Sustainable Development via Optimal Integration of Surface and Groundwater in Arid Environment: Nile River Quaternary Aquifer Case Study

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Abstract:
Egypt is an arid country with scarce and limited renewable water resources. Water availability is one of the main problems facing the water resources planning, development and management. A reliable source of surface water is limited and groundwater, which is a vital resource, is used to meet the water demand for agricultural purposes. Due to the limitation of the available areas for agriculture, a government policy started to reclaim the highly elevated desert fringes in many locations in Upper Egypt such as Wadi Al Assiuti, West El Fashn Project, West Samalut Project, West Tahta Project, East Luxor reclamation area, and West Esna Project. However, different operation and traditional management practices for meeting water requirements in these areas using unlined surface water canals and traditional flooding irrigation system lead to water logging in the low lying lands causing soil stalinization and water logging problems. Previous studies recommended optimal integration of groundwater with surface water in a conjunctive use system to mitigate this problem. However, there was no detailed analysis and optimization approach to analyze the economic and reliability benefits from different conjunctive use alternatives. In the present study economic assessment of potential and feasible conjunctive use alternatives and planning were explored for Wadi Al Assiuti Area. Quasi 3-D numerical model was developed using TRIWACO Package and GIS based comprehensive database to simulate the steady and transient flow in saturated and unsaturated zones. The calibrated model was used to assess the appropriate scenarios for applying the conjunctive use and assessing these scenarios. An economic-engineering network flow optimization approach was used to analyze the economic and the reliability benefits from different conjunctive use alternatives. It has been found that integrated management under flexible water allocation can generate sustainable development through minimizing the problem of water salinization and the cost of water pumping and consequently economic benefits to the Wadi. The GIS based model has been proven to be an efficient tool for formulating integrated and sustainable management plan. The Quaternary alluvial aquifer system considered as a promising aquifer. About 48,000 m^3/day can be abstracted from two well fields to supply the required water for future development. Monitoring system is required to assess the deep aquifers within the study area.

Keywords: Integrated water resources management, Conjunctive use, Flow model; Surface water/aquifer interaction; Water balance; Aquifer recharge.

1. Introduction

Increasing demand and decreasing water quality have put enormous pressure on the agriculture sector to use its available water resources more efficiently. These pressures are a resulting in increasing the demand for food and inter-sectoral competition for water, from the municipal and industrial sectors. Therefore, in future, irrigation contribution to food security will largely depend on the use of low-quality water in agriculture in addition to renewing efforts to achieve water conservation. Conjunctive water use refers to simultaneous use of surface water and groundwater to meet the increasing demand. Conjunctive management, by contrast, refers to efforts planned at the scheme and basin levels to optimize productivity, equity, and environmental sustainability by simultaneously managing surface and groundwater resources. In many systems and basins, such planning is needed to raise crop water productivity. As a result, groundwater can play a powerful drought-mitigating role when surface and groundwater are managed and used conjunctively.

Along the Nile valley there are many areas were reclaimed in the desert fringes (Dawoud, 1997). One of these areas is Wadi Al Assiuti, where a number of groundwater wells were drilled for irrigation, domestic and industrial uses. The study area is located in the eastern side of the River Nile facing Assiut Town and lies between latitudes 27^{o} and 27^{o} 30$^{/}$ N and longitudes 31^{o} 15$^{/}$ and 31^{o} 45$^{/}$ E as shown in Figure (1). Topographically, the low land ranges between contour lines 50 and 180 m. and it is surrounded by the high land which represents the carbonate plateau. It ranges in elevation between 200 and 450 m above main sea level. Wadi Al Assiuti is one of the largest wadis in Middle Egypt, with a remarkable dry drainage basin, whose main channel reaches about 186 km in length. It includes potential soils where classifications indicated the suitability of the Wadi for agricultural development if irrigation water is available (Elewa, 2008).

The previous studies on Wadi El Assiuti (Yan et al., 2004; Ashmawy and Nassim, 1998 ; RIGW, 2000 ; Dawoud et al., 2006; MWRI, 2001) indicated that the existence of two possible sources of replenishment to the shallow aquifer in the area: 1) Surface water infiltration along the runoff streams through transmission losses which is mainly developed in the Quaternary alluvium aquifer (Dawoud, 1997; Attia, 1989; Warner et al., 1991) and 2) Deep groundwater upward discharge from the Nubian aquifer through deep major faults feeding the Quaternary alluvium aquifer (Yan et al., 2004). The data collected from old production wells drilled by Assiut Governorate and recent observation wells drilled by the Research Institute for Groundwater (RIGW) were evaluated and assessed to calculate the groundwater potentiality. These wells are grouped in three wellfields, as shown in Figure (2). Groundwater abstraction has many advantages such as low cost and readily available water for agricultural, domestic and industrial uses in the new development activities within the Wadi. On the other hand, over abstraction of groundwater has imposed some serious problems due to lowering the water table and groundwater quality deterioration. During the past ten years, the use of groundwater has created some critical issues on the management of groundwater resources within the study area.

Recently, due to land reclamation in Wadi Al Assiuti, it was very important to evaluate and manage both surface water and groundwater using the conjunctive use approach. This will lead to better understanding and assessing the technical, the economic and the environmental impacts resulting from crop substitution/subsidy changes, pumping surface water to the highly elevated reclaimed desert. Conjunctive use planning not only involves development of groundwater resources in addition to surface water resources, but the optimal development of the two considering the land, water and the matrix of dynamic ecological system taking into account the specific spatial and temporal availability and variability of each river basins. Also, their inter linkages and the economics of development and transportation of the total water resources to satisfy the multifarious and often conflicting demands with due consideration of socio-economic technological considerations should be considered. Traditionally in the Nile valley, surface water is managed by the farmers. In the old land, groundwater is only a supplemental water resource for the farmers. Under these conditions, groundwater management is mostly neglected during the last several decades.

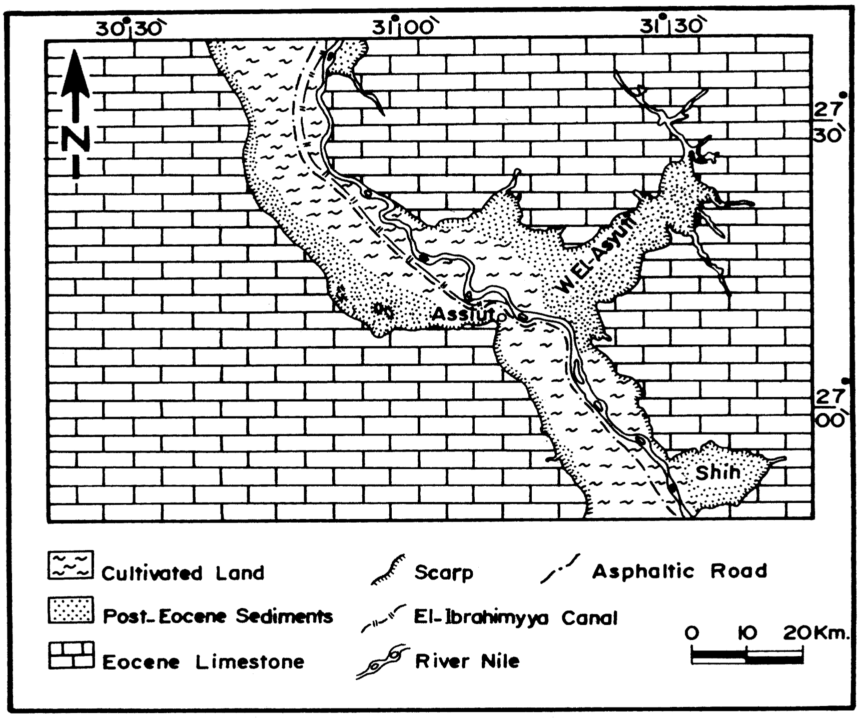

Figure 1: General Location map of the study area.

