USE OF INFORMATION TECHNOLOGY TO SUPPORT INTEGRATED WATER RESOURCES MANAGEMENT IMPLEMENTATION

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ABSTRACT

While progress with Integrated Water Resources Management (IWRM) is fundamental to sustainable development, a prerequisite for furthering this process is an effective computerized system that serves the data and information needs of all stakeholders, and promotes equity through good governance. Developing an IWRM information system is a challenge in developing countries with limited resources. In most developing countries, water information systems at local administrative levels are generally absent or severely degraded, and management decisions are mostly based on unreliable data and information. A lack of data and obsolete data capture and/or information management systems are common issues, resulting in inadequate data/information to support IWRM implementation. An innovative, inclusive approach is required that will unleash the full benefit of a number of powerful technologies to capture, manage, and disseminate water related data and information in a cost effective and sustainable manner.

The Egyptian Ministry of Water Resources and Irrigation (MWRI) has a long-term goal of reorganizing internal functions and operations through a process of local governance consolidation and ministry-wide decentralization, including de-evolution of authority to the local government level. With that, the MWRI has adopted a policy to integrate all water management functions at the district level to support the decentralized management process.

The USAID/Egypt-funded Livelihood and Income from the Environment (LIFE) Integrated Water Resources Management (IWRM) Project was designed to focus on implementing policy reform measures on a large scale, covering 27 irrigation districts over 1.2 million acres of Egyptian cultivated land. Implementation of the project began in October 2004 with three main objectives: (1) Consolidate MWRI district offices (i.e., irrigation and drainage) (2) Promote stakeholders' participation through the formation of Branch Canal Water Users' Associations (BCWUA), and (3) Support equitable allocation of water resources at the district level.

Under the equitable allocation of water resources objective, a series of activities were carried out to support the development of district water information systems. The effort focused on providing technical assistance on the design, construction, and implementation of information

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systems in support of water management decision making at the 27 irrigation districts. The information systems component of the project consists of two major technologies: database management and digital mapping systems. While the database management and mapping systems evolved independently, both are integrating, analytical, and strategic technologies that are complementary to each other. The convergence of both technologies offers extraordinary opportunities for producing information management tools that connect disparate, but indispensable, threads of spatial and non-spatial data across different information systems and management units. These tools create broader knowledge and understanding for decision makers at the district, directorate, and central levels.

This paper will discuss the development of the information systems that comprise the seven database management systems (six tabular and one geospatial) to provide timely information in support of decentralized decision-making for improving water management at the district level. These information systems have now been implemented at the 27 (Integrated Water Management Districts) IWMDs under the project with great success. It is anticipated that the information systems will be introduced and implemented by the MWRI at other districts in the near future.

INTRODUCTION

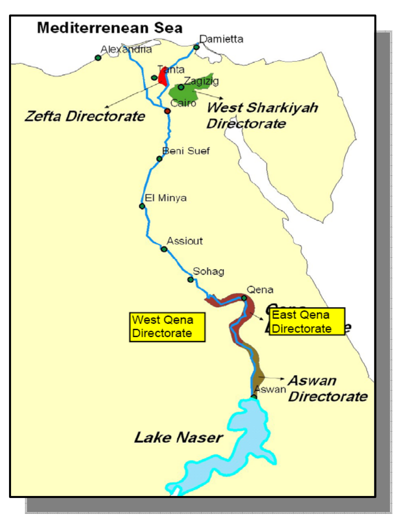
Under present operational and administrative conditions in the MWRI, the irrigation management services are carried out through line department directives and functions emanating from the central ministry to lower line offices at the inspectorate and district levels. The objectives of a policy reform were to move toward the goal of reorganization of the MWRI internal functions and operations, including devolution of authority to the local level, thereby decentralizing water management and eliminating district-level inefficiencies and redundancies.

An operational IWMD is expected to achieve the following targets:

- Improved water use efficiency
- Maintained irrigation and drainage system, and
- Improved service delivered to water users.

