the R.M.S error for the final calibration run for transient flow.



Standard Error of the estimate =0.016 m

Root Mean Square =0.043 m

Correlation Coefficient =0.999

Figure (5.9) Calculated versus observed heads, the second phase of calibration

Figure (5.10) shows the current piezometric heads in 2007

(RIGW database)

Chapter six

Future Groundwater Development in Girga

6.1. Introduction

In many countries of the world, the problem of providing adequate water supplies has become a very critical issue resulting from the increasing demand for water which is directly proportional to the explosive increase of population and the rapid development of industry. To meet the tremendous and intensive needs for water, all available resources should be exploited. To achieve this task, it is necessary to set integrated plans for managing and developing the available water resources in the most appropriate manner, along with increasing the overall water use efficiency.

The primary objective of water resources development is to insure water availability where and when needed. Water availability is not only dependent on the absolute quantity of average annual yield, but is more a function of hydrologic variability and the effective use of storage facilities to dampen the consequences of this variability . Construction of surface water reservoirs may be confronted by environmental and/or economic constraints that reduce their feasibility. Moreover, the conveyance of water from these reservoirs may be subject to pollution and /or high water losses and delivery costs.

Aquifers can play an important role in such situations. Aquifers, under certain conditions, can be considered potential seasonal and/ or long- term storage reservoirs, along with serving as conveyance media. Groundwater storage can be one of the most efficient mechanisms for supplementing seasonal and long –term deficits in surface water. The storage capacity of a groundwater basin is analogous to the storage capacity of a surface reservoir, without the loss of water through evaporation which is a characteristic of surface reservoirs. Water deliveries from surface reservoirs to the locations where the water is needed may be costly and is subjected to conveyance losses and pollution. On the other hand, groundwater can be pumped locally, irrespective of the recharge locations. In addition, under certain conditions, groundwater withdrawals result in drainage provisions (tube- well drainage); thus eliminating the need for extensive drainage networks and costly pumping stations.

6.2. Simulation and discussion of the groundwater development strategies:

1- Several options for groundwater development can be initiated depending on the objectives behind such development and system constrains.
2- The proposed strategies of the groundwater development in the study area which are depending on the clear understanding of the interaction between the surface water system and the groundwater system in the Nile Valley are:

a. Pumping against present drainage surplus all the year. Various pumping rates (schemes) can be tried starting from the minimum rate obtained from the calibration of the zoomed model. This strategy presents long-term groundwater development in conjunction with surface water.
b. Pumping of the maximum possible capacity that can continue for at least five successive years, the aquifer is left to refill during a number of years until it is almost recovered using the decided pumping rate from the long-term strategy. To test these strategies, in this study region, a representative sample (Pilot area) of the Nile Valley region is selected to apply these strategies and assess the impacts on surface water and groundwater systems in detailed view.
c. The long-term groundwater development strategy where a number of pumping schemes are simulated and tested.
d. The schemes are tested on their effect on the regional drawdown and return flow to the River under present situation of the surface water reclamation on the fringes.
e.

The Following table will summarize the scenarios that will be simulated in the studied area. The table represents the increase in the percentage of pumping in each scenario showing if the increase will be applied on the reclaimed area only or on all the area. The table also shows the irrigation methods used in each scenario in the reclaimed lands.

Table (6.1) summary for applied scenarios

Sc. No.	**Increase in pumping % applied on**		**Irrigation method for reclaimed**
	Reclaimed	**Old land**	
Sc.1	60%	60%	Traditional
Sc.2	250%	250%	Traditional
Sc.3	200%	—	Modern
Sc.4	350%	350%	Modern

6.2.1. First Scenario (Base Scheme):

This scenario represents 60 % increase of pumping of the year 2007 on all the area which is the same rate of increase in pumping from the year 1990 until 2007.

This scenario applies the existing irrigation method (Basin irrigation) which is used currently in the old lands and new reclaimed lands. Figure (6.1) shows the mass balance of the groundwater aquifer for this scenario. Figure (6.2) shows the piezometric heads of the studied area in 2050.

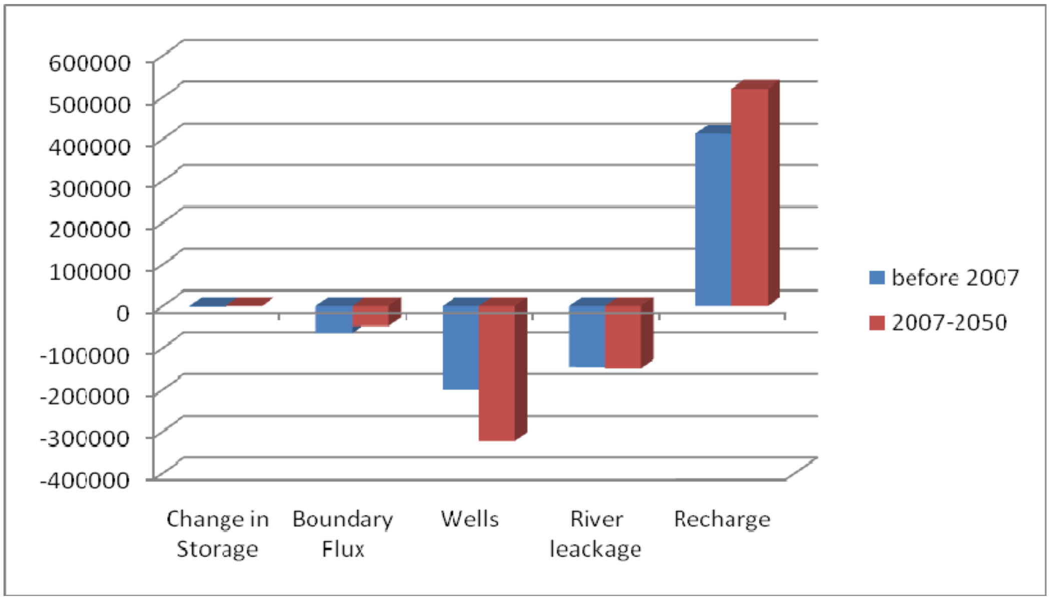


Figure (6.1) Mass Balance for First Scenario in m^3

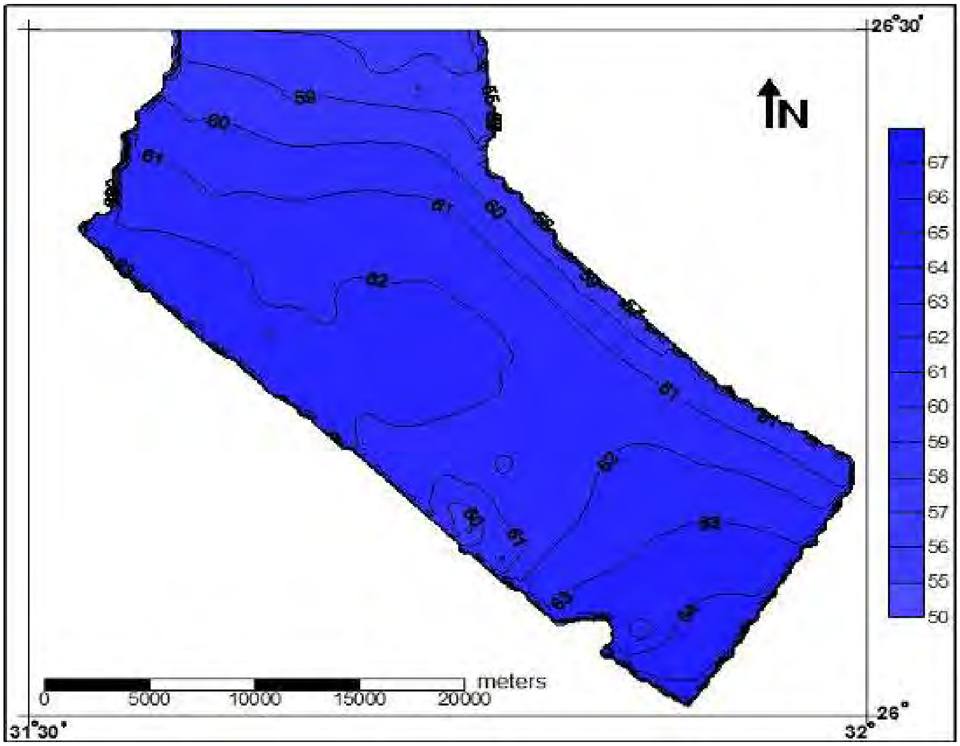


Figure (6.2) Piezometric heads in meters for studied area in the year 2050

The system remains balanced during this scenario with a maximum drawdown of 2 m in the southern part of the reclaimed area keeping the interaction between the River Nile and the Nile aquifer system (River Nile acts as a drain for the aquifer).

This Scenario is suitable for steadily long-term planning resulting in a total reclaimed area of 10,200 feddans.

6.2.2. Second Scenario:

It is a long term scenario with 250 % increase in pumping of 2007 on all the area till the year 2050. This scenario applies the existing irrigation method (basin irrigation) on all the area. This scenario will allow lifting surface water from the adjacent old lands to the reclaimed dessert lands to recover the drawdown due to the increase of pumping. This amount of surface water will be substituted by groundwater well fields for command irrigation area in old land similar to Tanda well field in El Minia Governorate. This scenario will keep the interacting relation between the River Nile and the Nile aquifer system where the River is acting as a drain, allowing the total reclaimed area to reach 20,000 feddans.

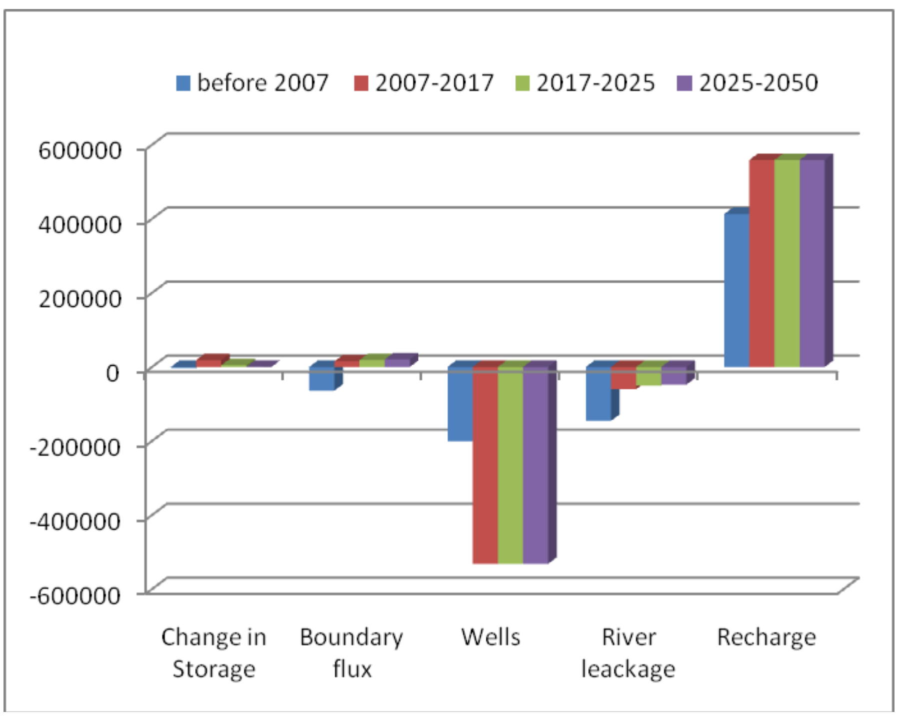


Figure (6.3) Mass Balance for Second Scenario in m^3

Figure (6.3) shows the mass balance of the groundwater aquifer for this scenario. Figures (6.4), (6.5), and (6.6) show the simulated drawdown in the study area under the purposed scenario in years 2017, 2025, and 2050.

