GROUNDWATER DEVELOPMENT IN THE NILE VALLEY, CASE STUDY: SOUHAG GOVERNORATE, GIRGA REGION

By
Eng. Eman Ragab Nofal
B.Sc. Civil Engineering

**A Thesis Submitted To the
Faculty of Engineering at Cairo University
In Partial Fulfillment Of the
Requirements for the Degree of
MASTER OF SCIENCE
IN
IRRIGATION AND HYDRAULICS**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
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FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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List of Symbols and Appreviations

V : Darcy velocity
K : hydraulic conductivity of the porous medium
I : hydraulic gradient
A : area perpendicular to the direction of flow
Q : rate of flow
h_1, h_2 : water levels measured at two points
L : length of flow path between the two points
T : time
P : fluid density
S : aquifer storativity
x ,y and z : Cartesian coordinates
C : Contaminant concentration
D_L : Longitudinal dispersion coefficient
D_T : Transversal dispersion coefficient
R : Retardation factor
n : Effective porosity
F : Mass flux per unit area per unit time
D_f : Diffusion coefficient
D_{11} : Longitudinal mechanical mixing component of dispersion
D_{22} : Transversal mechanical mixing component of dispersion
α_L : Longitudinal dispersivity
α_T : Transversal dispersivity
K_d : Distribution or adsorption coefficient
ρ_d : Bulk density of the soil
$I_{sur.}$: Surface water inflow
I_G : Groundwater inflow in longitudinal direction

R : Natural replenishment from precipitation

P : Groundwater extractions

0.95P : 95% of groundwater extraction used again for irrigation

C.U. : Consumptive use volume

G_N : Groundwater seeping to Nile

G_T : Groundwater inflow in several directions

O_G : Groundwater outflow in longitudinal direction

D : Drainage discharge

ΔS : Change in storage

RIGW : Research Institute for Groundwater

IWACO : Consultants for water and Environment

DNAPL : Dense nonaqueous phase liquid

ICID : International Commission on Irrigation and Drainage

MWRI : Ministry of water Resources and Irrigation

m+SL : Above mean sea level

m-SL : Under mean sea level

MOC : Method of characteristics

MMOC : Modified Method of characteristics

NW-SE : North West - South East

E-W : East - West

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Finally, I would like to dedicate this work to my daughter.

Abstract

Egypt's water resources are limited and unevenly distributed over the country. 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. On the other hand, the government has increased its plans regarding to expansion in land reclamation activities needed to secure food for the ever increase in population. All the above mentioned facts keep the researchers in the field of groundwater looking forward to have a role in solving the existing water problems. Obviously, most of the land reclamation activities are implemented in the fringes of the Nile Valley and 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. Among other groundwater management tools, the conjunctive use of both surface and groundwater could be applied within these areas.

The present study covers the Girga region (located in the vicinity of Souhag Governorate), where the land reclamation activities has been started since the early eighties. Where about 165 km2 are planned to be reclaimed based on groundwater. Till the year 2000, only an area of 90km2 was reclaimed. The main objective of the study is to evaluate the groundwater potential within the study area and assess the behavior (both qualitative and quantitative) of the Nile aquifer system under proposed different groundwater development (pumpage) schemes.

To fulfill this objective a comprehensive hydrogeological study was implemented including a field work and carrying out of several pumping tests 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 where the latest MODFLOW package, version 4.2 was used. Several groundwater development schemes were proposed and evaluated based on the relative changes in both drawdown and salinity. Some of these scenarios were proposed by the researcher to be considered as a future groundwater development plan for the study area.

Chapter one

Introduction

1.1. General background:

Water scarcity is considered as the main challenge in the coming century with its effects being felt in many parts all over the world. Consequently the balance between the development requirements and the ideal management of water resources will take a great importance for scientists and researchers.

As water is the essential commodity to mankind, the largest available source of fresh water lies below the surface of the earth. Groundwater is an important source of water supply especially in arid and semi-arid zones. In such areas, the assessment of groundwater recharge is one of the key challenges in determining the sustainable yields of aquifers.

Groundwater is an important source of water supply in irrigation, industries, municipalities and rural districts that continues to increase. The continued availability of groundwater as a natural resource of fresh water depends on an understanding of its physical characteristics, water movement and its safe utilization. In other words, it is necessary to know how the system operates, and to understand how groundwater reservoirs are replenished before planning for any management by establishing the water balance.

Groundwater steadily gained importance in Egypt's national water policy during the last two decades. This policy aims at assuring safe drinking to Egypt's growing population, increasing the efficiency of the overall water use for irrigation and providing water for expansion of new reclamation land.

1.2. Problem identification:

Egypt resources are limited and unevenly distributed over the country. Populated areas are confined to the Nile banks where most of the facilities are available; thus resulting in a continuous pressure on the available land and water resources in Nile valley and delta

Egypt is a very arid country .The average annual rain fall seldom exceeds 200 mm along the northern coast; declining rapidly to inland area; and become almost nil south of Cairo. The main source of surface water is the Nile River. Under the 1959 treaty with Sudan, 55.5 billion m^3 are allocated to Egypt. The other source of water is groundwater. Aquifers in Egypt can be divided into two categories; aquifers in the Nile flood plain and desert fringes, and aquifers in the remaining deserts and Sinai.

The source of replenishment of the Nile Valley and Delta aquifer is form the Nile system (river course, canals and irrigation application). Accordingly, groundwater in this category is not a resource in itself, and the aquifer may thus be considered a storage reservoir .The total annual storage capacity of the Nile flood plain (Valley and Delta) is about 500 billion m^3 (RIGW database).The second category is in the Sinai desert where deep aquifers with almost non-renewable water exist. Nowadays, the total annual water use in Egypt is estimated at 60 billion m^3 (RIGW database) from surface water and reused water (groundwater and drainage water) Agriculture accounts for 84%. Current estimates indicate the total water demand will increase to more than 70 billion m^3 by the year 2010.

Groundwater development can play important role in solving water resources scarcities or difficulties with simple structures. The greatest potential for groundwater development may be through the conjunctive use with surface supply systems to alleviate the water resources deficits and irrigation problems. Egypt had faced drought condition of the Nile water during several years in the eighties.

The users and farmers had to increase the groundwater pumpage recovering the shortage and overcoming the irrigation problems. It was emergency action without planning. At that time, it was considered temporal scheme of the conjunctive use between surface water and groundwater achieving an integrated water resources management. In this study, a groundwater flow model has been used to simulate and assess the behavior of the Nile aquifer system under proposed groundwater pumpage schemes. This study has been carried out to examine Nile aquifer system as storage reservoir under various pumping schemes.

Groundwater development of the renewable aquifers may sometimes be attracted to over pumping on spatial and/or temporary bases; and then leave the aquifers to recover for another period or from adjacent aquifers. So, the future strategy needs to maintain sustainability of the groundwater resources by understanding interaction between the surface water system and the ground water system.

1.3. Study objective and methodology:

The main objective of this study is to assess the behavior of the Nile aquifer system under proposed groundwater development (pumpage) scheme in selected area representing the Nile valley region. The proposed strategies of the groundwater development; in this study, are depending on the clear understanding of the interaction between the surface water system (Nile River) and the ground water system under various conditions.

This main objective will be achieved by:

- Choice of a representative area of the Nile Aquifers system in Nile Valley

- Using the appropriate numerical flow model to simulate and assess the water balance of Nile groundwater system
- Formulating and applying different groundwater development scenarios concerning future demands and available lands for reclamation.
- Assessing the effect of the proposed scenarios on the hydro geological system in terms of quantity and quality.

1.4. Study work plan:

In order to fulfill the objective of the study, the following activities are carried out:

- Review the previous studies and the implemented groundwater schemes in Nile valley
- Collect data of the physical setting of the selected study area
- Review of the geology and hydrogeology of the study area.
- Collect field data including groundwater levels, groundwater samples and conducting pumping tests.
- Modeling the groundwater flow in the study area.
- Evaluate the groundwater status in the study area using groundwater flow model.
- Study the impacts of the proposed strategies for future development schemes on groundwater state (quantity and quality).
- Assess the groundwater potential facing the future water resources scarcities.

1.5. Chapters description:

This research is organized in seven interrelated chapters, leading to the presentation of future development of groundwater resources scenarios with the response of the system

- **Chapter 1:** (introduction) presents, briefly, the problem identification, the research objective, work plan and the organization of the study.

- **Chapter 2**: (literature review) presents the review of groundwater flow and solute transport principles .Also, the chapter reviews the groundwater flow modeling methods and the previous studies relevant to this research.

- **Chapter 3**: (hydrogeology and water balance of the Nile valley aquifer) introduces the hydrogeology setting of the Nile valley region. The chapter reviews the previous studies concerning ground water - surface water balance of the Nile aquifer system using analytical and modeling methods .The results from proper analysis and understanding of the interaction between the Nile aquifer and Nile River is an initial step to formulating future scenarios of controlled groundwater development

- **Chapter 4**: (hydrogeological settings and field investigations of the study area) presents the physical and hydro geological setting for Girga area such as topography, land use, stratigraphy, and groundwater aquifer system. It surveys the field investigation which had been carried out regarding to the groundwater levels monitoring, recent abstraction inventory and collecting groundwater samples Also, it presents the records and the analysis of pumping aquifer tests in the desert fringe of the study area.

- **Chapter 5:** (numerical modeling of the flow system) introduces the modeling methodology, the selected simulator and the conceptual model of the study area. The chapter presents the calibration process, leading to the calibrated model and the water balance of the study area under steady state (1990), and unsteady state conditions (1990 to 2007).

- **Chapter 6;** (future development scenarios of groundwater system) presents the Nile valley system response to different pumpage schemes regarding to the drawdown and its response on the water balance (recharge &discharge) and the river fluxes. This chapter, also, presents the particle tracking and the ground water quality impacts under the pumping schemes

- **Chapter 7:** (conclusions and recommendations) presents the final conclusions and outcomes of this study regarding to results analysis. The chapter outlines the recommendation for future development of groundwater resources for sustainable development of the new settlements in the desert fringes of the Nile valley region.

Chapter two

Governing Equations and Literature Review

2.1. Introduction

Groundwater is an important natural resource. Many agricultural, domestic and industrial water users rely on groundwater as the sole source of low cost, high quality water. However, in recent years it has become apparent that many human activities can have negative impacts on both the quantity and the quality of the groundwater resources. An example is the reclamation of many areas along the Nile Valley fringes and excessive pumping in some of these areas. One way to objectively assess the impact of proposed activities on groundwater quality and quantity is through the use of groundwater flow and solute transport models.

Groundwater modeling is an important tool in gaining insight in the hydrogeology of the region. The model is a representation of the reality and if properly constructed, can be valuable predictive tool for management of groundwater resources. The validity of the predictions will depend on how well the model approximates the field conditions. Accurate field data are essential when using a model for predictive purposes. However, an attempt to model a system with inadequate field data can also be instructive as it may serve to identify that area where detailed field data are criteria to the success of the model (Herbert, 1982). In this way, a model can guide data collection activities.

This chapter summarizes the basic concepts and definitions of terms related to groundwater flow, solute transportation of chemical concentrations and relevant background of hydro geological frame work of Egypt.

2.2. Basic equation of groundwater flow:

Groundwater flow through aquifers is governed by Darcy's law and the continuity equation, describing the conservation of fluid mass. Darcy's law states that:" the flow rate thought a porous medium is adversely proportional to the length of the flow path."

Darcy's law is application only for laminar flow, and is expressed in its simplest form as

$$Q=Av= KiA \tag{1}$$

$$Q=KA\,(h_1-h_2)/L \tag{2}$$

Where:

v = Darcy velocity [L/T]

K= hydraulic conductivity of the porous medium [L/T]

i= $(h_1-h_2)/L$ = hydraulic gradient [-];

A= area perpendicular to the direction of flow [L^2];

Q=rate of flow [L^3/T];

h_1, h_2=water levels measured at two points [L];

L= length of flow path between the two points [L]; and

T= time [T]

The specific discharge or Darcy's velocity, q, is given by:

$$q = \frac{Q}{A} \tag{3}$$

And the seepage velocity, v, defined as the discharge rate per unit of pore area, is expressed as:

$$v = \frac{Q}{\theta A} = \frac{q}{\theta} \tag{4}$$

Where Θ is the porosity of the medium. The seepage velocity is the average velocity of fluid element through the voids.

The equation of continuity for a steady state flow condition can be written as:

$$\left[\frac{\partial(\rho v_x)}{\partial x}\right] + \left[\frac{\partial(\rho v_y)}{\partial y}\right] + \left[\frac{\partial(\rho v_z)}{\partial z}\right] = 0 \qquad (5)$$

If the fluid is incompressible, ⌠(x, y, and z) = constant; and equation (5) reduces to:

$$\left[\frac{\partial v_x}{\partial x}\right] + \left[\frac{\partial v_y}{\partial y}\right] + \left[\frac{\partial v_z}{\partial z}\right] = 0 \qquad (6)$$

Substitution of Darcy's law for v_x,v_y and v_z in equation (6)

Yields the equation of steady state flow through an anisotropic saturated porous medium:

$$\left[\frac{\partial[K_x(\frac{\partial h}{\partial x})]}{\partial x}\right] + \left[\frac{\partial[K_y(\frac{\partial h}{\partial y})]}{\partial y}\right] + \left[\frac{\partial[K_z(\frac{\partial h}{\partial z})]}{\partial z}\right] = 0 \qquad (7)$$

for an isotropic (k_x=k_y=k_z)and homogeneous [$k_{(x,y,z)}$=constant] medium, equation(7) reduce to the well known la Place equation :

$$\left(\frac{\partial^2 h}{\partial x^2}\right) + \left(\frac{\partial^2 h}{\partial y^2}\right) + \left(\frac{\partial^2 h}{\partial z^2}\right) = 0 \qquad (8)$$

The equation of continuity for unsteady flow of water through a porous medium is:

$$-\rho\left[\frac{\partial v_x}{\partial x}\right] - \rho\left[\frac{\partial v_y}{\partial y}\right] - \rho\left[\frac{\partial v_z}{\partial z}\right] = \rho s\left[\frac{\partial h}{\partial t}\right] \qquad (9)$$

Where:

ρ= fluid density;

S= aquifer storativity; and

x ,y and z are the Cartesian coordinates .

