Sustainable Development and Management of Water Resources in West Nile Delta, Egypt

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ABSTRACT

Egypt is a hyper arid country with limited water resources and less than 5% of its physical area inhabited due to the limitations on water resources in terms of rates and distribution. The major source of fresh water comes from the Nile, being fixed at 55.5 billion m^3/year. The second source of water is groundwater available from both renewable and nonrenewable aquifer systems with a maximum sustainable potential of about 15 billion m^3/year. However, due to its wide distribution, groundwater is considered main source of fresh water for both rural and agriculture supplies. During the last two decades, land reclamation projects and community settlements took place in many regions, including the West Nile delta. Some have been based on surface water diversions from the Nile (e.g. South El Tahrir, New Ameriya, El Nubariya and El Bustan) while others are totally dependent on local groundwater withdrawals (e.g. El Sadat city, Wadi el Natrun and Wadi el Farigh).

The study area of this research is a part of the western Nile Delta. It is located on the right side of the Cairo-Alexandria desert road, limited by latitudes 30º 15′ - 30º 50′ N and longitudes 30º 00′ - 30º 48′ E, with an area of about 3100 km2. It is bounded by El Nubariya canal from the Northeast, El Nasr canal from the Northwest, El Rayah El Naseri from the East and Wadi El Natrun depression from the southwest.

The study area is suffering from continuous groundwater depletion in the groundwater-based development region while in the surface water-based regions (especially Nubaryia) water logging and soil salinization are prevailing mainly due to seepage from the main canals.

In this paper, investigations such as field, office and modeling are made to study the impacts of some water management strategies, involving the application of conjunctive use of groundwater and surface developments, on the sustainability of existing developments.

INTRODUCTION

Water Resources and Country Development

Egypt is a hyper arid country with limited water resources and less than 5% of its physical area inhabited due to the limitations on water resources in terms of rates and distribution. The major source of fresh water comes from the Nile, being fixed at 55.5 billion m^3/year. The second source of water is groundwater available from both renewable and nonrenewable aquifer systems with a maximum sustainable potential of about 15 billion m^3/year. However, due to its wide distribution, groundwater is considered main source of fresh water for both rural and agriculture supplies. During the last two decades, land reclamation projects and community settlements took place in many regions, including the West Nile delta. Some have been based on surface water diversions from the Nile (e.g. South El Tahrir, New Ameriya, El Nubariya and El Bustan) while others are totally dependent on local groundwater withdrawals (e.g. El Sadat city, Wadi el Natrun and Wadi el Farigh).

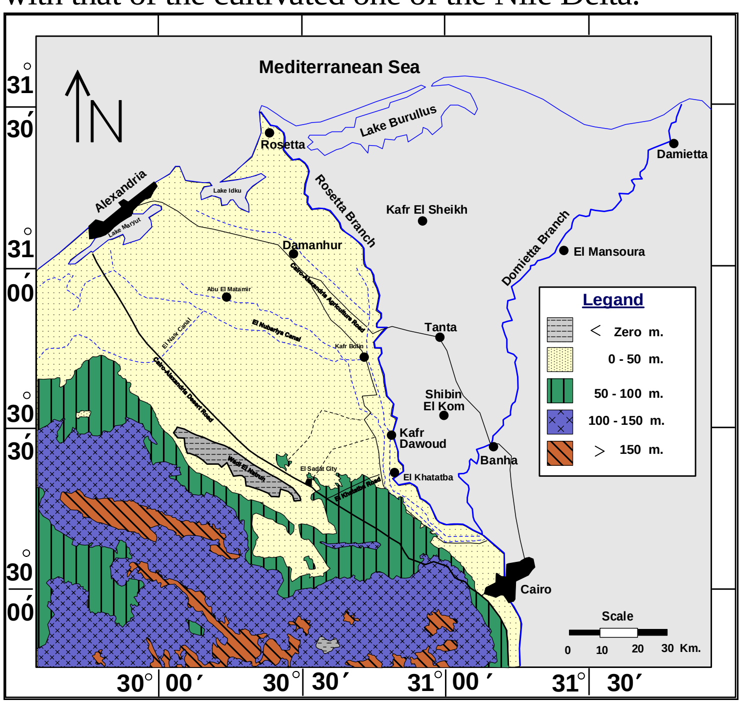
Interpretation of pumping and recovery test data using Ground Water Software® for Windows (GWW), version (1.10). Simulation of groundwater levels using mathematical model (Visual Modflow software ®) – code version (4.20). [1], [2] and [3]

Sustainable development is the centerpiece and key to water resource quantity and quality, as well as national security, economic health, and societal well-being. The word sustainability implies the ability to support life, to comfort, and to nourish. For all of human history, the Earth has sustained human beings by providing food, water, air, and shelter. Sustainable also means continuing without lessening**.** Development means improving or bringing to a more advanced state, such as in our economy [4].

The purpose of this research is to detect the effect of the previous investments on the groundwater potentialities especially in the study area under applied developing policy and the other future supposed scenarios by invoking a groundwater mathematical model (Visual MODFLOW) to forecast the impacts of these exploitations to insure sustainable development in this promising area.

Physical Setting of the West Delta Region

The Nile Delta is a flat area (a nearly level plain) with an average northward gradient of 1:10,000 from Cairo to the Mediterranean Sea, where the land surface slopes gently northwards [5] and **[6].** The western Nile Delta fringe is generally characterized by slightly undulating topography and higher land comparing with that of the cultivated one of the Nile Delta.



