Assessing the Impacts of Agricultural Water Management on Ecosystem Services in the Nile Delta

Draft Report

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Contents

1 Introduction

Egypt suffers from water scarcity and farmers are often forced to use alternative water resources including recycled and untreated wastewater with elevated levels of non-point source pollutants. However, continued use of poor quality water reduces land and water productivity and threatens the health of the overall ecosystem. The rising demand for water is also reflected through increased competition among different water users including agriculture, aquaculture, livestock, recreation, tourism, horticulture, etc, in addition to demands of drinking water and industry. Agriculture is by far the largest consumer of water in Egypt. Hence any improvement in agricultural water management will result in reduced demand in the sector and free up a highly demanded and scarce resource for use by other sectors.

Egypt is one of the most arid countries of the world. About 97% of Egypt's water resources originate from outside its borders. This makes proper water management vital. Challenges include limited water resources and growing demands, resulting in a need to set priorities for water allocation. Another challenge is the degradation of water quality due to water recycling with inadequate treatment. Agricultural drainage water contains salts due to soil leaching, in addition to nutrients, pesticides, and herbicides. In addition, most drains receive also increasing amounts of municipal and industrial wastewaters. It is known that all drains in Upper Egypt flow back to the Nile by gravity, whereas in the Nile Delta and Fayoum a large portion of the drainage water is reused through reuse pump stations. Reuse may be practiced through major pump stations which lift drainage water from major drains to major canals, or through relatively small pump stations which are used for intermediate drainage reuse at lower levels of the system. Other means of reuse is the direct use of drainage water by farmers for irrigation, which is called unofficial drainage water reuse. Drainage water reuse has been estimated by the MWRI at 6.4 BMC in 2010.

The objective of this study is to test and identify appropriate water and land management strategies that will increase water and land productivity, reduce the demand for chemical fertilizers, increase farmers' income, and minimize the negative impacts of agriculture on the ecosystem. This will be done through targeted studies that:

a) Quantify the impact of improved technologies on water saving and their potential contribution to increasing available water supply along the canal (head, middle and tail end)
b) Analyze alternative water allocation scenarios using a river system model which is used to assess tradeoffs and estimate water that can be saved from the agricultural sector for utilization by other economic sectors, or for horizontal agriculture expansion
c) Analyze the effect of outflow of water from agriculture for downstream users, and on dependent ecosystem services

2 Methodology

The methodology adopted for achieving project objectives is presented in this section.

2.1 Selection of study area

In order to test proposed management strategies, a pilot area in the Nile Delta Region had to be selected. Selection criteria included the following:

- Different types of water uses
- Availability of data
- Accessibility
- Cooperation of stakeholders

The following areas were identified as potential pilot areas:

- Bahr Muwiess, Sharquia
- Miet Yazid, Kafr Elsheikh
- Mahmudia, Beheira

Finally, the pilot area of Abul Akhdar Canal in Sharquia was selected. A brief description of the study area follows.

2.1.1 The Eastern Nile Delta

The Eastern Nile Delta is bounded by Damietta Branch in the west and Suez Canal in the East. The southern boundary is delineated by Ismailia Canal, while in the north it borders the Manzala Lake (Figure 1).

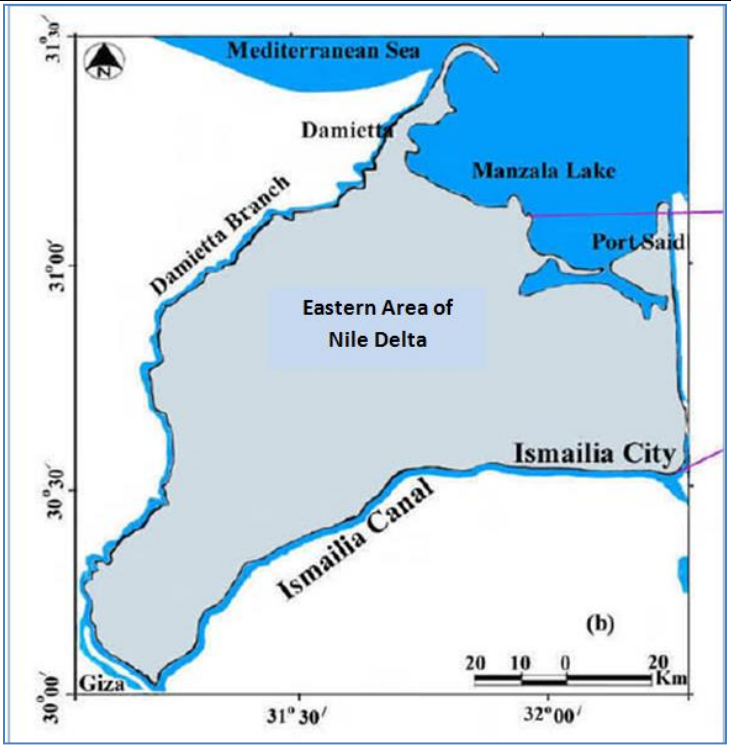


Figure 1: The Eastern Nile Delta

Agricultural lands are characterized by fertile Nile alluvium in the western part near Damietta Branch, turning towards desert lands in the east, where some land reclamation projects have been executed during the last decades (Figure 2).

Figure 2: Agricultural lands in the Eastern Nile Delta

Agriculture in the Eastern Nile Delta is characterized by small farm holdings with an average size of less than 2 feddan. The main summer crops are cotton, maize and rice. The main winter crops are wheat and berseem, which is used to feed livestock. Field irrigation is implemented by subdividing the field in very small checks and flooding them.

Irrigation water supply is regulated at the apex of the Nile Delta, near Cairo. At this location the Delta Barrages were constructed and the water is distributed over the main canal intakes. The Eastern Nile Delta of about 1,880,000 feddans has nine of such intakes. Figure 3 shows the Irrigation Canal Network of the Eastern Nile Delta. Water distribution to the main side branches (average size 150,000 feddan) of these irrigation command canals is by discharge control. The minor irrigation canals (called distributary canals) with an average command of 9,000 feddan are under rotation. Water supply to these canals is below land surface and control is based on downstream level. Farmers use diesel pumps to lift irrigation water from mesquas, which are side branches of the distributary canal, to irrigate their land. Nearly all irrigation canals, branches, distributaries and mesquas, have tail end connections with the drainage system to prevent flooding of agricultural land in emergency situations.

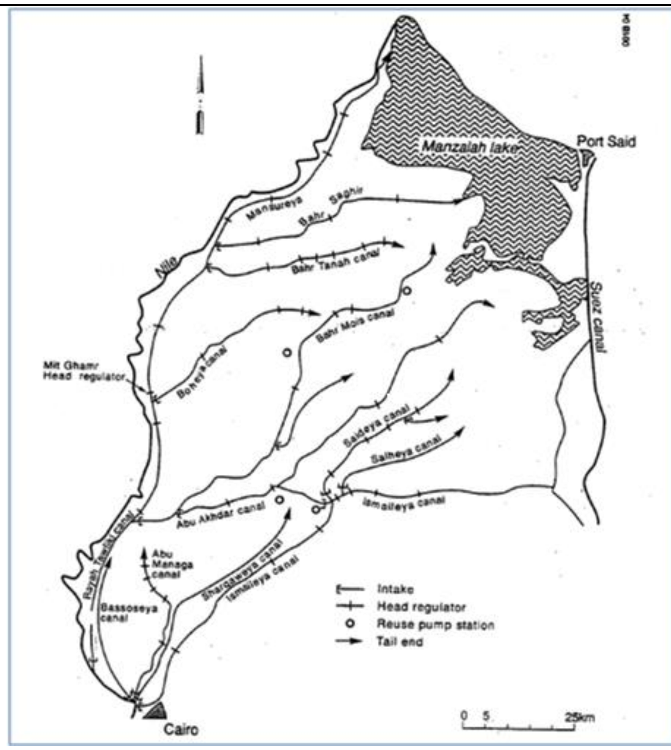


Figure 3: Irrigation canals distributing water in the Eastern Nile Delta Region

The drainage system is a separate dendritic canal system to collect the agricultural drainage water, irrigation water losses and the sewage water from villages in the Nile Delta. Drainage water is conveyed to the north, where the majority discharges in the coastal Manzalah Lake. The Manzalah Lake is an important resting place for migratory birds and provides fish to the local population. The efficient main canal and farming systems in the Eastern Nile Delta are enhanced by the reuse of drainage water practices at regional and local level. However, salt balances clearly indicate the drawbacks of these practices (Roest 1990). Official reuse of drainage water in the main system adds 3% of the total water supply, but adds 51 % to the salt load in the main canal system. Similarly, unofficial reuse of drainage water and groundwater add 18% to the irrigation water supply to farmers, but 85% to the salt load. According to this analysis, the major source of salt in the Eastern Nile Delta is the upward saline seepage in the northern part of the Delta.

In addition to official drainage water reuse through reuse pump stations, an additional unofficial reuse rate of about 13% and 4% of groundwater utilization (percentages relative to quantity of surface water diverted to farms through irrigation canals) takes place at farm level to compensate for shortages in water supply to tail end farmers (Roest 1990). Taking into consideration that a certain amount of leaching is required for sustainable field irrigation water management, the system operates at a high efficiency at farm level.

2.1.2 Sharquia Governorate

Sharquia is the third most populous of Egypt's 27 governorates. With an area of about 4,180 km^2 it covers most of the Eastern Nile Delta (Figure 4). Its capital is Zagazig.

Figure 4: Location map of Sharquia Governorate

According to population estimates from 2015 the majority of residents in the governorate live in rural areas. Out of an estimated 6,485,412 people, 77% live in rural areas as opposed to only 23% in urban areas. The population density is about 1,600/km^2.

2.1.3 The study area

The study area is located in Sharquia Governorate and represents the command area of Abul Akhdar Canal, which takes off from km 12 from the right bank of Bahr Muwiess. It serves a total area of about 280,000 feddan. The canal receives 45% of the flow of Bahr Muwiess, the flow of which varies between 4 Million m^3/day during least demand to 11.75 Million m^3/day during peak demand. Abul Akhdar Canal has a total length of about 100km.

Figure 5: Intake of Abul Akhdar Canal from Bahr Muwiess

Figure 6: Telemetry station at the intake of Abul Akhdar Canal

The canal delivers mainly irrigation water, but feeds also some 7 drinking water stations, and a number of small to medium size industries. The last reach of the canal has a length of about 34.5 km and faces severe water shortages due to upstream abstractions, in particular due to (partly illegal) rice plantations in the upstream. This leads to feeding the canal from the end by the polluted drainage water from Bahr El-Baquar Drain to satisfy water requirements. Towards the end of the canal, some fish farming activities exist on drainage water. Summer crops include rice, maize and cotton, while in winter sugar beet, wheat, berseem and vegetables are cultivated. Water shortages lead often to disputes among farmers, and also between farmers and operational staff of the Ministry of Water Resources and Irrigation.

Figure 7: Regulator on Abul Akhdar Canal

Figure 8: Rice cultivation from Abul Akhdar Canal

Figure 9: Drinking water intake station on Abul Akhdar Canal

Figure 10: Government fish farm towards the end of Abul Akhdar Canal

Figure 11: Reuse pump station to pump drainage water from Bahr El-Baquar Drain into last reach of Aboul Akhdar Canal

The study area intersects with 5 Irrigation Districts. The following map extracted from the developed geospatial database shows administrative boundaries intersecting with the study area.

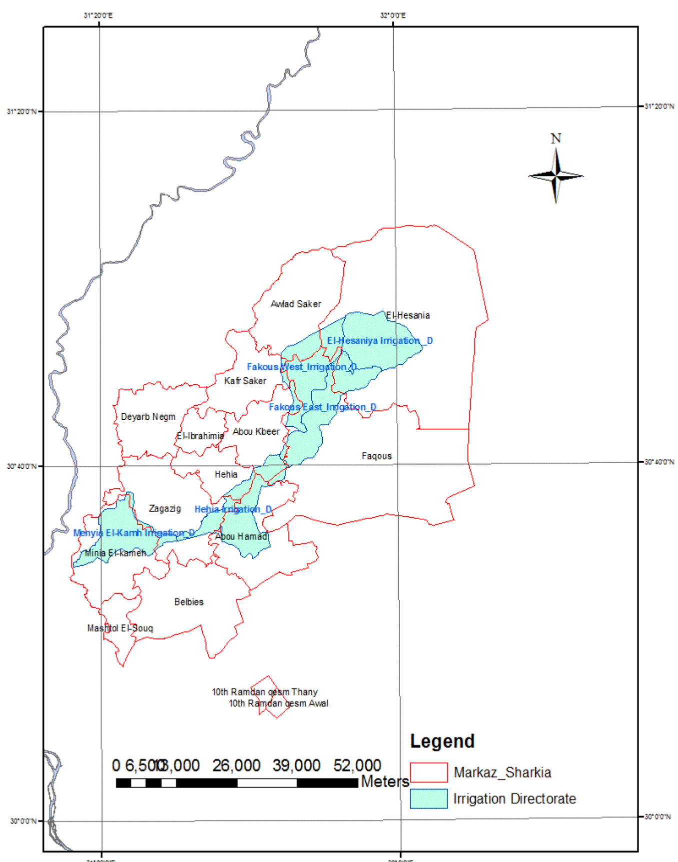


Figure 12: Administrative Boundaries (Markaz) and Irrigation Directorates intersecting with the study area

The following map shows the command area of Abul Akhdar Canal, which represents the hydrologic boundary of the study area. This map represents a map prepared by district Engineers during 2015 to schedule rice rotations.