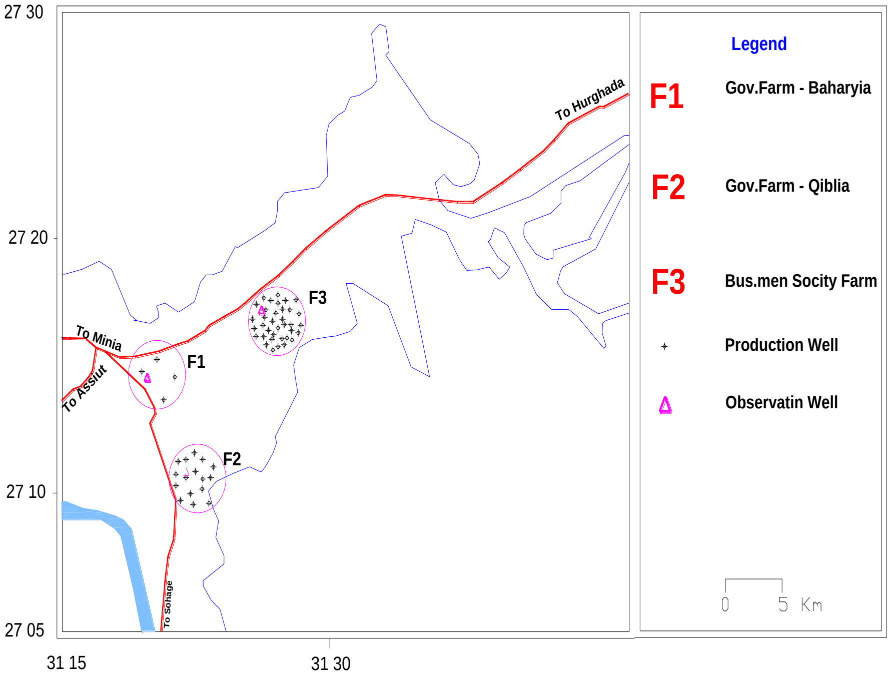

Figure 2: Wells location map of the study area

Conjunctive use of water resources often leads to an increase in the available and utilizable water resources and takes economic advantages in using surface water flowing under gravity and reliability of extensive groundwater resources to overcome the uncertainty of monsoons. Another aspect of conjunctive use deals with the utilization of saline groundwater and surface water to bring down the salinity of mixture within usable limits. In this way, irrigation supplies during crucial periods, when freshwater supplies are lacking or inadequate may be met. Also, this will help to evaluate the hydrological and economic effects of changing irrigation technologies, crop rotations, or drainage infrastructure.

The question of what possibilities exist for more efficient use of groundwater and surface water in these reclaimed desert fringes can be answered. An optimization model was developed as shown in Figure (3). This optimization model was applied to the flow model of the alluvial aquifer to develop withdrawal rates that could be sustained relative to the constraints of critical groundwater area designation. These withdrawal rates form the basis for estimates of sustainable yield from the alluvial aquifer and from surface water canals specified within the alluvial aquifer model. A management problem was formulated as one of maximizing the sustainable yield from all ground-water and surface-water withdrawal cells within limits imposed by plausible withdrawal rates, and within specified constraints involving hydraulic head and stream flow. Steady-state conditions were selected because the maximized withdrawals are intended to represent sustainable yield of the system (a rate that can be maintained indefinitely).

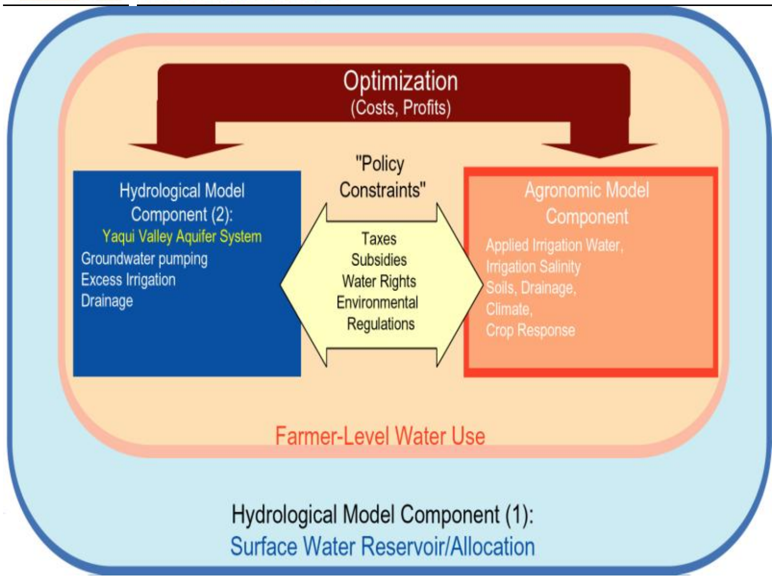

Figure 3: Optimization Model Development

2. Geological Setting

Based on geological map shown in Figure (4), the surface geology is built up of different rock units as follows:

a) *Tertiary rocks:* They are differentiated into two successive horizons which are from top downwards as follows:

- *Paleogene carbonate;* they are represented by G. Tarawan limestone Formation (Paleocene), Wadi Irkas Limestone Formation (L. Eocene), El Minia Limestone Formation (L. to M. Eocene).
- *Neogene carbonate;* they are represented by Alam El Khadem and El Saff limestone Formations (Pliocene).

b) *Quaternary sediments:* They are represented by gravel plains (Pleistocene) and alluvial deposits (Holocene).

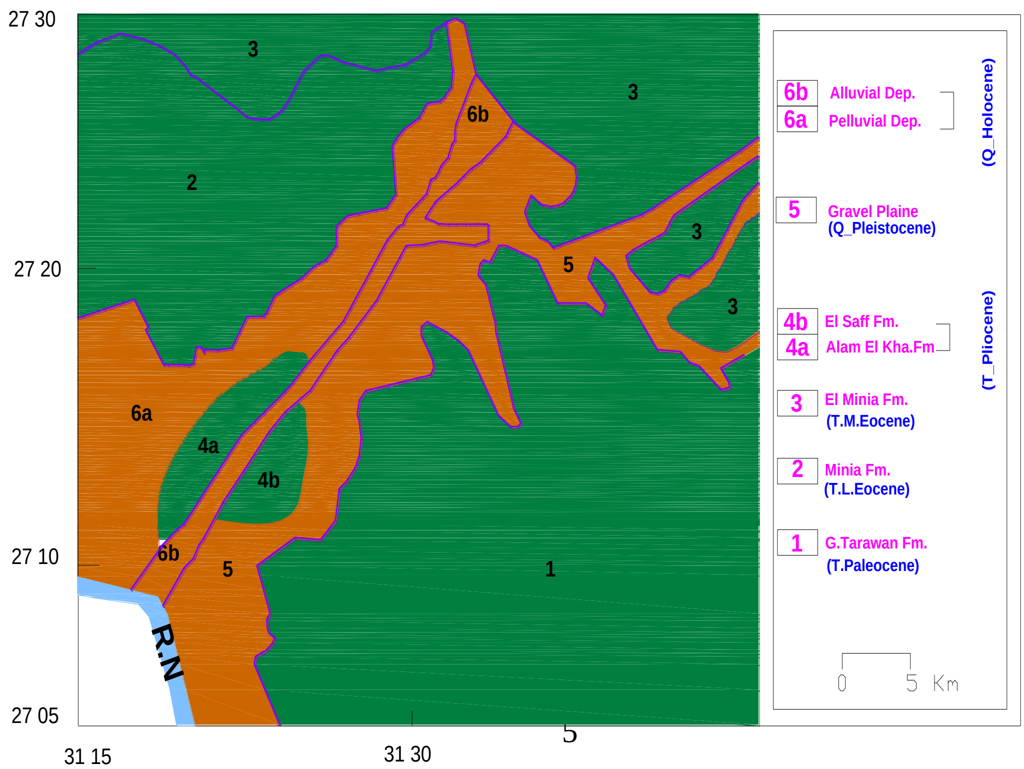

Figure 4: Geological map of the study area

RIGW drilled nine shallow and deep observation wells distributed on three fields: Governorate Bahariya Field (F1), Governorate Qiblia Field (F2) and Businessmen Society Field (F3) as shown in Table (1). In each well field, pz1 tapped the deepest horizon, pz2 tapped the middle horizon and pz3 tapped shallowest horizon. Data of these observation wells in addition to more than 70 production wells in the area of study gave more information about the subsurface geology through well logging, analyses of sedimentary samples as well as geologic cross section as shown in Figure (5).