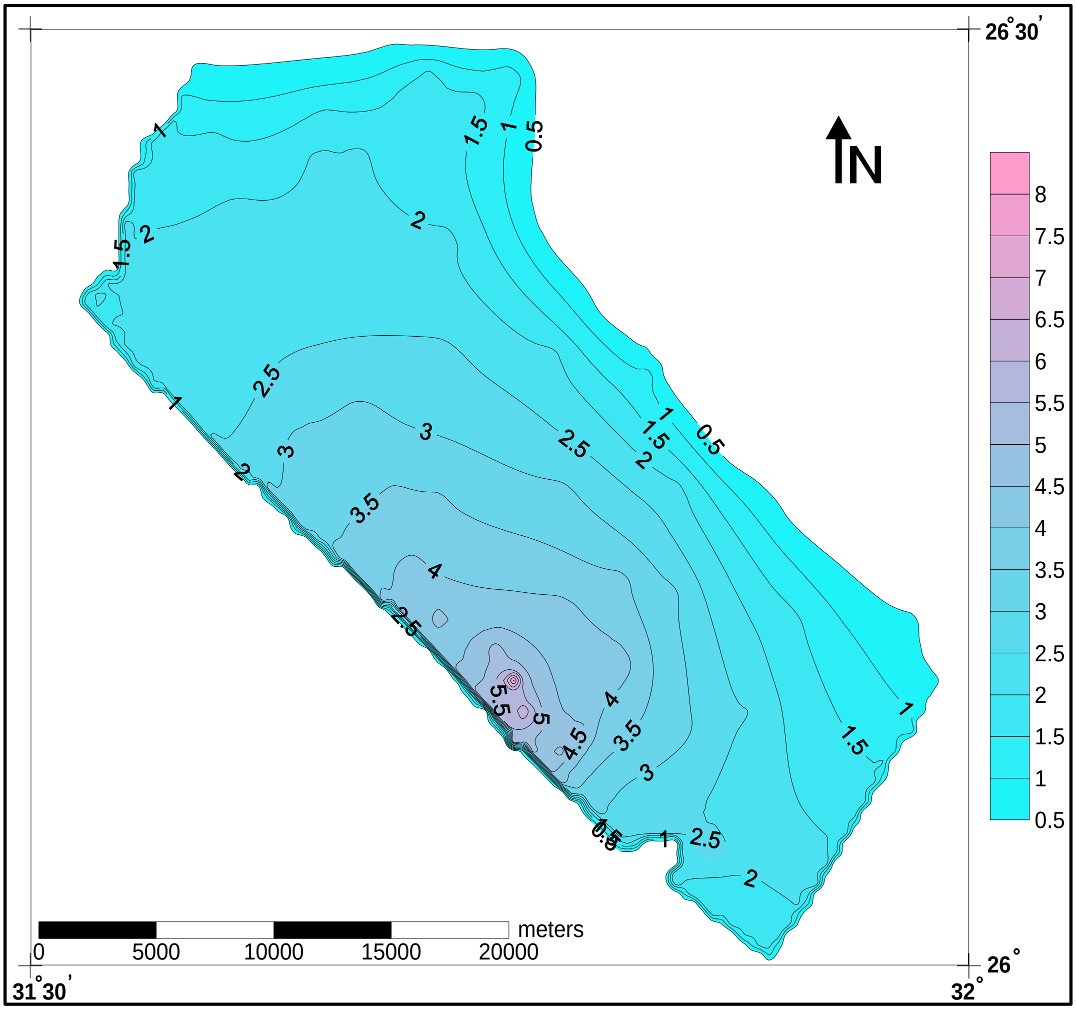


Figure (6.4) Drawdown in meters for second scenario in the year 2017

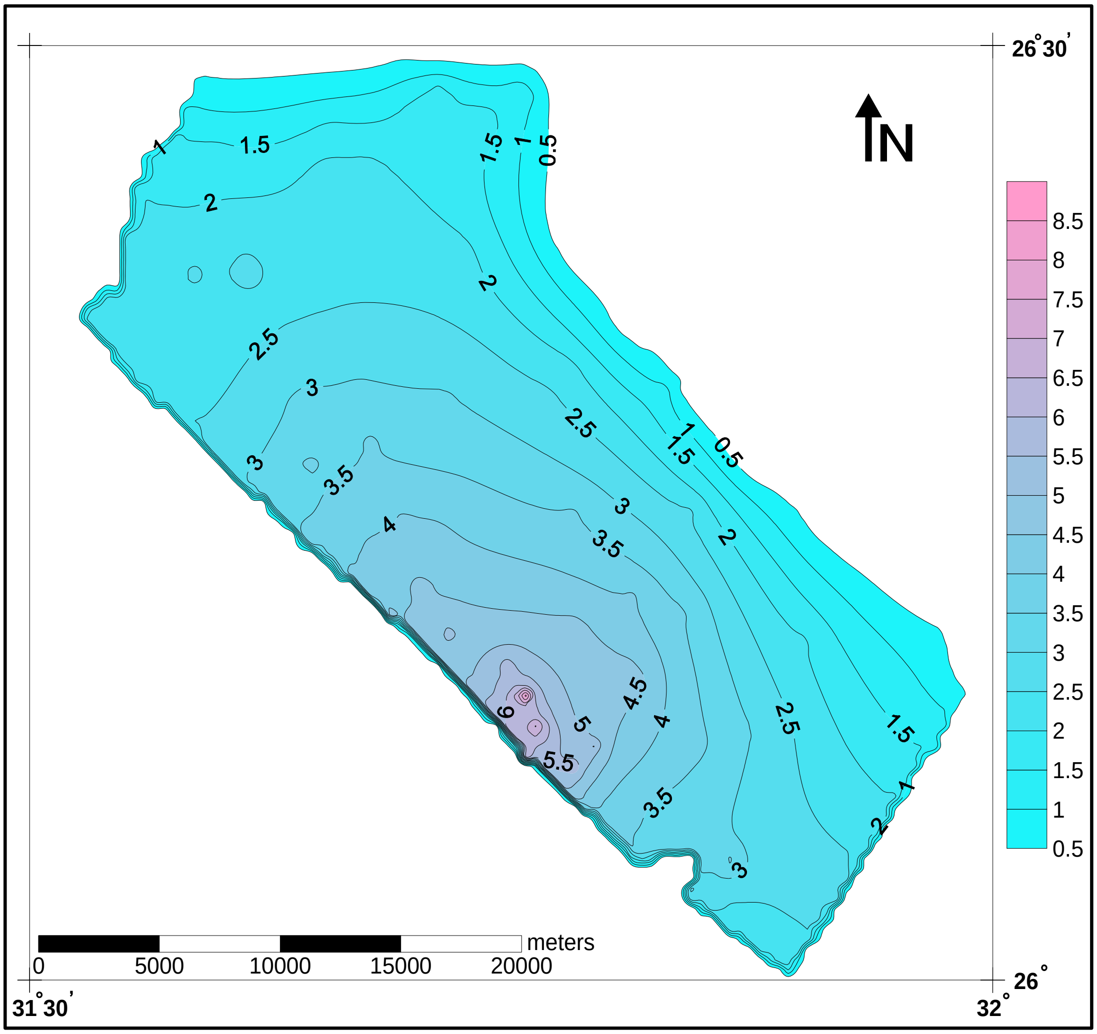


Figure (6.5) Drawdown in meters for second scenario in the year 2025

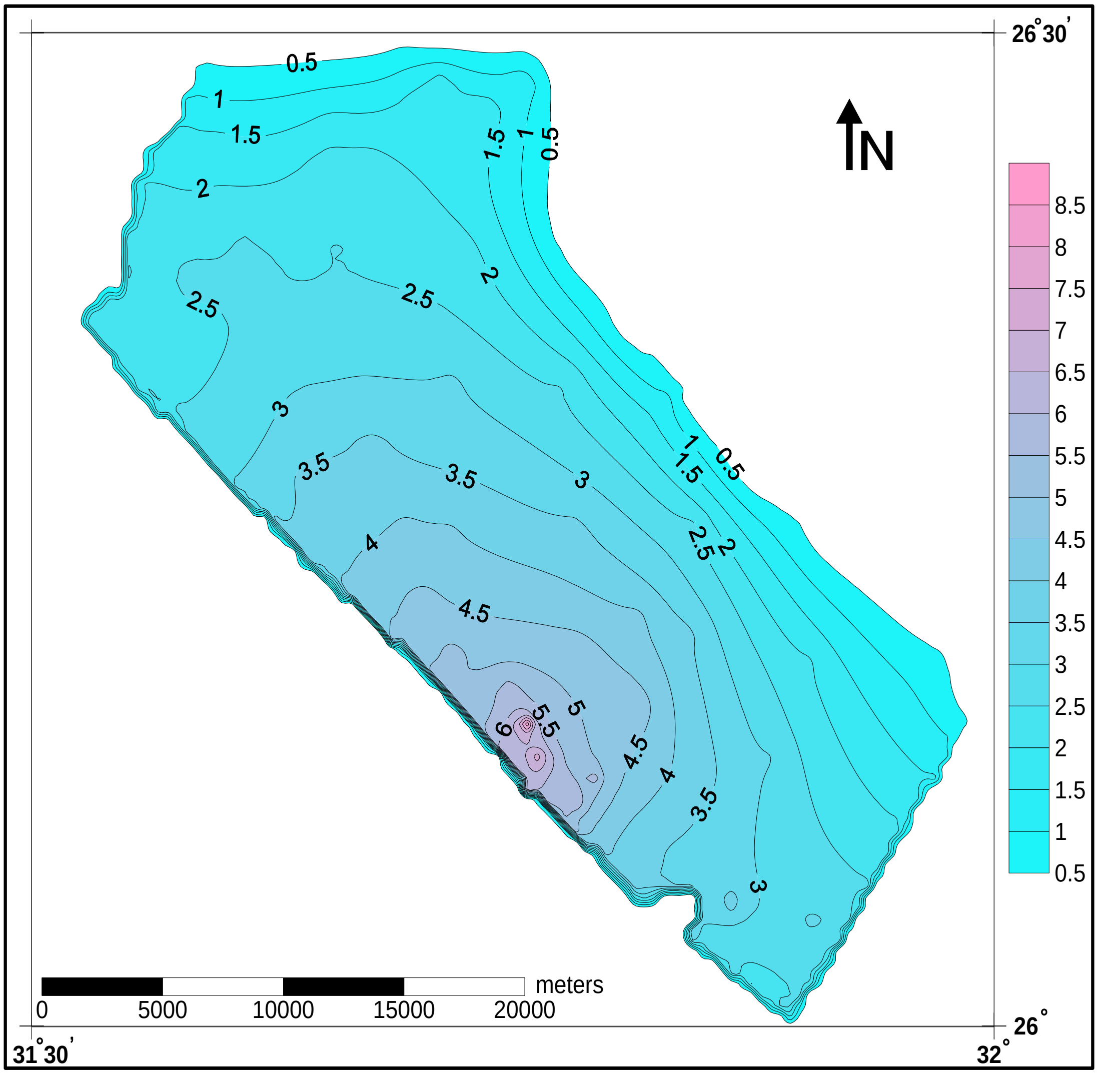


Figure (6.6) Drawdown in meters for second scenario in the year 2050

The basin irrigation method is compensating part of the resulted drawdown which is about 4 m except in a small portion reaching 8.5 m at the edge of the reclaimed lands. This is a good scenario in keeping the system balanced with some misused water in the applied irrigation method, although it acts as an indirect source of recharging the aquifer.