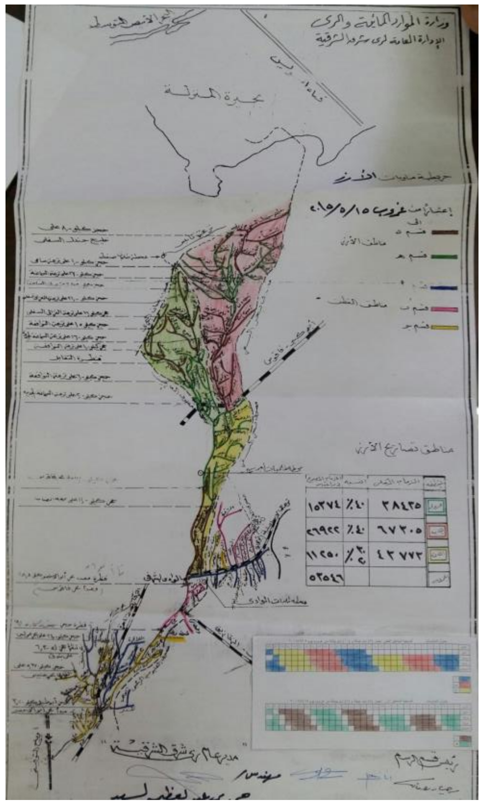


Figure 13: Map prepared by MWRI staff for the study area

Annex 1 presents Progress Report No. 1 (August 2015) which provides further details about study area selection and characteristics.

2.2 Data collection activities

Upon selection of the study area, several visits were conducted to get acquainted with the study area and to meet with stakeholders. Data requirements were identified and a data collection form (Arabic and English) was prepared and sent to stakeholders. Data about the following items within the study area was requested.

Data collection form for Abul Akhdar Canal study area:

1. Bio data and command area description (area served, main cropping pattern, population, branches canals….)
2. Historical record of the discharge from Abul Akhdar intake (m^3/day)
3. Historical record of the water level (m) for Abul Akhdar at different locations (H, M, L)
4. Number of domestic water plants? And the inflow data for each plant (m^3/day)
5. Any data, records, observations about water quality along the canal
6. How many industrial activities exist along the canal? Is there any discharge from those industries to the canal?
7. Detailed GIS map for the command area and separate maps for each district
8. Detailed map for the main drains serving this command area
9. Data about drainage pumping stations (Q&Q)
10. Schematic diagram and cross section of the canals
11. Any information about municipal wastewater and how it is dealt with
12. Data about existing WWTP
13. Information about the location and areas of aquaculture activities
14. Water balance of the canal (variation of discharge along the canal and uses of abstractions)

Data collection took place in the study area and through meetings with district Engineers in Sharquia and in Cairo. The project team explained the project concept and objectives. District engineers explained their jurisdiction and the main features of the irrigation and drainage system within the command area. They highlighted daily and seasonal operational water problems. The data collection form was distributed to the participants and data collection methodologies and challenges were discussed. Annex 1 provides further details about data collection activities.

Figure 14: District Engineers during a workshop in ICARDA office (18/8/2015)

2.3 Assessment of data limitation

Data collected was carefully analyzed for consistency and completeness. Some limitations within the collected data were observed, notably:

- Most received data were not linked to location (coordinates). Maps were in different paper formats either hand-drawn or as schematic. No GIS maps were available. This poses some limitation on visualization of modeling outputs.
- Discharge is not measured within the study area. Therefore received data about actual flows are mere estimates by district engineers. This poses severe limitations on any modeling activities as the flow value is a key input parameter.
- Although the district engineers know the system by heart, no data base is kept about history of the system. Thus, district engineers are able to report about present problems and hot spots. However, they are not able to accurately recall how the situation was a few years in the past, nor how it is expected to be after a few years in the future.
- It was agreed to develop a GIS of the study area with the help of district engineers. This will provide a framework for data storage and retrieval by district engineers to be continually updated. It also provides a tool for presentation and discussion with stakeholders and decision-makers. Details about GIS system development are presented in Chapter 3.

2.4 Assessment of capacity limitations (Training needs assessment)

During meetings and interaction with district engineers, certain capacity development needs were identified. District engineers indicated their willingness and need to receive training on developing and using GIS maps for the study area. Training needs assessment was performed by project staff with the director of Sharquia Irrigation Directorate and with district engineers and it was agreed to provide training on GIS and water allocation and planning modeling. The training was carried out in the form of on the job training on actual data of the study area. District engineers representing all districts within the study area participated in the training. Annex 2 presents Progress Report No. 2 which reports on training activities.

2.5 Development of Geospatial database for the study area

A geospatial database for the study area was prepared. This was carried out through on the job training of district engineers on Geographic Information Systems (GIS). This activity covered software installation and activation, data formats, data entry, data transformation, geo-referencing, linking GIS to Google Maps, developing layers, preparation of GIS of the respective irrigation/drainage districts, formatting and output preparation etc. Details about this activity are presented in Chapter 3.

2.6 Modeling of water allocation in the study Area

In order to assist district engineers in planning water allocation, modeling of the water resource system was introduced. The model would serve as a platform for better understanding the dynamics of the system. It would provide a means for communicating and discussing water issues with stakeholders. Further, it would serve as a tool to develop and assess scenarios of water allocation and future impacts of water strategies and policies. Ultimately, it would assist in contributing more accurate data to the national water resources plan about the study area. Details about this activity are presented in Chapter 4.

2.7 Water saving & water use efficiency in the study area

Outreach activities have been carried out to raise awareness of district engineers and farmers of potential for irrigation water saving. Figures 15 and 16 show photos taken during a field visit in October 2015. Presentations about water saving potential through knowledge gained from previous ICARDA projects was conveyed to district engineers through workshops during the course of the project. Simulations carried out using the developed modeling framework gave estimates in potential savings for different water saving scenarios.

Figure 15: Project staff with district engineers and farmers in the field

2.8 Workshop for on the job tanning on Geospatial data and water allocation modeling

A workshop was held for training of district engineers on the development of a geospatial data base of the study area and on developing a water allocation model of the study area. The workshop ran for 4 days (November 13 – 16, 2016) in Cairo and was attended by 12 district engineers representing the 5 Irrigation and Drainage Districts of the study area. The workshop covered in depth GIS training, introduction to water resources planning and modeling (national and local scales), and water saving technologies.

Details of the workshop are presented in Annex 2. Annex 3 contains a CD with training material, presentations, handouts and manuals.

2.9 Results dissemination

Project results were presented during a special side event of ICARDA during the Ministry of Water Resources and Irrigation Conference “Research and Technology Development for Sustainable Water Resources Management (REDWARM)”, which was held during the period November 4 – 6, 2016 at the City Stars Hotel in Cairo. The conference was attended by key executives of the Ministry of Water Resources and Irrigation and by a group of national and international specialists in the field. The project presentation highlighted achievements of the project to date and the linkage between district based water resources planning and the National Water Resources Plan. Annex 4 presents the schedule of the ICARDA side event and the PowerPoint presentation presented during the conference.

3 Development of Geospatial Data base of the study area

National agricultural production, on a sustainable basis, depends mainly on the judicious use and management of water resources. In order to achieve an economically sound society, environmental sustainability and wise utilization of natural resources, it is necessary that a comprehensive Integrated Information System be developed to provide systematic and periodic information and its status to managers, planners and decision makers. These resources need proper evaluation that can be done through interactive interpretation in a relational database system. The project aimed at developing and demonstrating the use of a spatial database to be integrated with the planning and management of resources for micro level planning that will support in entry, storage, manipulation, analysis and display of spatial data on a low cost computer configuration.

3.1 Introduction

Discussion with staff of irrigation and drainage districts indicated the need for developing a database and standardizing data entry and presentation. Staff indicated the need for capacity building in the field of Geospatial data collection, analysis, storage and retrieval. Hence training of the staff on the software ArcGIS was carried out in the framework of the project. The training was carried out on actual data of the study area provided by the staff. The data collected was transformed to a standard format and the GIS system of the study area was hence developed.

3.2 Data Collection

Data of the study area were collected from different sources including Irrigation and Drainage Directorates in Sharquia Governorate, the Information Center of the MWRI and the Information Center of the Egyptian Public Authority of Drainage Projects (EPADP). Data were received in different formats including hard copy and digital (excel, pdf, word and shape files). Data included maps, schematics, tables, and text.

The command area of Abul Akhdar Canal includes the following Irrigation Directorates:

- Menia El-Quamh Irrigation Directorate
- Hehia Irrigation Directorate
- Sharq Faqus Irrigation Directorate
- Gharb Faqus Irrigation Directorate
- Al-Hussaineya Irrigation Directorate

The command area includes the following Drainage Directorates:

- Sharquia
- North Sharquia
- South Sharquia

Data collected included also drinking water treatment plants and reuse pump stations. The following table summarizes the received data formats:

Data type	Received format
Canal network layout of the different Irrigation Directorates	PDF
Drainage network layout of the different Drainage Directorates	Image
Location maps of drinking water treatment plants	PDF
Drainage network layer	Shape file
Irrigation directorate boundaries	Shape file
Irrigation district boundaries	Shape file
Drainage district boundaries	Shape file
Reuse pump station location map	Shape file
Irrigation canal network	Shape file

The following images show examples of received data formats.

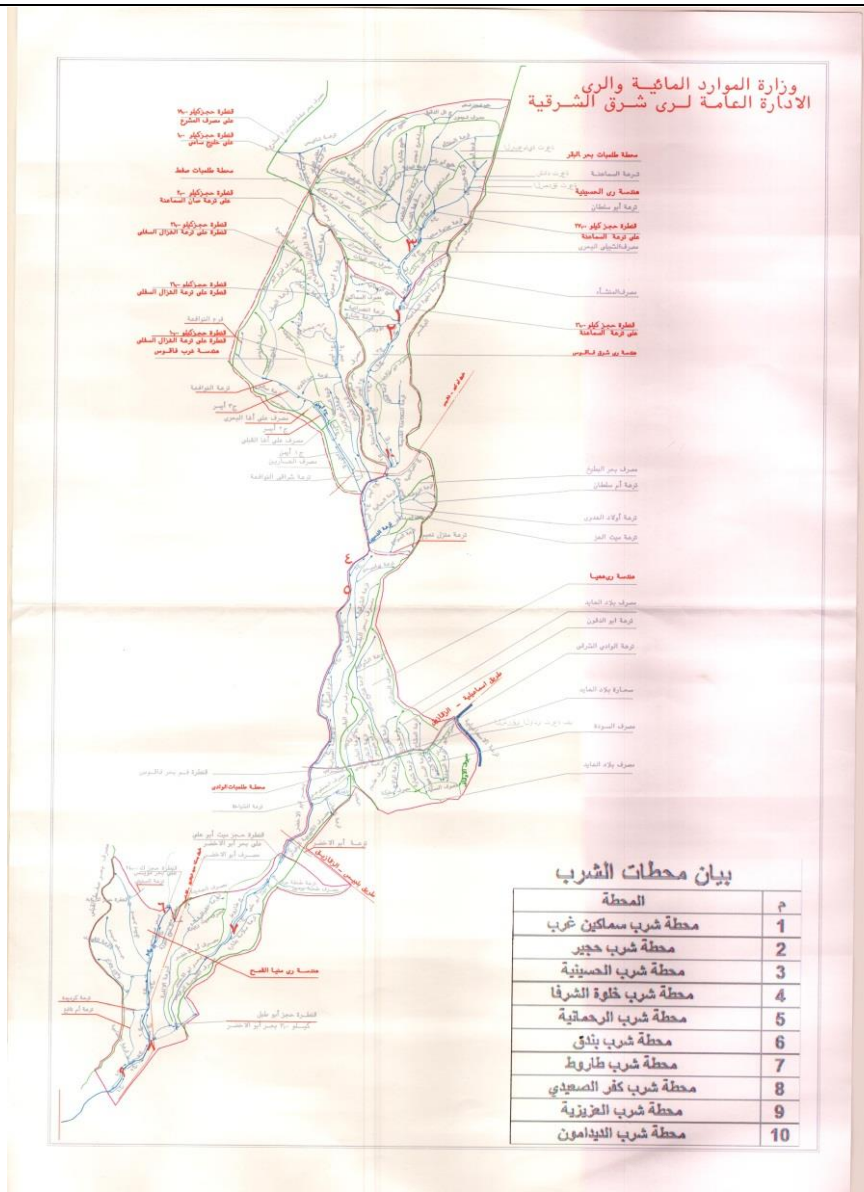


Figure 17: Received map of drinking water treatment plants locations in study area