(Figure 1) Orographic map of the West Nile Delta area modified after [6]

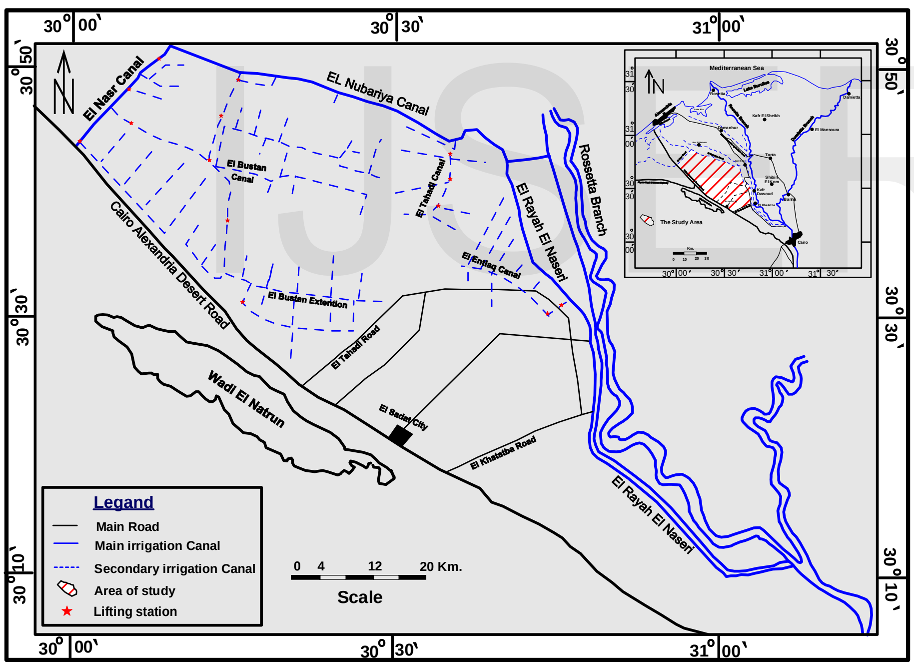
Generally, the land surface west of the Nile Delta slopes northward and eastward in the direction of the Mediterranean Sea and the Rosetta branch of the Nile. The slope rises gradually towards the desert and the low relief becomes slightly undulating (Fig. 1).

The Western Nile delta is dominated by arid to semiarid climate in the south, while in the north (along the coastline) a Mediterranean climate is prevailing.

Main Surface Water Systems in the West Nile Delta Region

The area west of the Nile Delta is characterized by a dense population, soil potentialities and water availability. A number of canals and drains dissect the region. The interconnection between surface water and groundwater systems is rather complicated and is seasonally variable. The surface water canals receive Nile water from the Rosetta branch of the Nile (Fig. 2). The main canals crossing the West Delta are:

1- El-Rayah El-Naseri, about 21.8 km in length;
2- El- Entlaaq Canal, about 23.5 km in length;
3- El-Nubariya Canal, about 50.3 km in length; and
4- El Nasr Canal, about 22.6 km in length



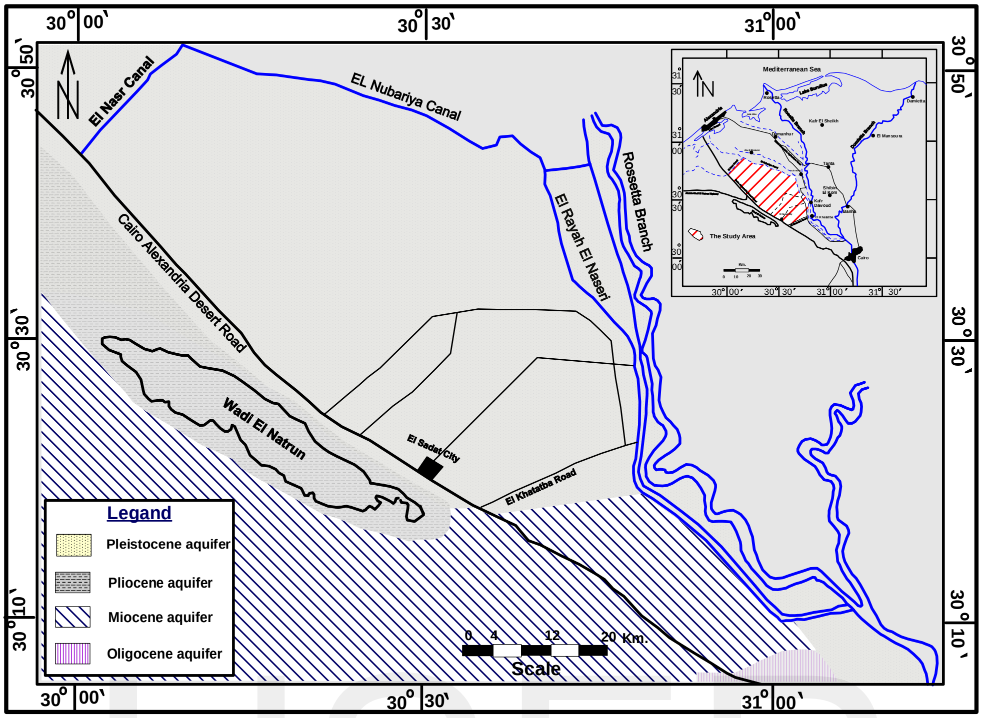
(Figure 2) Surface water systems in the area of study area modified after [6]

The existing surface water canals are mainly excavated through the Quaternary deposits which results in a direct connection between the surface water and the shallow groundwater in the Pleistocene aquifer.

Geomorphologic and Hydrogeologic Characteristics

The West Nile Delta has a lithostratigraphic succession built up of sand, gravel and clay deposits belonging to the Quaternary time (Holocene and Pleistocene). Environmentally, the Pleistocene sediments in the area are formed of Deltaic facies composed of gravelly sands and sands intercalated with thin clay layers and capped by lagoon facies composed of sands, clay and gypsiferous clay.

The Western Nile Delta consists of two main aquifer systems, Nile Delta and Moghra aquifer (Fig.3):



(Figure 3) Distribution of different aquifers in the area of study modified after [6]

- The Moghra Aquifer System consists of Miocene sand and gravel of the Moghra formation. In Wadi el Natrun depression, the Moghra aquifer is confined by a thick Pliocene sequence. In other areas, the aquifer is phreatic. The Moghra aquifer and the Nile Delta aquifer are hydraulically connected.

- The Nile Delta Aquifer (Quaternary) consists of Pleistocene sands and gravels with some intercalation of clay and is present in the east of Cairo Alexandria Road. The aquifer is underlain by marine Pliocene clays. It is covered by a silty and sandy clay layer in some parts of the study area. This covering layer forms part of the aquifer system as it confines the productive zone (considered as an aquitards). In the rest of the area the aquifer is unconfined.