6.2.3. Third Scenario:

It is considered a long term phased groundwater development strategy with 200% increase in pumping of the year 2007 on the reclaimed area only. This scenario assumes applying “modern irrigation methods” in the reclaimed lands to fulfill the Improvement Irrigation Program of the MWRI as it saves 40 % of the used water. Using modern irrigation methods in the reclaimed lands is one of the effective tools to achieve the future requirement for water and food security.

This scenario sustains the interaction between the River Nile and the Nile aquifer system balanced keeping the River acting as a drain for the aquifer. The scenario allows a total reclaimed land of 25,000 feddans resulting of a drawdown of 12.5 m in a limited portion in the reclaimed lands. Figure (6.7) shows the mass balance of the groundwater aquifer for this scenario. Figures (6.8), (6.9), and (6.10) show the simulated drawdown in the study area under the purposed scenario in years 2017, 2025, and 2050.

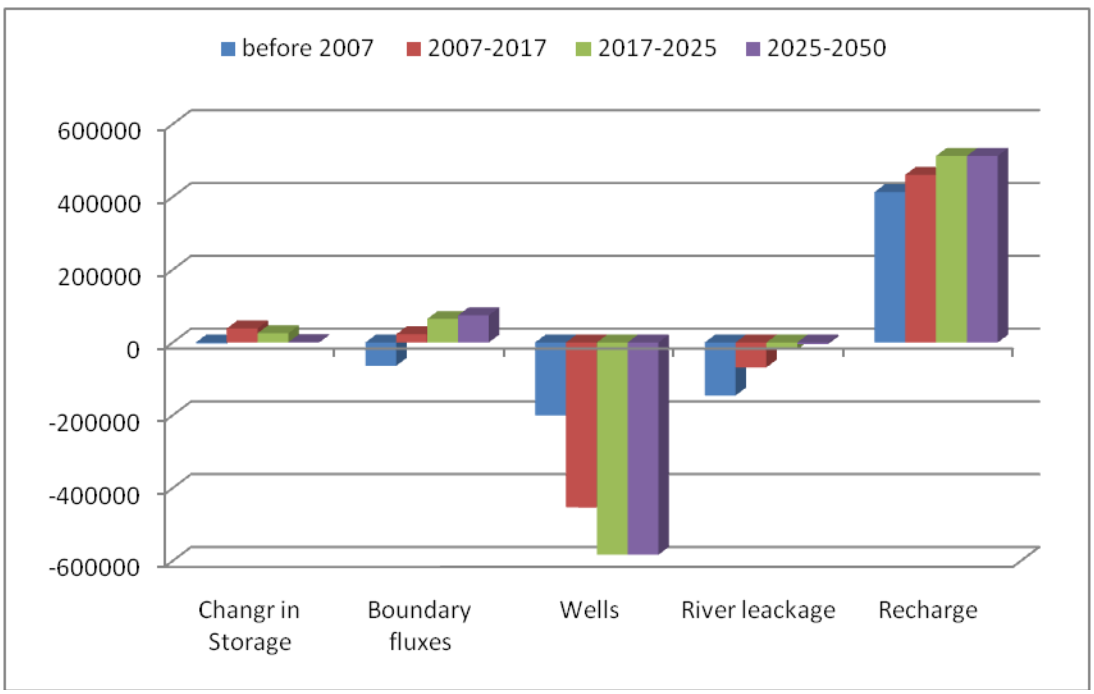


Figure (6.7) Mass Balance in m^3 for third Scenario

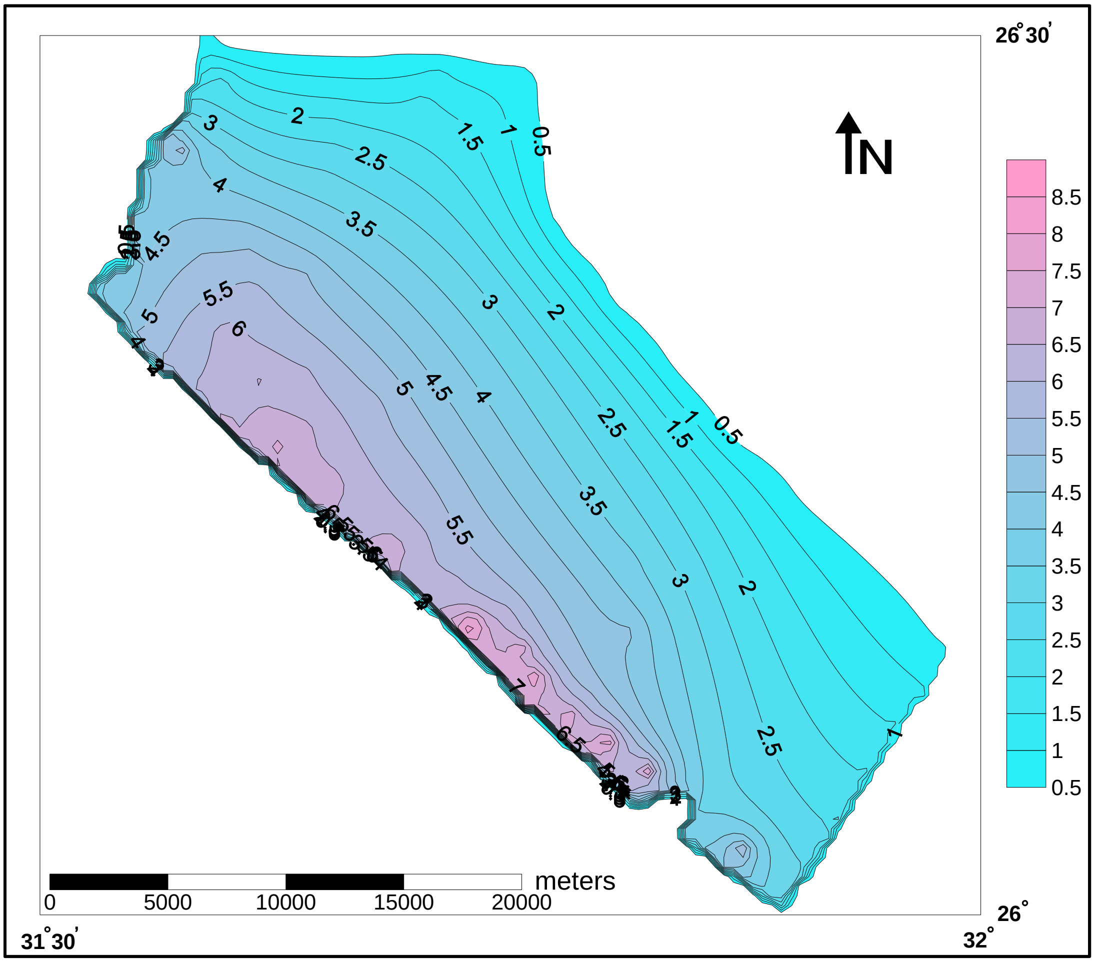


Figure (6.8) Drawdown in meters for third scenario in the year 2017

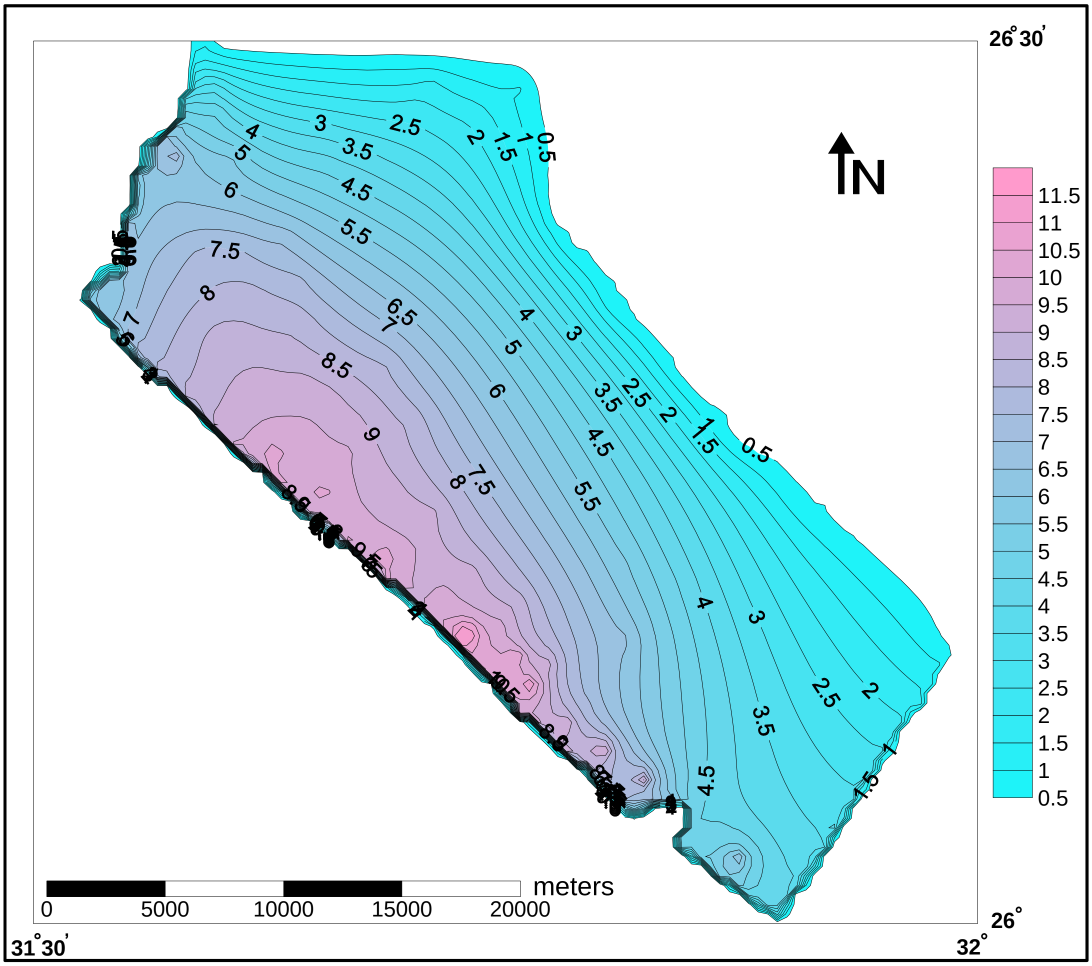


Figure (6.9) Drawdown in meters for third scenario in the year 2025

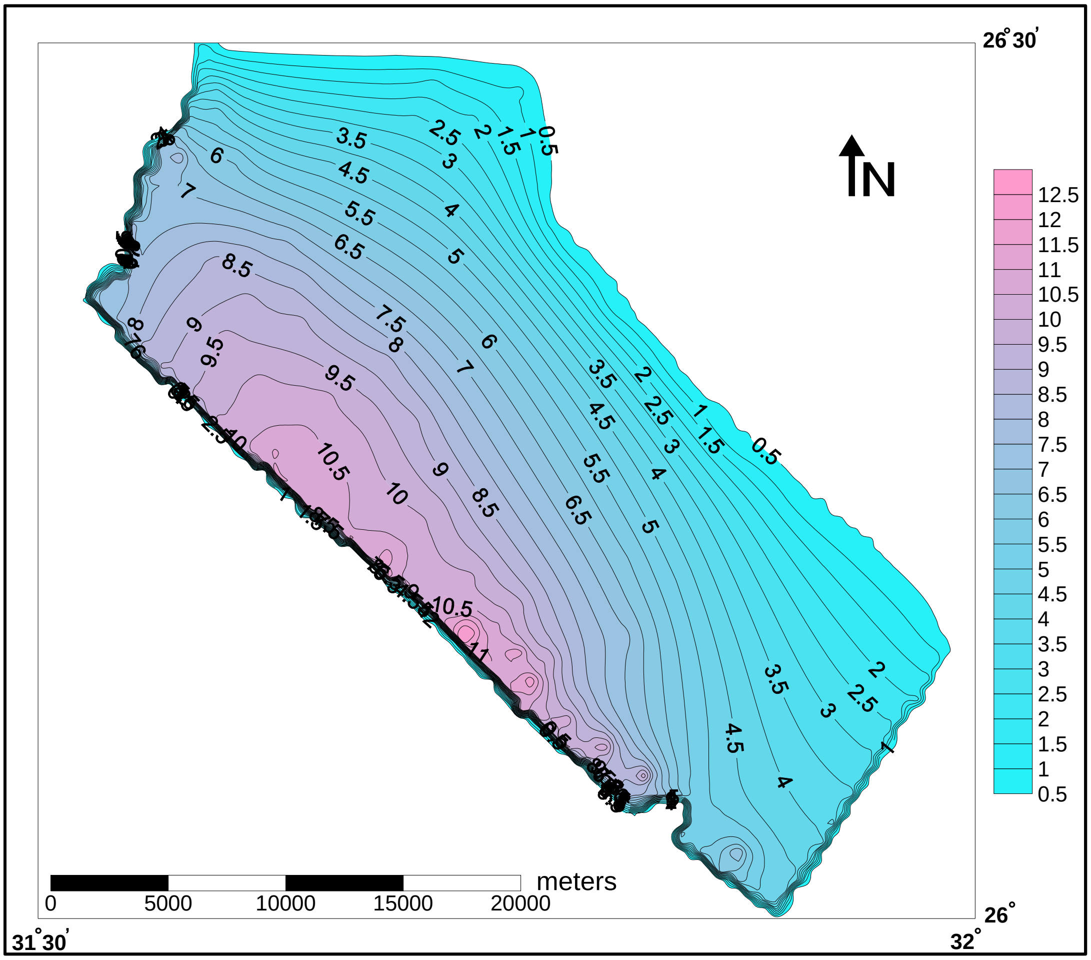


Figure (6.10) Drawdown in meters for third scenario in the year 2050

6.2.4. Fourth Scenario:

It is a long term groundwater development strategy with 350% increase in pumping of the year 2007 on all the studied area assuming new irrigation methods in the reclaimed lands. This scenario applies conjunctive use of surface water and groundwater in the old lands to reallocate the saved surface water for New National Projects and/or climatic changes that may result in decreasing in the Nile water. The mass balance of the groundwater aquifer for this scenario, shown in Figure (6.11), shows that the behavior of the River Nile has changed from being a drain to become a recharging source to the aquifer in the year 2017. To avoid the discharging of the River Nile water into the aquifer, the development has to stop after phase one (250% increase in pumping of the year 2007 through 2050) and to avoid the predicted drawdown that can reach 16 m, And to allow the aquifer a chance to recover. Figures (6.12), (6.13), and (6.14) show the simulated drawdown in the study area under the purposed scenario in years 2017, 2025, and 2050.