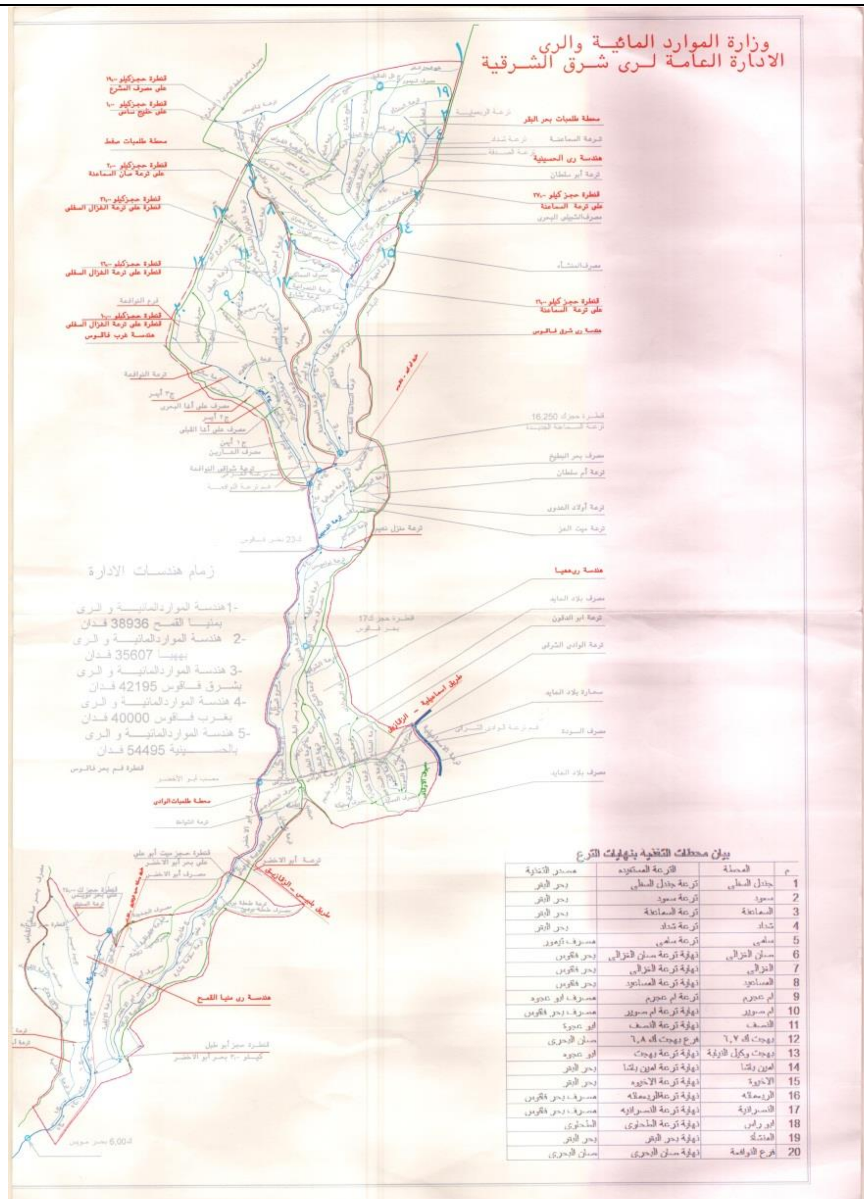
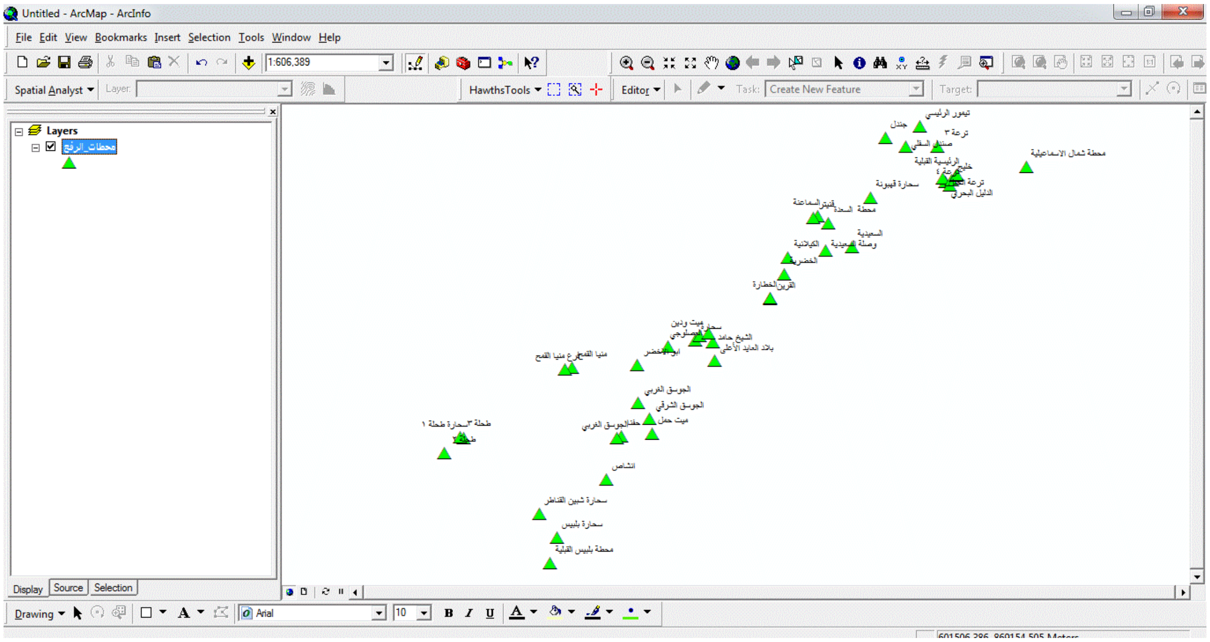
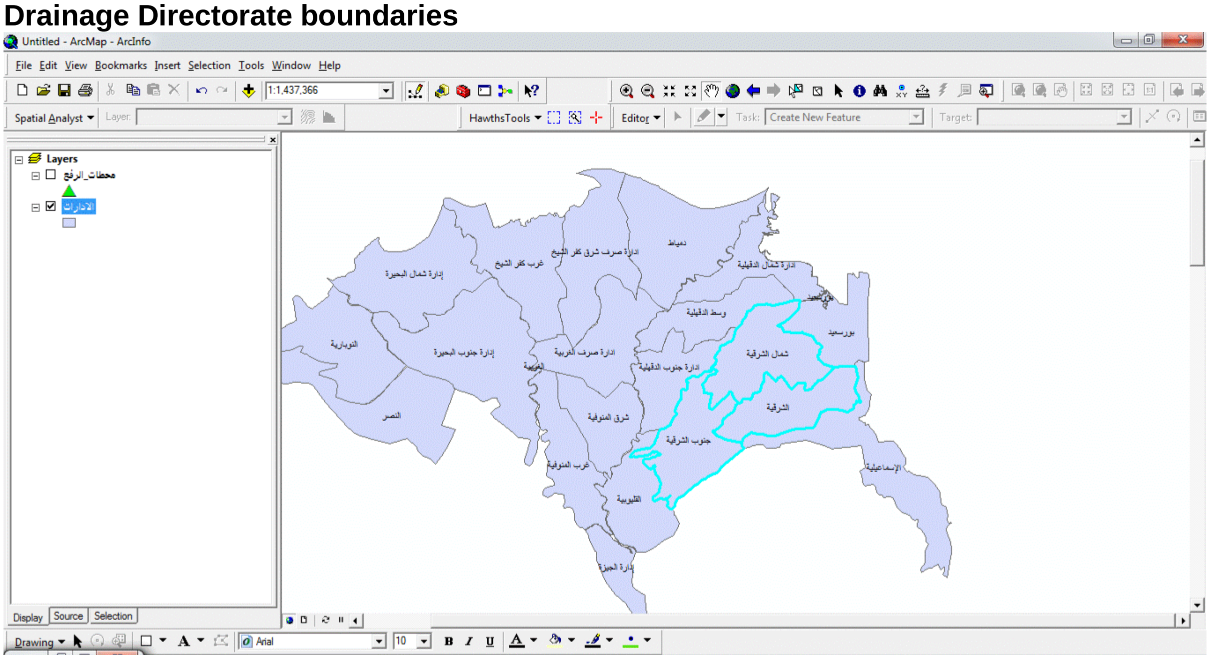


Figure 18: Received map of reuse pump station locations in the study area

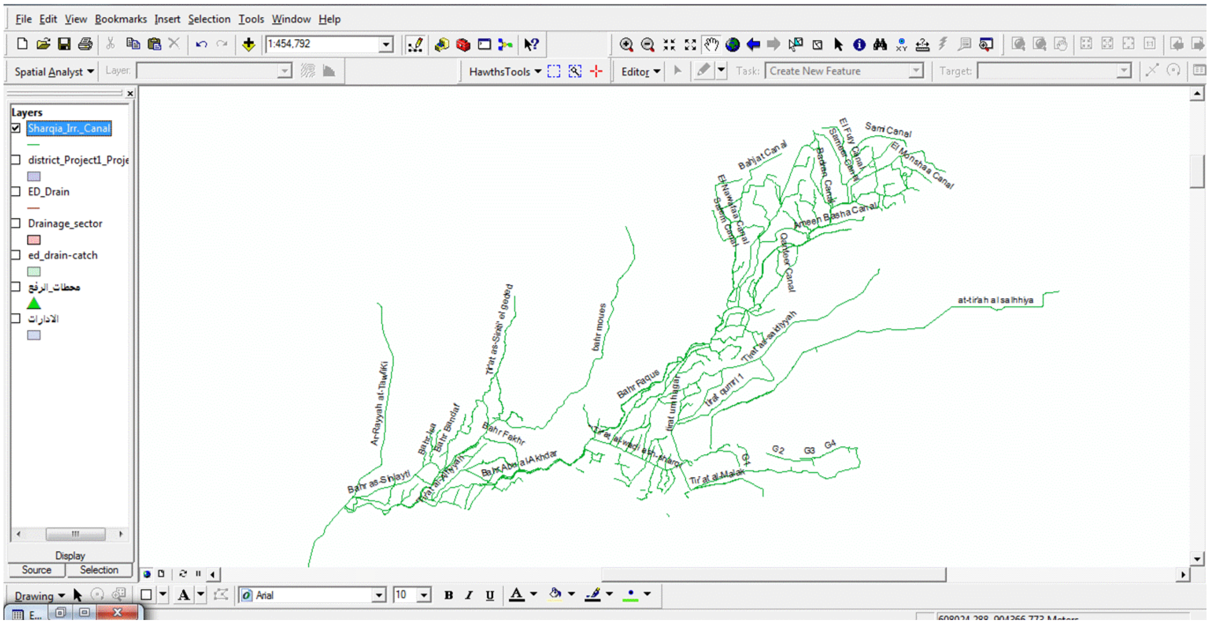
Reuse Pump Station Locations



Drainage Directorate boundaries



Canals network



Irrigation Directorate boundaries

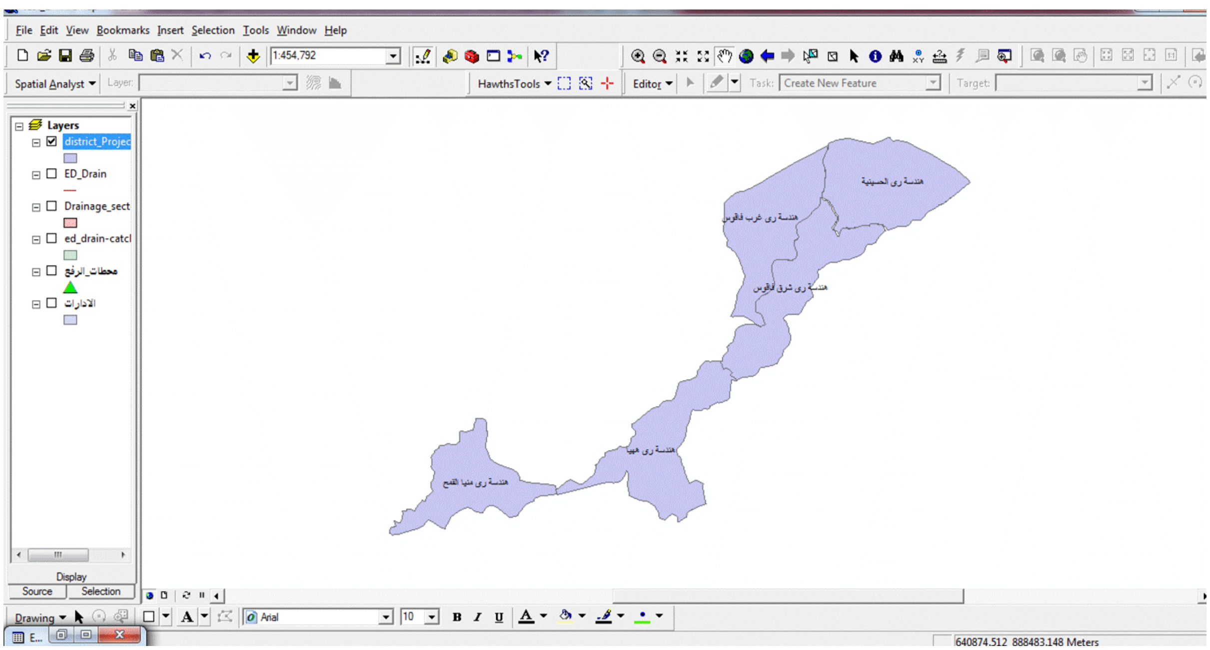


Figure 19: GIS layers of the study area

3.3 Data analysis, processing and verification

The first step in developing the geo-spatial data base is surveying of the data and information about the irrigation and drainage systems available at the irrigation and drainage directorates of the study area. Other collected data included drinking water stations, feeding stations and available information about hydraulic structures. These irrigation and drainage networks and its relationships were verified through several meetings with the technical engineering staff and managers at these directorates. The data from the geospatial database of the MWRI were exported to excel files and aligned with data received from the irrigation districts to facilitate revision with district engineers and resolving of any discrepancies. Further, schematic diagrams provided by district engineers were inspected and discussed with the district engineers to understand the relationships between the different components of the system. In addition, Google Maps were consulted to guide in updating some features.