For a homogeneous isotropic aquifer, the groundwater unsteady flow equation becomes:

$$\left(\frac{\partial^2 h}{\partial x^2}\right) + \left(\frac{\partial^2 h}{\partial y^2}\right) + \left(\frac{\partial^2 h}{\partial z^2}\right) = \frac{S}{K}\left(\frac{\partial h}{\partial t}\right) \qquad (10)$$

Equation (10) is the general flow equation describing the hydraulic head at any point in a three – dimensional unsteady flow field. Equation (8) and (10) can be solved if, at the boundaries, either the flux or the hydraulic head are known.

2.3. Principles of pollution plume migration in groundwater flow:

When a contaminant is introduced to groundwater it spreads and moves as a result of;

(1) Advection which is caused by the flow of groundwater,

(2) Dispersion which is caused by mechanical mixing and molecular diffusion, and

(3) Retardation which is caused by adsorption. The two-dimensional equation that describes transport of contaminants in groundwater in a homogenous, isotropic medium can be written as follows (Javandel, Doughtly, and Tsang, 1984):

$$D_L \frac{\partial^2 C}{\partial x^2} + D_T \frac{\partial^2 C}{\partial y^2} - V \frac{\partial C}{\partial x} = R \frac{\partial C}{\partial t} \qquad (11)$$

In which:

C = contaminant concentration [L/T^3];

V = average pore water velocity [L/T];

D_L = longitudinal dispersion coefficient [L^2/T];

D_T = transversal dispersion coefficient [L^2/T] and

R = retardation factor [-].

2.3.1. Advection

When groundwater moves, it carries with it chemical constituents. This transport of chemicals with the fluid movement is called advection, the contaminant moves with the flow of groundwater according to Darcy’s Law:

The pore or actual seepage water velocity, V can be calculated as:

$$V = \frac{Q}{n.A} \qquad (12)$$

In which:

n = effective porosity

When only advection is considered, a contaminant moves with the groundwater flow at the same rate as water that means that V is a conservative estimation of the migration velocity of the contaminant in groundwater.

2.3.2. Dispersion

Dispersion is the result of two processes; molecular diffusion and mechanical mixing.

- **Molecular diffusion**

Molecular diffusion is the process whereby the ionic or molecular constituent moves from regions of higher concentrations to regions of lower concentrations the greater the difference the greater the diffusion rate. Molecular diffusion can be expressed by Fick’s Law as:

$$F = -D_f . \frac{dC}{dx} \qquad (13)$$

In which:

F = mass flux per unit area per unit time,

D_f = diffusion coefficient and

dC/dx = concentration gradient.

Fick's Law was derived for chemical in unobstructed water solutions, when this law is applied to porous medium; the diffusion coefficient should be smaller because the ions follow longer paths between particles and because of adsorption. This application yields an apparent diffusion coefficient D* represented by:

$$D^* = w \cdot Df \tag{14}$$

Where: w is an empirical coefficient that is less than 1. (Perkins and Johnston, 1963) suggested an approximate value of 0.707 for w. (Bear, 1979) suggested that w is equal to the medium tortuosity with a value close to 0.67. Values of D* for major ions can be obtained from (Robinson and Stokes, 1965).

- **Mechanical mixing**

Mechanical mixing dispersion is the result of velocities variations within the porous medium and can occur both in the longitudinal direction of flow as well as in the transverse direction (Liu and Liptak, 2000). According to (Bachmat and Bear, 1964), the mechanical mixing component can be assumed proportional to the seepage velocity as:

$$D11 = \alpha_L \cdot V \quad \text{And}$$
$$D22 = \alpha_T \cdot V \tag{15}$$

In which:

D_{11} = longitudinal mechanical mixing component of dispersion,
D_{22}= transversal mechanical mixing component of dispersion,
α_L = longitudinal dispersivity,
α_T = transversal dispersivity and
V = average pore water velocity.

Thus the hydrodynamic dispersion coefficients can be written as:

$$D_L = D_{11} + D_f = \alpha_L \cdot V + D^* \quad \text{And}$$
$$D_T = D_{22} + D_f = \alpha_T \cdot V + D^* \tag{16}$$

The dispersivity coefficients α_L and α_T are characteristics of the porous medium. Representative values of dispersivity coefficients can be determined from breakthrough column tests in the laboratory or tracer tests in the field (Anderson, 1979).

2.3.3. Retardation

Retardation in migration of the contaminant in groundwater is due to the adsorption mechanism and can be calculated as follows:
Assuming linear model:

$$R = \left[1 + K_d \frac{\rho_d}{n} \right] \tag{17}$$

In which:
K_d = distribution or adsorption coefficient,
ρ_d = bulk density of the soil and
n = porosity of the soil.

The length and the width of the plume are affected by the groundwater velocity and the aquifer hydraulic conductivity. The plum is more elongated in groundwater with high velocity than in groundwater with low velocity (Palmer, 1992). The contaminant plume usually moves in the same direction as groundwater; however, this movement may not occur with DNAPL (dense nonaqueous phase liquid) that can sink to the bottom of the aquifer and flow with gravity in the opposite direction to groundwater flow.

2.4. Groundwater Flow Models

Several types of models have been used to study groundwater flow system. They can be classified into three broad categories:

1- Physical models including sand tank model.

2- Analog models including viscous fluid model, electric analogy model, magnetic and heat models.

3- Mathematical models including analytical models and numerical models, which include finite difference, integrated finite difference models, finite clement and boundary element models (Prickett, 1975). Usually, more than one method of modeling can be applied to a given problem.

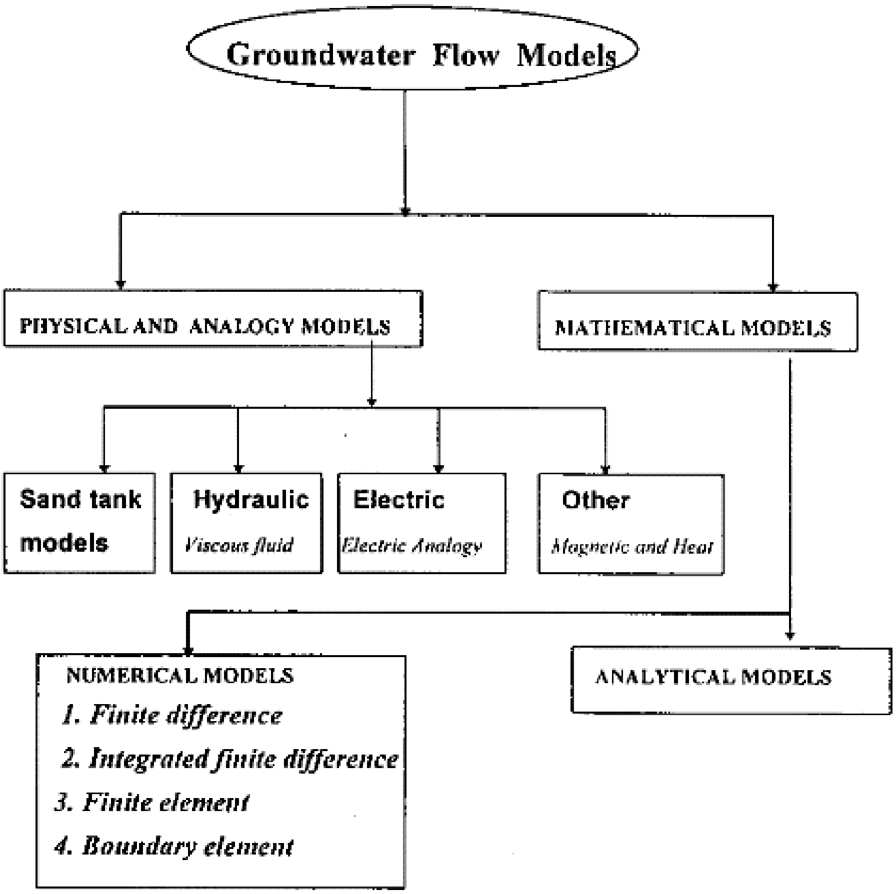

Figure (2.1) shows the different types of groundwater flow models.

The selection of the suitable method depends on some factors; such as time, cost, objectives of the study and accuracy of input data and anticipated results.

2.4.1. Physical sand tank models

A sand tank model consists of a tank filled with an unconsolidated porous medium through which water is induced to flow. A major drawback of sand tank models is the problem of scaling down a field situation to the dimensions of laboratory model. Phenomena measured at the scale of the sand tank model are often different form conditions observed in the field, and conclusions drawn from such models may need to be qualified when translated to a field situation. It is not practical tool to simulate the real situation under different boundary conditions and heterogeneous media. However, it can be helpful in observing the real shape of the of groundwater flow in the aquifers.

2.4.2. Physical analog models:

The groundwater flow can be described by differential equations derived from basic physical principles. Other phenomena, such as the flow of electric current through a resistive medium or the flow of heat through a solid, also operate under similar physical principles. In other words these systems are analogous to groundwater systems.

The two types of analogs used, most frequently, in groundwater modeling are viscous flow analog models and electrical analog models.

a) Viscous flow models

Viscous flow models are known as Hele-Shaw or parallel plate models because a fluid more viscous than water (for example; oil) is made to flow between two closely spaced parallel plates, which may be oriented either vertically or horizontally. Applications of the vertical models have involved bank storage adjacent to streams, seepage through dams, seawater intrusion and artificial recharge phenomena. Applications of the horizontal models have included mainly studies of the regional effects of pumping, recharge, evapotranspiration and flow in multiple layered aquifers. The most comprehensive article describing vertical or horizontal viscous fluid models is given by (Collins et al., 1972).

b) Electrical analog models

Electrical analog models were widely used in the 1950 before high-speed digital computers became available. These models consist of boards wired with electrical network of resistors and capacitors. They work according to the principle that the flow of groundwater is analogous to the flow of electricity. This analogy is expressed in the mathematical similarity between Darcy's law for groundwater flow and Ohm's law for electricity flow. Changes in voltage in an electrical analogy model are analogous to changes in groundwater piezometric head. A drawback of electrical analog model is that each one is designed for a unique aquifer system. When a different aquifer is to be studied, an entirely new electrical analog model must be built.

2.4.3 Mathematical models

A mathematical model consists of a set of differential equations derived from the application of mass conservation principle and Darcy's law that govern the flow of groundwater. Mathematical models of groundwater flow have been in use since the late 1800^s (Herbert F. Wang and Mary P. Andderson, 1982). The reliability of predictions using a groundwater model depends on how well the model approximates the field situation. Simplifying assumptions must always be made in order to construct a model because the field situations are too complicated to be simulated exactly.

For many problems, the assumptions that must be made to obtain an analytical solution are not realistic. For example, many analytical solutions required that the medium be homogeneous and isotropic. In these cases, we must resort to approximate methods using numerical techniques to solve the mathematical model. These numerical techniques provide a relation for operating on the differential equations that make up a model and for transforming them into a set of algebraic equations. Before digital computers were widely available, only hand calculations were possible, and approximating techniques were of limited value. When high speed digital computers become widely available, one can solve large number of algebraic equations by iterative techniques or by direct matrix methods.

a) Analytical models:

Analytical models are developed to solve the groundwater flow equation for certain simplified boundaries and initial conditions. The equations of the groundwater flow which take the form of partial differential equations are usually set up with simplified boundary conditions. The solutions are presented in the form of tables of well functions, type curves and other graphical presentations. In a sense, these analytical solutions are models of the particular conditions, since the solutions are based upon simplified boundary conditions, their applications to field problems are somewhat limited. The most advantage of using analytical models in groundwater flow can be summarized as follow:

1. Analytical models are probably the most efficient alternative when data necessary for identification of the system are sparse and uncertain.
2. Where applicable, these models are the most economical approach.
3. Experience modelers and complex numerical codes are not needed.
4. The input data are usually very simple and do not require detailed familiarity with the codes.

But the most important limitations of the analytical models are:

1. The available analytical models are limited to certain idealized conditions and may not be applicable to most of the field problems with complex boundary conditions.
2. Spatial or temporal variations of system properties such as permeability and dispersivity cannot be handled with analytical techniques.

b) Numerical models

Numerical models are generally required to solve complex geometry, boundary conditions and equations describing coupled and uncoupled processes in heterogeneous and isotropic formations under various initial and boundary conditions. In most numerical models the governing equations are approximated by algebraic equations relating unknown variables at discrete nodal and different times. Many powerful methods are available for this purpose. The various numerical models differ mainly in the way the system of equations is derived, and sometimes also in basic approach to the problem.

- **The Finite difference method**

The finite difference method is probably the oldest numerical method (Forsythe and Wason, 1960). In this method a system of nodal points is superimposed over the problem domain. In the finite difference approximation, derivatives are replaced by differences taken between nodal points. There are more than one finite difference technique to be used for the approximation of derivatives such as forward differences, backward differences and central differences. There are two types of finite difference grid, the block-centered grid as shown in Figure (2.3) and the mesh centered grid as shown in Figure (2.4).