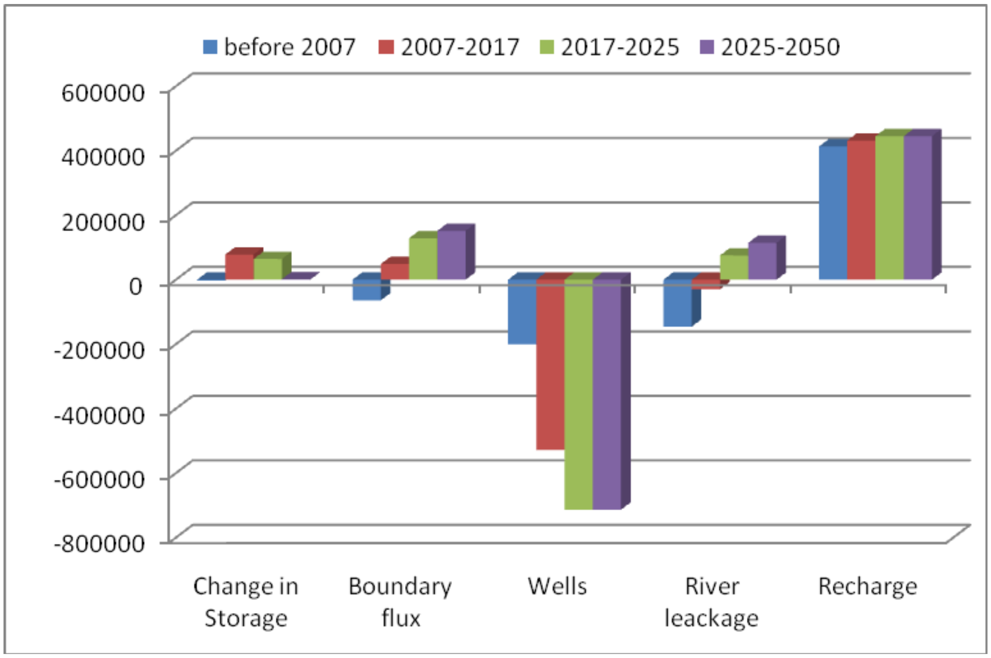


Figure (6.11) Mass Balance in m^3 for Fourth Scenario

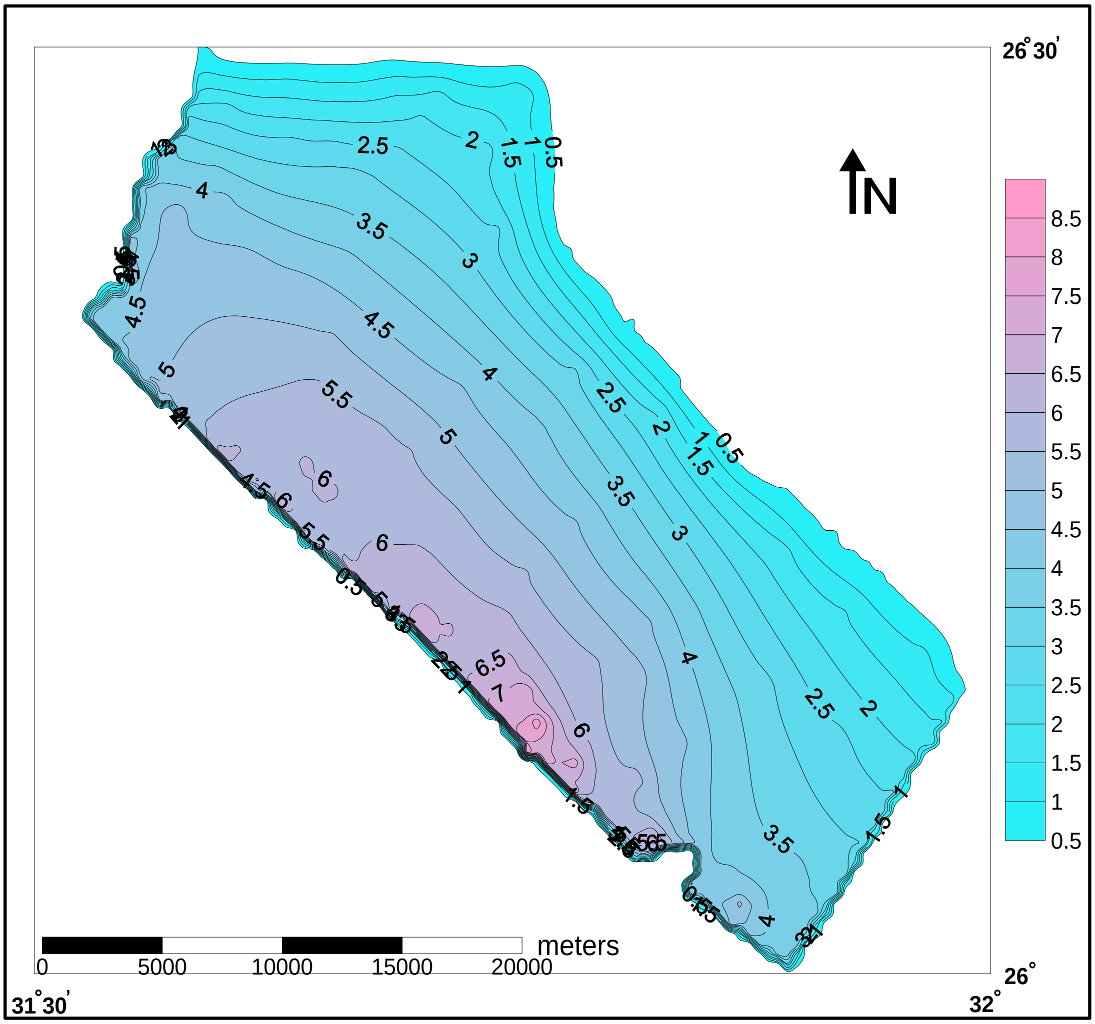


Figure (6.12) Drawdown in meters for Fourth scenario in the year 2017

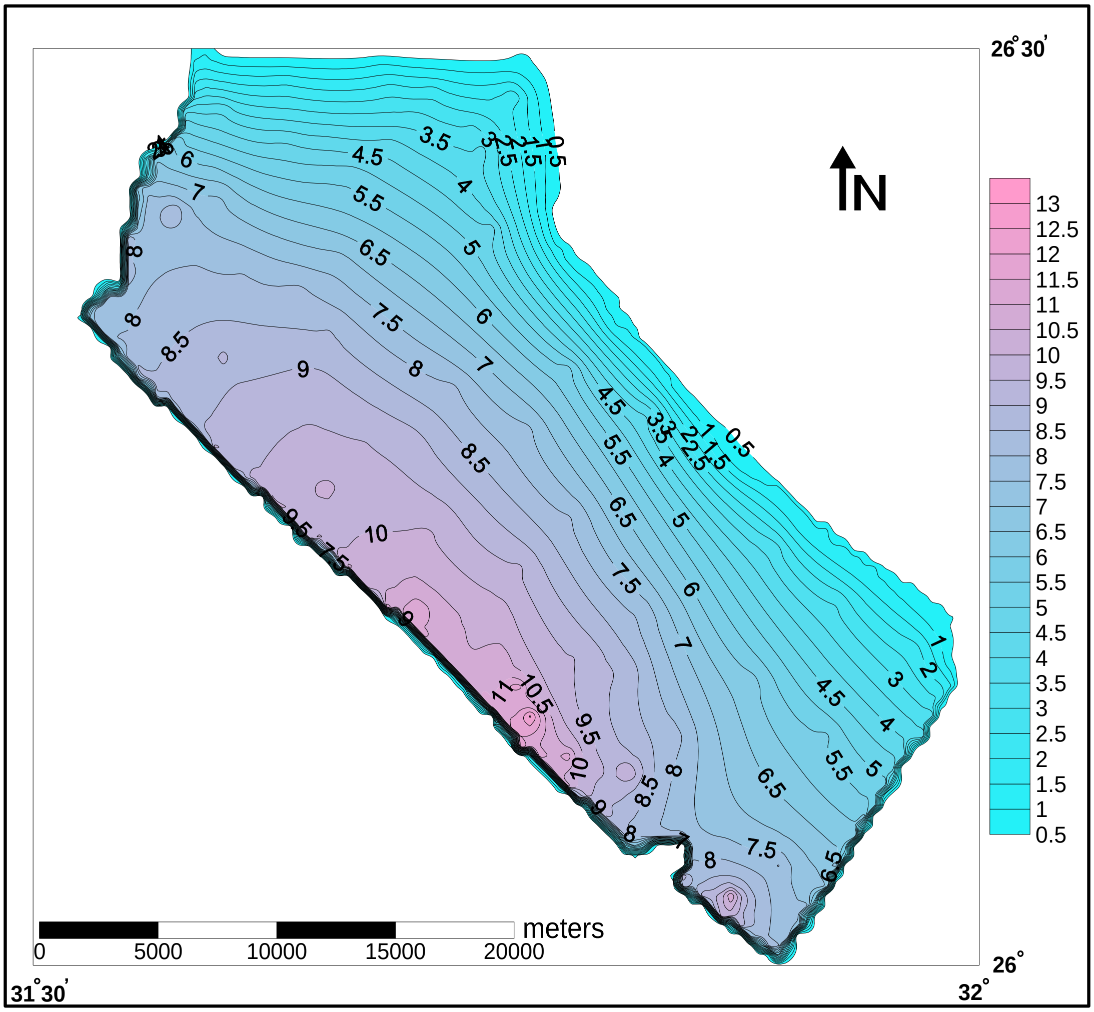


Figure (6.13) Drawdown in meters for fourth scenario in the year 2025

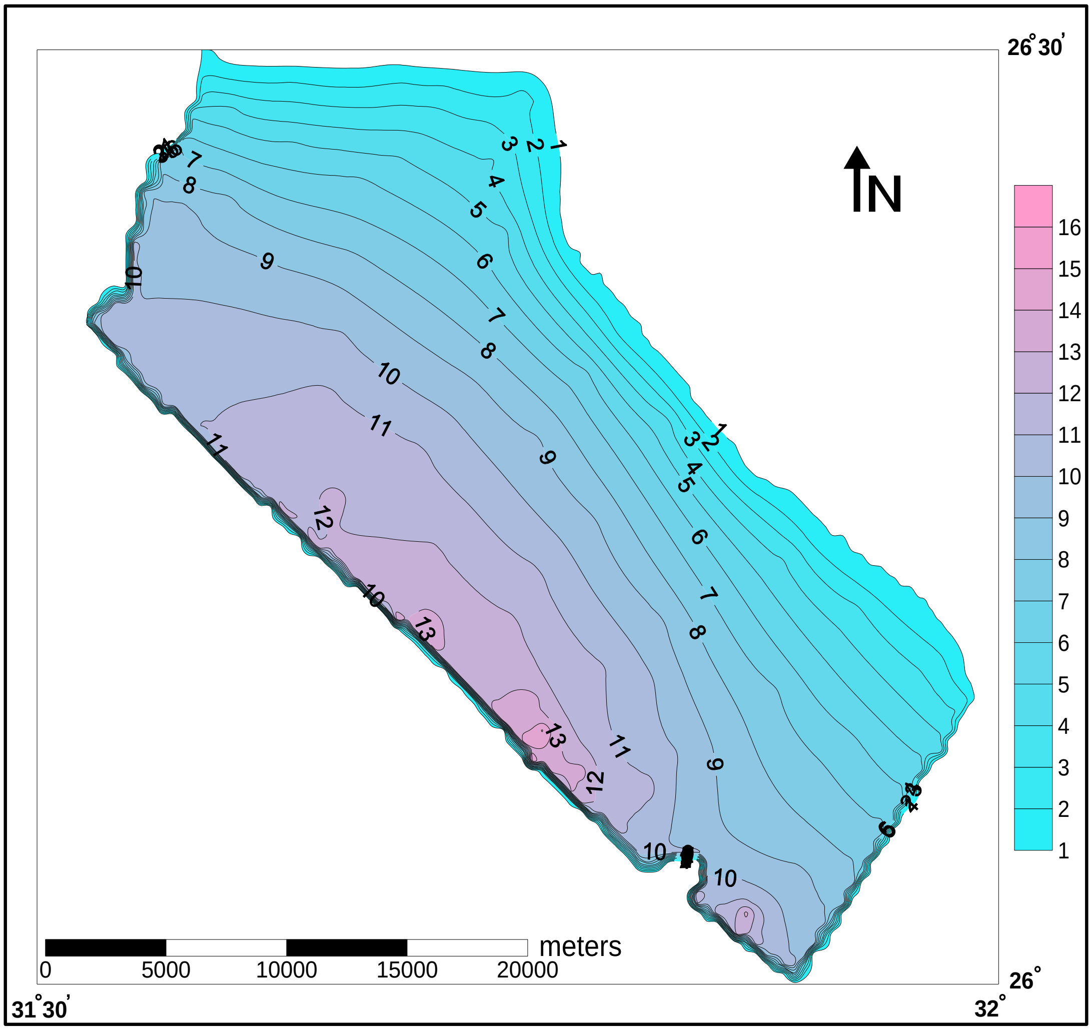


Figure (6.14) Drawdown in meters for fourth scenario in the year 2050

6.3. Impact of groundwater development on groundwater quality

Regarding the National Water Policy till the year 2017, treated waste water is considered one of the water resources. For the horizontal expansion plans, some of the reclaimed areas will use treated waste water as the source of irrigation. Ministry of Agriculture and Ministry of Environment started planting wood forests on Treated Waste Water. Thirteen forests have been planted till now in the Nile Valley and the Delta. The study simulated a farm in the modeled area is irrigated by treated waste water.

Treated waste water farm:

- The farm is located in the reclaimed area.
- The area of the farm is about 800 feddans.
- The farm is irrigated by primary treated waste water with concentration 1000 mg/l
- The model traced the transport of the contaminant under dispersion and advection with time under selected scenarios.

6.4. Particle tracking for the pollutant:

MODPATH engine has been used to track 26 particles that were released at the location of the treated waste water farm. The imaginary paths of water particles moving through the simulated groundwater system were computed with their travel time.

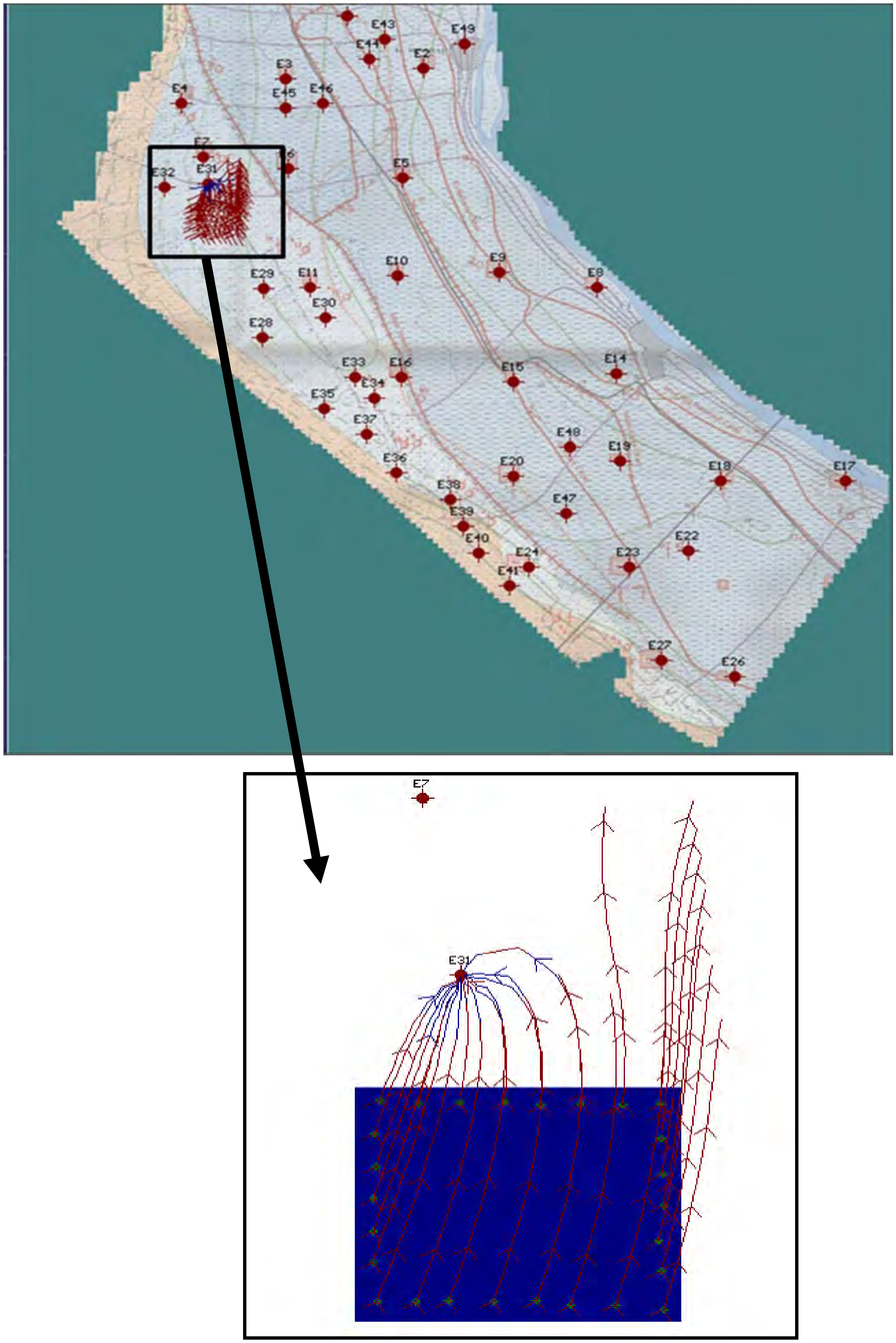


Figure (6.15) Particle paths for the pollutant released in the farm location

The particle tracking using MODPATH shows that particles moves with the main direction of the flow (from south to north) except in the locations where it reaches the radius of influence of a pumping well where, it moves with the pumped flow. Figure (6.15) shows particle paths for the pollutant released in the farm location. It shows the location of the particles in year 2050.

6.5. Quality Scenarios:

MT3D engine has been used to assess the groundwater quality. The change in concentration of the studied pollutant (constant concentration = 1000 mg/l found in the irrigation water) was studied under the effect of advection and dispersion.

6.5.1. First Scenario:

The first quality scenario was applied on the first scenario for the flow (base scheme - 60% increase in pumping of the year 2007).The results showed that 10% of the pollutant concentration is found in the irrigation water that reaches the nearest well in the year 2050 after travelling a distance of 950 m. The 10% concentration reached a depth of 45.7 m. Figure (6.16) shows the degradation of the contaminant concentration and Figure (6.17) shows a cross section for the migration of the pollutant in the main direction of the flow (south to north).