The data was processed to achieve a unified and mutually compatible system in several steps including transforming to digital, geo-referencing and extracting layers of interest. The following two figures summarize the main data considered and the different data sources consulted.

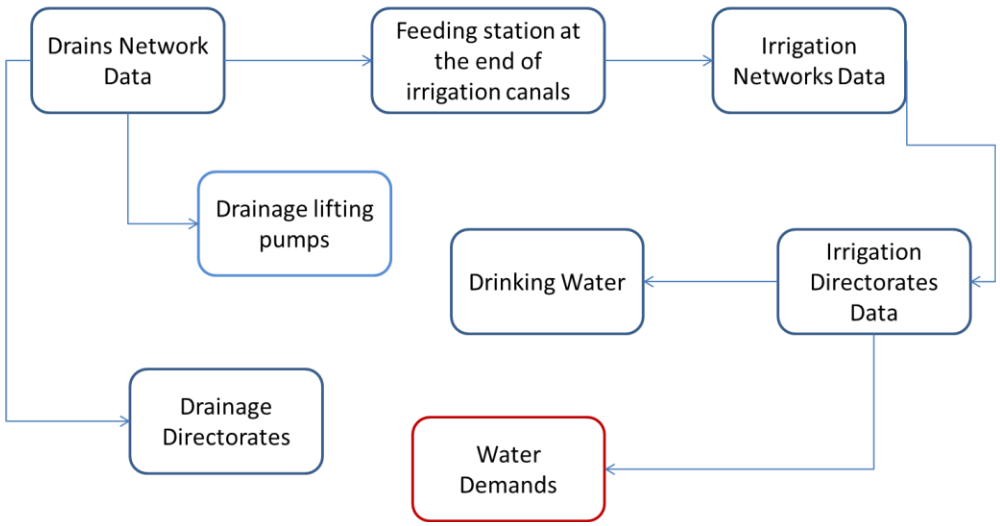


Figure 20: Diagram of the data considered in developing the geospatial database

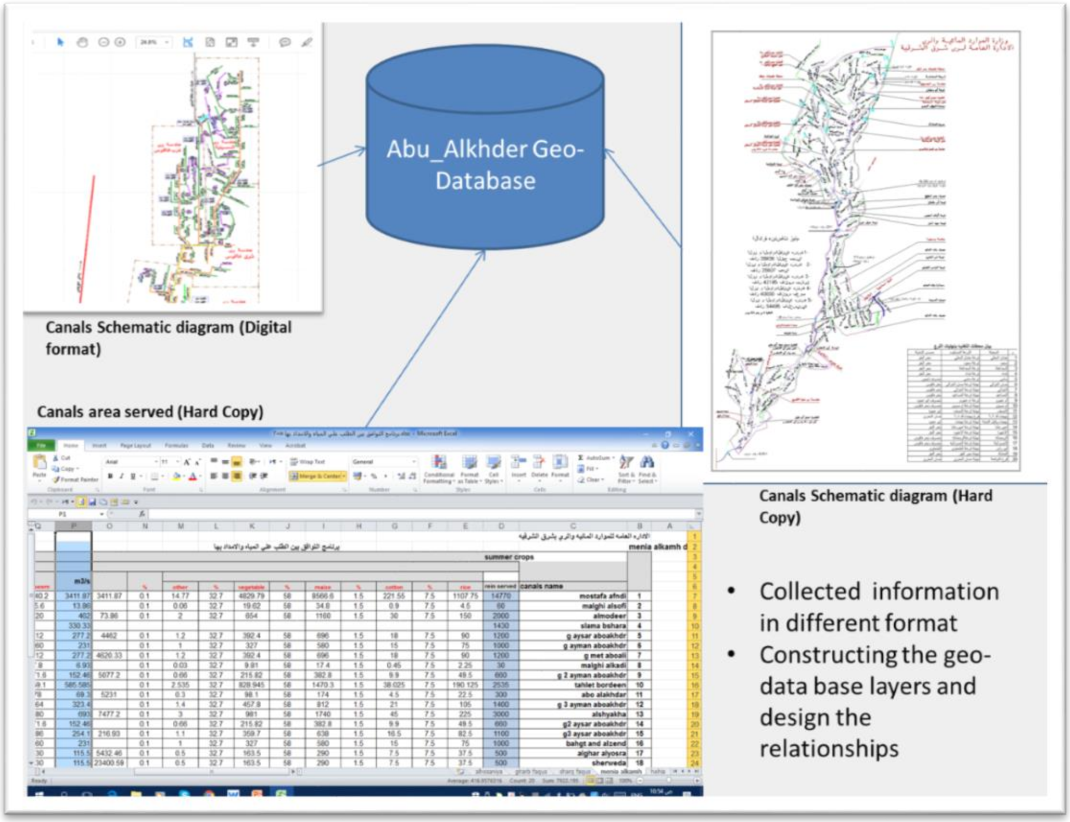


Figure 21: Examples of data sources processed and stored in the spatial database

Data were processed and entered to ArcGIS 9.3 software and the following steps were carried out:

- Hard copy data was transformed to digital format
- Using control points for geo-referencing the data
- For the digital data (shape file format) the projection system was unified according to:
    - Projected coordinate system name: Egypt_Red_Belt
    - Geographic coordinate system name: GCS_Egypt_1907
- Building the relational database using the coding system

3.4 Developed layers

Maps prepared were put in final format with the legend and project logo. The following layers were developed in cooperation with district engineers. Figures 22 and 23 show samples of developed layers.

1- Administrative boundaries
2- Irrigation Canals
3- Drains
4- Feeding stations
5- Drinking Water Stations

6- Hydraulic Structures

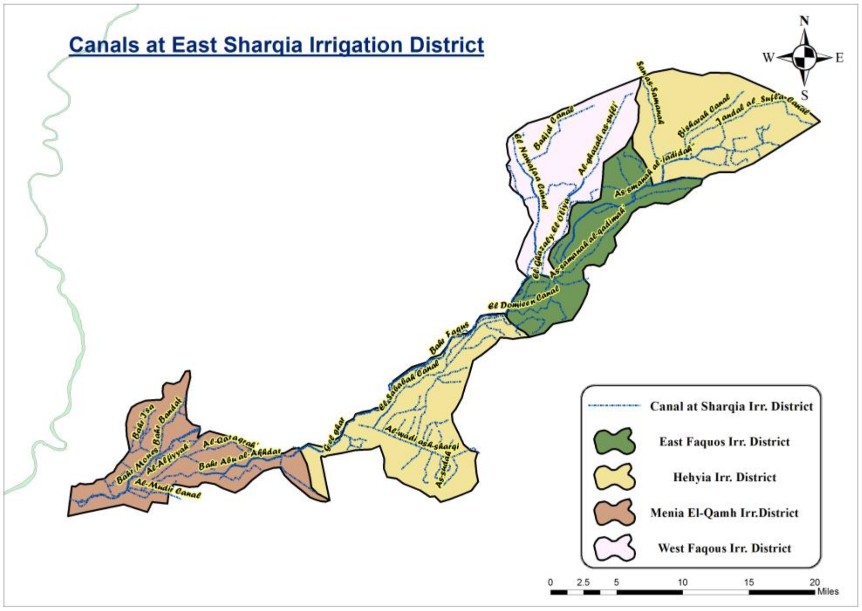


Figure 22: Canals layer of the geospatial database

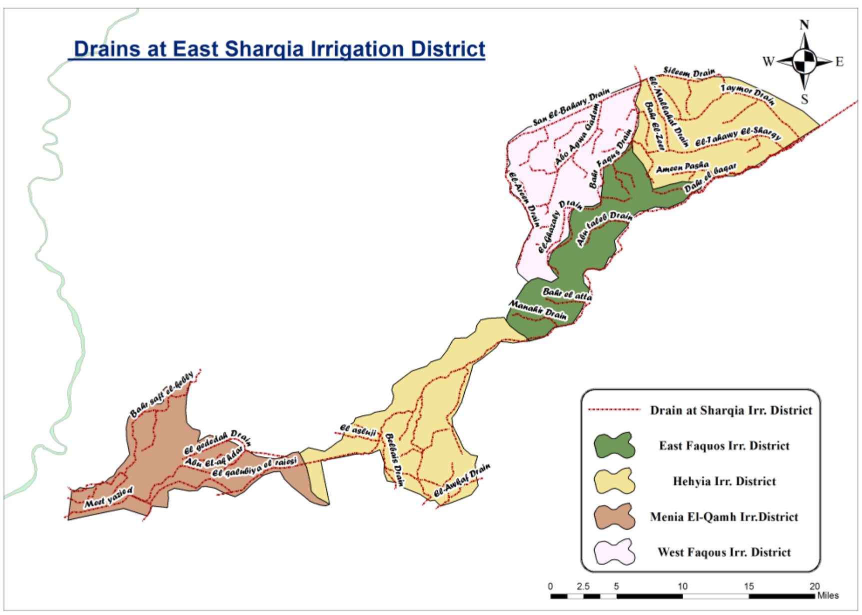


Figure 23: Drains layer of the geospatial database

3.5 Conclusion and Recommendations

The following summarize the main findings and recommendations of the geospatial database development phase.

- The enthusiasm of the engineers to learn the concepts and tools new to them was remarkable.

- There is need for further training to help the engineers use and master the models in their day to day work.
- After analyzing the water resources system on the models, it became evident that the jurisdictive boundaries do not coincide with hydrological boundaries. The engineers prepared recommendations to adjust jurisdictive boundaries accordingly.
- It was recommended to apply the geospatial data base for:
  - Storing water system information
  - Storing and retrieving operational data
  - Storing and archiving data about problems and complains (spatial and temporal)
  - Contacting different entities to get a better picture of the cropping pattern (Ministry of Agriculture and Land Reclamation, Remote Sensing) in addition to analyzing aerial photos using advanced methods.

4 Modeling of water allocation in the study Area

A water allocation model was prepared for the study area with active participation of district engineers. This may be regarded as a first step of introducing water allocation at the district level. This section reports on the process of model selection, application, verification and implications.

4.1 Introduction

Modeling of water resources may help in decision making and in operation of the water resource system. Several approaches exist. The selection of the approach to be applied depends a/o on the purpose of the modeling activity and on data availability. Available models may be classified broadly into three groups:

1. Hydrologic models
2. Hydraulic models
3. Mass balance models

A brief description of the different types of water resources models follows.

4.1.1 Hydrologic models

Hydrologic models are used for modeling hydrological processes of rainfall, runoff, infiltration, stream flow, detention, etc. Required data include topographic data of the study area, climate data, morphology, soil characteristics, land use patterns, cropping patterns, aquifers etc (Figure 24).