RESEARCH OBJECTIVES AND METHODOLOGY

The main objective of the present research is to investigate the impacts of possible future development scenarios that can conserve the groundwater-base resource. This is carried out through simulation and prediction of the impacts of the various developmental scenarios. This has required various activities, as follows:

- Field Investigations, including:
  1) A reconnaissance of the various geomorphologic and geologic features in the study area.
  2) Measurement of depths to water and water levels using the available water points in the study area.
  3) Conduction of pumping tests using some selected production wells in the study area.
  4) Collection of groundwater samples from shallow wells (less than 65 m.) and deep wells (65 - 170 m.).

5) Detecting the Electrical Conductivity (E.C.) as a measure of the total dissolved salts (TDS) and hydrogen ion concentration (PH).

- Office Works, including
  1) Construction of water level maps, depth to water maps, hydrogeological cross sections and preparing all the graphical representation of the analytical results, and all maps.
  2) Construction of groundwater hydrographs.
  3) Interpretation of pumping and recovery test data using Ground Water Software® for Windows (GWW), version (1.10).
  4) Simulation of groundwater levels using mathematical model (Visual Modflow software ®) – code version (4.20).

SPECIFICS OF THE STUDY AREA

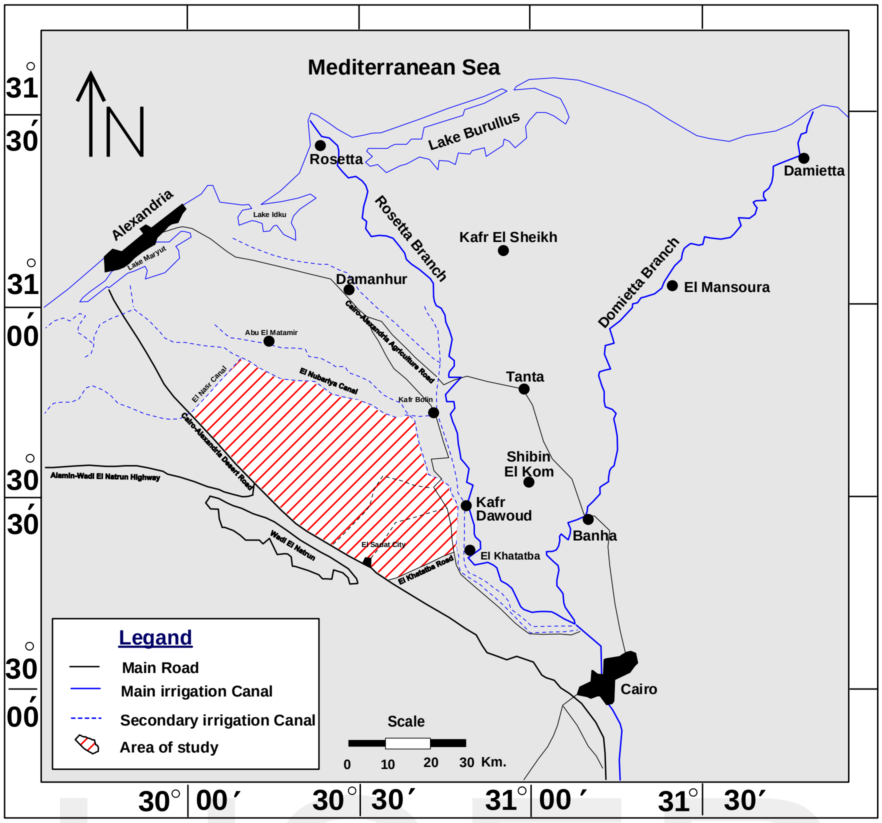
Location and Physical Setting

The study area is located within the western Nile Delta fringe on both sides of the Cairo-Alexandria desert road. It has a trapezoidal shape. It is limited by latitudes 30º 15′ - 30º 50′ N and longitudes 30º 00′ - 30º 48′ E, with an area of about 3100 km2. It is bounded by El Nubariya canal from the Northeast, El Nasr canal from the Northwest, El Rayah El Naseri from the East and Wadi El Natrun depression from the southwest (Fig. 4). The ground elevation of the study area ranges between approximately 50 m "+MSL" at Sadat City and 10 m nearby El Nubariya (Fig. 5).

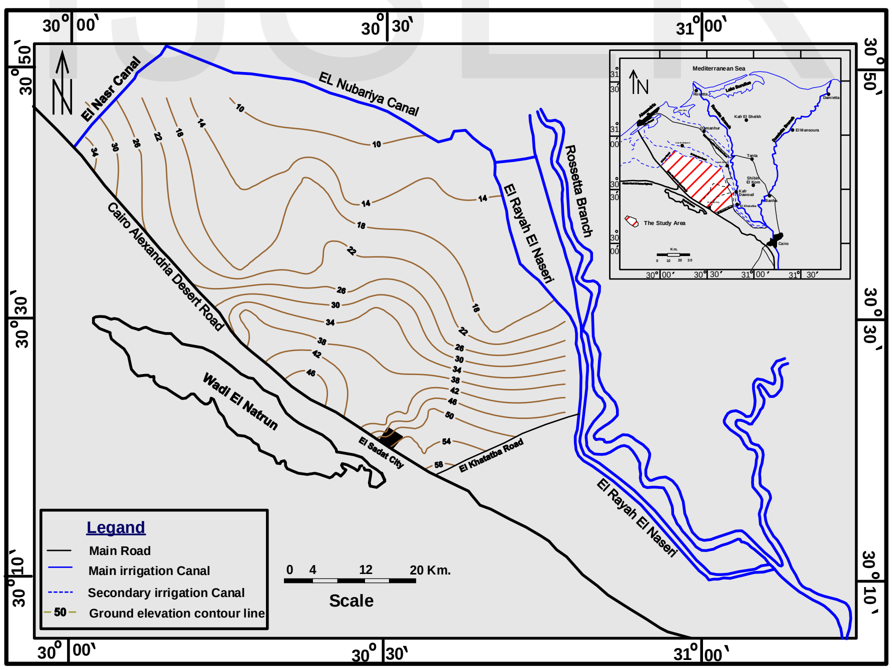
At the north of the study area, the general low elevation of the land and the seepage from the canals in the absence of suitable drainage, have resulted in drainage problems (water logging). Salt accumulation has taken place on the land surface and in the entire soil profile as a result of the high evaporation rates that characterize the study area.