The difference between them lies mainly in the way in which flux boundaries always are located at the edge of the block. In a mesh centered grid, the boundary coincides with a node. In large general computer codes, the finite difference mathematics for boundaries are more easily treated with the block-centered approach.

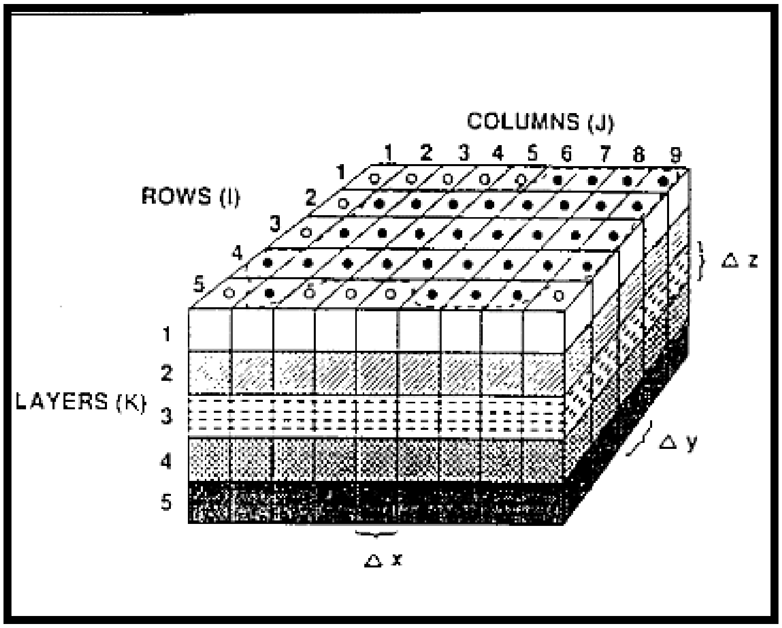

Figure (2.2) Schematic diagram of a full three-dimensional model (Forsythe and Wason, 1960)

- **The Finite element method**

The finite element method is another powerful numerical simulation method. In groundwater flow problems, the region is subdivided into small elements, such that for each element the flow is described in terms of the head in the nodal points. A system of equations is obtained from the condition that the flow must be continuous at each node.

The method is based on assuming an approximate solution. There will be a residual resulting from applying this approximate solution at the nodal points. By pushing this residual to be zero, a system of linear equations will result and the solution of this system of equations leads to obtain the unknown heads at the nodal points. In the finite element method one can use triangular elements grid which is the simplest than the square elements grid in the finite difference. A disadvantage of the finite element method is the need for formal mathematical training to understand the procedures properly and its generally higher computation costs (Wang and Anderson, 1982).

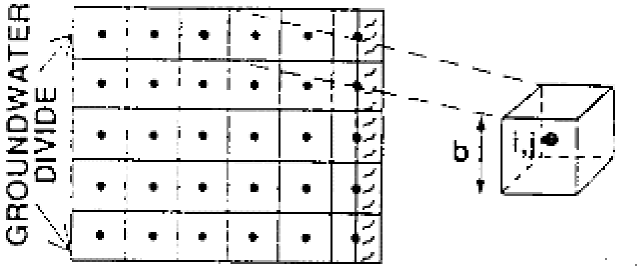

Figure (2.3) Finite difference grid with block centered nodes (Forsuthe and Wason, 1960)

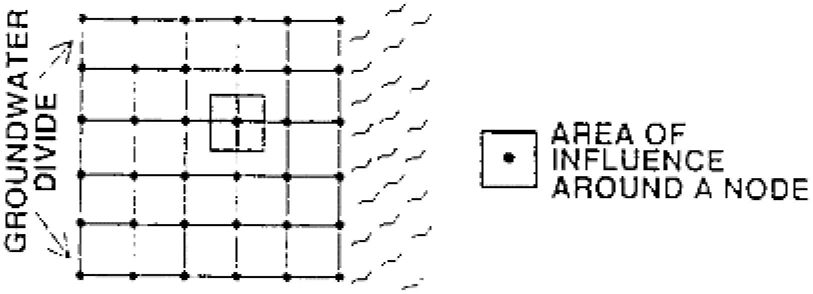

Figure (2.4) Finite difference grid with mesh-centered nodes (Forsuthe and Wason, 1960)

2.5. Hydrological framework of Egypt

2.5.1. General Background

Egypt is an arid country, where only 3.4 % of the area is inhabited. Water is a major constraint to the development of the country. In hydrological terms, the Nile Valley is a long narrow basin. Since the precipitation is negligible, there is only one source of replenishment: Nile water from High Dam. Due to the continuous growth of population and the urgent need for food security, expanding the reclamation of new lands within the unlimited desert area of Egypt, has started with the desert fringes of the Nile Valley and Delta. So, groundwater becomes an important integral part of the water resources of the national policy. Efficient management of water and land resources is required to increase and sustain crop productivity in arid areas. Integrated use of surface and groundwater is now recognized as a significant strategy for optimum utilization of regional water resources, especially to control water logging and soil salinization in some local areas along the Nile Valley. Groundwater steadily gained importance in Egypt’s national water policy during the eighties. This policy aims at assuring safe drinking water to Egypt’s growing population, to increase the efficiency of the overall water use for irrigation and to provide water for the expansion of agricultural area.

2.5.2 Hydrological setting of Nile Valley

General background

Egypt covers an area of about one million square Kilometers. It is divided geographically into four areas: (1) the Nile Valley and Delta, including El Fayoum depression and Lake Nasser; (2) the Western Desert, including the Mediterranean littoral zone and the New Valley; (3) the Eastern Desert, including the Red Sea littoral zone, the islands and the high mountains; and (4) Sinai Peninsula, including the littoral zones of the Mediterranean, the Gulf of Suez and the Gulf of Aqaba.

The country lies for the most part within the temperate zone, and the climate varies from arid to extremely arid. The air temperature frequently rises to over 40˚ C in daytime during summer, and seldom falls to zero in winter. The average rainfall over Egypt as a whole is only 10 mm/year. Along the Mediterranean, where most of the winter rain occurs, the annual average rainfall is less than 200 mm/year, decreasing rapidly inland. The annual evaporation rates over the country are in excess of 3,000 mm/year.

The hydrography of Egypt comprises two systems: (i) a system related to the Nile; and (ii) a system related to the rainfall in the past geological times, particularly in the Late Tertiary and Quaternary.

The Nile system comprises the Valley and Delta regions, which are morphologic depressions filled with Pliocene and Quaternary sediments. In the Nile flood plain there are extensive man-made drainage systems, especially in the traditionally cultivated old land. Some extend to the fringes where land reclamation takes place. Such drainage systems discharge to the Nile itself or to the sea.

The other hydrographic system in Egypt is the complex network of dry streams (wadis), the formation of which dates back to past wet periods in the Tertiary and Quaternary. This system covers more than 90 % of the surface area of Egypt, including the Western Desert, the Eastern Desert, and Sinai. The main catchment areas drain towards the Nile Valley and Delta, to the coastal zones, and to inland depressions.

The landscape in Egypt can be broadly divided into the elevated structure plateaus and low plains, which include the fluviatile and coastal plains. These geomorphologic units play a significant role in determining the hydrogeological framework of Egypt. The structural plateaus constitute the active and semi- active watershed areas. The low plains can contain productive aquifers and are also, in some places, areas of groundwater discharge.

The Nile flood plain is mainly occupied by agricultural activities. On its fringes, new irrigation areas are being developed using river water or groundwater.

The hydro geological framework of Egypt comprises six aquifers systems in Egypt, as shown in figure (3.1): The Nile aquifer system assigned to the Quaternary and late Tertiary. It occupies the Nile floodplain region and the desert fringes where 90 % of Egypt's population lives. The Nubian sandstone aquifer system assigned to the Paleozoic-Mesozoic. It is found mainly in the Western Desert. The Moghra aquifer system assigned to the lower Miocene. It is located mainly in the western edge of the Delta. The Coastal aquifer system assigned to the Quaternary & late Tertiary. They are located along the northern & western coasts. The Karslified carbonate aquifer system assigned to Eocene and to the Upper Cretaceous. It predominates in the northern part of the Western Desert.

The Fissured and Weathered hard rock aquifer system assigned to the Pre-Cambrian, and mainly found in the Eastern Desert and Sinai.

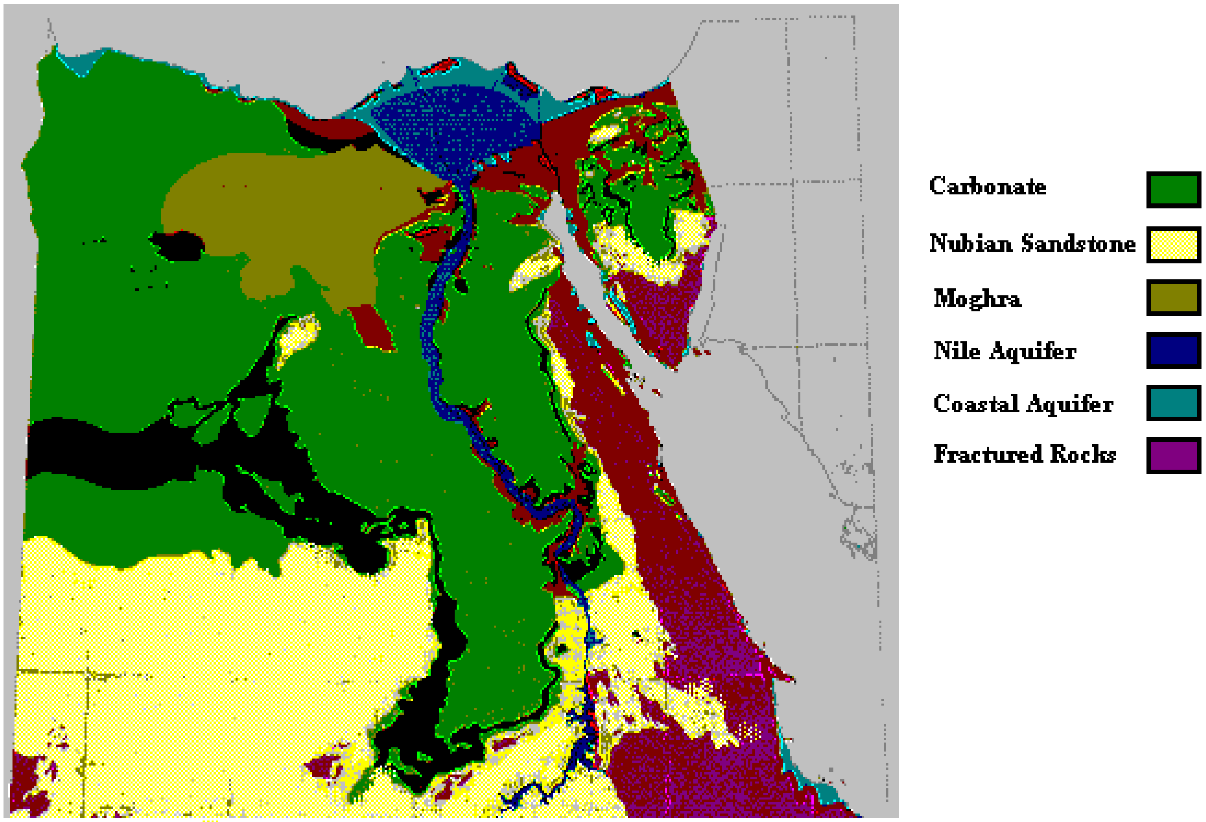

Figure (2.5) Hydro Geological framework of Egypt (RIGW database)

2.6. Previous work:

El Arabi, 1984 had been carried out to establish the water balance of the Nile valley, in view of defining the present situation and the interrelationships of the groundwater system. The results of that study indicated the possibility of operating withdrawals of water from the aquifer system and constitute a first step toward a more comprehensive scheme of conjunctive use of surface and groundwater resources and more efficient drainage system for the area. That work had indicated that generally the local groundwater flow condition deviated greatly from the prevailing regional conditions.

Thus, local investigations were recommended to take place before the design groundwater operating scheme.

Attia, 1985, had identified the prevailing problems in the Nile valley regions (Upper Egypt) prior to the development of operation schemes. The analysis of the Nile valley water systems was carried out through the application of a one layer finite element simulation model AQUIFEM-1. The two-layer groundwater hydraulics/quality model, WTSHED7, was developed and calibrated for a reach of the Nile Valley that represents the whole region. Development and evaluation of operation policies were made to test their impact on: Additional water provisions, namely; groundwater and surface water; Drainage; and groundwater quality. These were carried out through the application of WTSHED7, which incorporates hydraulic and quality parameters of surface water, water table and groundwater. Finally, a procedure was developed to help the designer or decision maker select the convenient management scheme for any region in the Nile valley, according to hydraulic and quality requirements.

RIGW-IWACO, 1989 had been carried out this study to predict the impact of future hydro geological measures on the groundwater system; a numerical groundwater flow simulation model (TRIWACO) had been adapted. Prior to this prediction, the model was calibrated according to historical data. The basic features for calibration were the piezometric heads in the traditional cultivated area and the water balance for the reclaimed desert area. A general evaluation for three different types of hydro geological measures was conducted viz. tube-well drainage, improvement of field application efficiency and lining of canals. More or less the same results can be obtained by operating the well field under construction in combination with improving the irrigation practices in the reclaimed areas.

Khater et al., 1991, studied the impact of desert reclamation on groundwater quality. They stated that the results from groundwater quality were found to be in agreement with the assessed distribution of groundwater vulnerability to pollution. Groundwater vulnerability, therefore, is considered a useful tool in the planning procedures for groundwater development. This may also direct the protection of the scarce and vulnerable groundwater resources.