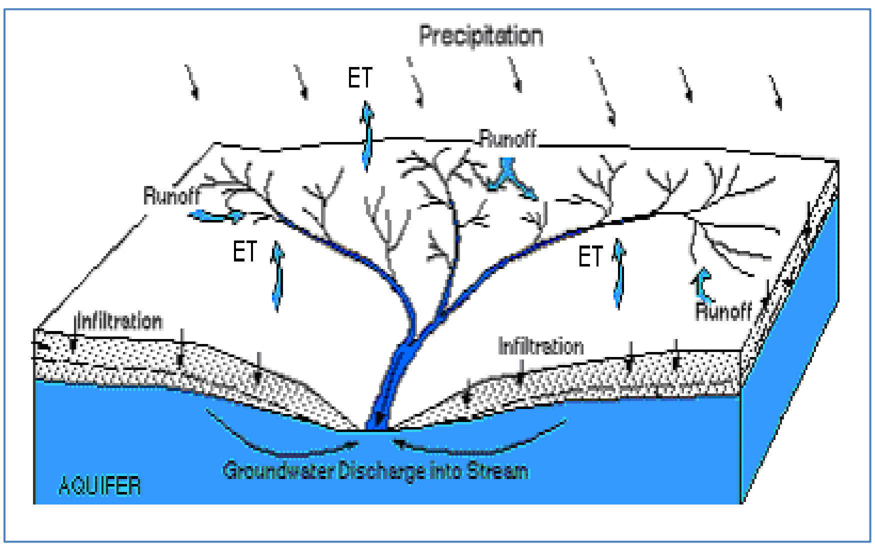


Figure 24: Conceptual presentation of processes simulated during hydrologic modeling

Climate in the study area is arid. Average annual rainfall is less than 50 mm scattered over the months of September to April (Figure 25). Maximum average monthly precipitation occurs in January of about 14 mm distributed over about 5 days. These amounts of rainfall are generally not significant to contribute to the water resources system and are usually neglected for planning purposes. Thus the study area is completely dependent on the water supplied through the water supplied by Abul Akhdar Canal (as well as subsequent reuse of applied water) to satisfy all its water needs. Thus hydrologic modeling might not be very useful for the study area.

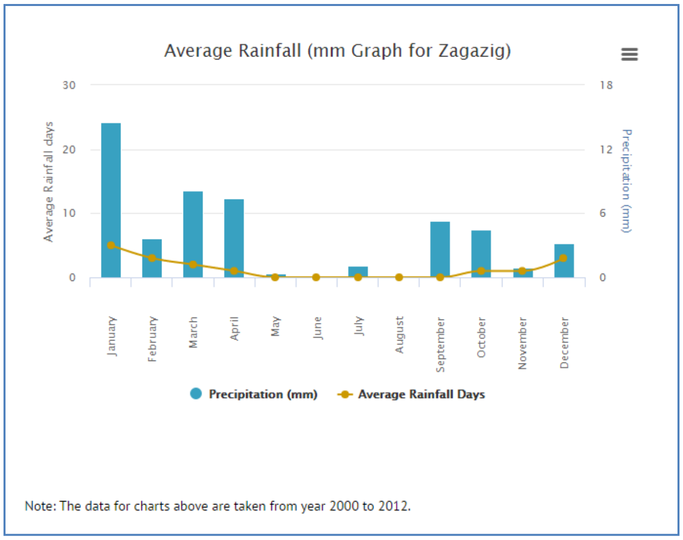


Figure 25: Average rainfall data for Zagazig, Sharquia (Source: worldweatheronline.com)

4.1.2 Hydraulic models

Hydraulic modeling is the most complicated and most data intensive modeling approach. It may be applied for operational purposes of the water distribution network. However, it requires details about network geometry (cross-sections, elevations, flows, hydraulic data of hydraulic structures, rating curves, topography, flows, velocities, water users, … etc). Such detailed data are not available for most districts. Further, actual cross-sections of earthen canals differ at present from design cross-sections. These cross-sections are also dynamic in nature, as they are altered by processes of sedimentation, erosion and canal maintenance (dredging). Further, the use of such models for operational purposes requires skilled users which might not be available at the district level. Therefore, hydraulic modeling is not recommended, at least at present, for the study area.

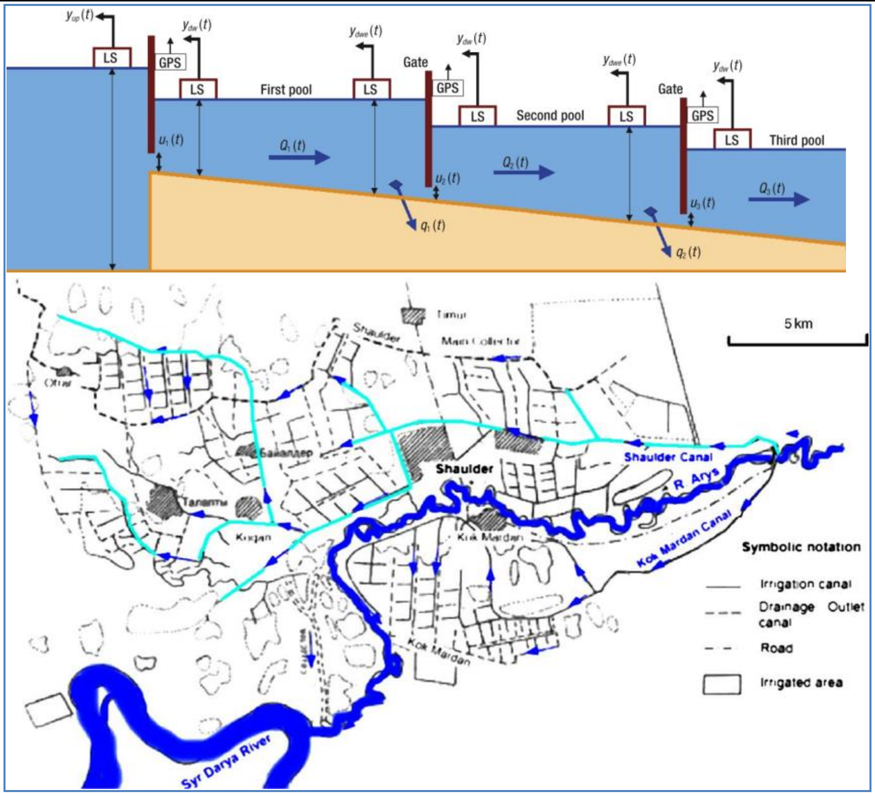


Figure 26: Hydraulic modeling approach

4.1.3 Water balance models

Water balance models are used to balance supply with demand. They are relatively simple to comprehend and apply. Water balance models may be set up on a spreadsheet. Computer based commercial and open source water balance models have also been developed. Such models require data about supply and demand. Supply data include stream flows, groundwater, reuse rates and desalination. Demand data include allocations for agriculture, drinking, industry and aquaculture. Environmental flow requirements may also be specified. The actual layout of the water system is not imperative to the modeling, although it is helpful for visualization and for some simple water quality modeling applications. The water balance modeling approach has been selected for the study area.

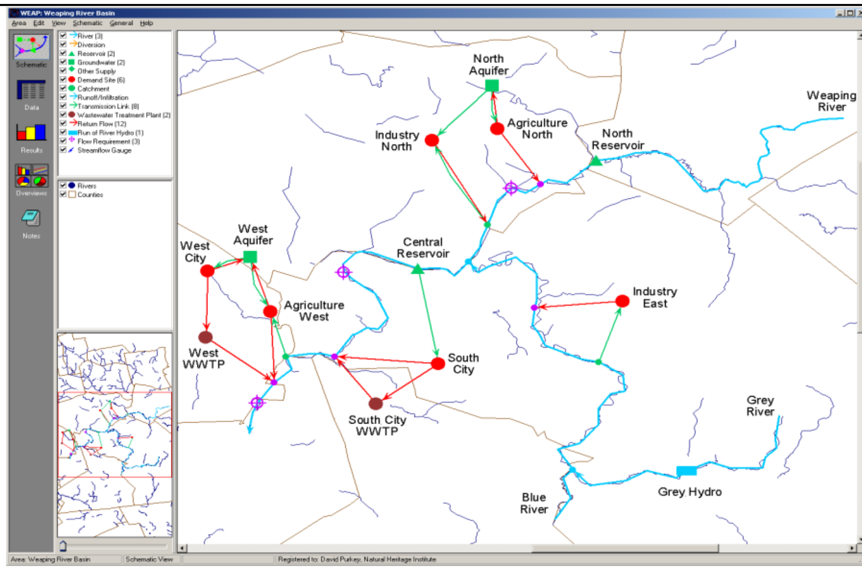


Figure 27: Supply and demand sides are simply represented by nodes in the water balance model

4.2 Model selection

Several models exist for modeling water allocation and planning. Among the most widely used is the Water Evaluation and Planning Model (WEAP) developed by the Stockholm Institute, USA. The model is free available for non-commercial registered users. District engineers were trained on the downloading, installation and registration process and all district engineers who participated in the training are now registered users. The model is an integrated watershed hydrology and water planning model. It has a GIS-based graphical drag & drop user interface. It enables physical simulation of water demands and supplies. Further it facilitates additional simulation modeling such as: user-created variables, modeling equations and links to spreadsheets and other models. The model has scenario management capabilities and watershed hydrology, water quality and financial modules. It can analyze the following situations:

- Sectoral demand analyses
- Land use & climate change impacts on hydrology
- Water conservation
- Water rights and allocation priorities
- Groundwater and stream flow simulations
- Reservoir operations
- Hydropower generation
- Pollution tracking
- Ecosystem requirements

4.3 Model application Methodology

The main input data for the WEAP model consitute supply and demand data. The prepared GIS map of the study area was entered to WEAP as a background layer to facilitate data entry according to geographic location. The following presents data preparation process.

4.3.1 Supply data preparation

Irrigation water is delivered to the study area through Abul Akhdar Canal. The canal feeds a network of about 200 canals ranging from 3rd to 7th order. For each canal, data about connectivity, command area and cropping pattern were collected. In order to be able to apply the water balance approach modeling, data about the variation of canal flow with time is required (at least average flow for each month). Unfortunately, flow data were not available except for an estimate of the flow of Bahr Muwiess and an estimate of the percentage of flow entering Abul Akhdar Canal. This is a major limitation for any modeling or planning of the system, as is discussed below. In order to prepare estimates of the flows, the flow entering Abul Akhdar Canal has been subdivided among the different branches according to command area. The following table summarizes the developed WEAP model structure.

In order to model the canal network, the system has been collapsed to five main reaches, namely Abul Akhdar, Bahr Faqus, Samaanah, Ghazaly and Nawafaa.

Table 1: Developed WEAP model structure

Layer Name	Data Represented	Function
Main Irrigation canals considered and their distributaries	• Bahr Mowees • Albu-AlAkder • Albu-AlAkder Branches • Bahr Faqous • Bahr Faqous Branches • ElSamaanah El-Gididah • ElSamaanah El-Gididah Branches • El-Nawafaa • El-Nawafaa Branches • El-Ghazaly • El-Ghazaly branches	Fresh water supply system
Drinking water treatment plants	1 station on Abul Akhdar 2 stations Bahr Faqous 4 stations on Samaanah	Drinking water abstraction points
Reuse pump stations	18 stations operating for 4 months on 5 drains: • Bahr El-Baqar • Taymour • Abou Agwa • Tahawy • Bahr Faqous • San El-Bahry	Other supply flow
Irrigation district boundaries	5 Main Irrigation Districts: Menia Elkamh, Hehia, Shark Faqous, Gharb Faqous, El Hussainia	Identify administrative boundaries within the study area

Figure 28 shows the irrigation canal network, while figures 29 to 32 show schematic diagrams of the main reaches and their distributaries.