Agricultural Expansion Projects

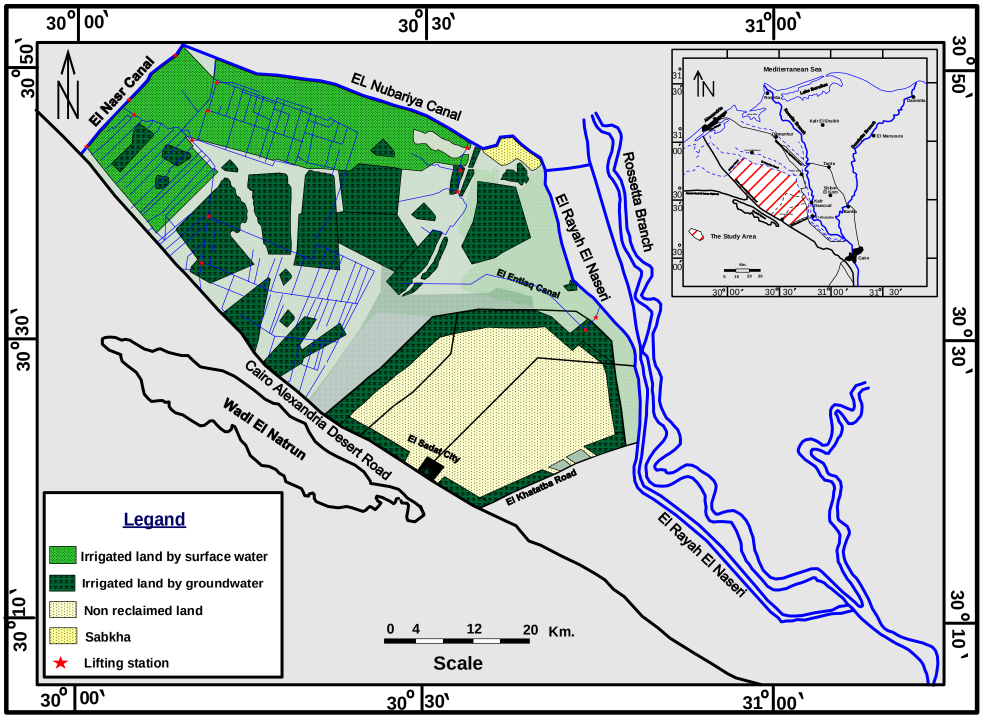
In the West delta region, extensive land reclamation projects, using surface water from El Nubariya main canal and its branches, started in 1950 and now cover about 300,000 Feddans. Additional extensions are expected be completed in the near future, depending on the conjunctive use of both surface and groundwater (Fig. 6).



(Figure 4) Location Map of the Study Area



(Figure 5) Topographic contour map of the studied area



(Figure 6) Land use map of the study area (Modified after [7])

Private reclamation projects, depending on groundwater, prevail in the south and east of Wadi El Natrun. The present cultivated areas with groundwater exceed 100,000 Feddans within the present area of study and are subject to expansion.

Aquifer Systems

Four hydrogeological cross sections were constructed from available data, to describe the lithological facies, hydro-structural setting and hydrogeological properties of the aquifer (Figs. 7, 8, 9 and 10).

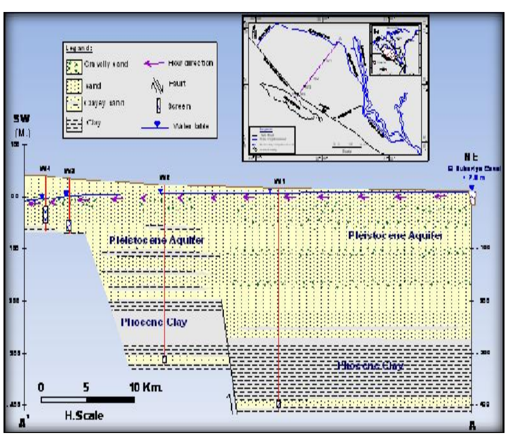


Figure 7. Hydrogeological Cross-Section A-A'

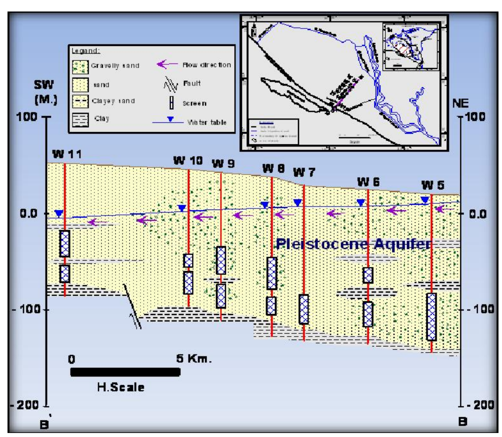


Figure 8. Hydrogeological Cross-Section B-B'

The hydro-structural setting has a great impact on the groundwater aquifer in the study area and its vicinities, where the Pleistocene water bearing formation was deposited on older sediments (Pliocene and Miocene) that has been affected by many NW-SE normal step faults with downthrown side to the east; which led to the Pliocene clay located in the west comes in contact with the Pleistocene deposits located in the east. Groundwater exists mostly under free water table condition in most of the area and partially under semi-confined condition at the northern part, where clay lenses are present in abundance.