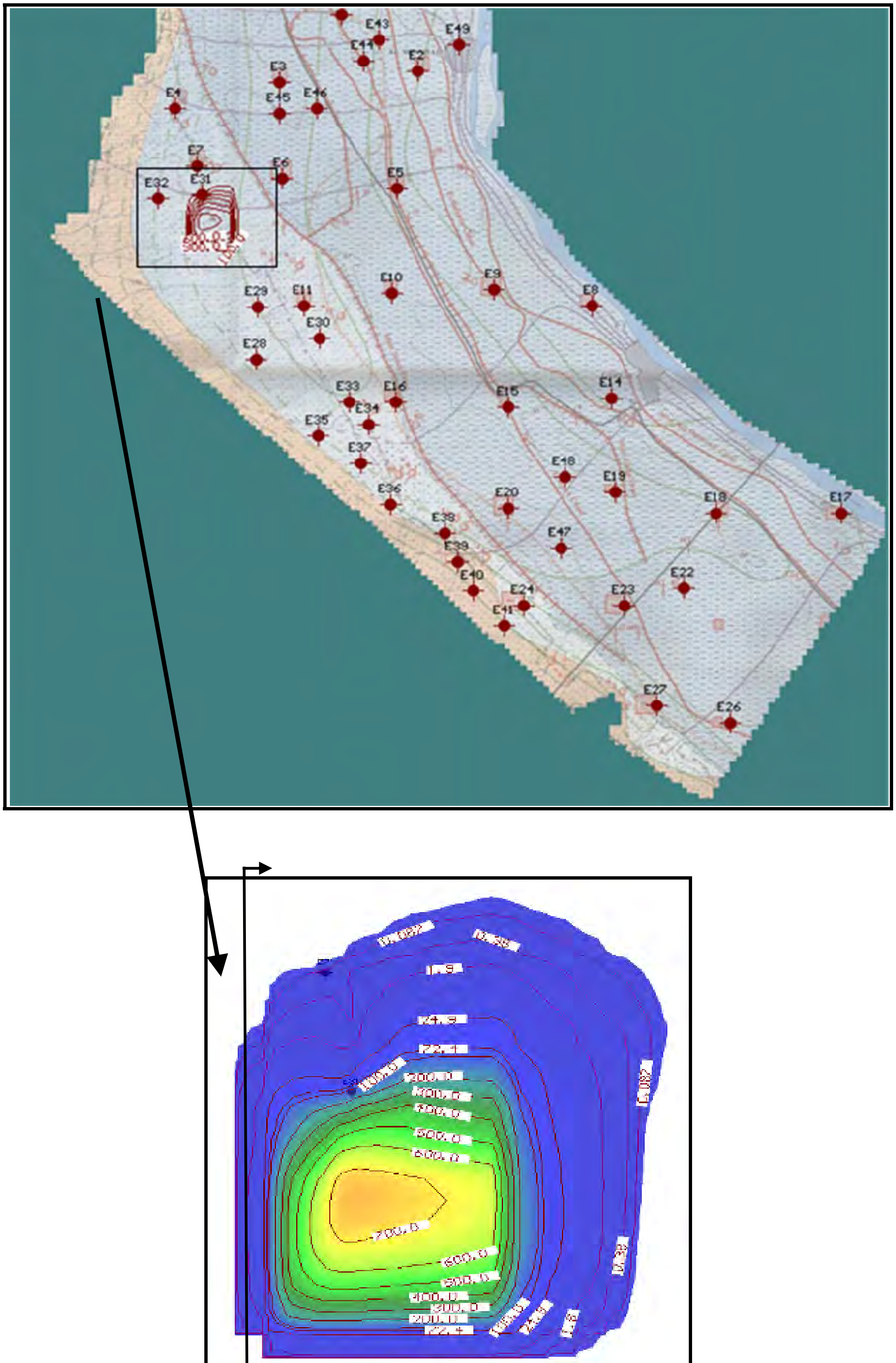


Figure (6.16) Shows the degradation of the contaminant concentration

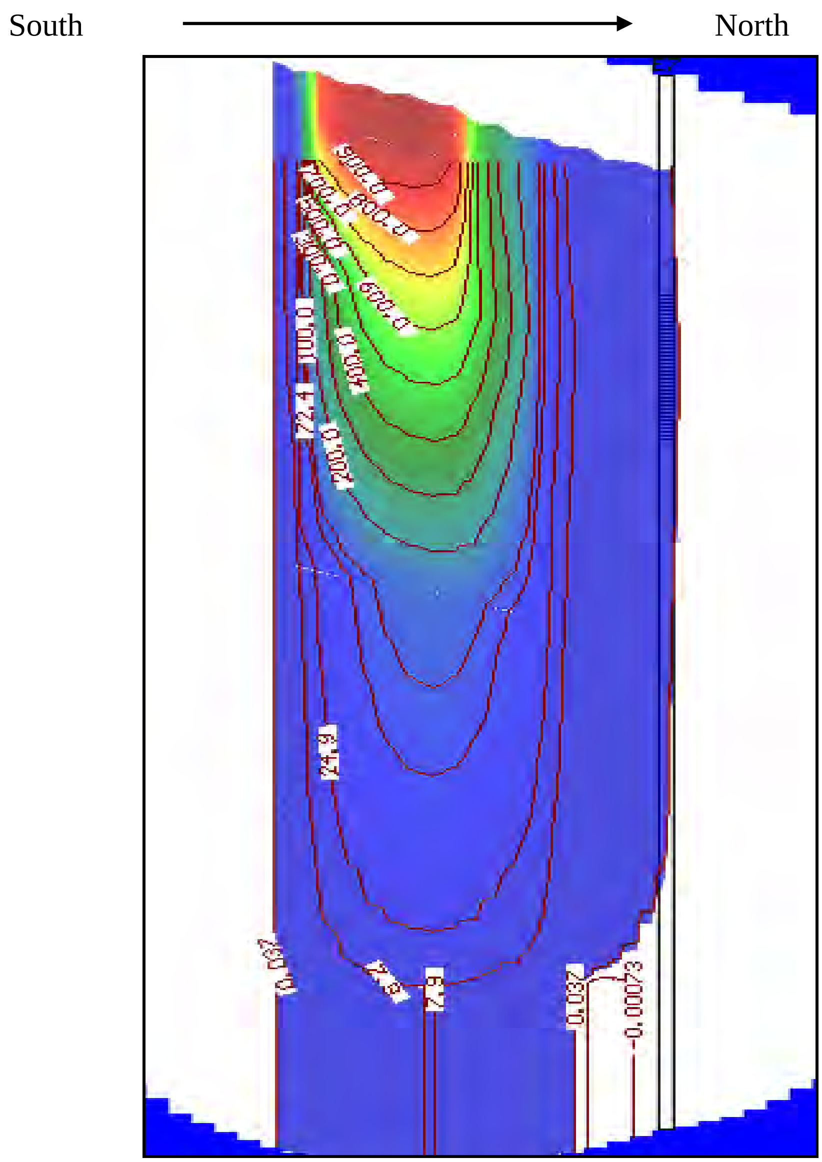


Figure (6.17) Cross section for the migration of the pollutant

The contaminant faded under the effect of dispersion and advection after 2.26 Km in the lateral direction and 1.32 Km in the transverse direction.

6.5.2. Second Scenario:

The second quality scenario was applied on the third flow scenario (250% increases in pumping of 2007 on all the area). The results showed that 10% of the pollutant concentration found in the irrigation water reached the nearest well in 2050 after travelling a distance of 0.95 km. The 10% concentration reached a depth of 71.9 m. Figure (6.18) shows the degradation of the concentration and Figure (6.19) shows a cross section for the migration of the pollutant in the main direction of the flow (south to north).

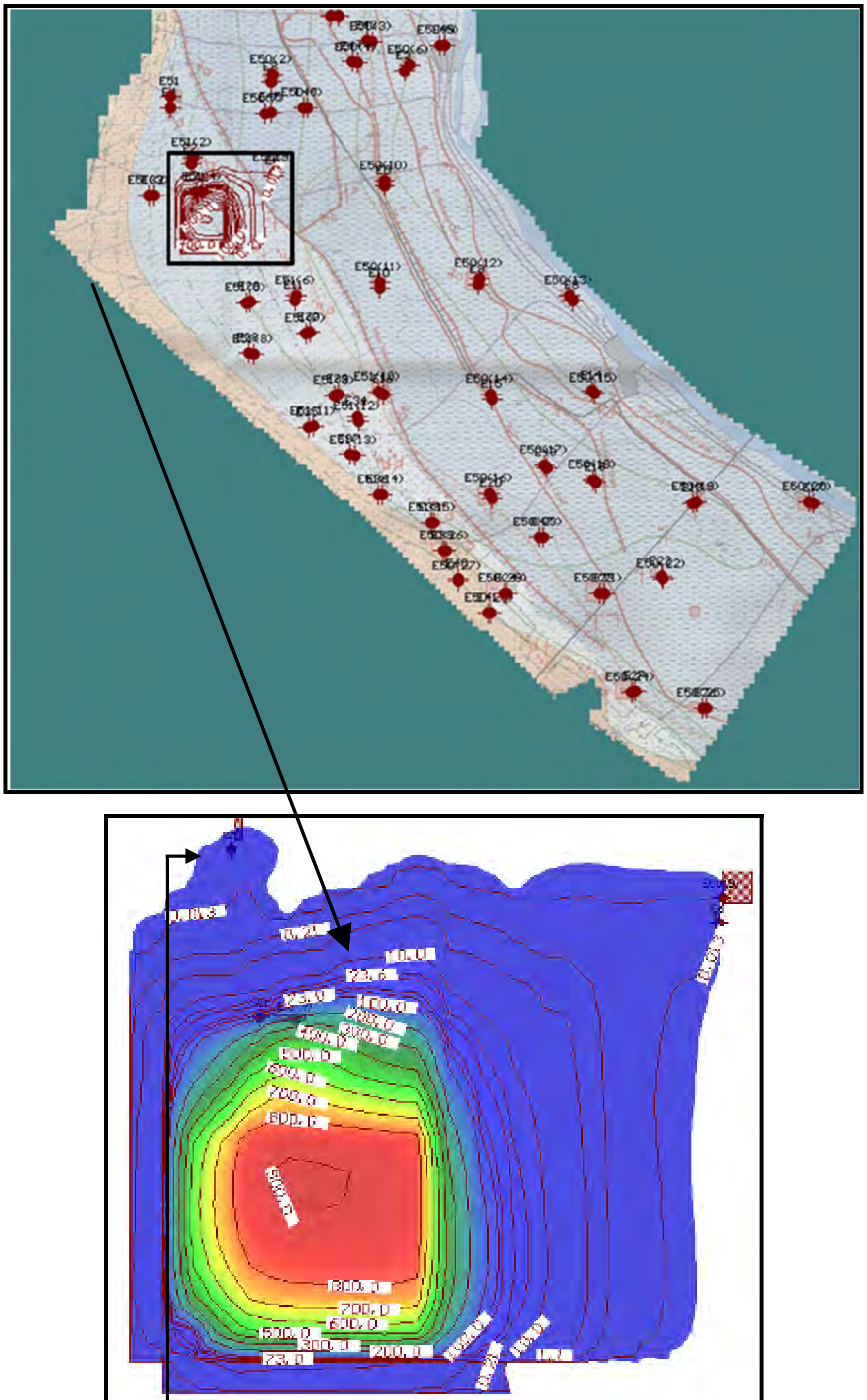


Figure (6.18) Shows the degradation of the contaminant concentration

The contaminant faded under the effect of Dispersion and Advection after 2.24 Km in the lateral direction and 2.23 Km in the transverse direction.