Latif et al., 1991, developed a conjunctive-use model to control water logging and salinization. Salt distribution in the crop root zone is modeled and its effects on crop yield are also taken into account in the model. The optimal groundwater extraction for stabilizing the water table in the study area at specific depths below land surface was calculated, which at the same time supplement the surface irrigation supply.

Attia et al., 1991, presented a technical evaluation of the groundwater development schemes in Upper Egypt. A case study on the feasibility of the groundwater development plan for low land area suffered from shortage of water and the adjacent area suffered from water logging as a result from seepage from the reclaimed land was implemented.

Sherif et al., 1995, had applied a two-dimensional finite difference model (Modflow 2.6) to simulate the groundwater conditions for an area in the Nile valley. The model had been used to investigate the effect of pumping 74 production wells on lowering the water table levels in the study area.

The results of the study concluded that after one year of pumping 4500 m^3 /day/well the maximum drawdown in the piezometric head was 1.8 m and the maximum drawdown in the water table was 1.4 m.

El Arabi et al., 1996, had used the ICID check-list to assess the scope of environmental effects of sewage water irrigation in El Gabal El Asfar farm which is situated on the eastern desert fringes of the Nile Delta. The aquifer was phreatic, being underlain by a deeper aquifer with clay layers separating both in the southern and western parts of the study area. The aquifer thickness varied from 25 m to 75 m, horizontal hydraulic conductivity ranged between 1 - 40 m/day. The aquifer was mainly recharged by percolation of excess irrigation water. Initial groundwater quality outside the study area is characterized by moderate salinity concentrations and the effluent quality reveals that chloride, sulphate, nitrogen, and salinity concentrations in groundwater were generally much higher than the average concentration in the sewage effluent. An accumulation of some heavy metals in the soils irrigated with sewage water was observed. The impact to the groundwater quality seems to be limited due to adsorption of the soil. The overall groundwater quality is negatively affected with respect to pesticides, nitrogen and phosphate. In addition; the shallow groundwater was polluted with fecal coliforms and boron which was above drinking water limits.

Dawoud, 1997, had studied the problem of water-logging and groundwater condition in west Tahta area, Souhag Governorate. A two dimensional finite element groundwater flow package were modified to take into consideration the interaction between groundwater heads in the aquifer and shallow groundwater table in the semi-pervious layer. Then, the groundwater conditions in the study area were simulated using the modified model. Three solution alternatives were applied to choose the suitable one. The vertical drainage is found o be the best economically and technically solution to overcome the problem of waterlogging and soil Salinization in the study area.

El Arabi, 1997, twelve ground-water samples were collected in Nag Hammadi area, from quaternary and plio-pleistocene age aquifers.

The isotopic data indicate that the main recharge source of the quaternary aquifer is the recent River Nile water, which is isotopically enriched from evaporation in Lake Nasser. Source of recharge to the plio-pleistocene aquifer are: (1) Old Nile water depleted in isotopic composition, which was trapped in the geological formation, characterized by low permeability and clay lenses prior to the construction of the Aswan High Dam ; and (2) The leakage of palaeo water from the deep aquifer system through main faults which bisect the study area. The variation in the chemistry of groundwater is thought to be related to mixing between the different water sources and leaching of fertilizers in the newly reclaimed areas in the desert fringes.

The contribution from the palaeo water in the deeper aquifer is expected to play a significant role in the development of ground-water resources in the study area which is under extensive reclamation. The unbalance between deep aquifer leakage and over extraction for crop requirements and ground-water return flow (recirculation of groundwater for irrigation) may cause deterioration of this Nile aquifer system. So, a ground-water quality monitoring program is therefore very important for environmental and sustainable management of these vital resources.

Shamroukh, 2001, had studied the effect of using chemical fertilizers on groundwater quality in the Nile Valley aquifer after the construction of the Aswan High Dam in 1968. A groundwater modeling system (GMS) was used to simulate the three-dimensional groundwater flow and contaminant transport in the Tahta region of the Nile Valley aquifer and to predict the future concentration of chemical fertilizers species. Results of transport simulation predict the occurrence of groundwater contamination at shallow depths (30m) due to high rates and method of chemical fertilizer applications. The study concluded that new deeper wells should be constructed. In addition the use of hand pumps in zones close to croplands (15m) must be avoided due to susceptibility to fertilizer contamination along with a proper management practices.

El Arabi, 2002, had stated that Nile aquifer system can be considered as a water conveyance media as well as storage reservoir. In that study predictions concerning the possibility of regulating the Nile aquifer system drought mitigation were carried out with the help of a simulation model on a sample region under various strategies. Results of this exercise extended to the remaining regions of the Nile aquifer system. The results also indicated that the total potential of groundwater that can be withdrawn from the Nile valley represented 18% of the available Nile surface water diverted to the Nile valley region with almost no adverse impacts.

El Arabi, 2003 had assessed the greatest potential for groundwater development which may be through the conjunctive use with surface supply system to alleviate the water resources deficits and irrigation problems. In that study a groundwater flow model had been used to simulate and asses the behavior of the Nile aquifer system under proposed groundwater pumpage schemes. The results of that study indicated that the Nile aquifer system in the Nile Valley region can be used as storage reservoir.

Chapter three

Reviewing Hydro Geological setting and Water Balance of Nile Valley Region

3.1. General background

The Nile valley is facing some problems constraining the development of the agricultural sector, namely: the continuous increase of population with uncontrollable rates, and the deterioration of some of the old cultivated lands due to the seepage of adjacent reclaimed lands and consequently the recent water logging problems. The water system of the Nile valley and the hydrological conditions are characterized as following:

- Fairly good soils on the valley fringes, where rapid expansions in agriculture development may take place, if water demands and proper drainage systems are satisfied. Several locations have, already been selected by the government according to a primarily soil survey (MOA,MOI);
- River interconnected aquifers with reasonable hydrogeologic water yielding and water transmitting parameters, and, initial suitable ground water quality.

The cultivated and irrigated part of upper Egypt extend from Aswan (24° north latitude) to the greater Cairo region (30° north latitude), a distance of nearly 900 kilometers (960 kms measured along the Nile courses) Figure (3.1). The average width of the valley ranges from 12 to 14 kilometers, confined on both sides between arid and desert plateaus extending to the red sea and, western plateau several depressions are found which are irrigated from natural fountains (springs) as wells. Unlike the oases, El-Fayoum, 90 kilometers west south of Cairo neighboring the valley and is fed by Nile water. Mean annual rainfall amounts about 30 millimeters at Cairo, being almost nil at Aswan.

The mean longitudinal slope of the valley floor is about 9 centimeters per kilometer; while the transversal slope ranges from 15 to 20 centimeters per kilometer.

Figure (3.1) Location Map of studied area

After the construction of the HAD and with the absence of an efficient drainage network, water table built up continuously as a result of seepage from canals and leakage from applied irrigation water. This resulted in increasing deep percolation from the upper clay-silt semi-confining layer to the underlying aquifers, and consequently, increasing in the groundwater heads.

Increase in groundwater heads directly affects the amount of leakage from the water table. This results in a continuous built up in the water table, creation of water logging problems and accumulation of salts in the root zone. Agriculture yield in some areas is suffering from these harmful effects. The Nile valley region has served by large system of drainage network (surface and tile drain) in the floodplain.

The ministry of Water Resources and Irrigation has a regional plan for land reclamation, depending on land surveys (carried out by the ministry of agriculture) and water availability. Part of the proposed areas has already been reclaimed under planed projects such as El-Fshn, Samalut and Tahta. While the rest are extending with unplanned private projects based on groundwater such as El Marshda and Girga reclaimed lands. The planed reclaimed lands have been supplied with Nile water, either directly diverted from the river, or from a main canal (Bahr Yussef). Most of these lands are on the valley fringes where ground surface is some meters higher than the adjacent old cultivated lands. This situation implies pumping the surface water from the water channels into the new water conveyors up to the reclaimed areas.

Previous studies and investigations carried out in these areas indicate that the same alluvial aquifer system that underlies the old lands extends under the fringes where the reclamation activities are taking place (RIGW-IWACO, 1989). A powerful potentiality for recharging the aquifer is thus introduced due to the hydraulic conductivity of the light soils of the high lands under reclamation.

The irrigated area of the Nile valley in the reach from Aswan to Cairo is about 900km long and has an average width of about 12 km, thus covering an area of almost 11 000 km^2. The valley is formed of alluvium consisting of gravel, sand, silt and clay. This alluvium is bordered by shoulders of Nubian sandstone; shale and clay, from Aswan to Esna, cretaceous formations; limestone and shale, from Nag-Hammadi to Cairo.The aquifer underlying the Nile valley can be subdivided into unconfined, semi-confined and confined, depending on the thickness and the hydraulic properties of the overlying layers. The Nile river cuts in a semi-confined aquifer. Most of the channel bottom is cut, however, in a layer of graded sand and gravel along the entire course of the river, thus providing hydraulic connection with the groundwater body. Further to the east and the west, except in certain locations run the unconfined aquifers. The surface covered by the phreatic aquifer is approximately 30% and that covered by the semi-confined is 70%, both of the total surfaces presently under irrigation.

The Nile alluvium consists of clay-silt deposits, which have a slow to moderate permeability. The thickness of such layer varies from zero, in the case of phreatic aquifer, up to 3 to 20 m in the case of semi-confined aquifers. The lower layer consists of graded sands and gravels, with depth varying between 25 and 60 m for unconfined aquifers and between 40 and 240 m for the semi-confined aquifers. Both types of aquifer are underlain by practically impermeable strata.

3.2. Physical setting

Climate: The Nile Valley is an arid region with almost no precipitation. The average maximum temperature varies from 21.6 ˚C in January to 37.0 ˚C in June. The minimum temperature varies from 6.1 ˚C in January to 21.7 ˚C in August. The mean monthly relative humidity during daytime varies from 53% in December to 24% in May (RIGW-IWACO, 1991).

Hydrography: The Nile valley region (approximately 11,000 km^2), is a morphologic depression filled with Pliocene and quaternary sediments. The Nile enters Egypt at Wadi Halfa, south of Aswan. This area is at present occupied by the high Aswan Lake. From Aswan to Cairo, the river meanders until it reaches Cairo, the total length of the river course between Aswan and Cairo is about 950 km.

Along its course, a good number of dry drainage lines join the Nile, and have their uptake areas located essentially in the eastern watershed (almost dead at present, but have been active during the wet episodes of the Pleistocene).

The western watershed is, morphologically less pronounced consequently short and almost insignificant. The natural drainage lines affecting the Nile valley are Wadi Qena and Wadi El Assiuty.

In the Nile valley flood plain, extensive man-made drainage systems exist especially in the traditionally cultivated old land. Some are extended to the reclaimed areas. Such drainage systems are discharging to the Nile itself either by gravity or by pumping.

Land use: With respect to land use, the Nile valley can be divided into 2 major portions, the agricultural lands and the desert.

The total area of the agriculture lands in Egypt were estimated at six million feddans, 35% of which is located in the Nile valley. Agriculture lands include the old lands, and the newly reclaimed lands as well as the scattered urbanized areas. In addition to agriculture, industrial activities are underway, mainly in the urbanized area.

The desert portion is on both sides of the valley. In these areas, petroleum exploration, extensive quarrying, and tourism activities take place.

Geomorphology: At the southern boundary of Egypt, at Wadi Halfa, the Nile passes into a narrow valley bordered on the eastern and western sides by low cliffs of sandstone (a portion of the Nubian sandstone complex) and granite (a portion of the Precambrian basement complex) which continues eastward to the red sea highlands.

From Wadi Halfa, in the south, to Aswan, in the north, the length of this portion of the Nile is about 300 km, and is occupied by the high Aswan Lake which extends beyond the borders into Sudan. The lake has a surface area of about 6,000 km^2, a mean width of about 10 km, and volume of water in storage of about 150 billion m^3.

At Aswan, the first cataract appears and is built of granite rocks. To the north of Aswan, the Nile valley continues into the Nubian sandstone rocks, becoming generally wider and bordered by narrow stripes of cultivated lands.

Between Aswan and Esna, a distance of about 160 km, the width of the valley reaches 20 km. at Esna, the sandstone cliffs, bounding the valley give place to limestone cliffs which rise in place to more than 600 m (amsl). This limestone is assigned to the Eocene. The Eocene limestone is underlain by palaeocene and upper cretaceous shale.

At Qena, the river Nile makes a great bend (Qena bend), and the limestone cliffs retain their high altitude. To the north of Qena, the limestone cliffs continue, and on the eastern side, their elevation is higher. The cliffs, which are in several places, affected by faults and dissected by the downstream portions of the complex dry drainage lines, continue to the latitude of Cairo city, where the valley opens out to the Delta.

The average width of the alluvial floor of the Nile valley between Aswan and Cairo is about 12 km, and that of the river course about 750 m. Throughout its entire course, the Nile tends to occupy the eastern side of the valley.

Closely connected with the river Nile is the Fayoum depressions, which is connected to the valley through a narrow gorge at El Hawara. Bahr Yussef enters El Fayoum through this gorge. Lake Qarun is a saline lake occupying the lowest portion of the depression, with its bottom at about 60 m (-amsl). To the west of the depression, a local natural excavation in the Eocene limestone exists and is known by Wadi El Rayan.

3.3. Hydro geological setting

Geology: The Nile valley is a structurally controlled cutting into the limestone plateau. The Nile valley was excavated during the late Miocene age. It was, later on, filled with Pliocene and Quaternary sediments; while its sides were made up of Eocene or upper cretaceous rocks.