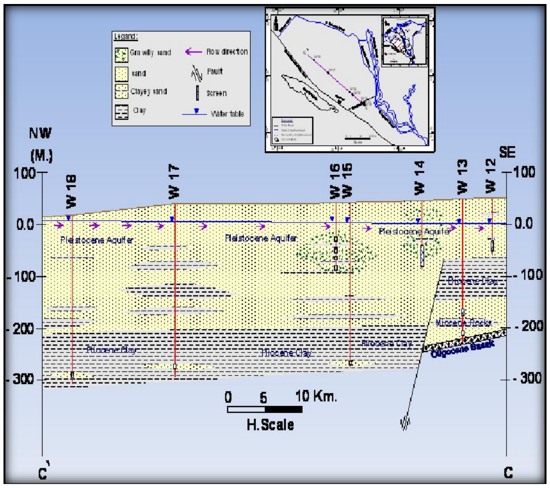


Figure 9. Hydrogeological Cross-Section C-C'

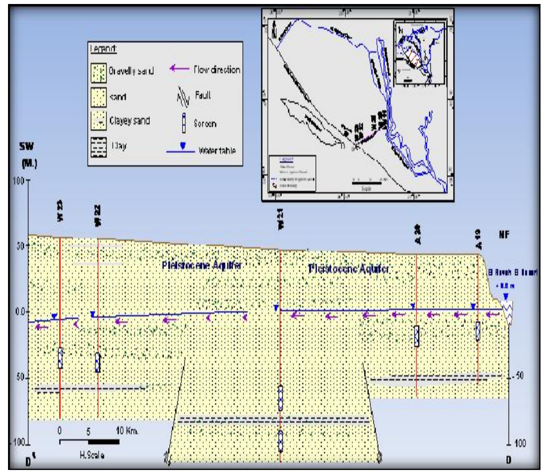
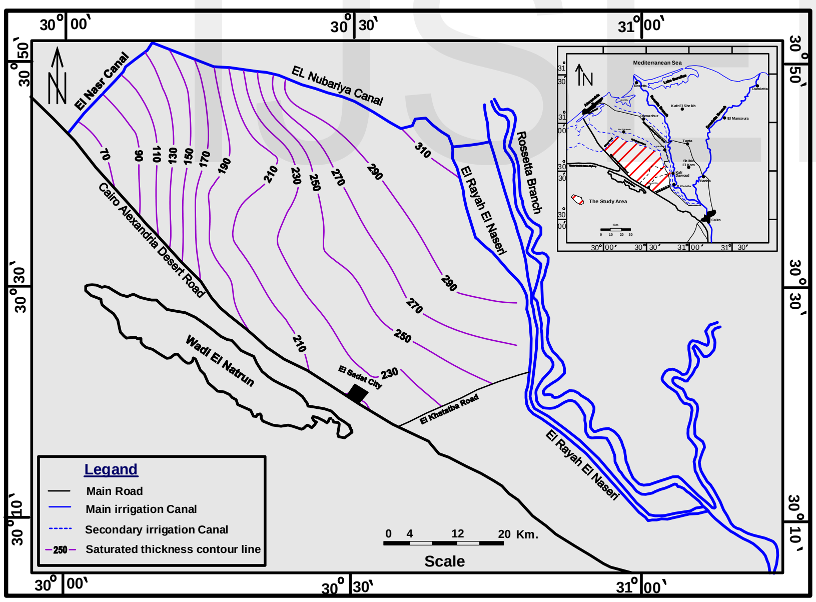


Figure 10. Hydrogeological Cross-Section D-D'

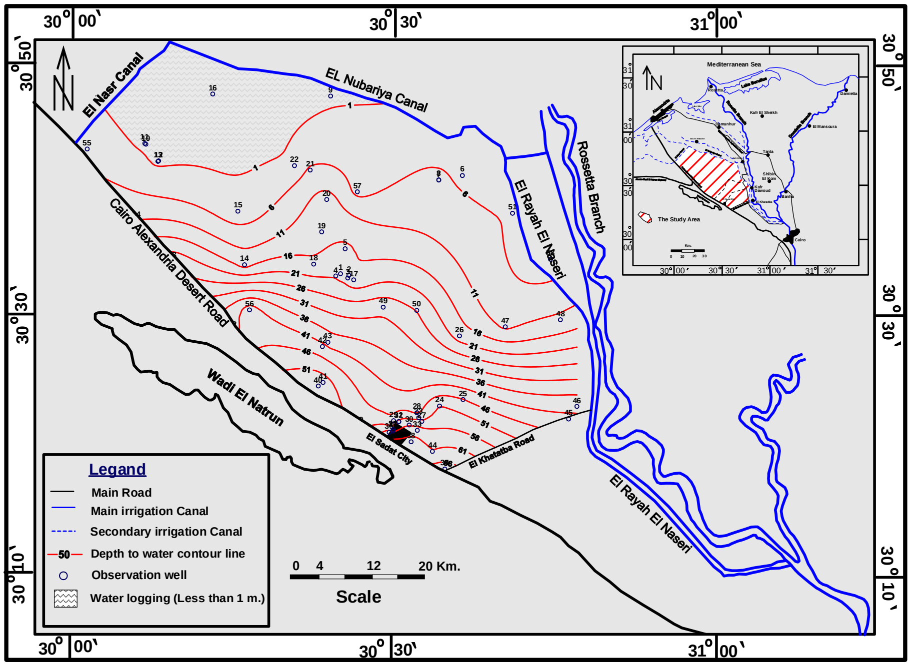
The saturated thickness of the aquifer increases gradually in the northeast direction (Fig. 11). It ranges from 100 m to 200 m in the southwestern portion (near Cairo-Alex. Desert Road), from 260 m to 280 m at El-Sadat City and from 300-320 m at the northeastern part.



(Fig. 11) Saturated thickness contour map of the Pleistocene aquifer in the study area

Groundwater movement and flow pattern

Groundwater mainly occurs under unconfined condition. A semi-confined behavior is detected in the north occasionally caused by the presence of local clay and silt layers in the upper saturated zone.



(Fig. 12) Depth to water contour map of the Pleistocene aquifer in the study area

The depth to groundwater (Fig. 13) differs according to the topography and hydrologic conditions. Near El Nubariya canal, it is very close to the land surface due to the seepage from the canal; then increases towards the southwest (the eastern boarder of Wadi El Natrun).