Table 1: Depth of Piezometric wells.

Field	Piezometric well	Depth (m)
Governorate Bahariya Farm (F1)	Pz1	315
	Pz2	142
	Pz3	70
Governorate Qiblia Farm (F2)	Pz1	250
	Pz2	175
	Pz3	126
Businessmen Society (F3)	Pz1	200
	Pz2	200
	Pz3	600

The subsurface geology is clarified in the area of study, from base to top as in the following:

- The Middle Eocene dolomitic limestone (El Minia Formation.) is recorded only in deep peisometric well pz3 in field no.3 (F3) at depths from 490 to 580 m (thickness is 90 m).
- The Pliocene shale (Alam El Khadem and El Saff Formations) are recorded in all wells, at depths from 200 to 490 m (thickness is 290 m).
- The Quaternary sediments are recorded in all the studied wells. They are represented by three cycles of sediments that change from sandy clay to clayey sand, with a thickness reach to about 200 m. They are consisting of three layers of sand.

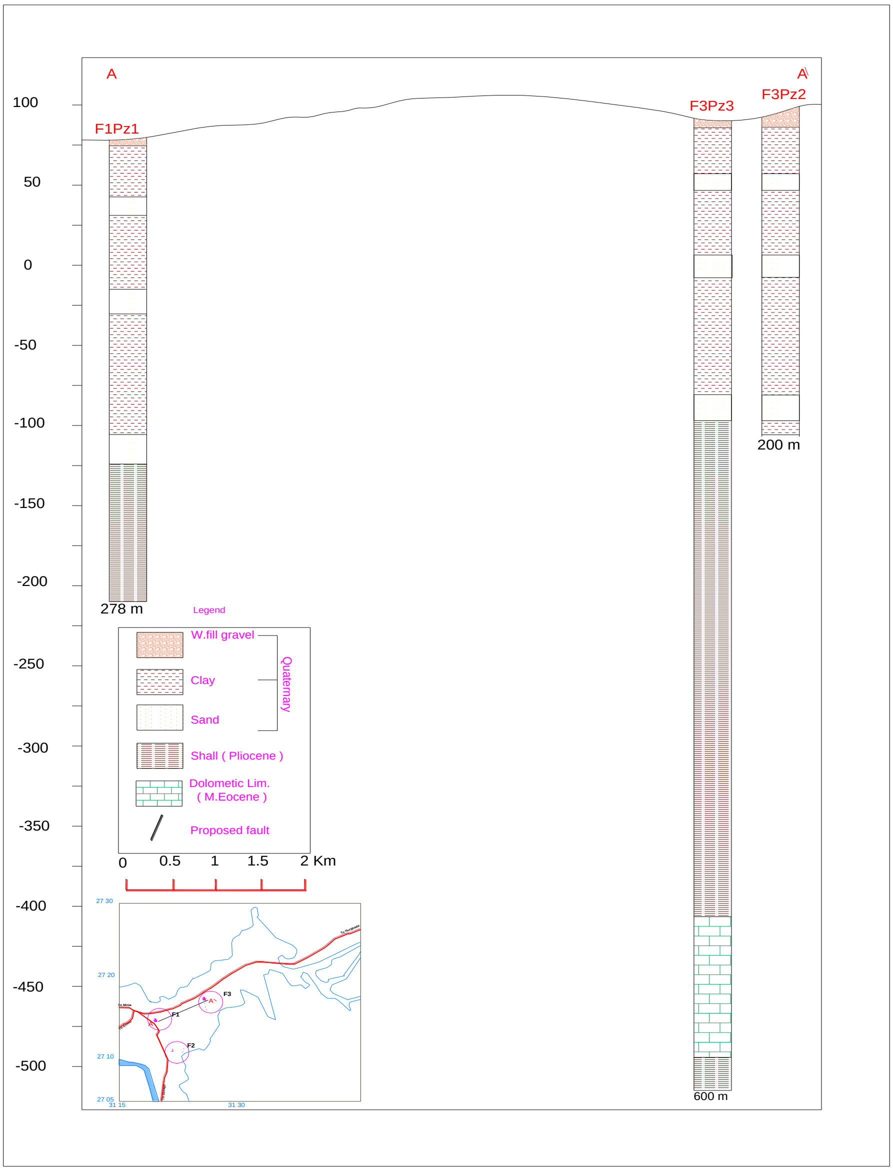

Figure 5: Geological cross section A'-A'

3. Hydrogeological Conditions

The data collected from well logging and composite logs of drilled wells, rock samples of the new observation wells and the aquifer hydraulic parameters, chemical analyses and the hydrogeological cross section were analyzed. The results indicated that there are two main aquifer systems in the study area; the Quaternary granular aquifer system and the Eocene carbonate aquifer system as described below (Abdallah, 2005).

3.1 Aquifer Characteristics

a) Quaternary aquifer

The Quaternary deposits in the study area are considered as semi-confined shallow aquifer in the eastern part which changes to a confined in the western part. It is composed of three water bearing layers as shown in Figures (6).

It is composed mainly of coarse to medium sand in the eastern part and medium to fine sand in the western part. Its thickness varies from about 50 m in the eastern part to about 70 m in the western part. Its salinity varies from about 900 ppm in the eastern part to about 1600 ppm in the western part. The increase of salinity may be due to the affect of leaching processes and the upward leakage from the deep aquifer through fault system. The upward leakage phenomena were recorded by Yan et. al. (2004). They estimated the groundwater recharge by 23000 m^3/day (70 % from Nubian aquifer and 30% from surface runoff). The main source of recharge is from the direct rainfall which falls down over the catchment area and the deep upward leakage from the Nubian sandstone aquifer through deep major faults.

b) Carbonate aquifer

The carbonate beds are exposed on the surface of the study area and represented by the outcrop of Paleogene and Neogene carbonate sediments and also found in sub-surface as Paleogene carbonates. The carbonate layer is recorded only in deep piezometric well (pz3) in field no.3 (F3) at depth 490 – 580 m. It consists of the dolomitic limestone of moderate permeability and can store and transmit water in and through the fissures and fractures. This carbonate layer could be recharged through upward leakage from the Nubian aquifer through deep major faults. It has groundwater salinity reach to 10000 ppm. This excessive salinity may possess marine origin and has the effect of leaching processes.