Regionally, the Nile valley occupies a fraction of the major sunclinal basin located on the western side of the great Nubian-Arabian massif. At Assiut, this basin has a depth on top of the basement exceeding 3,000 m. in this basin, the upper part of the sedimentary section is dominated by carbonates and shales belonging to the late cretaceous-Eocene age; while the lower parties mainly composed of sandstone faces (Nubian sandstone complex). This section is overlain (in Nile valley) by the Pliocene Quaternary sediments.

The basin was affected by tensile stress that are responsible for the formation of a complex of faults trending NW-SE. The valley is crossed by 2 major fault system, a southern system oriented E-W, affecting much of the high dam lake area; and a NW-SE, system affecting the conspicuous graben structures, has allowed for the complications of the geometry of the Quaternary aquifer in the valley

Aquifer systems: Within the Nile valley region, regional and local aquifers are encountered:

Nile system aquifer: Is the most important regional aquifer. It consists of Pleistocene graded sand and gravel. It is covered with Holocene silt and clay (semi-confining) with a thickness varying between 0 and 20 m. In the desert fringes, outside the floodplain, the semi-confining layer vanishes, and phreatic conditions prevail. The aquifer is underlain by Pliocene marine clay. The position of the base of the aquifer, relative to mean sea level, ranges from 0 (near the fringes), to more than 300 m in the centre below the mean sea level (Souhag and Minia) Figure (3.2, a-b-c-d-e-f). The saturated thickness of the aquifer ranges between 0 to more than 300 m. The aquifer tranmissivity ranges from (20,000 m^2/day) in the centre of the floodplain to less than (500 m^2 /day) at the edges (Attia, 1985).

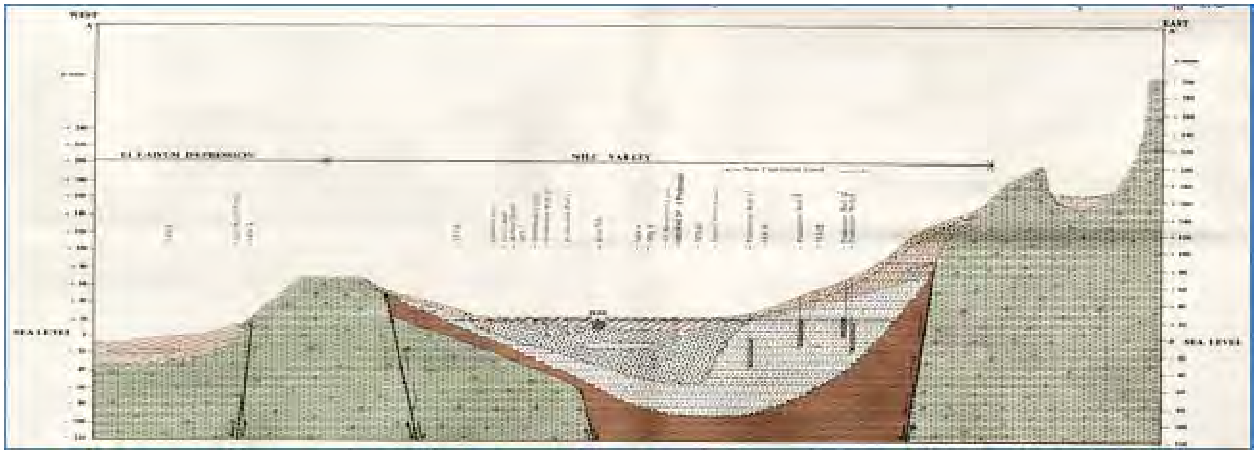

Figure (3.2, a) Hydrogoelogical cross section for Bany sewaf region (RIGW)

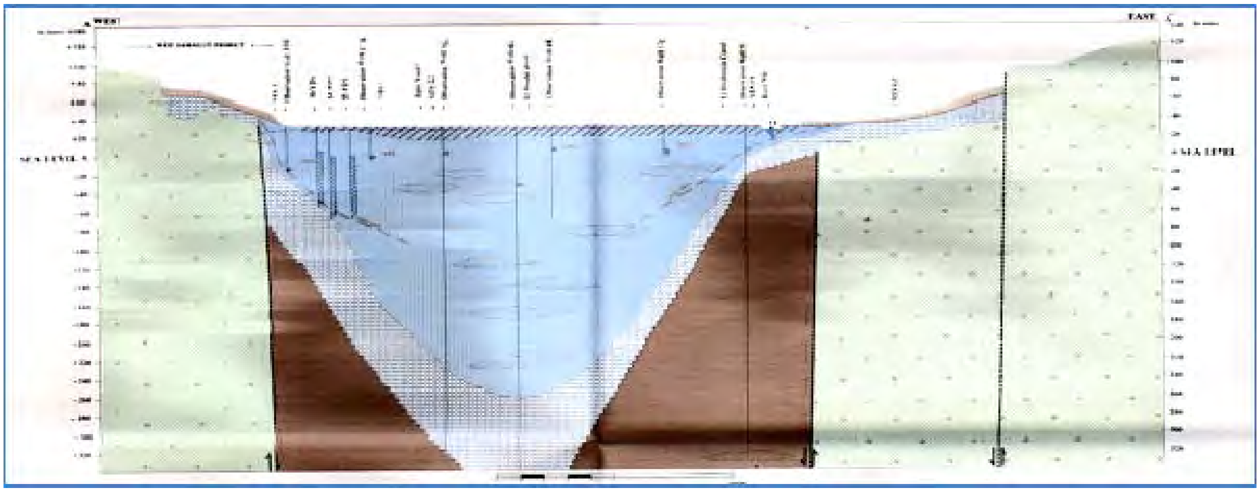

Figure (3.2, b) Hydrogoelogical cross section for Almenia region (RIGW)

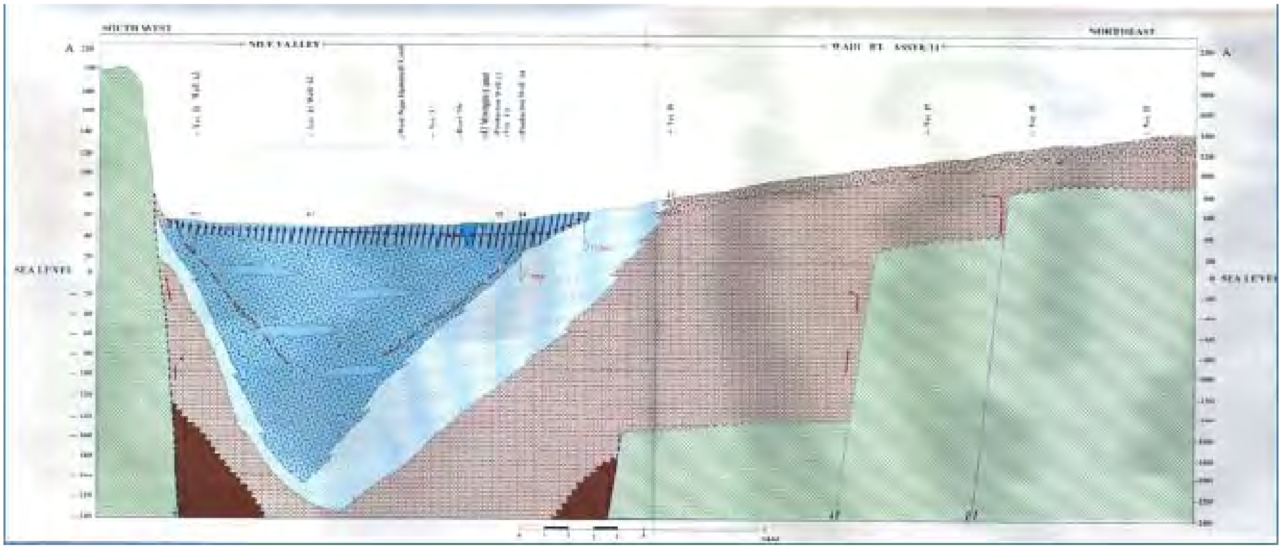

Figure (3.2, c) Hydrogoelogical cross section for Assuit region (RIGW)

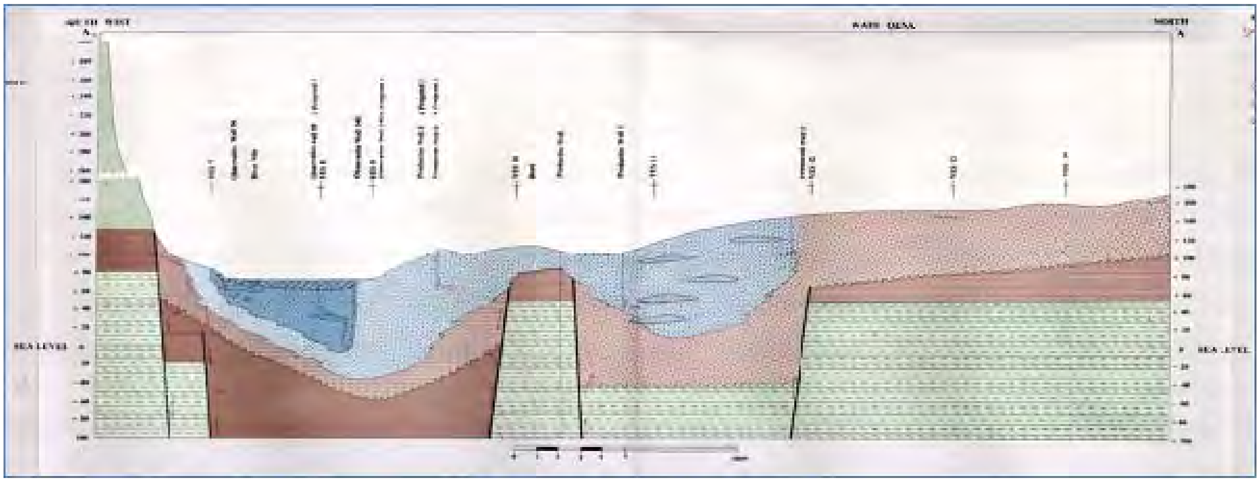

Figure (3.2, d) Hydrogoelogical cross section for Qina region (RIGW)

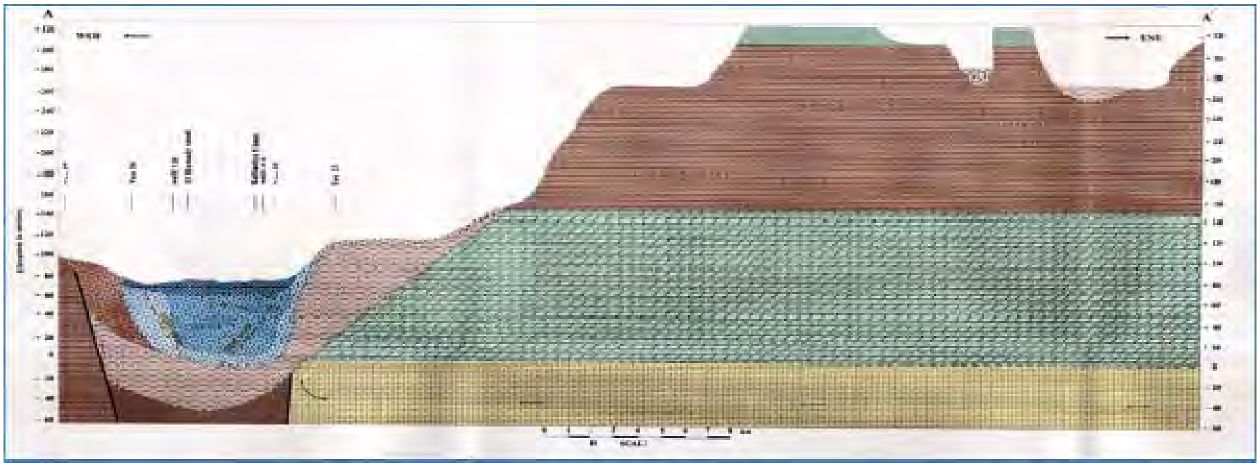

Figure (3.2, e) Hydrogoelogical cross section for Asna region (RIGW)

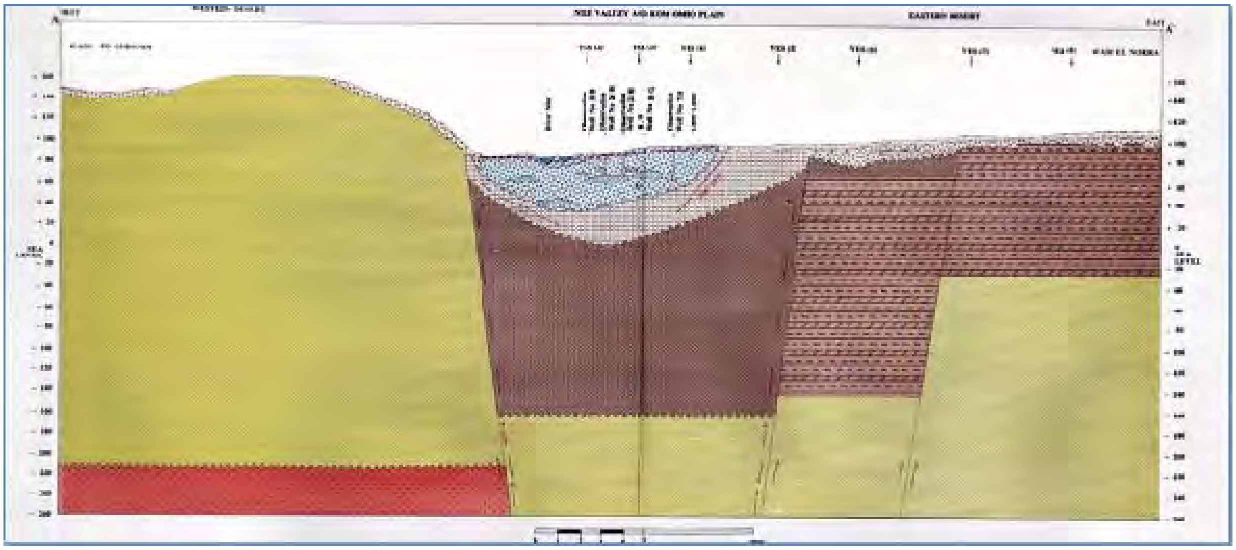

Figure (3.2, f) Hydrogoelogical cross section for Kom Ambo region (RIGW)

Nubian sandstone aquifer is the second most important regional aquifer, being the first if extensions are considered. The aquifer is exposed from Qena southward, being confined by clays and shales in the north. The base of the aquifer (cretaceous rocks) slopes, from ground level (south of Aswan) to 2,000 m below mean sea level near Cairo. The saturated thickness is between few meters to more than 1,000 m. transmissivity ranges from (500 m^2/day) to (6,000 m^2/day).