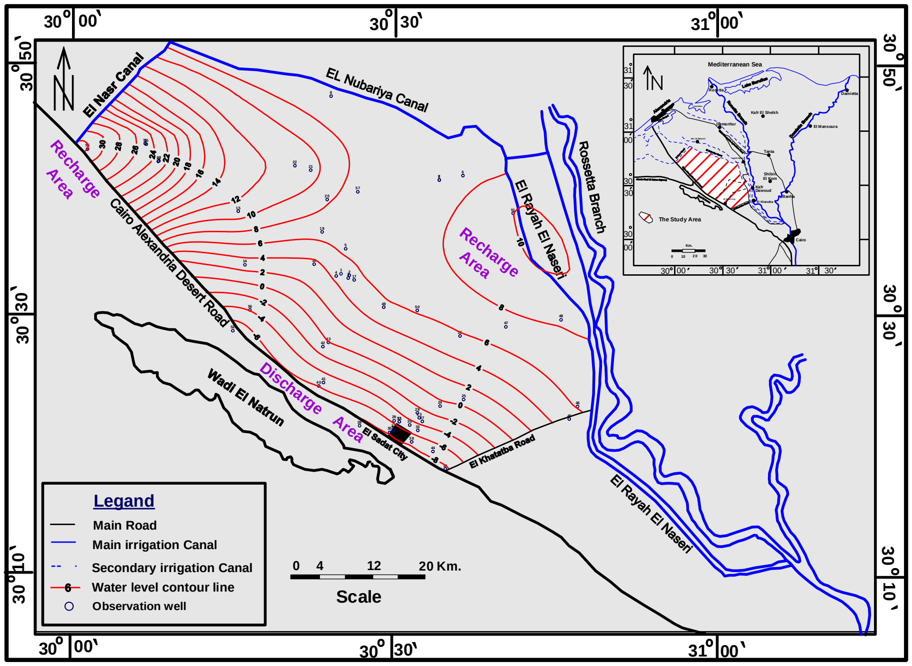
The groundwater levels (Fig. 14) for May (2010) indicate the following:

- Generally, the groundwater levels decrease from north to south and from east to west both towards Wadi El Natrun.
- The high groundwater levels associated with the reclamation projects are marked by the formation of water mounds at the area surrounding El Nasr Canal.
- Two main directions of groundwater recharge are detected the first one is from El Nasr canal and the second is from El Rayah El Naseri.

Accordingly, the following conclusions can be withdrawn:

- The main sources of recharge to the groundwater of the Quaternary aquifer are surface water courses (El Nubariya, El Nasr canals, and El Rayah El Naseri) and lateral subsurface flow from the Nile basin aquifer.

- Natural discharge occurs in the western and southwestern portions of the study area, in addition to the lateral flow toward Wadi El Farigh depression at the southwestern area. Artificial discharge, on the other hand, takes place through pumping from existing wells. In the western and southwestern portions of the study area, groundwater is extracted to satisfy local irrigation, domestic and industrial needs.



(Fig. 13) Water levels contour map of the Pleistocene aquifer in the study area

SIMULATION

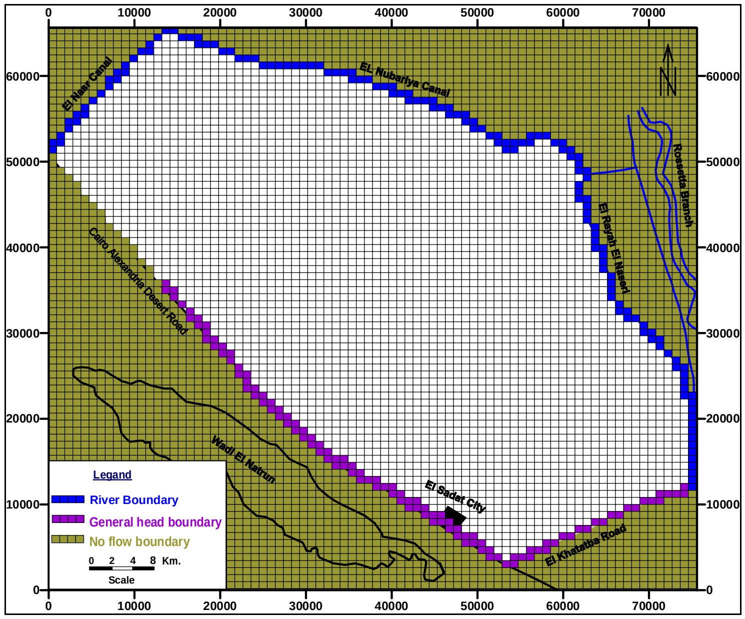
The Simulation Package

The simulation package is VISUAL MODFLOW PROGRAM 4.2; which is based on the finite difference technique for professional applications in three-dimensional groundwater flow and contaminant transport simulations. This fully integrated package combines MODFLOW, MODPATH, MT3D, MT3DMS, RT3D, PESST and SEAWAT with the most intuitive and powerful graphical interface available. The model grid input parameters and results can be visualized in cross-section or plan view at any time during the development of the model or while displaying the results.

Model Grid and Boundaries

The model grid consists of 6400 cells. Relatively small cells were used in the significant areas. The boundaries (Fig. 15) are delineated as follows:

- The northern, northeastern and northwestern boundaries are flow boundaries including El Nubariya, El Rayah El Naseri and El Nasr canals with seasonally head variations.
- The southern and southeastern boundaries are considered general head boundaries.
- The southwestern boundary is considered a no-flow one as the water levels contour lines resulting from El Nasr canal are vertically dissecting the Cairo Alex. Desert Road.



(Figure 14) Model Grid and Boundaries

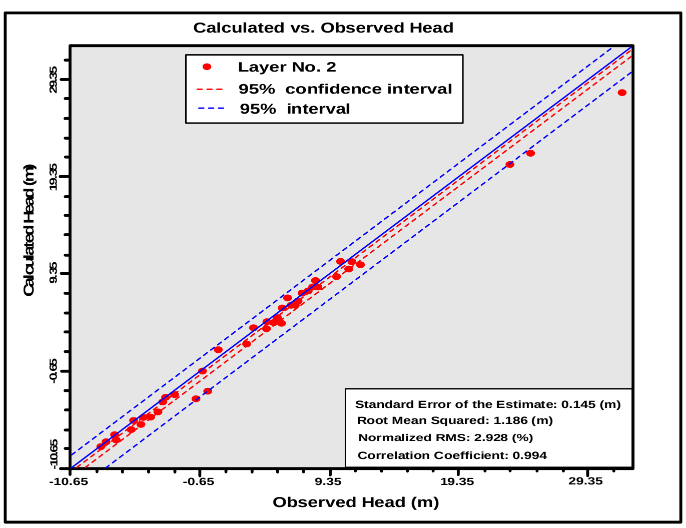
Simulation Data

The main input data include:

- The topographic contour.
- The top and base of the Pleistocene aquifer.
- The horizontal hydraulic conductivity of Pleistocene aquifer (varying from 5 to 100 m/day).
- The vertical hydraulic conductivity of the clay cap, taken at 0.05 m/day.
- The mean rainfall (ranging from 5 to 50 mm/year).
- The rate of extraction (about 1,353,000 m3/day for 2010).