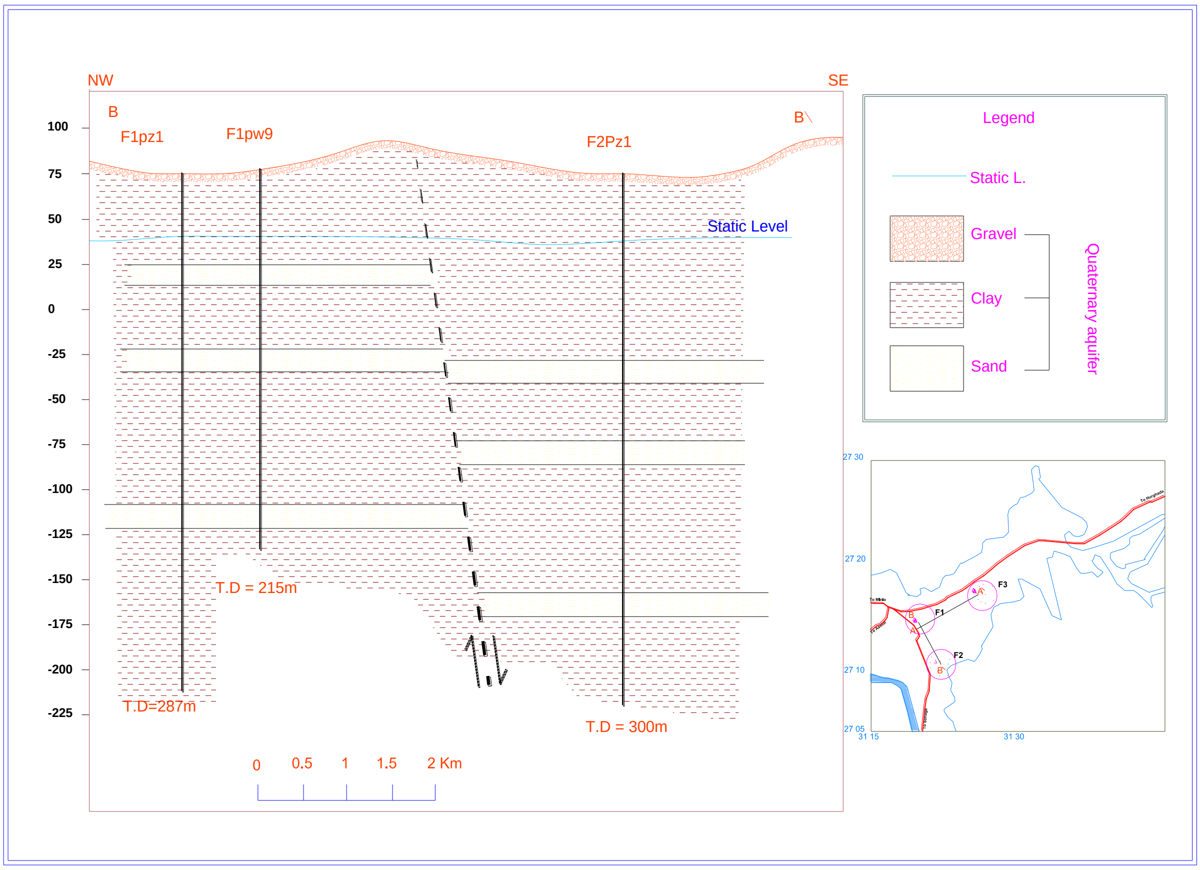

Figure 6: Hydrogeological cross section B-B/

3.2 Groundwater Water Levels

The static water level measurements were obtained from the observation wells in meter and collected in Table (2). These measurements show that the drawdown of static level became more than 2 meters in year due to extraction from upper layer of the second field (F2) and the middle layer of the third field (F3). The water level map of the Quaternary aquifer shows that the groundwater flows from the north eastern part to the south western part of the Wadi El Assiuti, water level change from 54 m above sea level in pw14 in Businessmen society farm (F3) to 33 m above sea level in pw10 in governorate Assiut farm (F1) as shown in Figure (7).

Table (2) Static water depth in Wadi El Assiuti during the years 2001 – 2004.

Field	Piezometric well	2001	2002	2003	2004	Total drawdown (m) 2001-2004	Annual average drawdown
F1	Pz1	31.45	32.57	33.70	34.83	3.83 m	1.13
	Pz2	31.90	32.84	33.78	34.72	2.82 m	0.94
	Pz3	30.79	31.15	31.52	31.89	1.10 m	0.37
F2	Pz1	32.29	34.59	36.90	39.21	6.92 m	2.31
	Pz2	35.78	36.96	38.14	39.32	3.54 m	1.18
	Pz3	35.64	37.38	39.12	40.86	5.22 m	1.74
F3	Pz1	58.19	59.63	61.07	62.51	4.32	1.44
	Pz2	69.00	71.25	73.20	75.30	6.30 m	2.10
	Pz3	63.28	61.70	60.18	59.66	--------	------

3.3 Aquifer Hydraulic Parameters

The main aquifer system is the Quaternary deposits. Pumping tests were performed to determine the hydraulic parameters of this aquifer. The pumping tests were carried out by RIGW in the three well fields, where three observation wells of 4" diameter were drilled at different depths around the production wells of 10" diameter which are located at different distances from it. The transmissivity was obtained from the analysis of the pumping test data by a continuous pumping test (24 hours duration) using Jacob's method as shown in Table (3).

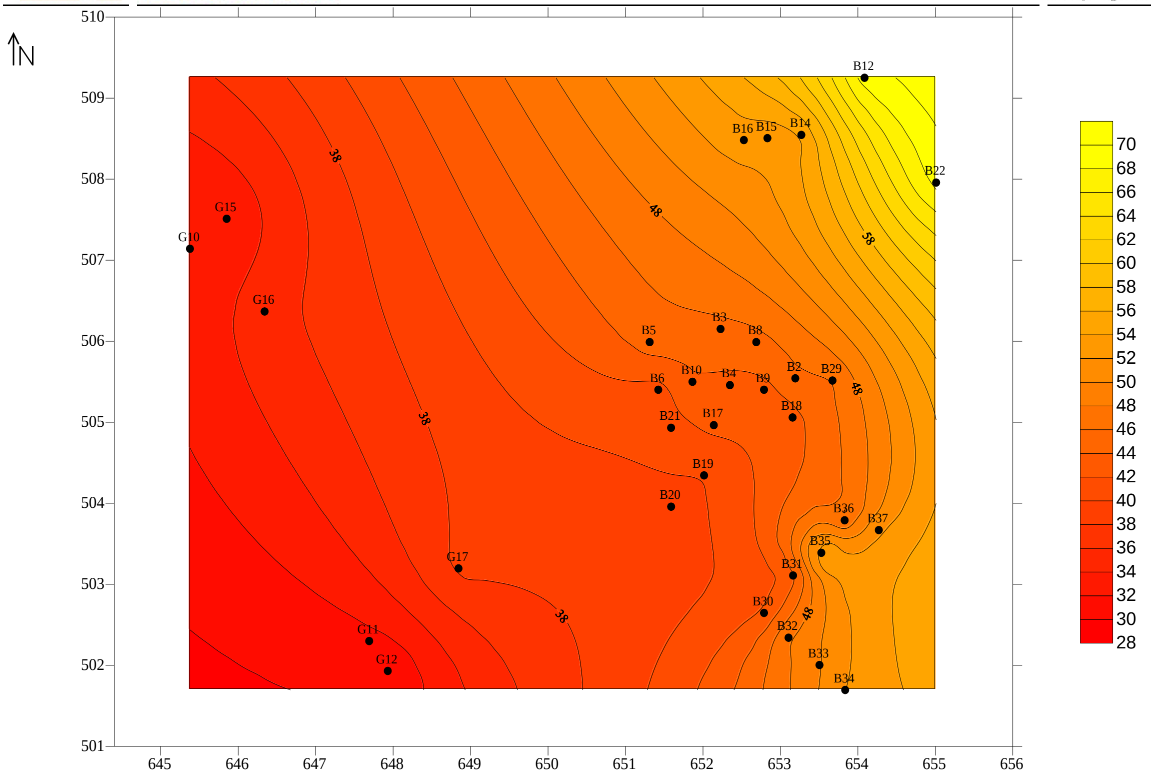

Figure 7: Water level map of the Quaternary aquifer in the study area

Table 3: Hydraulic parameters of the Quaternary aquifer system in the study are.

	Transmissivity (T) m^2/day	Storativity (S)
Pw10, F1	564.69	0.00716
Pw12, F2	109.80	0.0145
Pw14, F3	66.55	0.038

3.4 Aquifer Recharge

Recharge to groundwater is largely derived from irrigation water. Recharge components include the deep percolation of surplus irrigation application (surplus to crop water requirements) and seepage losses from irrigation canals (in some cases possibly also from the drains). Recharge from surplus irrigation application has been estimated by many authors and researchers using numerical modeling and water budget analysis as shown in Figure (8) (Attia, 1985; Dawoud, 1997; RIGW, 2000). The recharge to the aquifer system ranges from 0.5 to 0.8 mm/day in the old agriculture land and ranges from 1.0 to 1.5 mm/day in the desert fringes for new reclaimed lands.