Local aquifers is consisting of plio-pleistocene sediments constitute a moderate source of groundwater in the wadis and along the fringes of the valley. Due to their contact with the Pleistocene aquifer of the Nile system, hydraulic interaction is also possible. The aquifer is generally phreatic, and its thickness varies from one place to another, ranging between few meters close to limestone plateau to more than 80 m near the Nile system.

Groundwater flow: groundwater heads fluctuates around the year with differences that might change from few centimeters to more than one meter. The average groundwater heads decreases gradually from 65 m (amsl), at Aswan, to 15 m (amsl), at Cairo. Generally in the Nile valley the depth to groundwater levels ranges between 1.5 m to 2 m from the land surface. The general flow direction is south-north. Near the fringes, flow direction is from the fringes to the Nile aquifer system and from the aquifer to the river

Recharge-discharge: the Nile aquifer system is recharged mainly from irrigation (seepage from canals and percolation from irrigation applications). Recharge from irrigation water varies according to the type of soil and irrigation method. In sandy areas (valley fringes) with basin irrigation, losses from irrigation vary between 1 and 2.5 mm/day. In silt-clay areas (semi-confined aquifers), recharge from irrigation is about 1 mm/day.

Recharge from rainfall is an important source, in the main wadis. In these areas, rainfall (100 mm/year) replenishes the plio-pleistocene sediments of the desert fringes.

Discharge from the aquifer takes place along the river course from the groundwater to the river, especially in the region Assiut-Giza (3 billion m^3/year), (Attia, 1985).

Groundwater extraction by wells is another important discharge component. The most important component is that taking place from the areas reclaimed with surface water on the fringes of the valley to the Nile valley system aquifer.

Groundwater potential: Groundwater potential, as used in this document, refers to the total rates that can be abstracted on a sustainable base; for future uses the term reserves is utilized.

Sustainability, on other hand, can be given several definitions. However, in all cases, the quality of the resources base should be maintained suitable to the originally allocated sector (i.e. no deterioration) and the environment enhanced.

The decision where to pump groundwater and in which quality depends on the groundwater potentiality in the region. The main factor affecting groundwater potential is the continuity of the source, both in term of quantity and quality. Quantity refers to the availability of the source, while quality refers to its suitability for specific use. The total potential of groundwater in the Nile valley region is 3.170 billion m^3/year and the total extraction for irrigation and drinking till year 2000, is 1.932 billion m^3/year (RIGW data base). Figure (3.3) shows groundwater potential map in the study area.

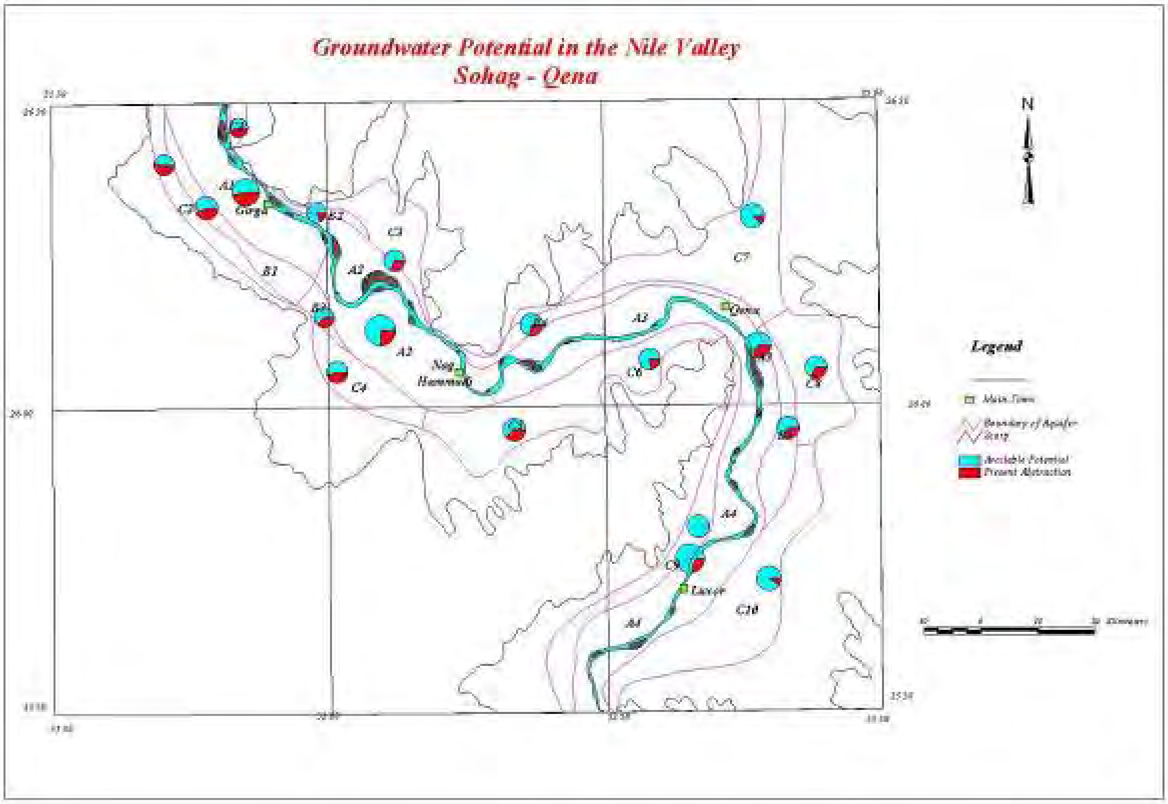

Figure (3.3) Groundwater potential map (RIGW)

3.4. Water balance of the Nile valley

Water balance is a necessary step to understand the present situation of any groundwater system. This chapter presents method of estimating the different components of groundwater balance and the equation of water budget in the general and pilot area.

The water balance study, mainly define the present hydro geological situation and the quantitative relationships between the elements of groundwater system and the others systems (irrigation and drainage) in any study area.

3.4.1. Analytical water balance for Nile Valley Region

El Arabi, 1984 This study was carried out to establish the water balance of the Nile aquifer systems in view of defining the present situation and the interrelationships of the groundwater system .This was mainly concerned with quantitative relationships between the elements of ground water system (water of the silty – clay formation and piezometeric head of the Nile alluvial aquifer) and the irrigation and drainage systems.

The water balance of any study area in Nile valley can be evaluated by balance equation for a period of one year, as follows:

$$I_{sur.} + I_G + G_T + 0.95P + R - C.U. - G_N - P - D - O_G = \Delta S \qquad (18)$$

Where

$I_{sur.}$: Surface water inflow, million m^3/ year

I_G = Groundwater inflow in longitudinal direction, million m^3/ year;

R = Natural replenishment from precipitation, million m^3/ year;

P = Groundwater extractions, million m^3/ year;

0.95P = 95% of groundwater extraction are used again for irrigation,
million m^3/ year

C.U. = Consumptive use volume, million m^3/ year;

G_N = Groundwater seeping to Nile, million m^3/ year;

G_T = Groundwater inflow in several direction, million m^3/ year;

O_G = Groundwater outflow in longitudinal direction, million m^3/ year;

D = drainage discharge, million m^3/ year;

ΔS = Change in storage, million m^3/ year;

The precipitation in the area under investigation could be neglected. Groundwater inflow and outflow in longitudinal direction are balanced, because of similarity. Equation (18) can be rewritten with form:

$$I_{sur.} + G_T + 0.95P - C.U. - G_N - P - D = \Delta S \qquad (19)$$

The components involved in any groundwater balance study and the made intervention in the hydrologic cycle, taking the form of modifications imposed on the various components of the water balance are discussed in details. The considered components are inflow and outflow of the groundwater through the boundaries of the aquifer; natural replenishment from precipitation, including a discussion of the types of precipitation, and their role in the replenishment process; return flow from irrigation and sewage artificial recharge; river – aquifer interrelationships; springs; pumpage and drainage; and change in storage.

The water balance of the study area results in weighted value for the mean annual daily drainage requirements amounting 2.5 mm/day. Out of this value 1.7 mm/day flows to the agricultural drainage –system and 0.8 mm/day flows as deep percolation to the aquifer and the Nile.

The results of analysis and study of the pilot area aquifer may afford the possibility of establishing a management level of the surface water and groundwater resources on the basis of conjunctive use. The possible advantages of operating the groundwater system in this manner for conjunctive use are:

1. It could provide a source of irrigation water which could be introduced into the existing surface water distribution system;
2. It could provide groundwater drainage and thus eliminate the need for a tile drainage network;
3. It therefore offers a relatively simple method of re-use of groundwater drainage water for irrigation which would not involve collecting large quantities of drainage water in one place for redistribution.

This work has indicated that generally the local groundwater flow condition deviates greatly from the prevailing regional condition. Thus, local investigations are recommended to take place before the design groundwater operation scheme.

Optimization techniques may be of great importance on selecting the best management policy applied to the pilot area based on conjunctive use concepts. The proposed approach could be through minimization of the investment, operation and maintenance costs of all the existing and proposed system (drain, water supply for irrigation, domestic and industrial uses, and tube wells).

3.4.2. Modeling for the Nile Valley Region

The groundwater flow in the Nile Valley Region is simulated by using TRIWACO model (El Arabi, 2003). TRIWACO is numerical program for quasi three-dimensional saturated groundwater flow, based on the finite element technique. The program is developed to take into consideration the interaction between the groundwater and surface water. The program can handle a variety of steady state and transient groundwater flow problems.

The Nile Valley which is a long narrow valley bounded by a limestone plateau is covered by a triangular element grid. The grid consists of 7919 nodes and 14655 element incorporating two aquifer layer and top system Figure (3.4). The top system is covering the area containing tile drains which is recharged by the excess irrigation water. Top system 5 represents the tile drain system in the old land in the TRIWACO Package. The recharge rate is dependent on the drainage resistance, the horizontal and vertical permeability and the thickness of the semi-pervious layer. Also, it depends on the wetted perimeter of the drains. The first aquifer is underlying the top system with average thickness 50 m. This aquifer is recharged by the net deep percolation from the top system and is discharged by the extraction with the pumping wells and the seepage to the River Nile. The second aquifer is underlying the first aquifer, and is not in hydraulic connection with River Nile. The bottom boundary of the second aquifer is an impermeable clay bed.

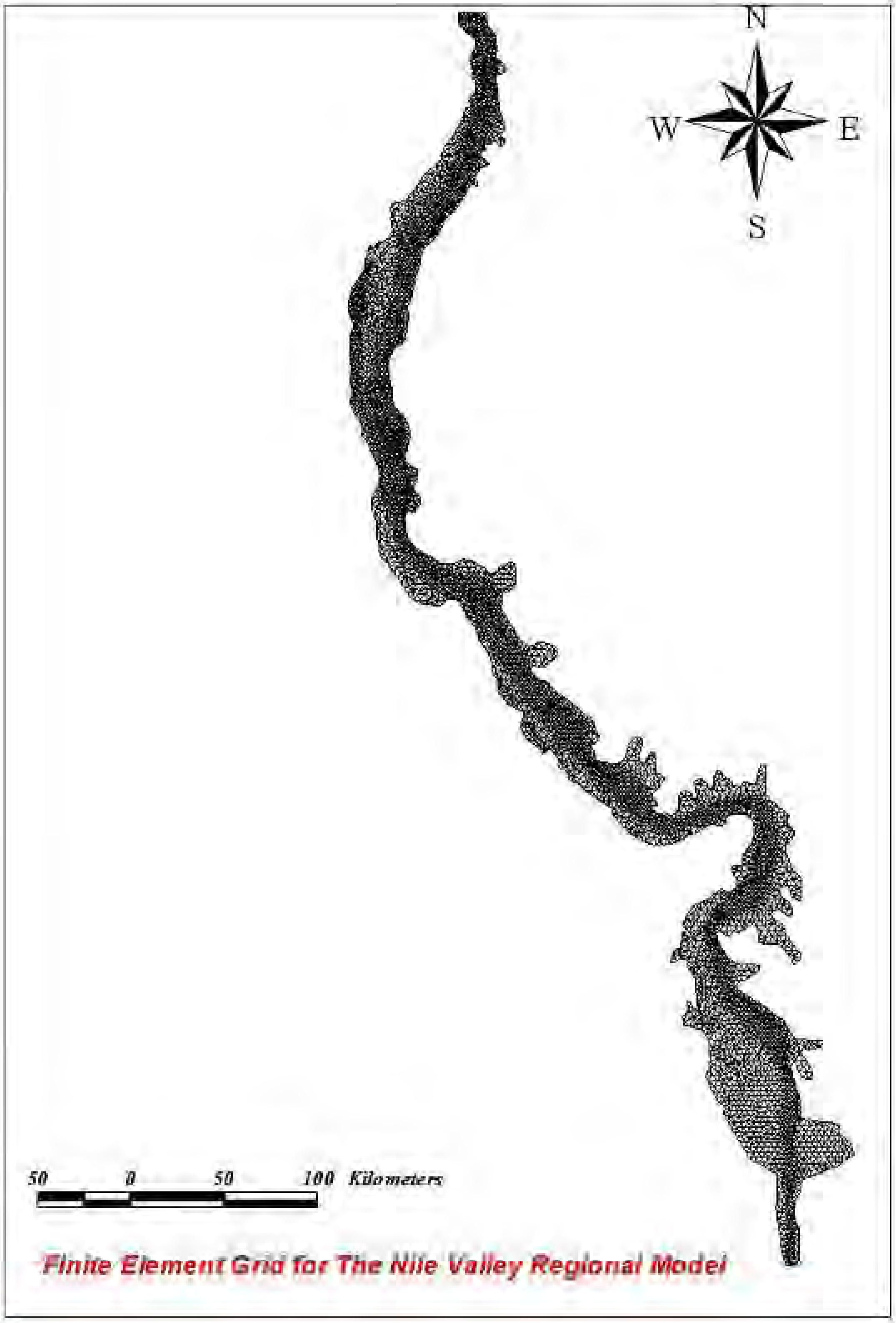

Figure (3.4) Finite Element Grid for the Nile Valley Regional Model (El Arabi, 2003)