Model Calibration

The model is calibrated for steady state flow conditions in 2010. An accepted match between the observed and calculated head was achieved (Fig.16).



(Figue 15) The Correlation between Observed and Calibrated

As a result, the calibrated head contour map is drawn (Fig. 17) and compared with the observed one (Fig. 18).

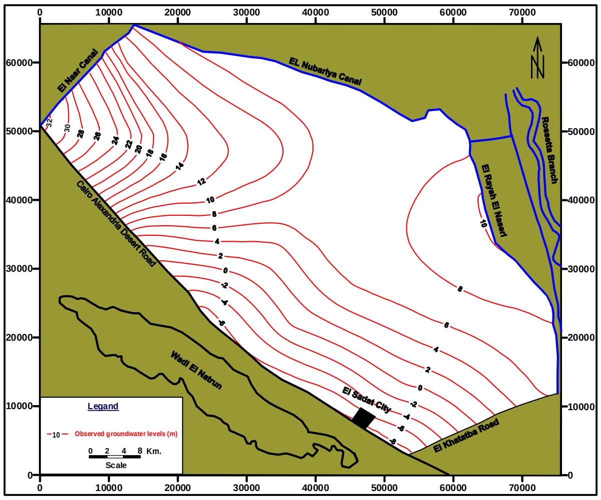


Figure 16. Observed Head Contour Map

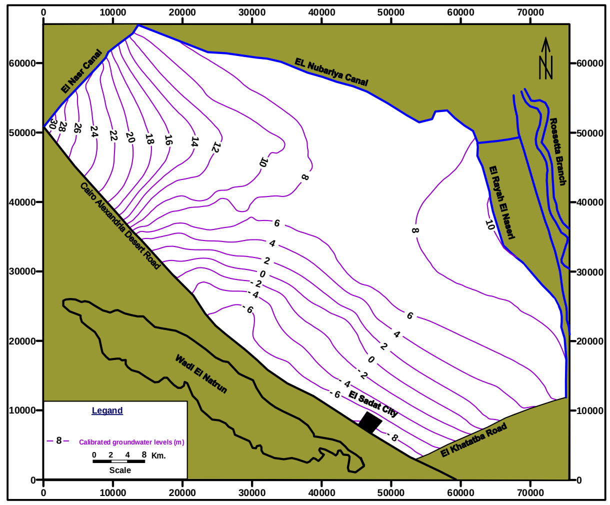


Figure 17. Calibrated Head Contour Map

DEVELOPMENT AND TESTING OF SCENARIOS

Proposed Development Scenarios

The calibrated model of 2010 has been run under the effect of different scenarios in the study area for 40 years. Two expected and two development scenarios are tested for their impacts on the aquifer system, as follows:

	Description of scenario
1	Continuing present situation for the next 40 years
2	Increasing the present pumping rates by 1.5 times
3	Decreasing the present pumping rate by 16% and supplying the deficit from surface water diverted from El Rayah El Naseri. Continuation for 40 years.
4	Similar as scenario 3; but with a transfer of irrigation in part of the northern portion from surface water to groundwater (an increase by 0. 05%) and lining of canals

Prediction of Impacts

The calibrated model is used to simulate the above scenarios (Figures 19 through 24). Results indicate that:

Scenario	Expected Impact
1	The max. Drawdown is expected to be 11.5 m and max. Build-up 2.5 m in 2050 Canals leakage will increase by 20%
2	The max. Drawdown is expected to be 15 m and max. Build-up 2.5 m in 2050 Canals leakage will increase by 48%
3	The max. Drawdown is expected to be 5 m and max. Build-up 3 m in 2050 Canals leakage will decrease by 29%
4	The max. Drawdown is expected to be 3.5 m and max. No Build-up in 2050 Canals leakage will decrease by 40%

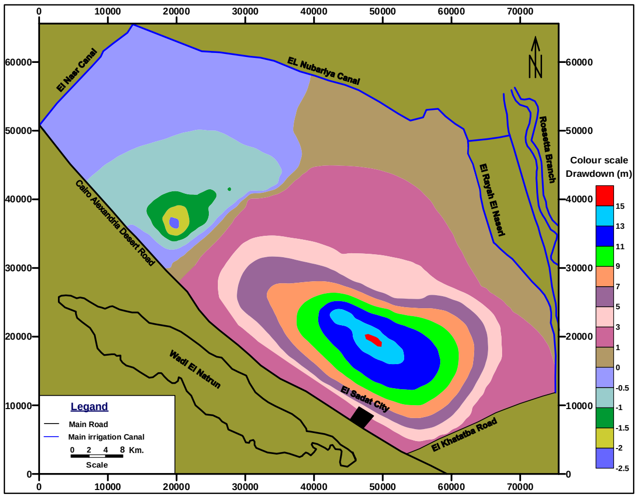


Figure 18. Expected Drawdown & Build up Contour Map in 2020 (*Scenario1*)

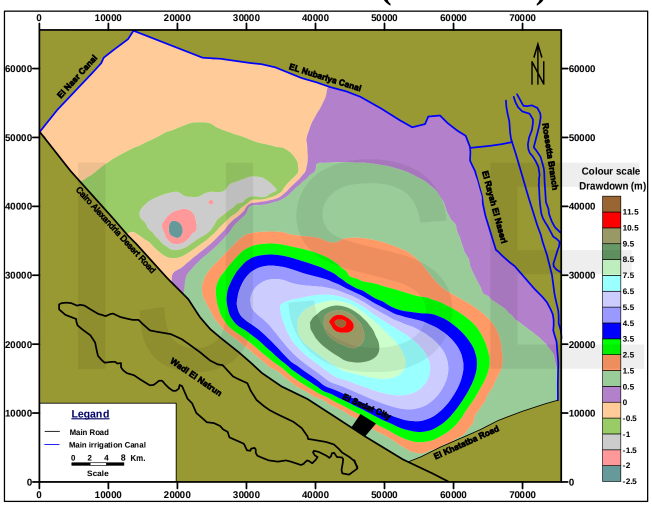


Figure 19. Maximum Expected Drawdown & Build up Contour Map in 2050 (*Scenario1*)