The definition an IWMD is:

The Integrated Water Management District is an entity that has sufficient manpower, material, and fiscal resources to operate and maintain all water resources under its jurisdiction [synthesis of several definitions; see APRP Report 49]. *All of the divisions support the water distribution process to ensure that water is delivered equitably, resulting in the various district water entities currently being merged to constitute a single entity referred to as an IWMD.*



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PROBLEM DEFINITION

In order make to that, district managers require timely information and data to provide a greater understanding of their irrigation systems and system performance. The knowledge required to support improved water management at the district level is inherently spatial and analytical in nature. With that, the information systems development activities under the IWRM project were specifically designed to provide the IWMDs with the capability of managing all of the data/information needed to support decentralized and integrated water management decisions in the IWMDs.

Non-IWMDs currently collect data for higher levels to make management decisions for them. That is, non-IWMDs do not prepare their own water requirements and rotations. Instead, they are prescribed by directorates about three times a year. Basic information on physical system components, water resources quantity/quality, and water demands is outdated.

Spatial relations and representation of water resource data have not been a requirement in non-IWMDs because decision making was mainly taking place at the directorate level. The non-IWMDs and directorates both depended on the paper sketches or schematics for their physical system components. These sketches are based on grossly outdated 1950 paper maps of scales 1:25,000 and/or 1:50,000 printed by the Egyptian Survey Authority (ESA). The ESA is currently updating the maps for the entire country but the printed version is not yet available and a digital version is cost prohibited.

INFORMATION SYSTEMS DEVELOPMENT ACTIVITIES

Under the project, the information system component consists of two major information technologies: database management and digital mapping systems. The database management system consists of PCs, Microsoft Office, and six database applications. The digital mapping system consists of PCs and GPS units, AutoCAD Map for the IWMDs and ArcGIS for the directorates.

The information systems were established to provide reliable sustainable computerized systems at the district level. Three major steps were taken:

1. Install computer hardware and software at the 27 IWMDs and five directorates;
2. Install IWMD water resources tabular databases at all the IWMDs;

3. Assign and train staff members from the IWMDs and directorates on computer basics, hardware maintenance, and database operations.

Hardware and Software

To introduce the computerized information systems at the IWMD, the first step was to provide needed computer equipment. The equipment for building the data management system was identified as follows:

At integrated districts level: desktop computers and peripherals with Windows XP, Office 2003, and Antivirus software, UPS and voltage stabilizers, Color printer, black and white printer, and local area network (LAN).

At Directorate level: desktop computers and peripherals with Windows XP, Office 2003, and Antivirus software, laptop, ArcView 9.2, UPS and voltage stabilizers, plotters, printes, scanners, LAN, USB mobile hard drives, DSL Internet connections.

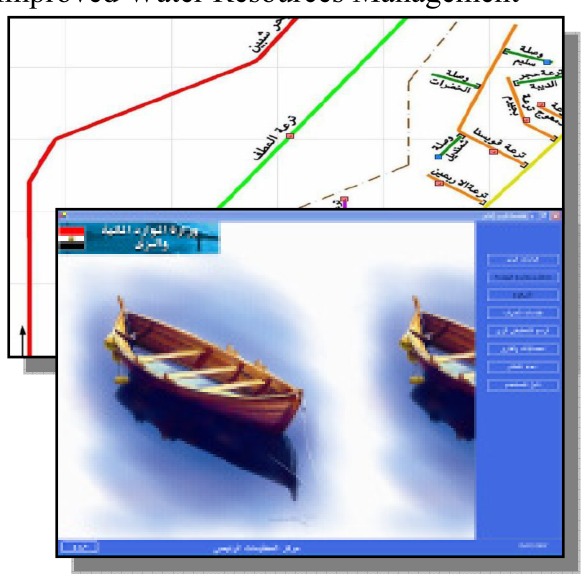
IWMD Databases

The six databases that were designed, constructed, and implemented at 27 IWMDs to provide timely data and information are: Water Level Database, Matching Irrigation Supplies and Demand (MISD) Database, Water Quality Database, Groundwater Database, Complaint Database, Violation Database.