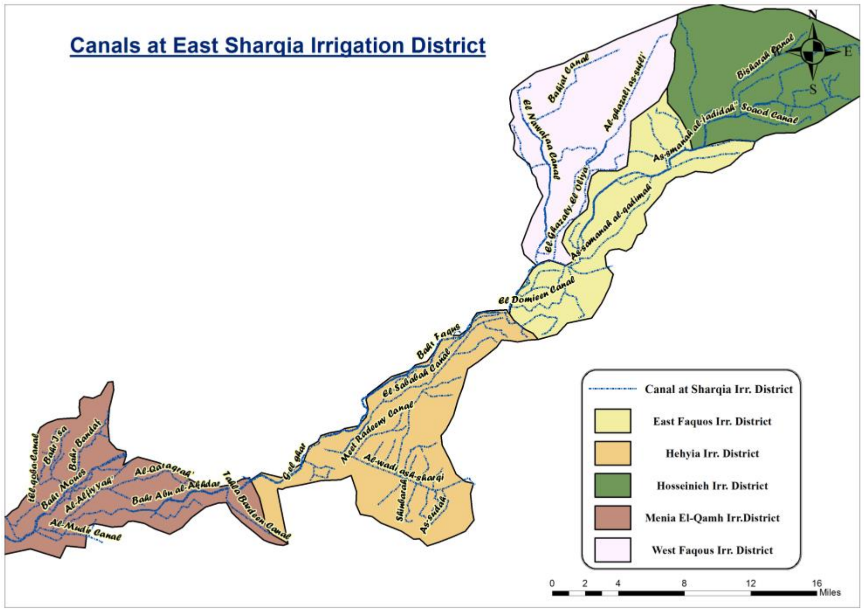


Figure 28: Canal network of within study area

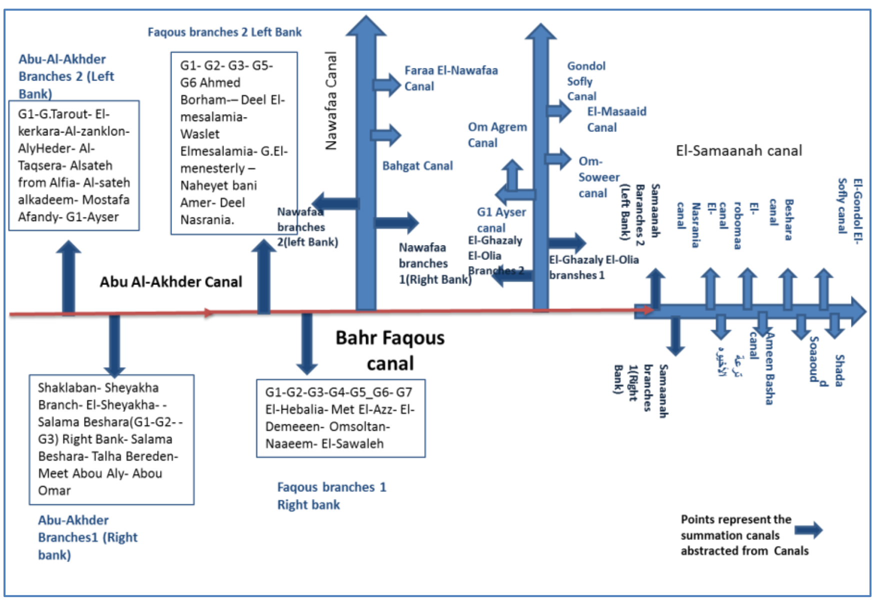


Figure 29: General Layout of modeled Irrigation System

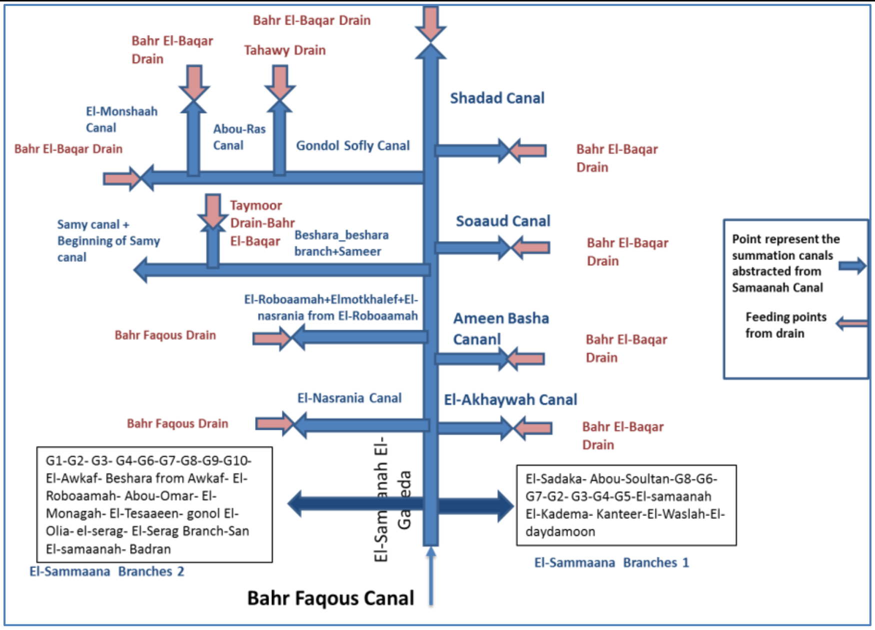


Figure 30: General Layout of Samaanah Canal

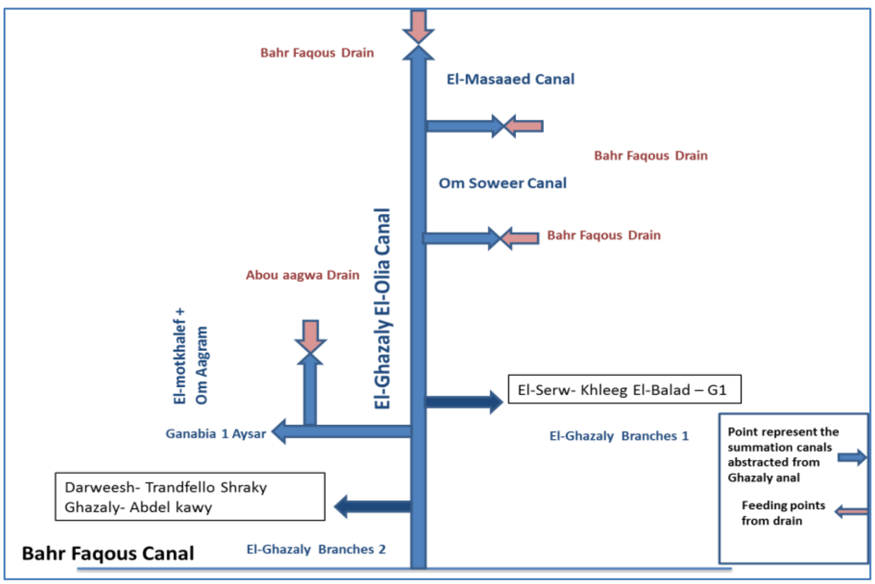


Figure 31: General Layout of Ghazaly Canal

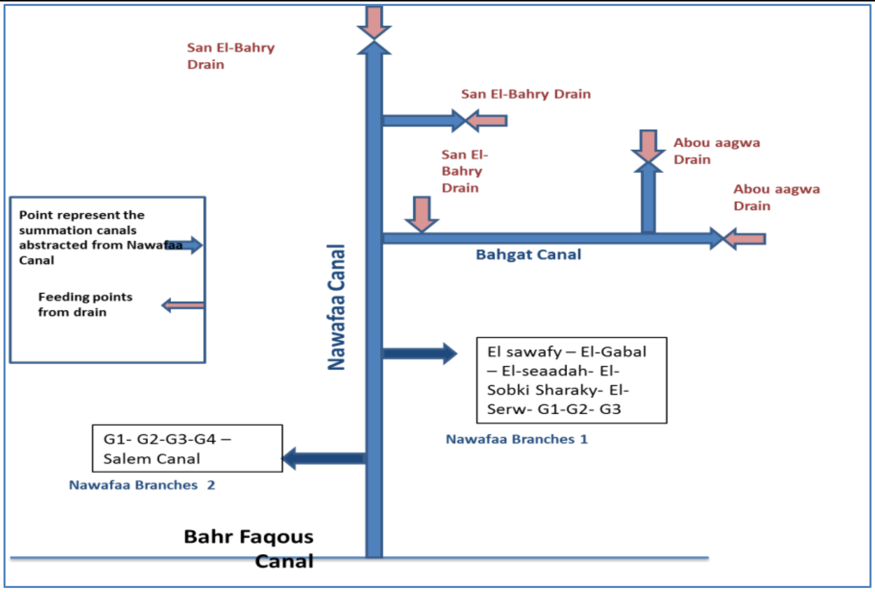


Figure 32: General Layout of Samaanah Canal

Details of collected data for all 200 canals are provided in Annex 5 subdivided according to irrigation district. Annex 6 provides processed data about canal length and hierarchy extracted from the GIS. The following table provides a summary of the data for the main branches of the system. The table shows that the total command area is about 257,000 feddan and receives about 951 Million m^3/year. This results in a water share of 3,700 m^3 per feddan/year of fresh water (not counting reuse or drinking water needs), which is quite low and raises question marks about the accuracy of the received data, particularly that a considerable portion of the cultivated area is rice (next section). Several iterations have been carried out with local staff back and forth to verify the data, but quoted figures are the best estimates they could provide.

Table 2: Water supply distribution relative to area served of each irrigated catchment

Branch name	Area Served (Feddan)	Flow Mm3/year
Abul Akhdar Branch 1	17,645	65.34
Abul Akhdar Branch 2	23,275	86.19
Bahr Faqous Branch 1	41,489	154.94
Bahr Faqous Branch 2	39,866	148.86
Samaanah Canal (direct abstraction)	10,566	46.09
Samaanah Branch 1	16,652	62.43
Samaanah Branch 2	21,520	79.76
Samaanah Distributaries (also fed from drains)	42,752	147.50
Ghazaly Canal (direct abstraction)	10,785	40.28
Ghazaly Branch 1	2,915	10.72
Ghazaly Branch 2	2,500	9.46
Ghazaly Distributaries (also fed from drains)	9,500	35.48
Nawafaa Branch 1	3,752	12.68
Nawafaa Branch 2	1,767	5.60
Nawafaa Distributaries (also fed from drains)	12,105	45.68
Total	**257,089**	**951.01**

Further, data about reuse water stations was collected. A total of 18 reuse stations operate in the study area during water shortages. The Figure 33 shows the GIS map prepared for the main drains within the study area, while Figure 34 shows the GIS location map of reuse stations.

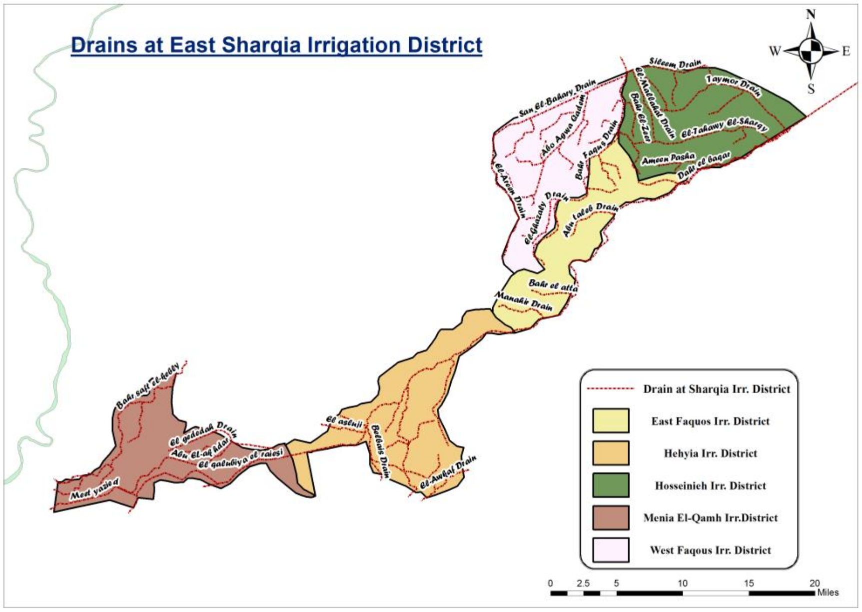


Figure 33: Main drains within the study area

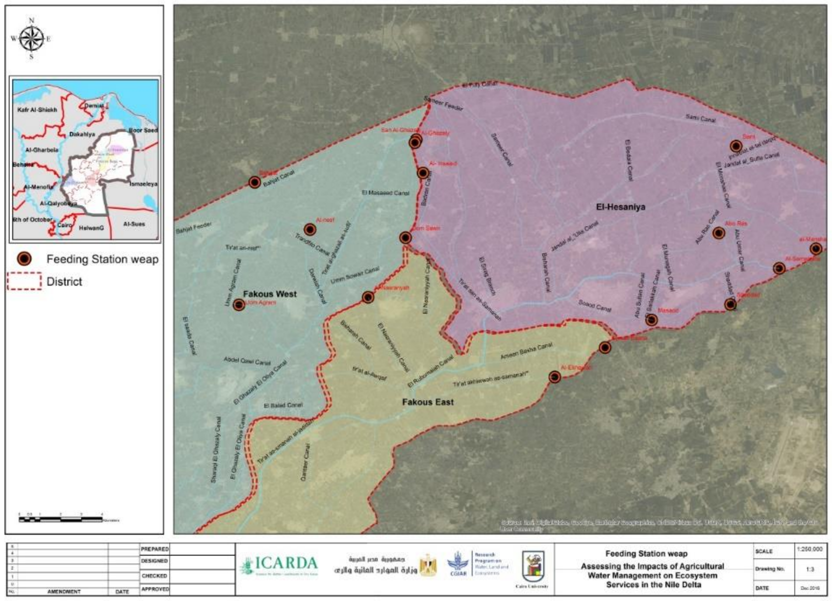


Figure 34: Location map of reuse pump stations

The following table provides data about reuse pump stations, feeding drains, receiving canals, and flow rates.