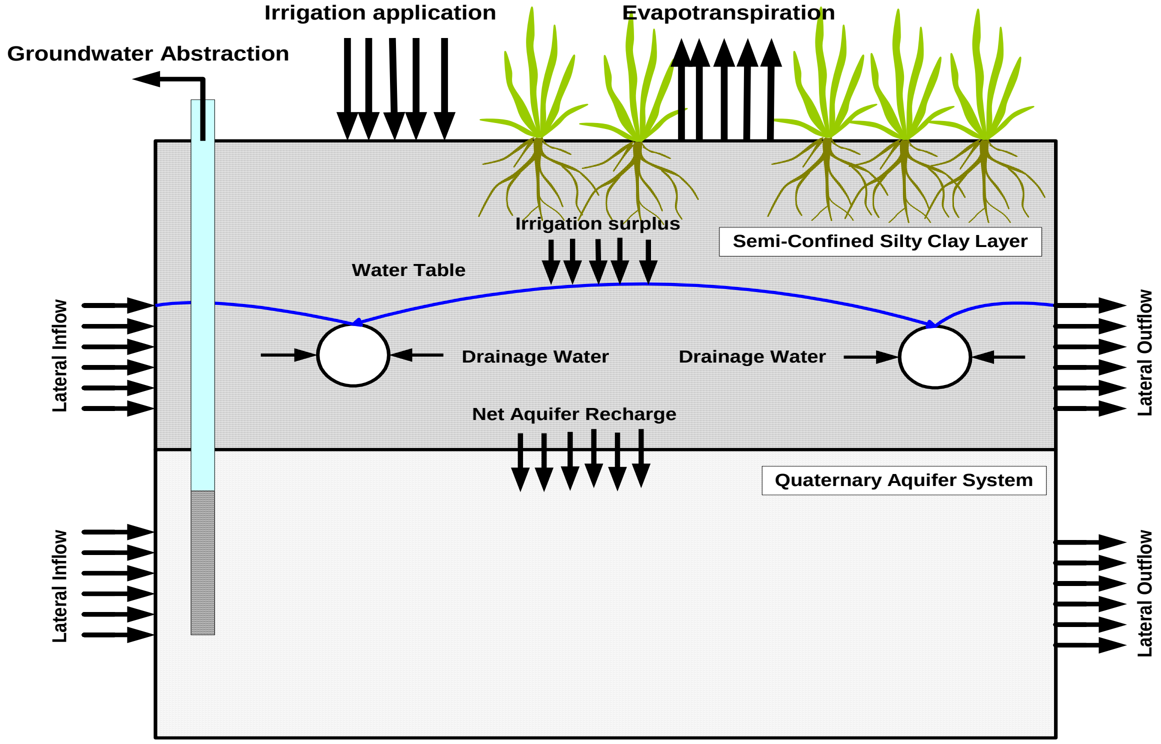

Figure 8: Aquifer recharge mechanism.

3.5 Groundwater abstraction and use

Groundwater is used for water supply and irrigation. Rural water supply is mainly from groundwater, while that of major towns is from groundwater and surface water. Although initially the groundwater use for irrigation was assumed to be only minor, there is clear evidence from the observed piezometry and from the balance between irrigation water supply (surface water) and irrigation demand that groundwater is used for irrigation during winter and summer periods. Data about groundwater abstraction have been extracted from the Research Institute for Groundwater database for 2000 (RIGW, 2000), which includes groundwater abstraction for irrigation and potable use. Additional data on groundwater use for irrigation from a 2000 well inventory provided significant further insight into the spatial distribution of abstraction. Analysis of hydrograph as shown in Figure (19) for RIGW observation wells indicated that the abstraction period starts in about early/mid January and continues until the middle/end of September, although piezometric data indicate that some abstraction may also occur within the period from September to December. It seems likely that the number of operating days per week varies depending on crop demand. Apparent piezometric recovery could thus also happen when operation of the wells reduces during low demand periods. Inflow across the edges of the Nile Valley is generally assumed to be non-existent, except possibly at the western edges of the Wadi Al Assiuti and Al Sheih.

4. Surface Water and Groundwater Interaction

To evaluate the effect of increasing the head pond of Assiut barrage, there is a need for enhanced linking of reservoir and stream/aquifer systems. In the past few years, many models treated the interaction between surface water and groundwater. Dawoud (1997) modified a two-dimensional multilayer groundwater flow model for simulating a stream/aquifer interaction. Numerous researchers including Morel-Seytoux et. al. (1985), Peralta et. al.

(1990), Ahlfeld and Minihane (2002), and Anderson (2003) treated the interaction between the stream and aquifer as a time dependant third type boundary condition (Cauchy Boundary Condition). The same mathematical approach used to describe stream/aquifer interaction can be used to describe interflows between a reservoir and an underlying aquifer. Reservoir/aquifer interflow can be significant where the reservoir bed is very conductive. Some other researchers including Loucks and Dorfman (1975) and Gundelach and Revelle (1975) have proposed linear programming models based on modifications of the linear reservoir description rule.

Hydrologic interaction between surface water bodies and aquifer systems occurs by subsurface lateral flow through the unsaturated soil by infiltration into or exfiltration from the saturated zones. For hydraulically connected stream-aquifer systems, the resulting exchange flow is a function of the difference between the river stage and aquifer head (Rutledge and Daniel, 1994). A simple approach to estimate flow is to consider the flow between the river and the aquifer to be controlled by the same mechanism as leakage through a semi-pervious stratum in the vertical dimensional (Rushton and Tomlinson, 1979). The flow is calculated with Darcy's equation, and is a direct function of the hydraulic conductivity and head difference. It can be expressed as follows:

$$q = \left(\frac{K_v}{b}\right)\Delta H \quad (1)$$

Eq. (1) can be rewritten in the following form:

$$q = C\,(H_{river} - H_{aquifer}) \quad (2)$$

$$\text{and } C = \frac{K_v}{b} \quad (3)$$

where q is the flow between the river and the aquifer (positive for baseflow - for gaining streams and negative for river recharge – for losing streams); C is a constant representing the streambed leakage coefficient (hydraulic conductivity of semi-impervious streambed stratum K_v divided by its thickness b); and ΔH is the difference between the water level in the river H_{river} and the groundwater level in aquifer system $H_{aquifer}$.

This equation is applied if the peizometric water table level lies in the semi-pervious layer representing the river bed deposits as shown in Figure (9). If the water table level falls below the bottom of the semi-pervious layer, leaving an unsaturated interval beneath that layer, the term ($H_{aquifer}$) in the equation will be simply the elevation of the bottom of the semi-pervious layer at that node. This means that once the water table falls below the semi-pervious layer, leakage from the river to the aquifer becomes independent of the water table level. The rate of leakage between the river and the aquifer will be expressed as follows:

$$q = C\,(H_{river} - H_{CBL}) \quad (4)$$

Where H_{CBL} is the base elevation of the river bed deposits.