The following presents a brief description of each of the six databases:

Water Level Database

The Water Level Database was originally prepared by the MWRI Information Center (MIC) under the Red Sea Sustainable Development and Improved Water Resources Management Project. It was updated in mid-2005 and upgraded again to the latest version (3.0) that was issued in August, 2006. The Water Level Database is a data management tool that archives, analyzes, and reports water levels for different sites. All of the canals were coded and tabulated as a part of the database. The paper register for the water levels from each IWMD were used to identify the number of sites required and located on the schematics of the database. The database has been customized for each IWMD with a canal schematic and dots for gauging sites. A user can click a canal on the schematics and enter the canal details and daily water levels via pop-up forms. Currently, water



levels at major control points within the IWMDs are collected three times a day (6:00 AM, 12:00 PM and 6:00 PM) and are recorded in a paper register and the database.

The figure below illustrates the main screen of the Water Level Database and the schematics for the canal network in an irrigation district (Captured from MIC Manual).

The Water Level Database exports specific data as shown below for use in the canal structure calibration worksheet by each IWMD.

Data Items for Canal Structures

	Arabic	English		
General Directorate			GD ID	
District			District ID	
Site Name			Site Code	
Structure Type			Structure Code	
Weir Crest Level				
Canal Name			Canal Code	
Canal Length				
Ave. Canal Width				
Reach Length				
No. of Gates				

	Gate 1	Gate 2	Gate 3	Gate 4	Gate N
Gate Width					
Bed Level					
Max allowable U/S					
Min Allowable U/S					
Max allowable D/S					
Min Allowable D/S					

Date	U/S Water Level (L1)	D/S Water Level (L2)	D/S Water Level from Weir (L3)	Total Gate Opening	Next Gauge Level (L4)

Data Items for Pump Stations

Data Item	Arabic	English		
Site Name			Site Code	
Structure Type			Structure Code	
Canal Name			Canal Code	
Canal Length				
Reach Length				

	Unit 1	Unit 2	Unit 3	Unit N
Pump Capacity				

				Unit 1		Unit N	
Date	U/S Water Level (L1)	D/S Water Level (L2)	Next Gauge Level (L4)	Hours	Q	Hours	Q

Data Items for Canal Network

	Arabic	English		
General Directorate			GD ID	
District			District ID	

Canal ID	Canal Name (Arabic)	Canal Name (English)	Canal Level/Rank
1-65	ترعة العاقي		1
1-65-1	ترعة البولي		2
1-65-2	ترعة الطوقي		2
1-62-1	ترعة العل		2
1-62-1-1	ترعة السلمي الشرقي		3
1-62-1-2	ترعة سحل العجب		3
1-62-1-3	ترعة سحل العديسات		3
1-62-1-4	ترعة السلمي الطرقي		3
1-62-1-4-1	جابق السلين		4
1-62-1-4-2	جابق الحوش		4

Data Items for Drainage Network

Drain ID	Drain Name (Arabic)	Drain Name (English)	Drain Level/Rank

The calibration worksheet developed by the IWRM project is based on six equations as follows:

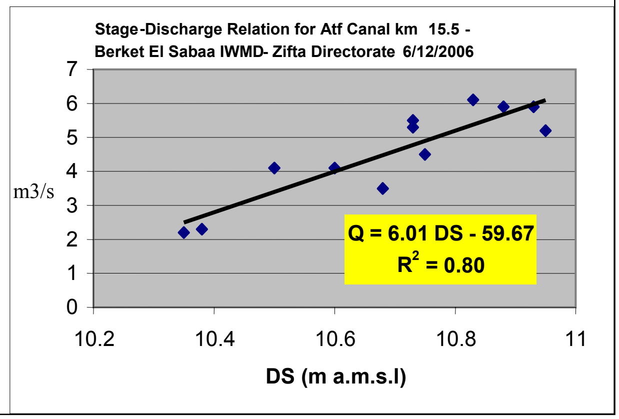
Order	Type of formula	Detailed	Needed data	Constants to be calibrated	Usual values
1	Weir	$Q = c \times H^n$	upstream water level	c, n	n around 1.5
2	Orifice	$Q = c_d A_o \sqrt{2gH}$	upstream and downstream levels of the of gate, gate opening A_o	c_d	c around 0.6-0.8
3	Manning (slope-area method)	$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{0.5}$	Reach length, water levels at head and tail of the reach, cross section data; bed level, side slopes, bed width	$\frac{1}{n}$	$\frac{1}{n} \equiv 20$ - 40 for alluvial canals $\frac{1}{n} \cong 60$ for lined canals
4	Simplified Manning	$Q = k h^{\frac{5}{3}} (L_1 - L_2)^{0.5}$	Reach length, water levels at head, L_1,and at tail of the reach, L_2, bed level, F $h=L_1-F$	K	localized
5	Stage-discharge	It takes different forms: i) Power $Q = a\, h^b$ ii) polynomial $Q = c_1+c_2\, \mathbf{h}+c_3 \mathbf{h}^2$	water level (or water depth), **h**	a,b for power formula and, c_1, c_2, c_3 for polynomial	b around 1.3-1.8
6	Linear stage-discharge (for small range of water levels)	$Q = a + b\, \mathbf{h}$	water level, **h**	a,b	localized

The following figure shows a sample of the calibration curve and data that had been provided by the Berket El Sabaa IWMD.

Flow Measurement on Atf canal

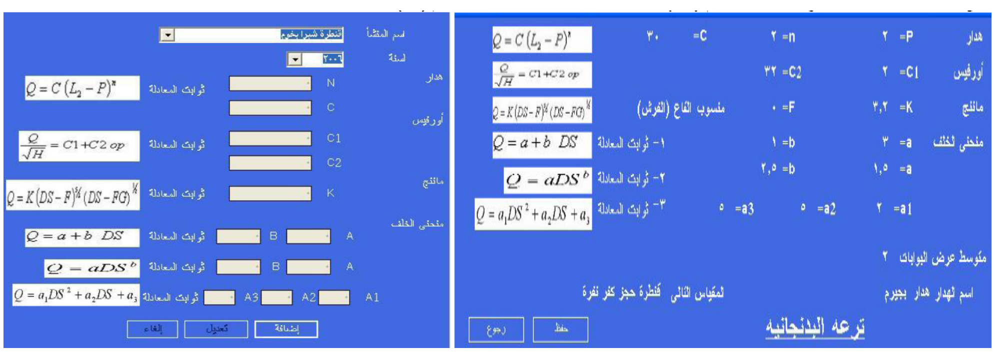
Site	Km 15.5
Area Served (feddans)	number of gates
Canal Length (m)	gate width (m)
Reach Lenth (m)	invert level (F)
Average Canal Width (m)	

Date	dswl	Q (m3/sec)
23/5/2005	10.68	3.34
6/5/2005	10.75	4.5
29/6/2005	10.93	5.9
19/7/2005	10.73	5.5
21/7/2005	10.88	5.9
21/8/2005	10.83	6.1
3/9/2005	10.73	5.3
10/9/2005	10.6	4.1
23/10/2005	10.35	2.2
8/11/2005	10.95	5.2
8/12/2005	10.38	2.3
17/12/2005	10.5	4.1
5/1/2006	10.68	3.5



Each one of the sites was assigned with a rating equation based on the availability of the water level data for that site. A correlation relation was established based on one year water level historical data. The calibrated equations for the sites were then entered into the Water Level Database and discharge information was automatically calculated by the database based on the rating equations.

The following figures show the screen for different coefficients on specific sites (Captured from MIC Manual).