The eastern and western boundaries are simplified and considered as no flow boundaries. The northern and southern boundaries are considered as specified constant head. The excess irrigation water is considered as the main source of the recharge on the top of the saturated groundwater aquifer. The excess rate of irrigation water varies from 3.0 mm/day in the old lands (flood plain) to 6.0 mm/day in the reclaimed lands. The total irrigated area (recharge area) is 10264 Km^2 (about 2443895 feddans)

This model is calibrated against groundwater heads of the observation points for 1997. The main calibrated parameter is the rate of recharge (excess of irrigation water). The model is calibrated under steady state condition with comparison between the observed and the calculated heads for the observation points with acceptable error. The results of water balance have estimated the total net recharge rate to the aquifer, 0.9 mm/day, including the seepage to the River Nile and the extraction Figure (3.5). The water balance also resulted that the difference between the recharge rates to the top system is 4 mm/day, and the net recharge rate to the aquifer (1) is 0.9 mm/day. From the analysis of water balance the rate of discharge into the drainage system is about 3.1 mm/day. Also the seepage rate from aquifer to the River Nile is about 0.4 mm/day, which amounts 1.64 Billion m/year. This seepage to the River Nile is in agreement with the previous study, (Fatma, 1985). The calibrated model is tested for doubling the extraction which resulted in about 0.3 m difference between the observed and the calculated heads covering the model area. This calibrated model is ready testing the measures of National water resources plan.

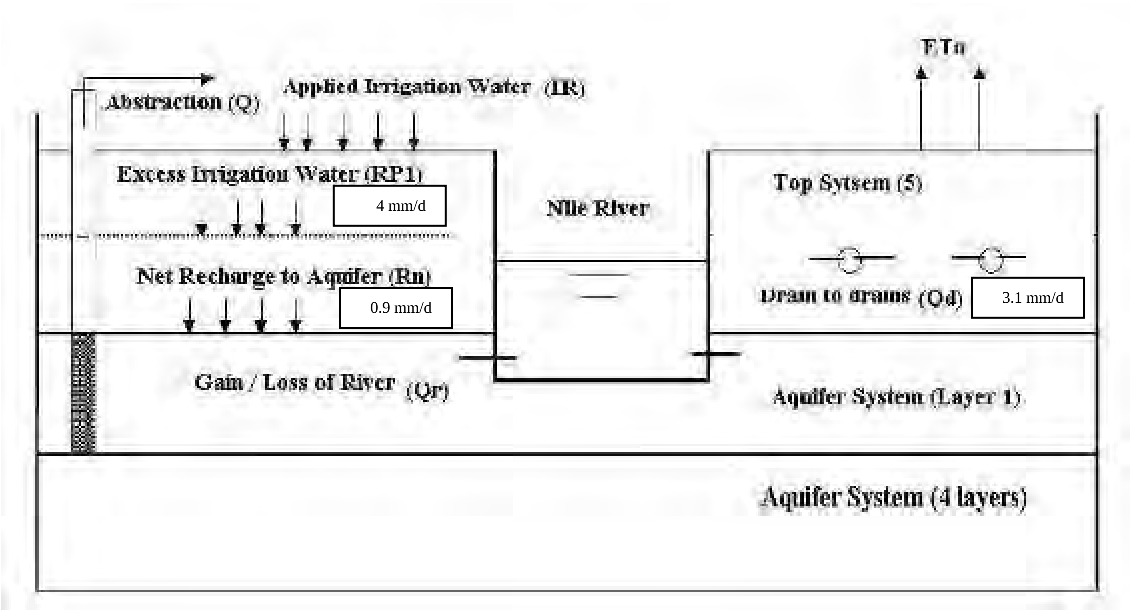

Figure (3.5) Shows the water balance for the Nile Valley (El Arabi, 2003)

3.4.3 Model Response to Assigned Measures:

A demonstration measure assuming double of the present abstraction has been assigned to test the model application under future proposed measures. Results obtained from the model prediction run under the assigned demonstration measure and the difference between calibrated water balance components are illustrated in figure (3.6)

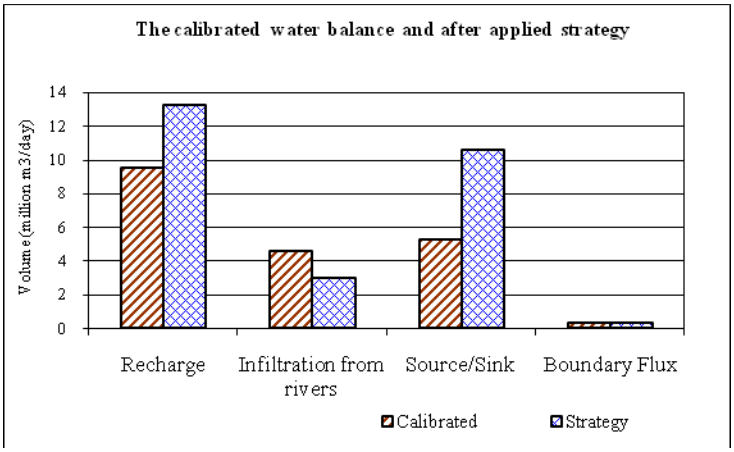

Figure (3.6) The calibrated water balance and applied strategy

From the analysis and the understanding of the water balance of the regional calibrated model of the Nile Valley and the results of the model response to this assigned measure has helped to determine the controllable issues used for developing the strategies of the groundwater development.

These issues are:

Groundwater pumpage near the fringes of the valley (where no surface water reclamation take place) would result in large drawdown and may introduce low quality water to the system.

Groundwater pumpage near the River course would result in adverse flow and no land drainage provisions, thus minimizing the net economic return from the groundwater development strategy.

Regional drawdown should not affect any existing groundwater scheme (public or private). Moreover, during the design phase, local drawdown (inside the wells) should be taken into consideration.

3.5. Ground water development in Egypt

Groundwater use for irrigation in Egypt dates back to ancient times. About 2500 years ago, groundwater was used to irrigate about one million acres of fertile land. In the western desert, there are still ample signs of ancient irrigation by deep wells, some are 200 meters deep. A number of these wells are still functioning in the oases of the western desert. The use of groundwater for irrigation continued over time and was quite common in the Nile valley and delta till the construction of the high dam. Tube-wells were successfully used by farmers for supplementary irrigation during the low- flow season of the river.

After the construction of the high dam, most farmers abandoned their tube-wells and depended on surface water. Recently, farmers in the old cultivated lands started to dig new wells to alleviate seasonal and spatial shortages in surface water supplies. Tube-wells are the only source of irrigation water in small scale reclamation schemes. In most cases, the cost of wells is borne by farmers. Individual farmers or groups of farmers share their wells.

Pumped groundwater in the Nile Valley and Delta is replenished by surface water or sea water (in the north). Therefore, the huge water- bearing formations underlying the Nile floodplain may be regarded as a subsurface reservoir. Like Lake Nasser, the groundwater reservoir can be used for intra-annual or intra-annual regulation of the Nile water resource.

Groundwater, therefore, forms an important component in the national water plans. These plans include policy guidelines and priority for the development of groundwater. One of the priorities for groundwater development is its use for domestic water supply. The required amounts for this purpose are relatively small compared to the total recharge. Groundwater development for agriculture, therefore, plays an important role in the water development plans of the country.

Attractive areas for groundwater development may be identified as follows:

Areas in the Nile flood plain where implementation of tile drainage is difficult or economically less attractive than tube- well drainage. These areas occur predominantly near the fringes of the Nile valley and delta adjacent to reclamation schemes.

Areas in the Nile floodplain from shortages of surface water. These shortages occur mainly during the summer months with high crop water requirements. Water shortages are either due to insufficient releases of surface water to irrigation command areas or inadequate distribution of water within the command areas.

Desert fringes of the Nile valley and delta. In these areas, the conjunctive use of groundwater and surface water or the use of groundwater alone may be more economic than the use of surface water.

The selection, design and operation of well-fields should be carefully investigated. The selection of well-field locations depends on many factors, among which, functioning of the irrigation and drainage systems, hydro geological situation, existing groundwater extractions and farmers acceptance are of special importance for the preliminary success of the system.

3.6 Examples of groundwater development schemes in Egypt

Groundwater irrigation schemes in the old land:

Groundwater pilot schemes have been implemented in the old land, one in the valley (Tanda well field) and another in the delta (Minufya well field). The command area of each scheme is about 4.200 acres. The areas used to be irrigated with surface water. The groundwater irrigation scheme of the Nile valley is accompanied with an improved irrigation distribution system (lined channels and pipes). In these schemes groundwater is the only source of irrigation.

The area (18 km^2) is located in the central part of the Nile Valley about 9 km west of the River Nile**. (Amer et, 1989).** The area is, at present, irrigated with Nile water from El-Arous main canal and four of its branches (Figure 3.8).after the implementation of the well-field, groundwater will be the only source of irrigation. The well-field consist of 73 wells, of witch 22 wells are stand-by. The well capacity is 350 m^3/hour (Attia,1985) wells are sited along the main and the branch canals(farmers requirements).

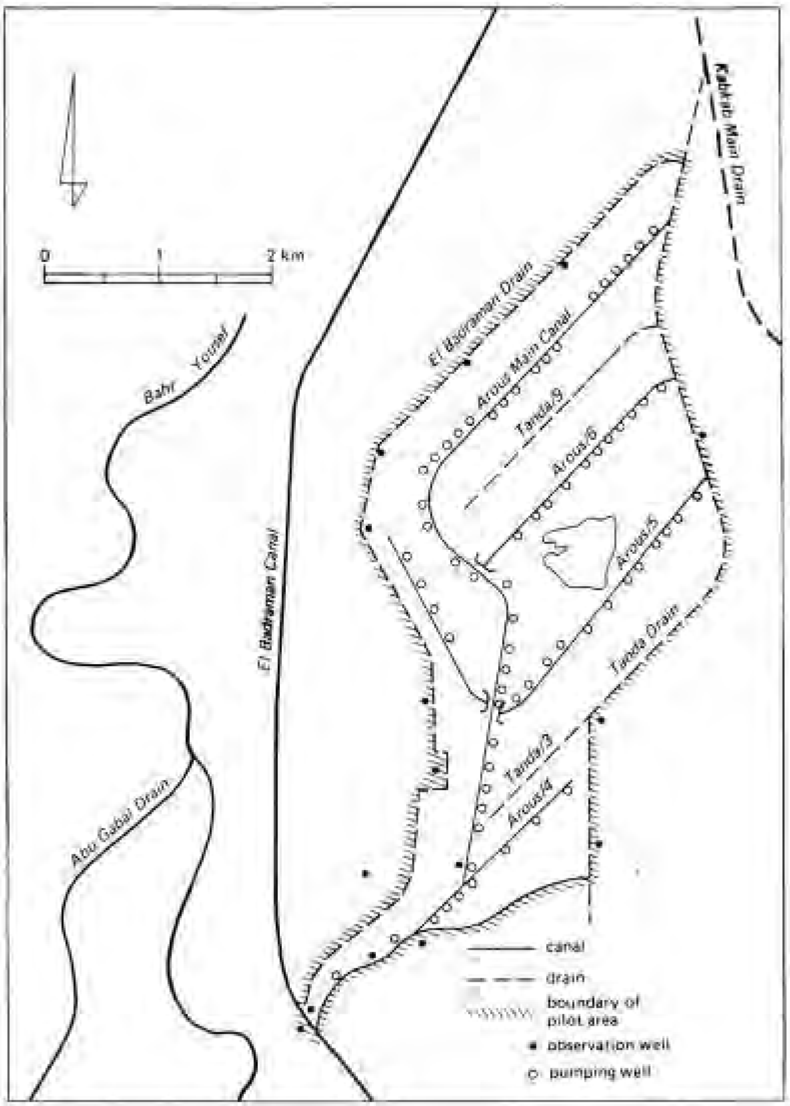

Figure (3.7) Irrigation system and location of wells in Tanda well field (Souhag)

Four operation schemes have been investigated. The well-field is, at one extreme, supposed to operate according to irrigation requirements of the pilot area “irr”, and, at the other extreme, to operate 24 hour/day all the year “irr+12”. Pumped water exceeding the irrigation requirement of the pilot area may be transferred to nearby areas. In a 100-year period following the operation of the well-field, no problems are expected with the quality of groundwater as it is related to its suitability for irrigation. The Nile Valley groundwater reservoir can be used for seasonal storage of water.