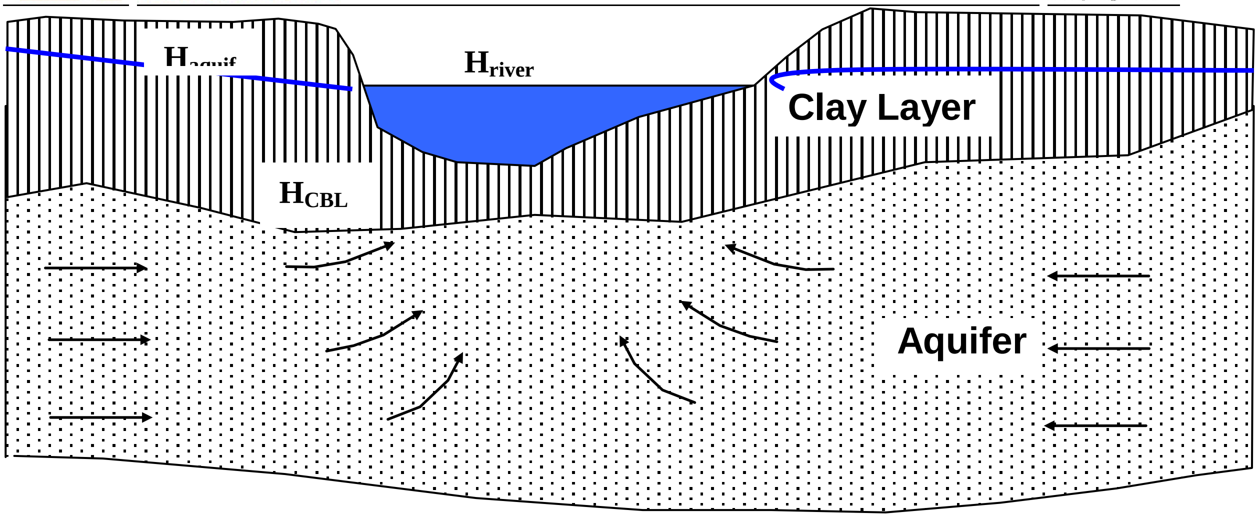

Figure 9: Definition scheme for surface water and groundwater interaction

The depth of river penetration into the aquifer system determines the hydraulic connectivity between the river and the aquifer system. A good hydraulic connection between the river and the aquifer exists, due to the absence of low-permeable deposits below the riverbed (Attia, 1989). The hydraulic conductance for the Nile River bed layer ranges from 1 to 10 days. The other main canals and branches run through the top clay layer which has less permeable silts and clays. The hydraulic conductance for these canals and branches ranges from 50 to 100 days based on the thickness of the clay layer. The conductance of the surface water bodies is considered as a calibration parameter due to its uncertainty.

5. Simulation of Aquifer System

5.1 Conceptual model formulation

5.1.1 Choice of model

The main scope of the modeling study was to assess the surface water and groundwater interaction. So, the model should be capable of simulating flows in the aquifer system as well as the interaction between the groundwater aquifer systems and the surface environment as has been discussed through equations 1 to 4. The TRIWACO package has been selected for the study, not only for its capabilities, but also in view of the extensive experience in the use of the model by RIGW staff. TRIWACO is a numerical program package for quasi three-dimensional simulation of groundwater flow under steady state and transient conditions, based on the finite element technique. It can be used to build models of groundwater flow in up to nine aquifers, separated by aquitards. The package consists of seven preprocessing, finite element and post-processing modules (TRIWACO, 1992). In TRIWACO multiple pumping and injection wells can be implemented (Q would be positive for injection wells and negative for abstraction wells). The model is capable of simulating the interaction between surface water bodies and groundwater.

5.1.2 Model boundaries and extent

The model extends beyond the study area relevant to the project to minimize the impact of uncertainty in subsurface boundary inflows and outflows on the area of main interest. However, modeling focus has been in the study area.

Two types of boundary conditions have been used. For certain areas a "no flow" boundary was specified (Neumann conditions). In this case the derivatives of the head (flux) across the boundary are set to zero. This type of boundary has been used for the eastern and western boundaries. The western boundary is a fault where no flow enters the aquifer system and the eastern boundary is a hard Pliocene clay layer which is considered as an impermeable boundary.

For other areas a fixed head boundary (Dirichelet Conditions) was used. In this case the derivatives of the peizometric head are constant and do not change with time. This head is specified by the model user across the specified boundary. This condition has been used for the northern and southern boundaries where the model boundaries cut the aquifer system along the Nile Valley. The river Nile branches form a naturally controlled head boundary to the aquifer system, and it is conceivable that the other main canals also act as a controlled head boundary.

5.2 Numerical simulation

The model comprises three layers representing the aquifer system. The top System, represents the zone between the ground surface and just below the level of the artificial drainage systems (about 1.5 m). Within this layer recharge is specified, while outflow to tile drains (if present) is calculated from the drainage system properties, the characteristics of Layer 1 and the position of the groundwater table relative to the drain level. The difference between recharge and outflow to the tile drains represents the exchange between the Top System and Layer 1. This exchange can be positive (inflow to Layer 1) or negative (outflow from Layer 1), depending on the outflow from the tile drains. If no tile drains are present, the exchange is equal to the recharge to Layer 1. Depending on the choice of recharge option, capillary flux would be simulated in this layer. Layer 1 represents the semi-confining layer (upper clay layer), which overlies the main aquifer. It is modeled as an aquifer in which vertical and horizontal flow is simulated. All surface water features such as the river, main irrigation canals and main open drains are included as 'rivers' in the model. The exchange between those 'rivers' and the aquifer systems occurs in Layer 1. The exchange between this layer and Layer 2 is through a leakage mechanism. Storage changes are only simulated if the model is run in transient mode. Layer 2 represents the main aquifer in which horizontal flow is simulated. Groundwater abstraction occurs from this layer, while storage changes (confined or unconfined, depending on the groundwater level relative to the top of the layer) are simulated if the model is operated in transient mode. The exchange with Layer 1 is through a leakage mechanism. Where the upper clay layer is not present, a thin Layer 1 is specified with a hydraulic resistance of zero. This ensures that the aquifer system acts as a single-layer phreatic aquifer.

Main irrigation canals and main open drains are included in the model as 'rivers'. Within the study area the main canals include the Naga Hammadi East and West canals, the Gergawia canal, the lbrihamiya canal, the El Sant, El Manna and Magrour El Assiuti canals. The main drains include the El Zinar drain and some of its main secondary drains, and the Abu Tig and El Badary main drains. Other canals and main drains located outside the study area are also included as 'rivers'. A low resistance for the River Nile was needed to accuratly simulate the flows in the vicinity of Assiut barrage and also the exchange between the river and the aquifer in the river section between Abu Tig and Tahta**.**

The aquifer comprises highly permeable sand and gravel and is of variable thickness. The thickness is greatest in the central part of the valley (locally in excess of 250 m) and reduces to less than 40 m near the edges of the valley (RIGW, 1991). Figure (10) shows a representative hydrogeological cross-section for the study area. In most of the valley the aquifer is overlain by a semi-confining layer, comprising clay and silt. This layer, which is not present along the outer edges of the valley and only locally near the river, varies in thickness with a maximum generally not exceeding 20 m (Abdallah et. al., 1999). The water-transmitting properties of the aquifer are excellent with transmissivity as high as 18,000 m^2/day in the central part of the valley (a direct reflection also of its greatest thickness in this part of the valley).