Matching Irrigation Supply and Demand Database (MISD)

As the Egyptian Ministry of Agricultural and Land Reclamation (MALR) was applying a policy of free cropping for farmers it was difficult to determine actual water demand, which led to a variance between water supply and demand that subsequently led to a shortage of water supply in some Districts and an excess of water supply in others.

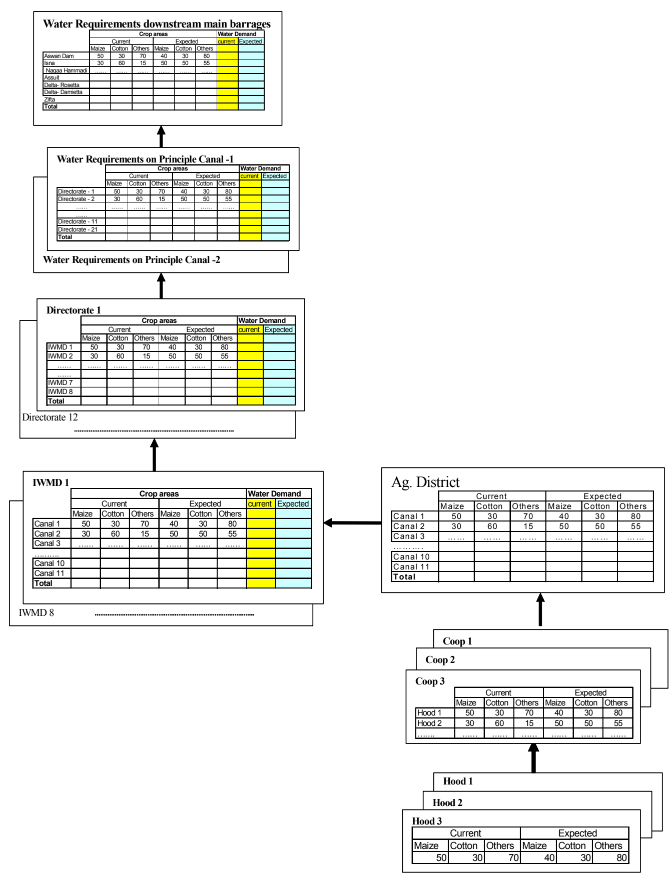
As the Egyptian MALR collected cropping information from farmers via field agents, it was decided that sharing this information with the Egyptian MWRI would be helpful in estimating water demand based on actual cropping patterns. In 1999, the MISD process had been initiated and was implemented in four pilot districts, followed by another 26 districts. Currently, about 100 districts, or about half of the total command area in Egypt, are applying the MISD process in their water management program.

The basic/preliminary arrangements for MISD implementation are; 1) formation of district joint committees; 2) adjustment and verification of the gross command area; 3) definition of the main crops for which to collect data; 4) crop data format; 5) type of data; 6) databases.

In terms of operation of the MISD, every two weeks the following activities are carried out:
MALR Extension agents collect crop areas and crop calendar for each Hood (Agricultural land parcel).

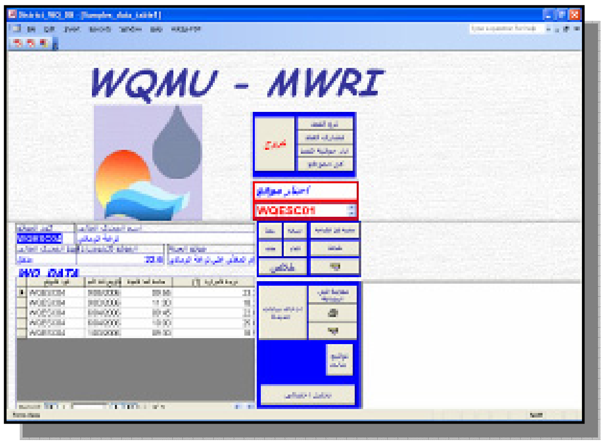
1. Crop data are sent to the Director of the Ag. Cooperative (village level) who compile the data within the Cooperative area.
2. Crop data are then sent to the Director of the Agricultural District for compilation and reconfiguration to match the irrigation command area and transmittal to the Irrigation District.
3. In the Irrigation District, crop data for current and next 15-day periods are used to calculate the biweekly water requirements for the district.
4. Biweekly crop data and water requirements are compiled at the Irrigation General Directorate, and sent first to the regional Water Distribution General Directorate and then to the Central Directorate for Water Distribution in Cairo.