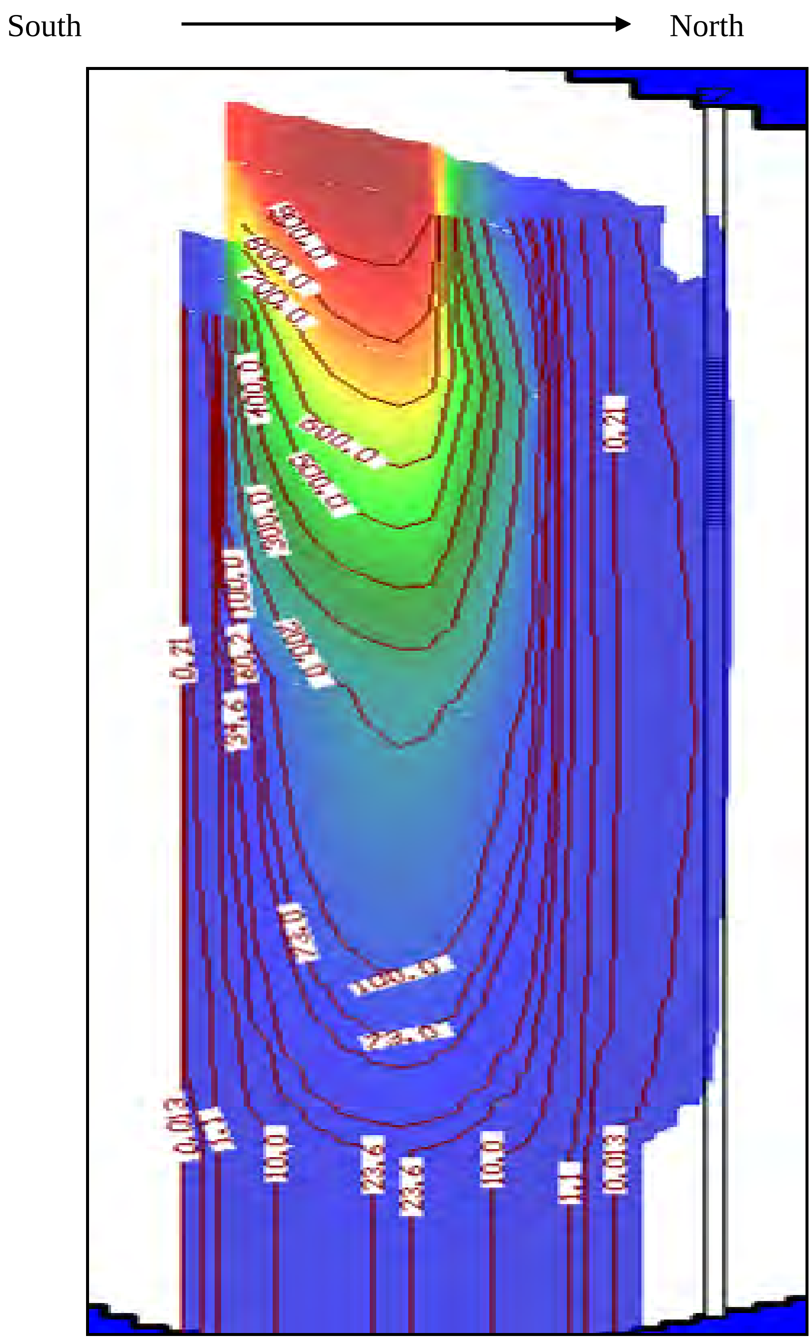


Figure (6.19) Cross section for the migration of the pollutant

Chapter seven

Conclusions and Recommendation

7.1. Summary:

Populated areas are confined to the Nile banks of the Valley and Delta where most of the facilities are available; thus resulting in a continuous stress on the available land and water resources within these areas. The Egyptian government has to come up with plans for the expansion in land reclamation activities to secure food for the ever increase in population.

Obviously, most of the land reclamation activities are implemented in the fringes of the Nile Valley and the Delta which characterized by medium to low groundwater potential. This urges the need for groundwater development and management within these areas and avoids any unplanned development activities which could harm the limited groundwater resources and the current land reclamation activities.

To fulfill this objective, comprehensive hydrogeological and geological studies were implemented including a field work including carrying out of several pumping test in order to delineate the hydraulic parameters of the existing aquifer. All these data were assessed and used to feed a numerical model covering the study area which is the latest MODFLOW package, version 4.2.

Several groundwater development schemes were proposed and evaluated, based on the clear understanding of the interaction between the River Nile and the Nile aquifer system, including conjunctive use, reallocating of surface water in the reclaimed area or to be used upstream the study area and assuming different irrigation methods.

The impact of any possible pollutant, which may occur in the reclaimed lands, was studied using MT3D engine. The migration of the pollutant and its change in concentration was simulated to study its impact on the groundwater status.

7.2. Conclusions:

Using MODFlow:

- The purposed four scenarios in this study proved the possibility in increasing the reclaimed area with a range of 10,000 feddans to 30,000 feddans through integrated management strategies.
- The increase in percentage of groundwater pumping ranges between 60 % and 350 % in the purposed scenarios. The resulting drawdown is 2 – 14 m, respectively.
- The increase in pumping should not exceed 350 %, to avoid changing in the interaction between the River Nile and the Nile aquifer system.
- To satisfy the water scarcity, modern irrigation methods (such as dripping irrigation) should be applied in desert reclaimation areas.
- Long term strategies can be implemented through phased development to avoid any extreme changes in the aquifer system and to allow the system a chance to recover.
- Fourth scenario can be implemented only for the first phase (250 % increase till the year 2050) reaching a drawdown of 8.5 m. This scenario can allow a total of water volume of 154 million m^3/yr to be re-allocated for large projects and/or climatic changes that may result in decrease in the Nile water. If this scenario is applied along the Nile Valley, it could save around 3 billion m^3/yr.

Using MT3D engine in studying treated waste water irrigation farm:

- First scenario of the solute transport indicated that only 10% of the pollutant concentration reached the nearest well in the year 2050 after traveling a distance of 950 m and a depth of 45.7 m. The contaminant would vanish at a distance of 2.26 Km in the lateral flow direction and 1.32 Km in the transverse direction.

- Second scenario of contaminant transport from the forest farm showed that the pollutant reached the nearest well with 10% of the pollutant concentration in the year 2050 but reaching a depth of 71.9 m. The contaminant would vanish in the lateral direction after a distance of 2.24 Km like the first scenario but after a distance of 2.23 Km in the transverse direction.
- Results indicated that increasing pumping in the reclaimed lands caused the pollutants to travel further and reach more depths.

Modeling of groundwater flow is helpful to formulate and assess groundwater resources plans for long term strategies and to understand the mechanism of the River Nile and the Nile aquifer system through purposed scenarios to face drought and/or future requirements.

The model is used to assess the impacts of groundwater development strategies to avoid negative impacts before the implementation phase.

The results indicate that the aquifer system in the Nile flood plain area can operate as a storage reservoir for long term and short term, to face water scarcity through different schemes of conjunctive use with surface water.

Results from the model indicate that pumping groundwater from old lands especially adjacent to the reclaimed lands, as conjunctive management, is an effective measure to control water logging and improve the agriculture drainage as it is clear from drawdown of water table in the top layer representing the semi Pervious layer in the floodplain.

7.3. Recommendations:

Based on the results of the purposed groundwater scenarios and the future impact on groundwater drawdown in reclaimed lands:

1. The study recommends supplying the southern zone of the reclaimed area with surface water, based on the horizontal expansion plan of MWR till the year 2017, where it is characterized by the lowest groundwater potential.
2. The study recommends having attention to conjunctive use of groundwater and treated waste water in reclaimed lands as a component of water resources in the national plan, in the year 2017.
3. The study recommends continuing detailed analysis for solute transport and pollutant migration from irrigated area with treated waste water for a certain pollutants under dispersion, retardation, chemical reactions and decay of the pollutants in the horizontal and vertical directions.

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ANNEX 1

Final Results Sheet

Client Name: **Groundwater Research Institute**

Nature of Sample: Water

Serial		1	2	3	4	5	6	7
Sample code		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Date of Arrival		**8/23/2007**						
Physicochemical Parameters								
pH	-----	7.48	7.8	7.14	7.65	8.32	7.1	7.72
Carbonate CO_3	mg/l	0	0	0	0	9.6	0	0
Bicarbonate HCO_3	mg/l	181.7	226	280	287	200	250	260
Total Alkalinity	mg/l	181.7	226	280	287	209.6	250	260
Electrical Conductivity (EC)	mmhos/cm	0.863	0.676	0.82	1.073	0.547	0.725	0.742
Total Dissolved Solids (TDS)	mg/l	537	418	529	664	340	449	456
Major Cations								
Calcium Ca	mg/l	30	28.8	36	45.2	25.6	32.4	33.2
Potassium K	mg/l	20	23	55	31	15	19.6	20
Magnesium Mg	mg/l	21.6	18.48	23.2	42	22.24	30	28.5
Sodium Na	mg/l	120	76	78	96	54	60	65.6
Major Anions								
Chloride Cl	mg/l	175	86.5	89	137	63.1	80.14	91.3
Nitrite NO_2	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Nitrate NO_3	mg/l	<0.2	9.28	54.7	12.6	0.2	2.3	5.36
Phoshate PO_4	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sulfate SO_4	mg/l	40	32.74	27.46	66	26.3	33.5	35.3
Trace Metals								

Aluminum Al	mg/l	<0.01	<0.01	<0.01	<0.01	0.024	0.008	<0.01
Arsenic As	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Barium Ba	mg/l	0.149	0.025	0.005	0.005	0.007	0.016	0.019
Cadmium Cd	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt Co	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium Cr	mg/l	<0.002	<0.002	<0.002	0.002	<0.002	0.003	<0.002
Copper Cu	mg/l	0.004	0.021	0.016	0.0206	0.008	0.01	0.009
Iron Fe	mg/l	0.290	0.085	0.215	0.169	0.129	0.217	0.133
Manganese Mn	mg/l	0.241	0.076	.038	0.042	0.0168	0.037	0.041
Nickel Ni	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Lead Pb	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Antimony Sb	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Selenium Se	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Tin Sn	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Strontium Sr	mg/l	0.313	0.065	0.089	0.214	0.067	0.185	0.135
Vanadium V	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc Zn	mg/l	<0.005	0.082	0.084	0.036	<0.005	0.036	0.034

Final Results Sheet

Client Name: **Groundwater Research Institute**

Nature of Sample: Water

Serial		8	9	10	11	12	13	14
Sample code		**8**	**9**	**10**	**11**	**12**	**13**	**14**
Date of Arrival		**8/23/2007**						
Physicochemical Parameters								

pH	-----	7.25	7.27	8.24	8.36	8.4	7.53	7.34
Carbonate CO_{3sz}	mg/l	0	0	0	24	33.6	0	0
Bicarbonate HCO_3	mg/l	225	210	300	316	241	458	359.6
Total Alkalinity	mg/l	225	210	300	340	274.6	458	359.6
Electrical Conductivity (EC)	mmhos/cm	0.608	0.631	0.708	1.567	0.862	3	2.93
Total Dissolved Solids (TDS)	mg/l	373	401	439	974	531	1850	1805
Major Cations								
Calcium Ca	mg/l	27.2	36.4	44	74	50.4	147.2	150
Potassium K	mg/l	13	12.8	12.6	38.16	25.3	33.5	32.8
Magnesium Mg	mg/l	28.6	25.3	34.7	48.16	30.3	43.5	52.8
Sodium Na	mg/l	46	46	45	152	73	405	380
Major Anions								
Chloride Cl	mg/l	58.5	62.34	56.8	179.4	88.9	500	526.6
Nitrite NO_2	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Nitrate NO_3	mg/l	0.4	0.2	<0.2	<0.2	1.97	69.1	56.5
Phoshate PO_4	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sulfate SO_4	mg/l	29.5	50.9	40.7	210	46.5	310.2	296.5
Trace Metals								
Aluminum Al	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Arsenic As	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Barium Ba	mg/l	0.023	0.094	0.068	0.0606	0.062	0.050	0.072
Cadmium Cd	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cobalt Co	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium Cr	mg/l	0.002	<0.002	0.0011	<0.002	<0.002	0.0077	0.014
Copper Cu	mg/l	0.006	0.002	0.006	0.0109	0.0157	0.0139	<0.002