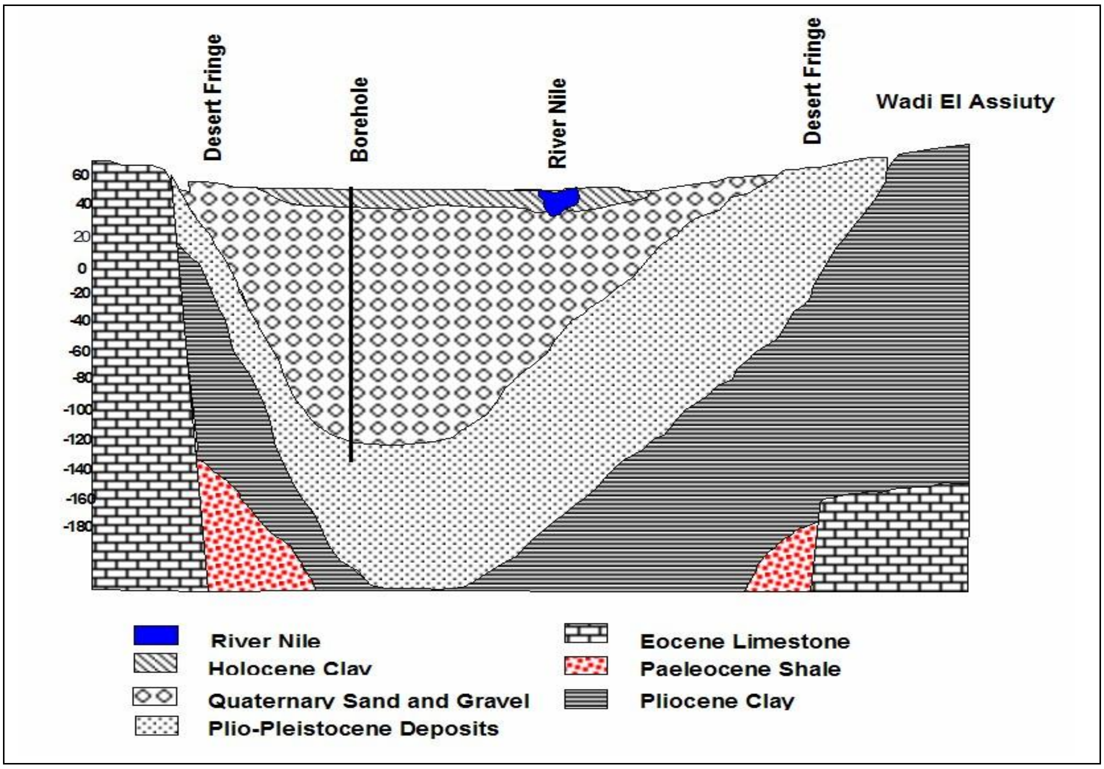

Figure 10: Hydrogeological cross section in the aquifer system.

The semi-confining layer has a generally assumed vertical permeability of about 0.1 m/day (Warner et al., 1991). It is likely that lower values apply in the central parts of the east and west bank, where clayey soils predominate. The groundwater table is generally in close proximity to the ground surface due to the extensive application of irrigation water. Regional piezometry indicates that groundwater movement is generally towards the River Nile on the east bank, while this is the reverse along most of the west bank between Assiut barrage and Tahta. The regional piezometric trends are also a close reflection of topographic trends, except in the areas immediately upstream and downstream of Assiut barrage. Local groundwater movement is complex due to micro-relief, the influence of irrigation canals and drains on groundwater piezometry, the rotational application of irrigation water and groundwater abstraction for water supply and irrigation.

5.3 Model calibration and verification

Although one generally strives at developing a well-calibrated groundwater model before assessing impacts, one needs to consider the adequacy of the available data to achieve a good model calibration. It is not so difficult to achieve a spatial match between observed and simulated average groundwater levels, as these are generally closely controlled by the ground surface or sub-surface drainage systems (due to the close proximity of the groundwater table to the ground surface). Under such circumstances one may reach 'acceptable' calibration for a relatively large range of aquifer properties. It is, in such cases, better to do comparative simulations of 'with' and 'without' project conditions for a range of aquifer properties and thus express impact in the form of a statistical distribution. This approach is, in effect, similar to performing a large number of model sensitivity runs, except that this would be done for both existing and future conditions. To limit uncertainty in model parameters the model has been calibrated and operated in transient mode. This has allowed for a more accurate assessment of the influences of varying river levels and seasonal variations in irrigation application.

5.3.1 Steady State Conditions

The model was calibrated and adjusted to steady state and transient modes as appropriate against the historical records of measured groundwater levels in the study area, using the records of 25 observation wells during the period from 1985 to 2001. The calibration process was done using trial and error procedure. In the trial-and-error calibration process for the developed groundwater model, it has been found that inaccuracy in topography does not affect the accuracy of the simulated depth to the groundwater level even though absolute levels of piezometry may be correctly simulated. A correct piezometric trend has been simulated with combination of aquifer hydraulic conductivity, recharge and river conductance. Also, it has been noted that a low resistance for the bed layer of the River Nile was needed to accurately simulate the flows in the vicinity of Assiut barrage and the exchange between the river and the aquifer systems. The calibration process was repeated until a good calibrated match between observed and calculated heads was finally achieved. Also, the comparison between the simulated groundwater levels indicate a reasonable agreement with the piezomteric pattern derived from monitoring data as shown in Figure (11).

5.3.2 Transient Model

The model has been calibrated for transient conditions for the last three year period (1999 – 2001). Using monthly stress periods, the model has been used to simulate water-level fluctuations according to recharge, abstraction and water level variations in river, canals and drains. To calibrate the model, the specific-storage values were adjusted until the model were approximately reproduced the range of water-level fluctuations in observation wells in the modeled area, as shown in Figure (12).

6. Groundwater Management Scenarios

The main criteria controlling the groundwater management scenarios are:

- Present agriculture area is about 2000 feddans; Development projects in Wadi El Assiuti depend essentially on groundwater which is extracted from Quaternary aquifer where 64 pumped production wells produce about 24,000 cubic meters per day, most of this water is used for irrigation. This amount is determined according to water requirements for each well, to keep an economic water depth and aquifer conservation from depletion.

- Future planes for extending of cultivated area is about 8000 feddans; Several scenarios were proposed, for extraction from the three fields (Governorate Bahariya farm, Governorate Qiblia farm and Besnousmen society farm) depends on a certain amount of water that will be extracted from wells field in the future. These scenarios are tabulated in Table (4).

The values of drawdown, static and dynamic water depth due to proposed abstraction during twenty years are tabulated in Tables (5 through 7) and illustrated in Figures (13 through 18).

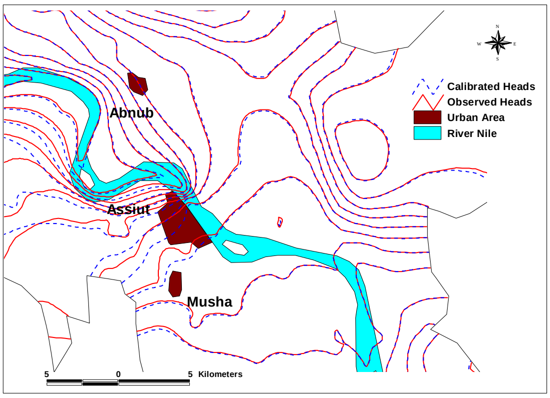

Figure 11: Comparison between calculated and observed groundwater heads for the calibrated model under steady state conditions.

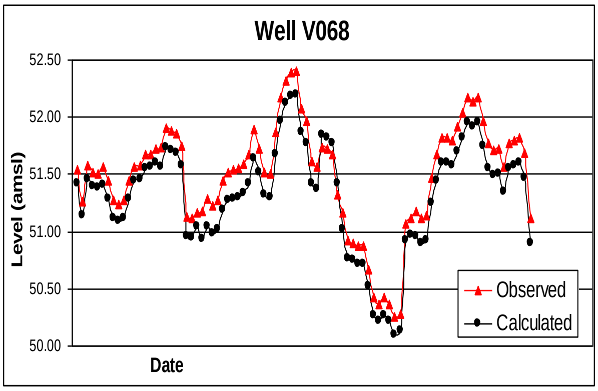

Figure 12: Comparison between observed and calculated heads for well V068 for the calibrated model under transient conditions.

Table 4: Management Groundwater Model (Proposed Scenarios)

	Discharge F1	Discharge F2	Discharge F3	Total discharge m^3/d
Scenario 1	3000	9000	12000	Q1= 24000
Scenario 2	4500	13500	18000	Q2= 36000
Scenario 3	6000	18000	24000	Q3= 48000

Where Q1 = Total Discharge in Wadi El Assiuti, 2004, Q2 = Q1 + 50 % of Q1, Q3 = Q1 + 100 % of Q1

Table 5: Measurements and results of scenario (1)

Static Depth to groundwater					
	Present (2008)	After 5 years	After 10 years	After 15 years	After 20 years
F1	32.05	39.37	41.13	42.03	42.67
F2	35.40	43.81	46.82	48.36	49.44
F3	53.40	68.06	79.04	84.64	88.61
Dynamic Depth to groundwater					
	Present (2008)	After 5 years	After 10 years	After 15 years	After 20 years
F1	40.80	48.12	49.88	50.78	51.42
F2	46.40	54.81	57.82	59.36	60.44
F3	76.40	91.06	102.04	107.64	111.61

According to the above different scenarios; the Quaternary alluvium deposits in Wadi Al Assiuti is considered as a promising aquifer due to its hydraulic parameters and the presence of more than source to replenish the aquifer which lead to very low drawdown ranges from 1 to 1.5 m in a year. So the extract rate Q3 from F1 and F2, can be achieved with maximum depth to the groundwater reaches 74.49 m after next 20 years. Average screen depth is 119 m in F3, where Q2 can be extracted at depth to groundwater reaches 114.87 m after next 10 years. Q3 can be abstracted from F3 with depth to groundwater reaching 105.71 m after the next five years.