Table 3: Reuse pump station data

Feeding Canal	Irrigation Water Supply (10^6 m3/year)	Feeding drain	Total Flow from Drain (10^6 m3/y)	Area_served (feddan)
Gondol Canal	38.49	Bahr El-Baqar Drain	22.68	11,157.0
Sooad Canal	3.93		12.96	1,140.0
Ameen Basha	8.59		6.48	2,490.0
Shadad Canal	1.38		12.96	400.0
Akhaywet El-Samaanh	12.07		12.96	3,500.0
End El-Samaanh	12.52		9.72	3,550.0
Samy Canal	37.95	Taymoor Drain	12.96	11,000.0
El-Nasrania Canal	4.14	Bahr Faqous Drain	9.72	1,200.0
El-Rebaomia	11.97		12.96	3,470.0
Monshaah	2.24		6.48	3,600.0
San El-Ghazaly	12.25		6.48	650.0
Total Samaanh Distributaries-Feeding from Drains	**145.53**		**126.36**	**42,157.0**
Om_Swear Canal	5.60	Bahr Faqous	12.96	1,500.00
El-Massaed	5.60		3.24	1,500.00
End-Ghazaly Canal	14.94		12.96	4,000.00
Om_Agrem	9.34	Abou Agwa Drain	6.48	2,500.00
Total Ghazaly Distributaries-Feeding from Drains	**35.48**		**35.64**	**9,500.0**
Bahgat Canal	25.49	Abou Agwa Drain	9.72	6,755.0
Bahgat canat at 6.7 km	13.59		6.48	3,600.0
End Nawafaa canal	6.60	San El-Bahary Drain	6.48	1,750.0
Total Samaanh Distributaries-Feeding from Drains	**45.68**		**22.7**	**12,105.0**

4.3.2 Demand data preparation

4.3.2.1 Agricultural water demands

The main water user in the study area is agriculture. Agricultural water demands have been estimated based on command areas and cropping pattern. Details about cropping pattern for all canals in the study area are provided in Annex 7. The following tables summarize the cropping pattern during summer and winter for the main canal branches.

Table 4: Summer cropping pattern of main branches command area

Canal name	Area served (feddan)	percentage of total cultivated area				
		Rice	Cotton	Maize	Vegetables	Others
Abul Akhdar	40,920	8%	2%	58%	30%	3%
Bahr Faqous	81,355	40%	10%	10%	20%	20%
Samaanah	91,490	40%	20%	10%	20%	10%
Ghazaly	25,700	59%	6%	20%	10%	5%
Nawafaa	17,624	59%	6%	20%	10%	5%
Total	**257,089**					

Table 5: Winter cropping pattern of main branches command area

Canal name	Area served (feddan)	percentage of total cultivated area				
		Clover	Gardens	Wheat	Vegetables	Others
Abul Akhdar	40,920.00	26%	22%	44%	3%	5%
Bahr Faqous	81,355.00	25%	6%	56%	5%	8%
Samaanah	91,490.00	15%	25%	25%	13%	22%
Ghazaly	25,700.00	25%	5%	58%	3%	10%
Nawafaa	17,624.00	15%	25%	25%	13%	22%
Total	**257,089**					

The WEAP model allows calculation of water requirements per time increment based on climate data and crop coefficients. Allowance is also provided to account for leaching requirements and losses within the system. Data of reference crop evapotranspiration (ET_o) was obtained from Soil and Water Research Institute of the Agricultural Research Center (2015). The following figures show the variation of monthly averaged ET_o with time of year and crop coefficients entered to the WEAP model.

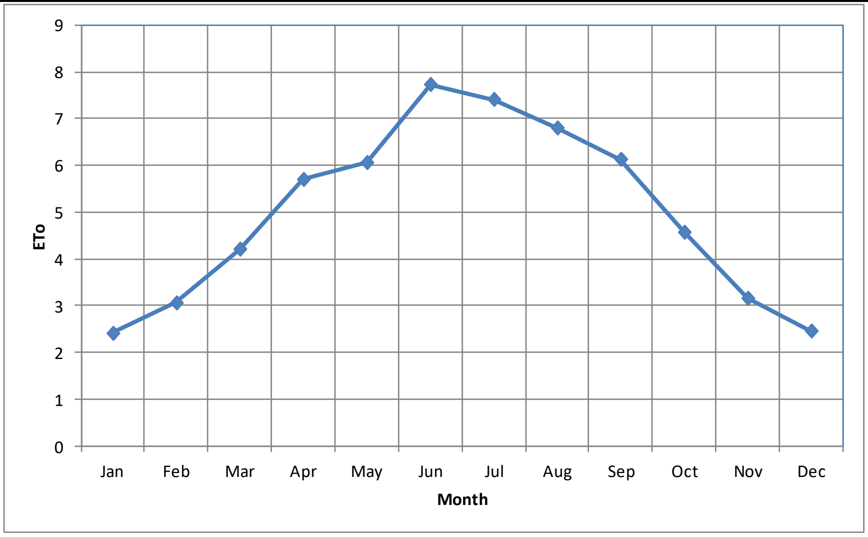


Figure 35: Variation of monthly average ETo with time in the study area

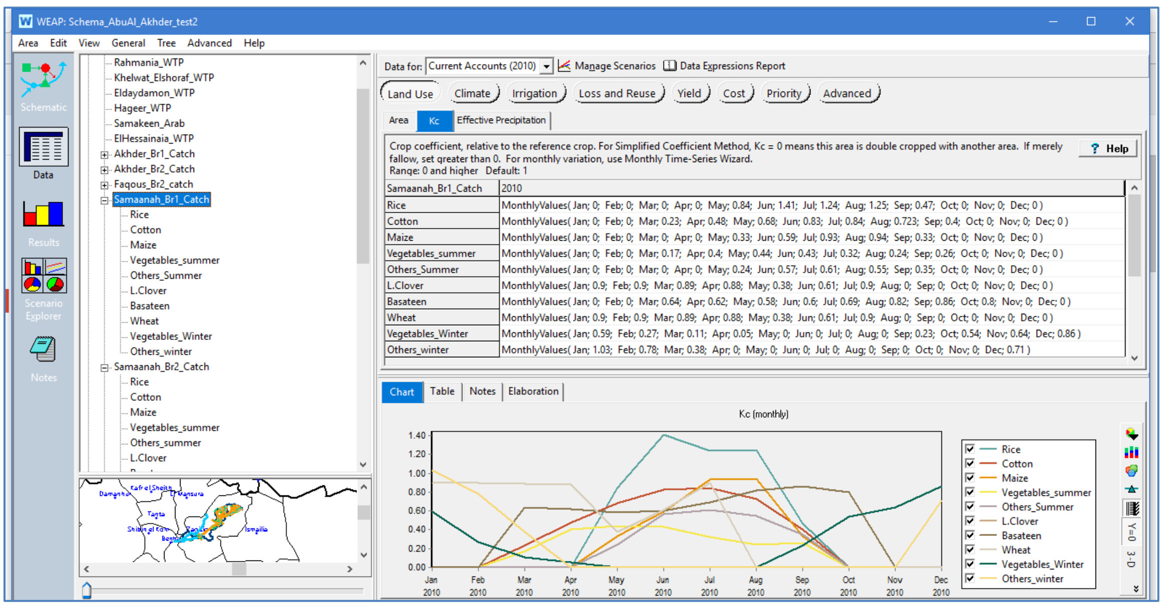


Figure 36: Monthly crop coefficients entered to WEAP model for demand calculations

Further, crop coefficients (K_c) for the summer and winter crops cultivated in the study area were obtained. The following table shows values of Kc.

Table 6: Monthly crop coefficients of summer and winter crops cultivated in the study area

	Summer					Winter				
	Rice	Cotton	Maize	Vegetables	Other	Long clover	Wheat	Garden	Vegetables	Other
January						0.9	0.7		0.59	1.03
February						0.9	0.81		0.27	0.78
March		0.23		0.17		0.89	0.8	0.64	0.11	0.38
April		0.48		0.4		0.88	0.7	0.62	0.05	
May	0.84	0.68	0.33	0.44	0.24	0.38	0.31	0.58		
June	1.41	0.83	0.59	0.43	0.57	0.61		0.6		
July	1.24	0.84	0.93	0.32	0.61	0.9		0.69		
August	1.25	0.72	0.94	0.24	0.55			0.82		
September	0.47	0.4	0.33	0.26	0.35			0.86	0.23	
October								0.8	0.54	
November							0.3		0.64	
December							0.54		0.86	0.71

Crop water requirements estimates were prepared based on two sources. The first is based on estimated water requirements of crops provided in the Annual Agricultural Statistical Year Book (2009), while the second estimate was calculated by the model using climate data and crop coefficients. An irrigation efficiency of 70% was assumed for the second estimate. The following tables show estimated annual water requirements of the different crops in the study area.

Table 7: Annual water requirements based on Annual Agricultural Statistical Year Book (2009)

Crop	WR (M3/Feddan)
Rice	5400
Cotton	3977
Maize	3507
S.Vege	2699
S.Others	3099
L.Clover	3407
Wheat	2400
Garden (Basateen)	3030
W.Vege	2699
W.Others	3030

Table 8: Annual water requirements based on climate data and crop coefficients

Crop	WR (M3/Feddan)
Rice	6595
Cotton	5000
Maize	3929
Summer vegetables	2624
Summer others	2935
Long Clover	4920
Wheat	2821
Garden (Basateen)	6113
Winter Vegetables	1988
Winter others	1476

4.3.2.2 Drinking water demands

Ten drinking water treatment plants exist in the study area. Seven of these plants are fed from the canal system of the study area, while the other three are fed directly from Bahr Muwiess. The locations of the stations feeding from the study area canal system are shown on the following map (blue circles), while the following table provides the daily abstraction of each station. The total flow rate amounts to about 67,500 m^3/day or 24.6 Million m^3/year, which represents only about 2.6% of the total fresh canal water delivered to the study area.

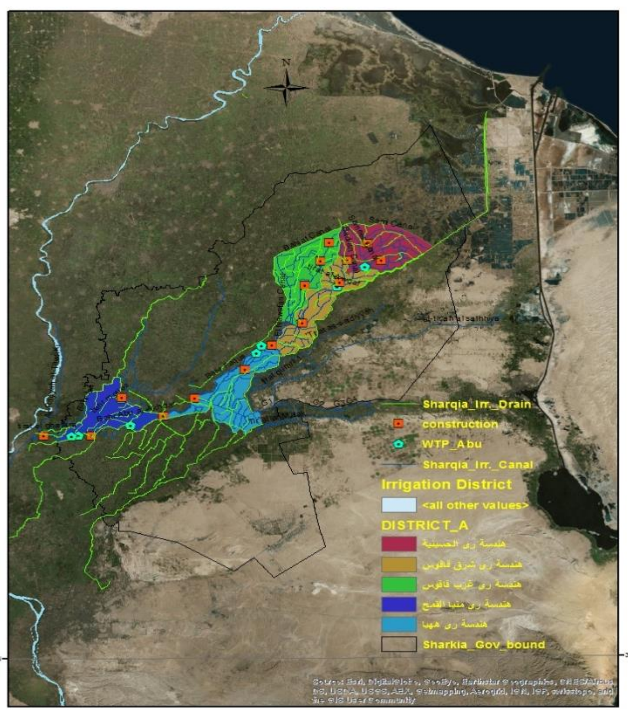


Figure 37: Location map of drinking water treatment plants

Table 9: Drinking water treatment plants daily abstractions

Drinking Water Plant	Feeding Canal	Abstracted water m3/day
Tarout	Abul Akhdar	4,320
El-Rahmania	Bahr Faqous 20.1 km	8,640
Khelwat El-Shorafa	Bahr Faqous 17.50 km	8,640
El-Daydamon	Samaanah Canal at 2.5 km	8,640
Hageer	Samaanah Canal at 16.25 km	7,000
Samakeen El-Arab	Samaanah Canal at 14.0 km	4,320
El-Hussainia	Samaanah Canal at 21.6 km	25,920
Total		**67,480**

The following snapshot shows demand side abstraction point representation in the WEAP model.