Tube-well drainage is economically attractive, especially through the savings in cost for the installation of a tile drainage system. Use of pumped groundwater for irrigation (or for other purposes) contributes to economic benefit of tube-well drainage. Development of groundwater in the Nile Valley will contribute to the reduction of major constraints in water management.

The role of "Irrigation Improvement Project" is to reduce the end cost of irrigation through the use of groundwater as: (i) the only source of irrigation of some command areas; (ii) supplemental irrigation source to augment the canal water during peak seasons; or (iii) to irrigate the tail ends of some commands. For Tanda well field 73 well was implemented and have operated since 1990. The command 500 feddans area has been irrigated with groundwater only using the improvement pipe canals.

- **Land reclamation schemes**

After the completion of the high dam several reclamation schemes have been developed. Irrigation of these lands was carried out mainly on surface water diverted from the Nile. Due to the full utilization of the river water at present, further land reclamation will take place with the help of groundwater. The majority of the land reclamation projects at present are carried out by individuals. Due to the lack of information, experience, and financial support, some of the wells, in the desert fringes, are experiencing degradation. The RIGW is at present carrying out investigations concerning the long- term impact of groundwater irrigation schemes in the desert fringes on the sustainability of the resource.

Reviewing the hydrogeological settings and the water balance of the Nile valley helped in further focusing on the study area.

Chapter four

Physical and Hydrogeological Settings of the Study Area

4.1. Introduction

Girga is one of the districts of Souhag Governorate in Upper Egypt. Farmers from traditional lands have moved to the desert and started to dig wells and cultivate new areas along the fringes. The continuous increase in demands in the desert areas is believed to affect the continuity of supply both quantitatively and qualitatively. In this chapter, the hydro geological conditions prevailing in the Girga region are presented. The information, in this chapter, is based on previous studies and recent field investigations.

4.2. Physical Setting

4.2.1 Location and topography

The reclaimed area is located in west Girga. Along the western fringes of the Nile Valley near Girga, a strip of land was reclaimed, since 1987, and is still increasing with time. The study area is located between latitude 26º00 N and 26º30 N approximately 11 km west of Girga, Figure (4.1).

The distance to the Nile River is about 13 km. The reclaimed area is subdivided into two parts. The northern part of the area has a length of about 20 km and an average width of 3 km. The southern part covers a length of about 22 km and an average width of 1.2 km.

The topography of the reclaimed area is characterized by gently rolling sand plains. The surface of the reclaimed area is characterized by a gently sloping surface within the area, being very steep towards the adjacent old lands (up to 10 cm / km). The study area is located between the topographic contour lines of 62 m and 150 m +MSL. The traditionally cultivated area is located in the topographical lowest part of the Nile floodplain adjacent to the reclaimed area. The elevation of the ground surface ranges from 62 m to 65 m +MSL.

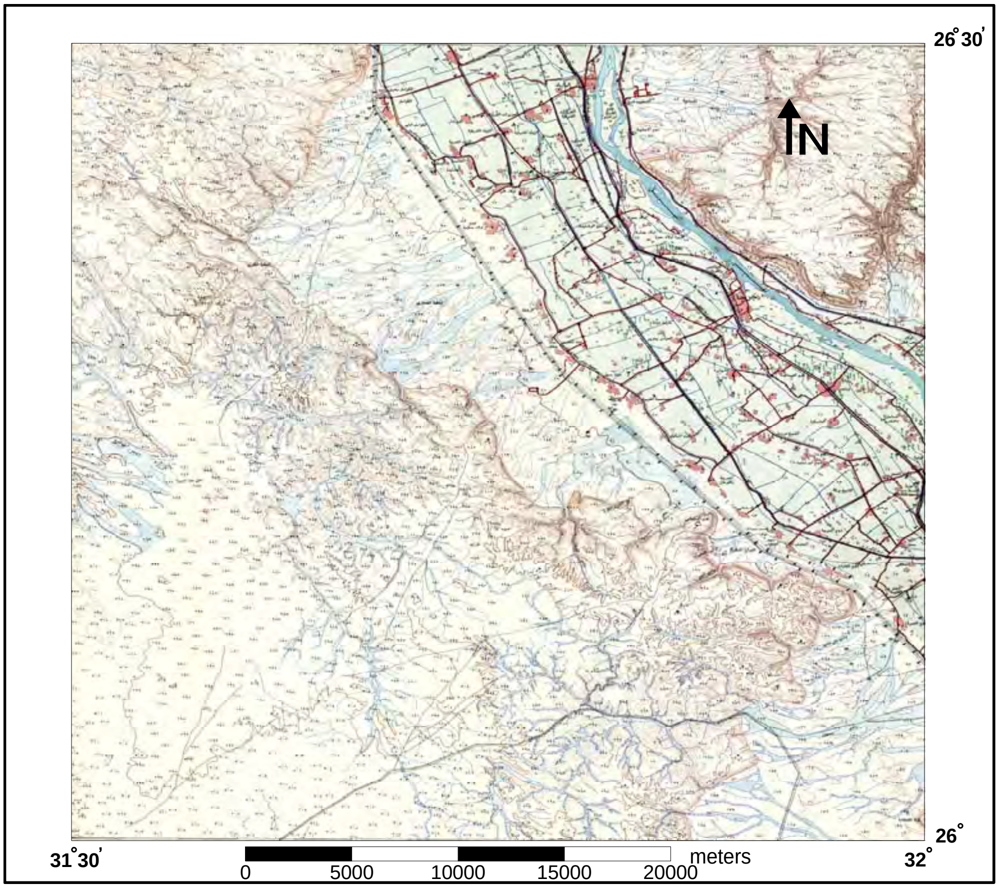

Figure (4.1) General topographic Map for Girga Region

4.2.2 Soils

The soils in the reclaimed area are characterized by a fine texture, predominantly consisting of fine sands. Clay is generally absent, except few locations. The upper soils change from the silty clays of the floodplain to the fine sands and silts in the reclaimed area. The transition between the reclaimed desert land and the floodplain is sometimes not realized as farmers have imported Nile mud into the reclaimed area to improve the soil structure and increase the fertility.

4.2.3 Land use

The traditionally cultivated area is entirely used for agriculture. The major winter crops are wheat, beans and berseam. The predominant summer crops are maize and cotton. The reclamation in west Girga started in 1987. Reclamation activities have initiated by private sector (farmers) with digging pumping wells. Figure (4.2) presents the land use of the study area. The total reclaimed area amounts to about 17600 feddans. But another 23277 feddans can be added to it, in the future.

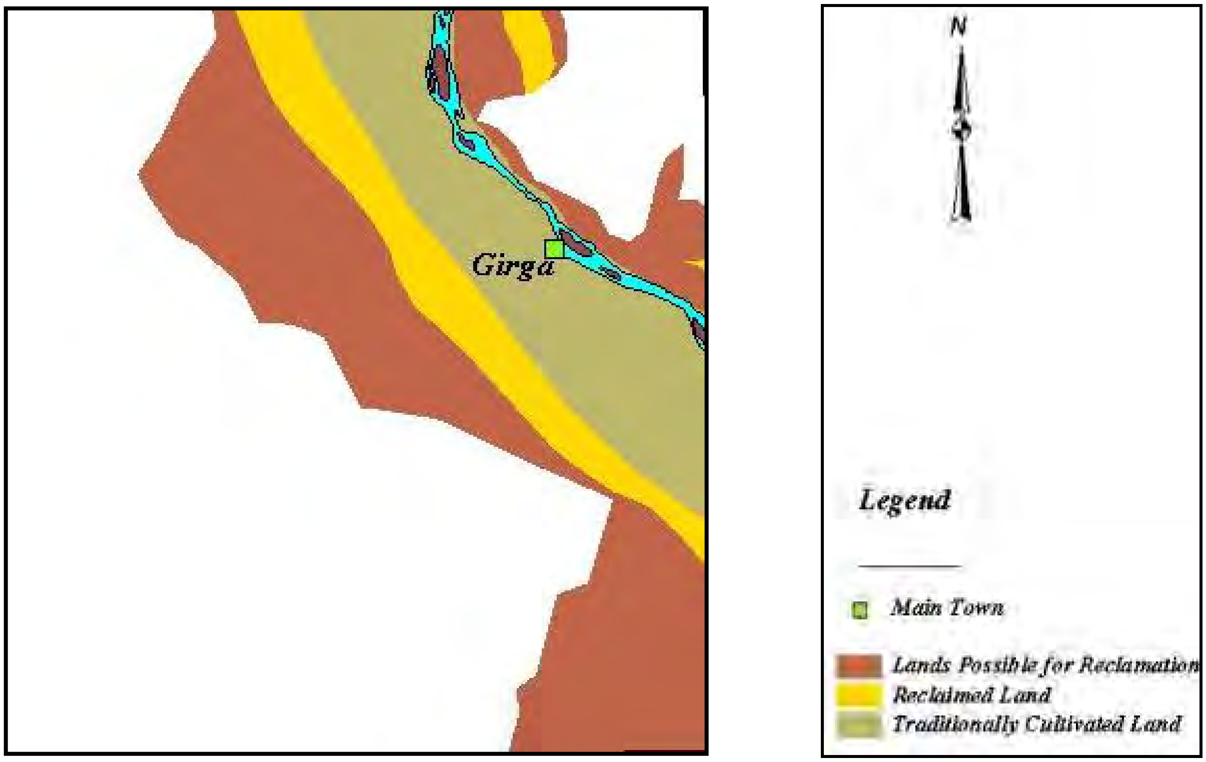

Figure (4.2) Landuse map for Girga Region (MWRI)

The reclaimed lands in the past two decades have increased with a noticeable rate towards the west direction. The landsat images of Girga region for year 1987 and 2000 assure the growth in the amount of the reclaimed areas. The green color which indicated the cultivated lands has obviously increased. Figure (4.3) shows the landsat image for year 1987 and Figure (4.4) shows the landsat image for year 2000.

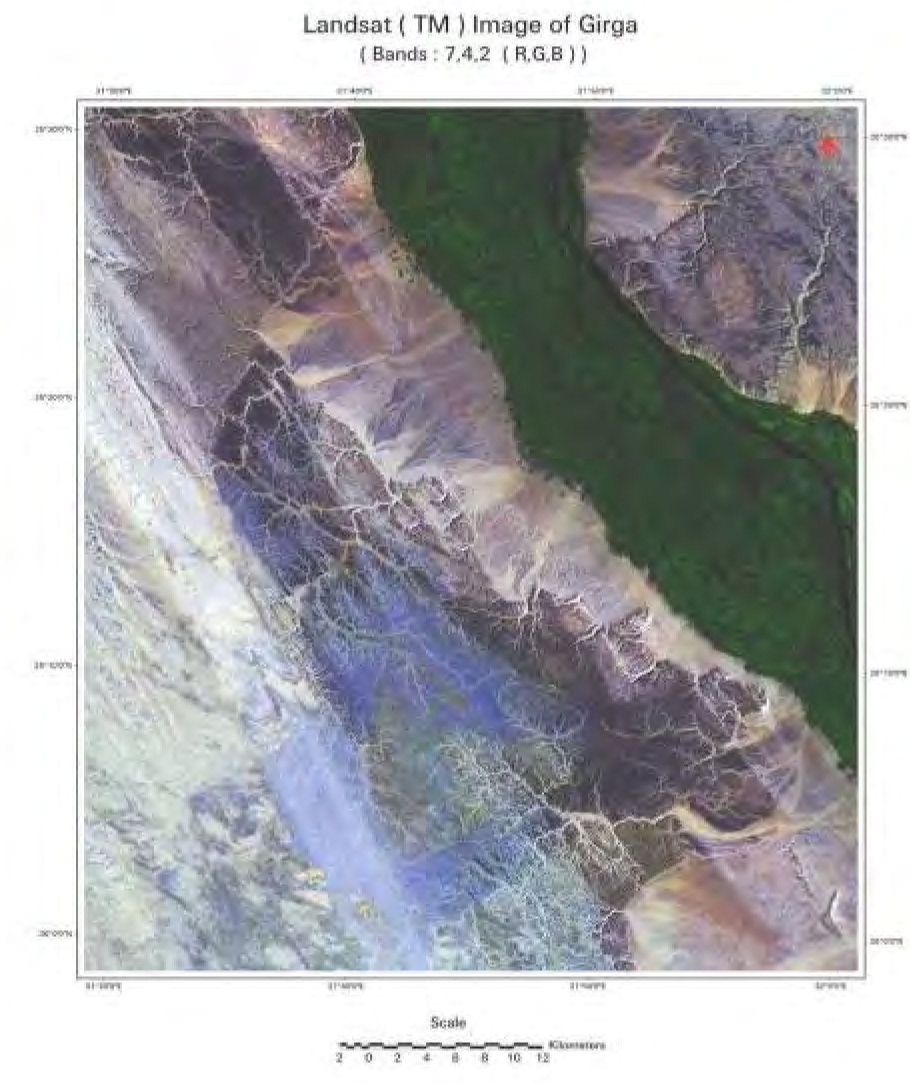

Figure (4.3) landsat image of Girga region in the year 1987 (Zaki, 2001)