Table 6: Measurements and results of scenario (2)

Depth to Static Groundwater					
	Present (2008)	After 5 years	After 10 years	After 15 years	After 20 years
F1	32.05	43.02	45.67	47.02	47.99
F2	35.40	48.01	52.53	54.84	56.47
F3	53.40	75.39	91.87	100.26	106.21
Depth to Dynamic Groundwater					
	Present (2008)	After 5 years	After 10 years	After 15 years	After 20 years
F1	40.80	51.77	54.42	55.77	56.74
F2	46.40	59.01	63.53	65.84	67.47
F3	76.40	98.39	114.87	123.26	129.21

Table 7: Measurements and results of scenario (3)

Depth to Static Groundwater					
	Present (2008)	After 5 years	After 10 years	After 15 years	After 20 years
F1	32.05	46.68	50.21	52.01	53.30
F2	35.40	52.22	58.24	61.32	63.49
F3	53.40	82.71	104.69	115.88	123.81
Depth to Dynamic Groundwater					
	Present (2008)	After 5 years	After 10 years	After 15 years	After 20 years
F1	40.80	55.43	58.96	60.76	62.05
F2	46.40	63.22	69.24	72.32	74.49
F3	76.40	105.71	127.69	138.88	146.81

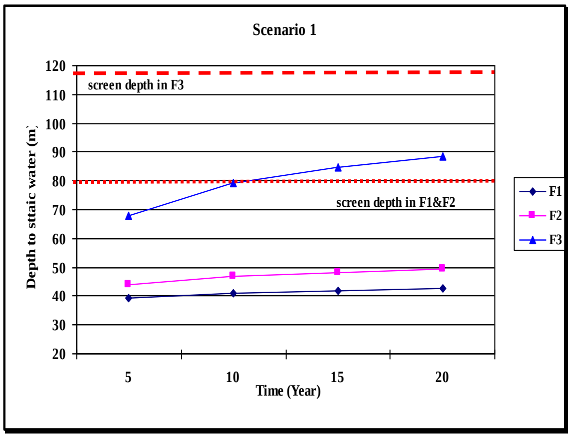

Figure 13: Scenario 1: static depth to groundwater in the study area

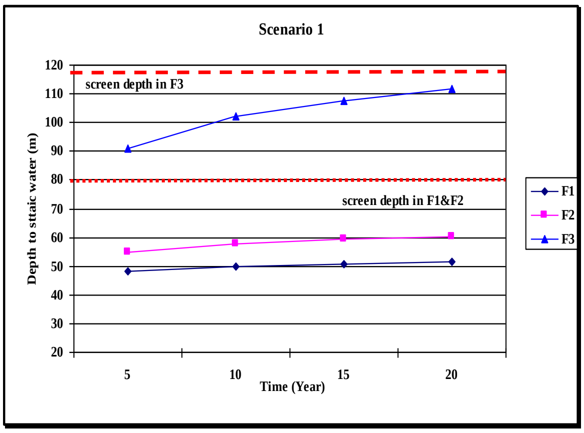

Figure 14: Scenario 1: dynamic depth to groundwater in the study area

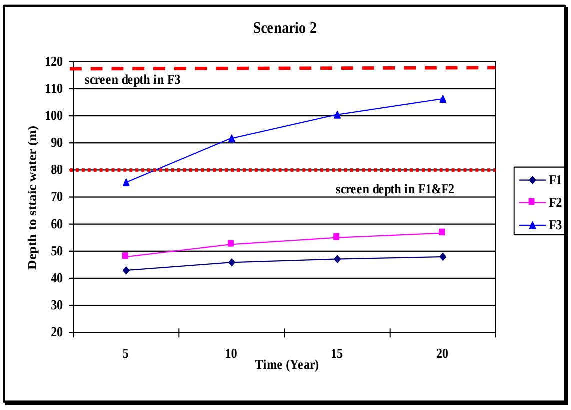

Figure 15: Scenario 2: static depth to groundwater in the study area

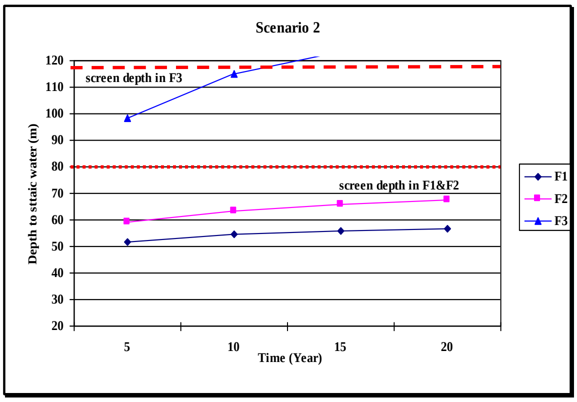

Figure 16: Scenario 2: dynamic depth to groundwater in the study area

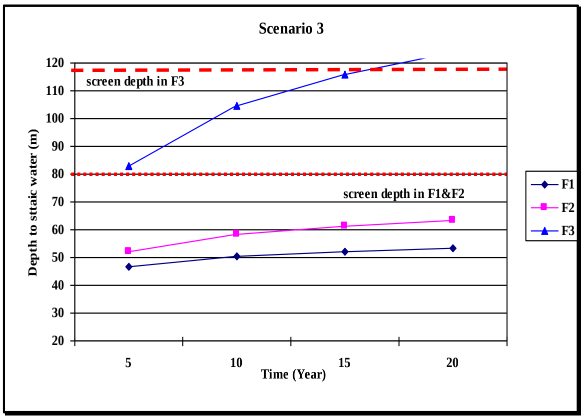

Figure 17: Scenario 3: static depth to groundwater in the study area

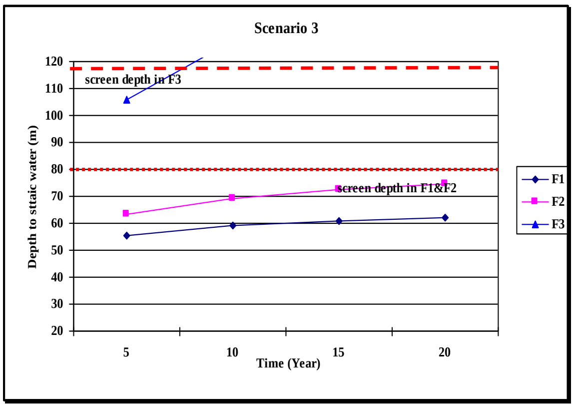

Figure 18: Scenario 3: dynamic depth to groundwater in the study area

7. Conclusions and Recommendations

- The Quaternary alluvium deposits is considered as a promising aquifer. It refers to a rate of drawdown ranges from 1 to 1.5 m in a year and due to the presence of replenishment source of the aquifer.
- Flow rate Q3 (48000 m^3/d) can be extracted from well fields F1 and F2, where average screen depths are 75 m and maximum dynamic water depth reaches 74.49 m after next 20 years.
- With average screen depths are 119 m in F3, we can extract Q2 (36000 m^3/d) where maximum dynamic water depth reaches 114.87 m after next 10 years or Q3 (48000 m^3/d) where maximum dynamic water depth reaches 105.71 m after next 5 years.

The present work recommended the following:

- Drill new shallow wells to increase the extraction by around 50 % to cultivate new area.
- Construct barrier and dams to store sufficient surface runoff to recharge the Quaternary aquifer.
- Drill new deep observation wells to evaluate the deep aquifer (Carbonate and Nubian aquifers).

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