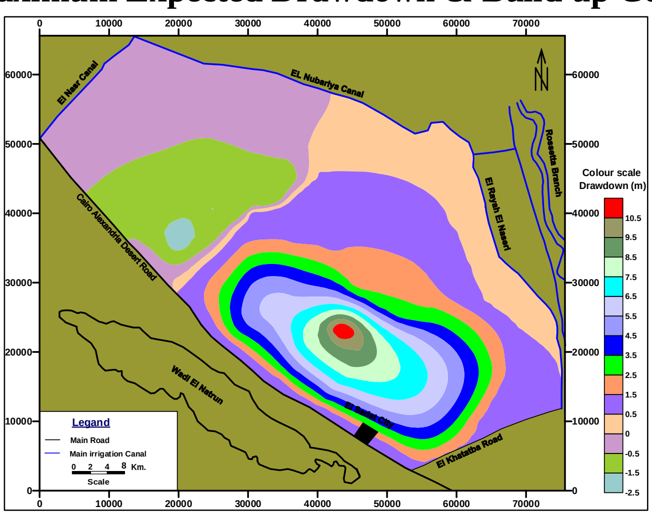


Figure 20. Maximum Expected Drawdown & Build up Contour Map in 2050 (*Scenario2*)

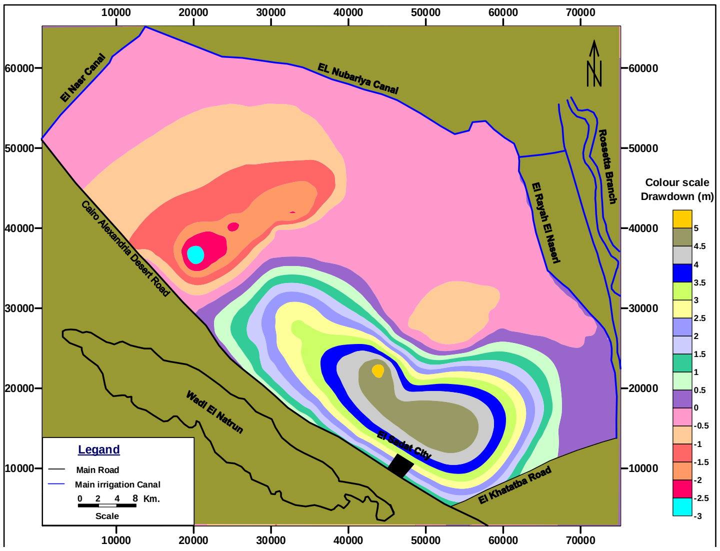


Figure 21). Maximum Expected Drawdown & Build up Contour Map in 2050 (*Scenario3*)

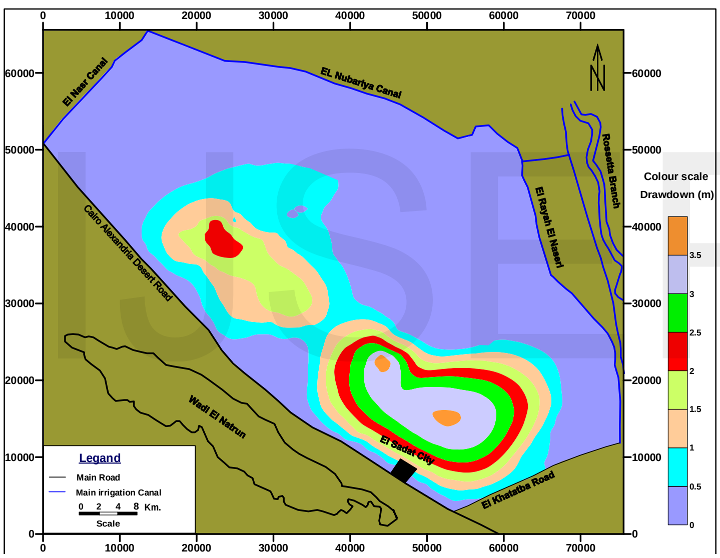


Figure 22. Maximum Expected Drawdown Contour Map in 2050 (*Scenario4*)

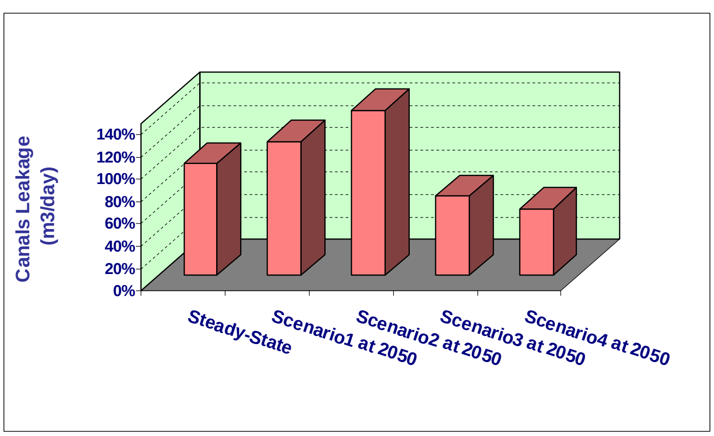


Figure 23. Percentage Change in Canals leakage due to the Application of Different Scenarios

CONCLUSIONS AND RECOMMENDATIONS

From the above results, the following can be concluded:

1. Both, Scenarios 1 and 2 are considered harmful and risky, causing large rates of leakage from the canals combined with large drawdowns.
2. On the other hand, both scenarios 3 and 4 can be considered safe from the point of view of the reduced leakage; while scenario 3 is risky with respect to the expected drawdown.

Accordingly, to ensure the sustainability of the groundwater and the surface water, it is recommended to:

1. Apply Scenario 4 in the studied region.
2. Extend the application of this study to other similar regions in the delta and its fringes and, possibly, in the Nile Valley.
3. Restrict groundwater allocation to those developments resulting in added value from water.
4. Implement a monitoring system to assess the periodical impact of development and update the model results.

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