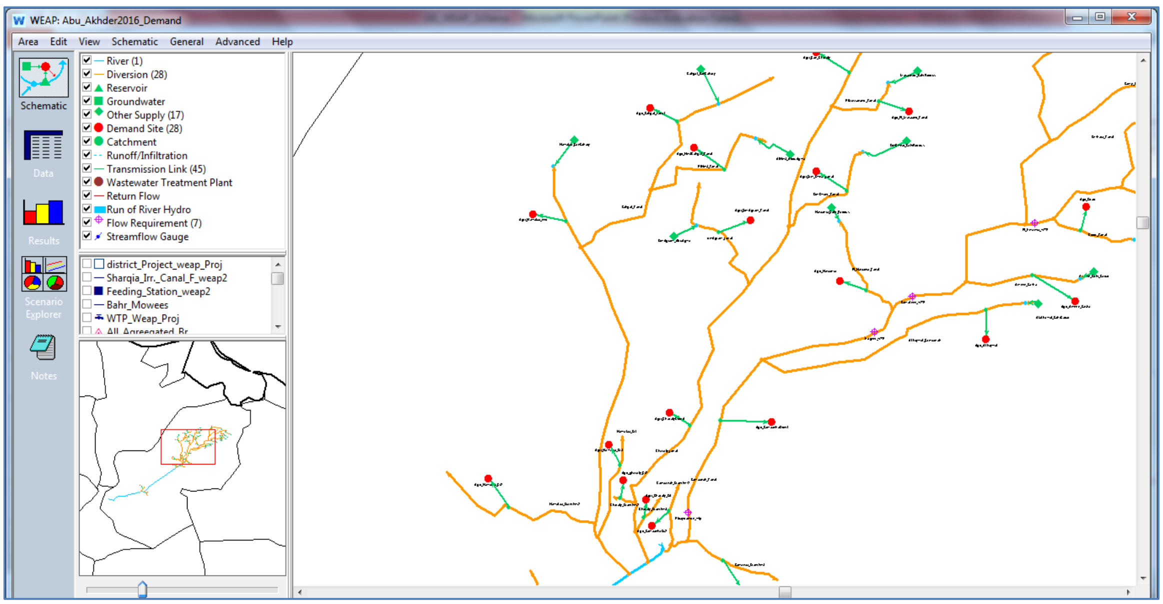


Figure 38: Demand side nodes representation in WEAP

4.4 Model application at baseline (current situation)

The WEAP model has been applied to simulate the present situation using the above mentioned supply and demand data. The demand side has been simulated twice to compare the two assumptions outlined in the previous section.

The following graph shows the model computations of agricultural demands based on Agricultural Statistical Year Book data for crop requirements (2009). The graph shows the calculated monthly water demands (in Million m^3) of the study area based on the cropping pattern. Highest demands are in June and July and reach about 313 Million m^3. Total annual demands based on these calculations amount to 1,706 Million m^3, which is much higher (almost twice as high) than the annual water supplied to the study area according to received data, which is about 951 Million m^3. When also including reuse amount of 181 Million m^3 per year, the percentage of demand coverage is 66% which is unrealistically low. Disregarding the actual results, which may be attributed to inaccuracy of received data, the capability of the model to predict timely variation of demands based on actual cropping pattern and climate and growing season was welcome by the district engineers as it gives them a clear and defendable estimate about actual demands which may serve for planning, water allocation, scenario assessment and as a negotiation tool when discussing with stakeholders.

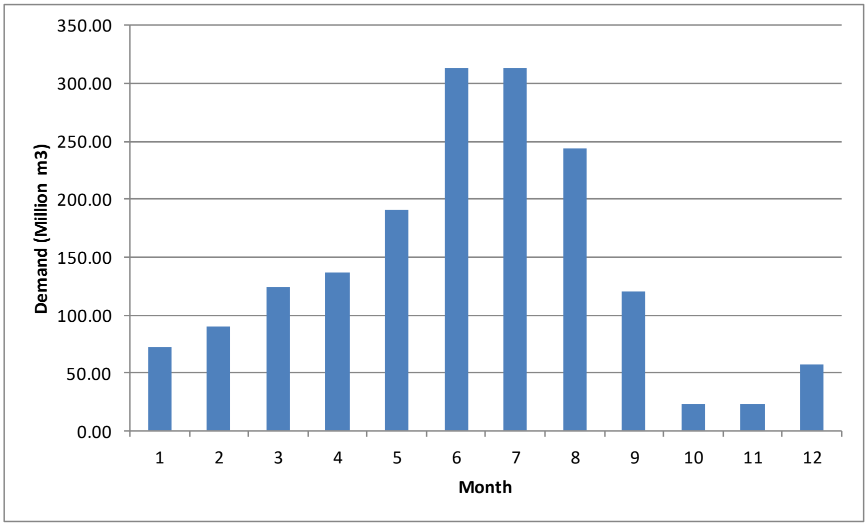


Figure 39: Computed demand for the whole study area

The model was also used to calculate the unmet demand per catchment. The following figure shows unmet demand for main catchments.

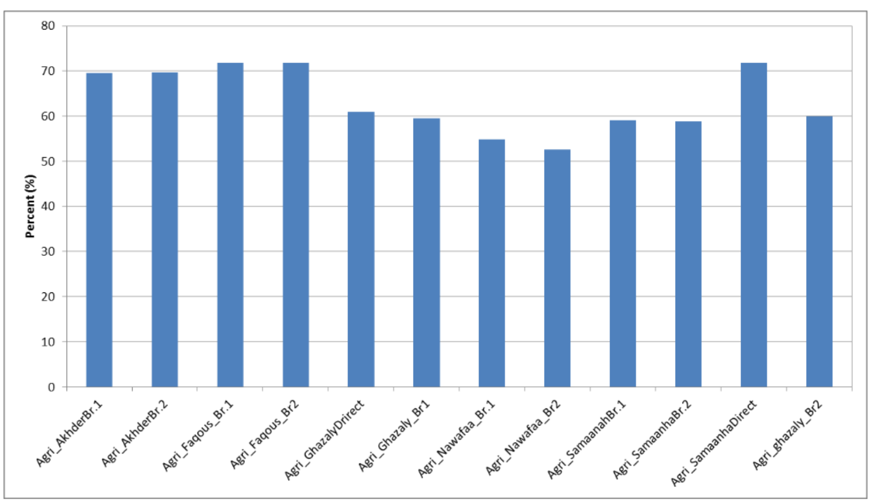


Figure 40: Unmet demand for the main catchments of the study area

Unmet demand at tail end catchments is more severe, as depicted in the following figure.

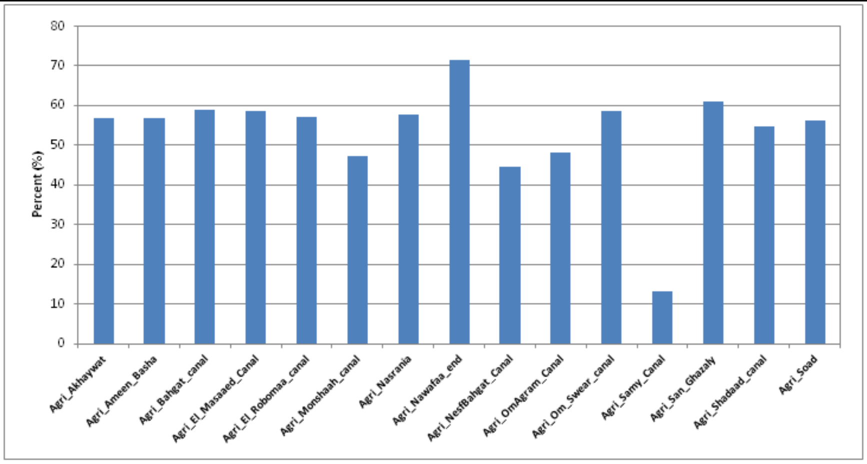


Figure 41: Unmet demand at tail end catchments of the study area

4.5 Model application as a tool to investigate scenarios/options

The model was also applied to investigate the potential reduction in pressure on water resources when using water saving technologies such as mechanized raised bed. This scenario has been applied to the agricultural areas using the same cropping pattern as above, but with application of raised bed technology to agricultural areas of wheat and maize. For these areas, a 25% reduction in demand has been applied, as is reported through several studies on raised bed technology. The following figure summarizes the results. It shows the unmet demand for the different catchments of the study area for the reference scenario using the two methods of calculation of water demands as compared to the application of raised bed technology. The figure reveals that most of the reduction is achieved in the upstream catchments which have a higher percentage of maize and wheat than the downstream catchments which grow predominantly rice. The calculations reveal that the unmet demand can be reduced by about 74 Million m^3 per year for the whole command area through raised bed technology. Although reduction is not dramatic, it reflects the potential of water saving technologies and the high impact of rice cultivation areas on water consumption.

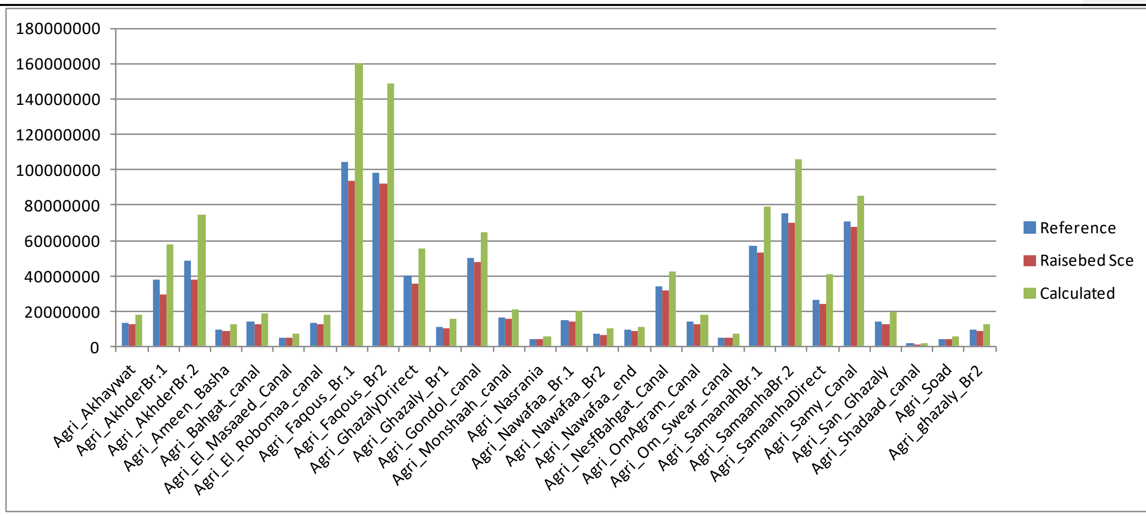


Figure 42: Unmet water demand in all catchments of the study area

5 Conclusions and Recommendations

The project aimed at testing and identifying appropriate water and land management strategies that would increase water and land productivity, reduce the demand for chemical fertilizers, increase farmers' income and minimize impacts of agriculture on the ecosystem. The project has addressed these objectives through working with district engineers in the study area to raise their capacity and to introduce state of the art computational tools that would allow them to respond to and manage a dynamic water system. Geographic Information Systems has been introduced for data standardization, manipulation, geo-referencing, storage and retrieval. This would enable district engineers to store important information about water supply and utilization, hot spots, problems and attempted solutions, what worked and what didn't work, etc. (the memory of the system). This database is vital for planning and management of such a dynamic system. It also facilitates preparation of output for decision makers. Another important component of the project was the introduction of computational modeling of the water system, based on a relatively simple to comprehend and apply water balance approach. This model enables district engineers to be able to compare supply to demand in a quantitative way and to appreciate the size of the problem. Further, it allows the comparison of supply and demand with time and the relatively accurate estimation of demands based on climate data, cropping patterns, crop coefficients, population counts, etc. This enables the evaluation of gaps between supply and demand and the impact of any proposed policies and interventions on the water balance at present and in the future (scenario analysis). Further it enables district engineers to actively participate in and comprehend the development of the national water resources plan, and to provide more accurate estimates of the local water balance of their jurisdiction as a building block towards a more realistic national plan.

In the course of the study, it was conceived that a major limitation lies in available data, particularly about actual flows. The discharge flowing into the study area is not measured but is rather an estimate as a percentage of the flow of the feeding Main Canal. The telemetry station at the reach entrance measures water levels and not flows. Further, it is assumed that the flow is constant at high flow for three months of the year and constant at low flow for 9 months of the year. Although this is very crude and unrealistic, this was the best estimate engineers at the Irrigation Directorate in Sharquia could provide. This had its implications on modeling results, as estimated demands turned out to be about double the water supplied to the study area. The discrepancy could be related to either an overestimation of cropped areas, an underestimation of supplied water or a combination of both. Reasons for inaccuracies could be attributed to the following:

- Supply side data:
  - The actual flows are not measured
  - Data about official reuse are very crude (pump flow rate and approximate number of months of operation)
  - There are no data about unofficial reuse rates
  - There are no data about actual groundwater abstractions
- Demand side data:
  - There are no accurate surveys about actual cropped area and actual cropping pattern (such as with the use of remote sensing)

- There are no accurate data about urbanization and loss of agricultural lands
- There are no reliable estimates about actual crop water consumption. For example for rice, quoted figures from different official sources varied between 5,000 and 9,200 m^3 per feddan per growing season.

Nevertheless, the project should be regarded as a step forward towards a bottom up approach of water resources planning and management. District engineers have been trained on technologies which enable them to better understand, plan and manage their system. They understand better the importance of data and information of the system. They are able to identify data needs and what needs to be measured and what could be estimated. They are able to evaluate the impact of water saving techniques and water policies. They are now prepared to contribute towards local and national water resources planning. In order to fully realize the benefits of the introduced tools, the following is recommended:

- Identify minimum data requirements for the proper planning and management of the system
- Institutionalize data collection, review, and storage on a regular basis
- Update the developed geospatial database regularly
- Provide further capacity building to district engineers as recommended in the conclusion of the training workshop
- Link district water planning as introduced through this project to the development of more accurate national water resources plans