Iron Fe	mg/l	0.176	0.545	0.562	0.493	0.409	0.39	1561
Manganese Mn	mg/l	0.038	0.136	0.140	0.544	0.479	0.0147	0.022
Nickel Ni	mg/l	<0.005	<0.00 5	<0.005	<0.005	<0.005	<0.005	<0.00 5
Lead Pb	mg/l	<0.005	<0.00 5	<0.005	<0.005	<0.005	<0.005	<0.00 5
Antimony Sb	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Selenium Se	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Tin Sn	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Strontium Sr	mg/l	0.175	1.25	0.839	0.648	0.282	1956	5788
Vanadium V	mg/l	<0.005	0.013	0.022	<0.005	<0.005	0.053	<0.00 5
Zinc Zn	mg/l	0.035	0.021	0.0106	<0.005	<0.005	0.0149	0.400

Final Results Sheet

Client Name: **Groundwater Research Institute**

Nature of Sample: Water

Serial		15	16	17	18	19	20	
Sample code		**15**	**16**	**17**	**18**	**19**	**20**	
Date of Arrival		**8/23/2007**						
Physicochemical Parameters								
pH	-----	7.54	7.45	7.43	7.73	7.64	7.88	
Carbonate CO_3	mg/l	0	0	0	0	0	0	
Bicarbonate HCO_3	mg/l	220	253	274	246	488	337	
Total Alkalinity	mg/l	220	253	274	246	488	337	
Electrical Conductivity (EC)	mmhos/cm	1.946	1.711	1.681	1.572	6.81	1.622	
Total Dissolved Solids (TDS)	mg/l	1209	1070	1046	978	4358.4	1014	
Major Cations								
Calcium	mg/l	62.8	66.8	65.2	60	300.4	64.8	

Ca								
Potassium K	mg/l	30	26	24.5	25	47	26.5	
Magnesium Mg	mg/l	55.2	46	50.4	48.3	114.2	51	
Sodium Na	mg/l	265	196	188	170	950	200	
Major Anions								
Chloride Cl	mg/l	390.5	271.4	264.3	239.4	1390	243.1	
Nitrite NO_2	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Nitrate NO_3	mg/l	11.17	1.31	1.04	<0.2	110.5	<0.2	
Phoshate PO_4	mg/l	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	
Sulfate SO_4	mg/l	275	208.8	190	174.6	720.1	181.9	
Trace Metals								
Aluminum Al	mg/l	<0.01	<0.01	0.007	<0.01	<0.01	<0.01	
Arsenic As	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Barium Ba	mg/l	0.052	0.044	0.033	0.085	0.05	0.117	
Cadmium Cd	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	
Cobalt Co	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	
Chromium Cr	mg/l	0.0026	<0.002	<0.002	<0.002	0.032	<0.002	
Copper Cu	mg/l	<0.002	0.003	0.002	<0.002	0.004	0.002	
Iron Fe	mg/l	0.734	0.631	0.794	0.728	2009	0.257	
Manganese Mn	mg/l	0.005	<0.01	<0.01	<0.01	0.006	0.031	
Nickel Ni	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	
Lead Pb	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	
Antimony Sb	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
Selenium Se	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
Tin Sn	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
Strontium	mg/l	3.25	2813	2.73	2089	9.66	0.5421	

Sr								
Vanadium V	mg/l	<0.005	<0.00 5	<0.005	<0.005	<0.005	<0.005	
Zinc Zn	mg/l	0.038	0.037	0.013	<0.005	0.034	0.045	

ANNEX 2

Khallaf village(Souhag) Governerate
Step drawdown test data

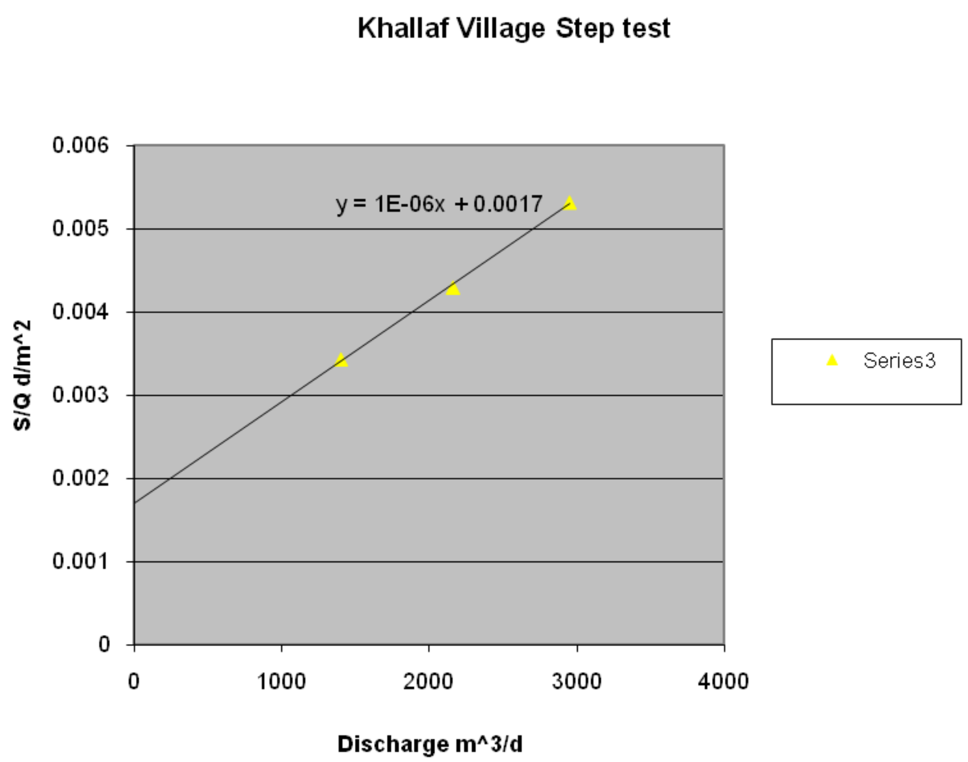
Step 1 Time (min)	Water level (m)	Drawdown (m)	Step 2 Time (min)	Water level (m)	Drawdown (m)	Step 3 Time (min)	Water level (m)	Drawdown (m)
0	46.1	0	0	50.9	4.8	0	55.38	9.28
0.5	48.4	2.3	0.5	53.15	7.05	0.5	58.5	12.4
1	49.3	3.2	1	53.43	7.33	1	59.4	13.3
1.5	49.43	3.33	1.5	53.58	7.48	1.5	59.62	13.52
2	49.5	3.4	2	53.66	7.56	2	59.78	13.68
2.5	49.55	3.45	2.5	53.73	7.63	2.5	59.9	13.8
3	49.6	3.5	3	53.78	7.68	3	59.98	13.88
3.5	49.65	3.55	3.5	53.83	7.73	3.5	60.05	13.95
4	49.68	3.58	4	53.88	7.78	4	60.12	14.02
4.5	49.7	3.6	4.5	53.92	7.82	4.5	60.16	14.06

5	49.72	3.62	5	53.98	7.88	5	60.21	14.11
6	49.74	3.64	6	54.04	7.94	6	60.3	14.2
7	49.75	3.65	7	54.08	7.98	7	60.33	14.23
8	49.77	3.67	8	54.12	8.02	8	60.36	14.26
9	49.79	3.69	9	54.16	8.06	9	60.4	14.3
10	49.81	3.71	10	54.2	8.1	10	60.45	14.35
12	49.84	3.74	12	54.23	8.13	12	60.5	14.4
14	49.88	3.78	14	54.27	8.17	14	60.54	14.44
16	49.93	3.83	16	54.32	8.22	16	60.6	14.5
18	49.98	3.88	18	54.36	8.26	18	60.64	14.54
20	50.02	3.92	20	54.38	8.28	20	60.67	14.57
22	50.04	3.94	22	54.4	8.3	22	60.7	14.6
24	50.06	3.96	24	54.42	8.32	24	60.74	14.64
26	50.08	3.98	26	54.44	8.34	26	60.77	14.67
28	50.26	4.16	28	54.47	8.37	28	60.8	14.7
30	50.12	4.02	30	54.49	8.39	30	60.83	14.73
35	50.15	4.05	35	54.52	8.42	35	60.88	14.78
40	50.18	4.08	40	54.56	8.46	40	60.93	14.83
45	50.21	4.11	45	54.63	8.5	45	60.98	14.88
50	50.26	4.16	50	54.66	8.53	50	61.04	14.94
55	50.3	4.2	55	54.69	8.56	55	61.09	14.99
60	50.33	4.23	60	54.75	8.59	60	61.12	15.02
70	50.39	4.29	70	54.82	8.65	70	61.17	15.07
80	50.43	4.33	80	54.87	8.72	80	61.22	15.1
90	50.46	4.36	90	54.91	8.77	90	61.29	15.19
100	50.5	4.4	100	54.95	8.81	100	61.35	15.25
110	50.54	4.44	110	55	8.85	110	61.42	15.23
120	50.59	4.49	120	55.05	8.9	120	61.46	15.36
130	50.64	4.54	130	55.09	8.95	130	61.52	15.42
140	50.67	4.57	140	55.13	8.99	140	61.56	15.46
150	50.69	4.59	150	55.17	9.03	150	61.59	15.49
160	50.71	4.61	160	55.21	3.07	160	61.63	15.53
170	50.73	4.63	170	55.23	9.11	170	61.66	15.56
180	50.76	4.66	180	55.25	9.15	180	61.69	15.59
190	50.79	4.69	190	55.28	9.18	190	61.71	15.61
200	50.82	4.72	200	55.3	9.2	200	61.73	15.63
210	50.85	4.75	210	55.32	9.22	210	61.75	15.65
220	50.87	4.77	220	55.35	9.25	220	61.77	15.67
230	50.89	4.79	230	55.37	9.27	230	61.79	15.69
240	50.9	4.8	240	55.38	9.28	240	61.8	15.7

S (m)	Q (m²/day)	S/Q
4.8	1400	0.003429
9.28	2160	0.004296
15.7	2950	0.005322

Step	Step 1	Step 2	Step 3
Q (m³/hr)	60	90	123
S (m)	4.8	9.28	15.7
S/Q (m³/d)	0.003429	0.004296	0.005322

S=C=	1.22E-06
B=	1.70E-03


Khallaf Village Step test
y = 1E-06x + 0.0017
S/Q d/m^2
0.006
0.005
0.004
0.003
0.002
0.001
0
0
1000
2000
3000
4000
Discharge m^3/d
Series3