The shown figure illustrates crop and water requirements data flow for the MISD process (Captured from MISD Guideline):



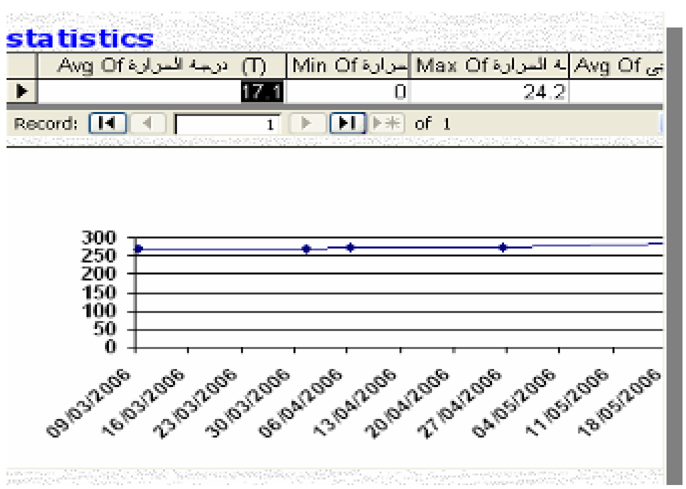
Water Quality Database

A water quality monitoring network was created at each IWMD. The average number of water quality sites per District is 15. Four parameters are measured, such as pH, BDO, Salinity, and temperature. The items are measured by using portable devices provided by the IWMD project. It was necessary to find a suitable method to manage all the collected water quality data for each District. The Water Quality database was prepared by the Water Quality Unit (WQU) through a Dutch-funded project and is currently used to store, analyze, display, and report water quality issues data in Egypt._The following figure shows the main screen for the Water Quality Database:

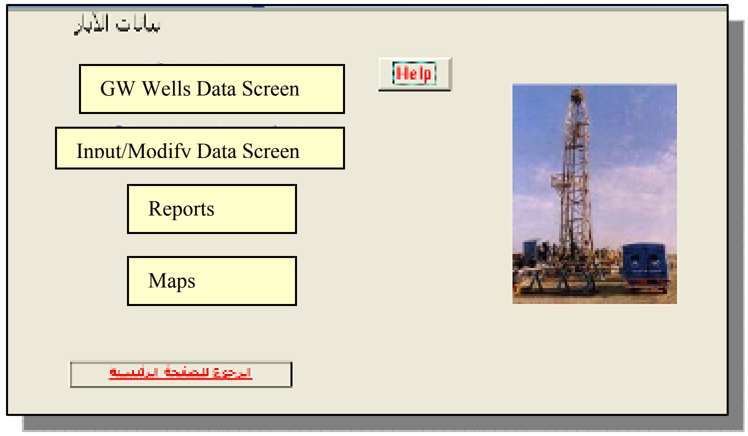


Using the Water Quality Database, new water quality locations can be added; sites can be retrieved by type (canal, drain, GW Well, or all types); quality data can be retrieved by site, by date, and/or by parameter. The user can also execute a statistical analysis using the stored data (average, Minimum, Maximum…etc).

The following figure shows an example of output:



Groundwater Database



A well inventory process was introduced to survey all the groundwater wells within each IWMD. The Groundwater Database includes all the parameters required to identify a groundwater well, starting from its location (GPS latitude and longitude) and to other technical data as shown in the table below.

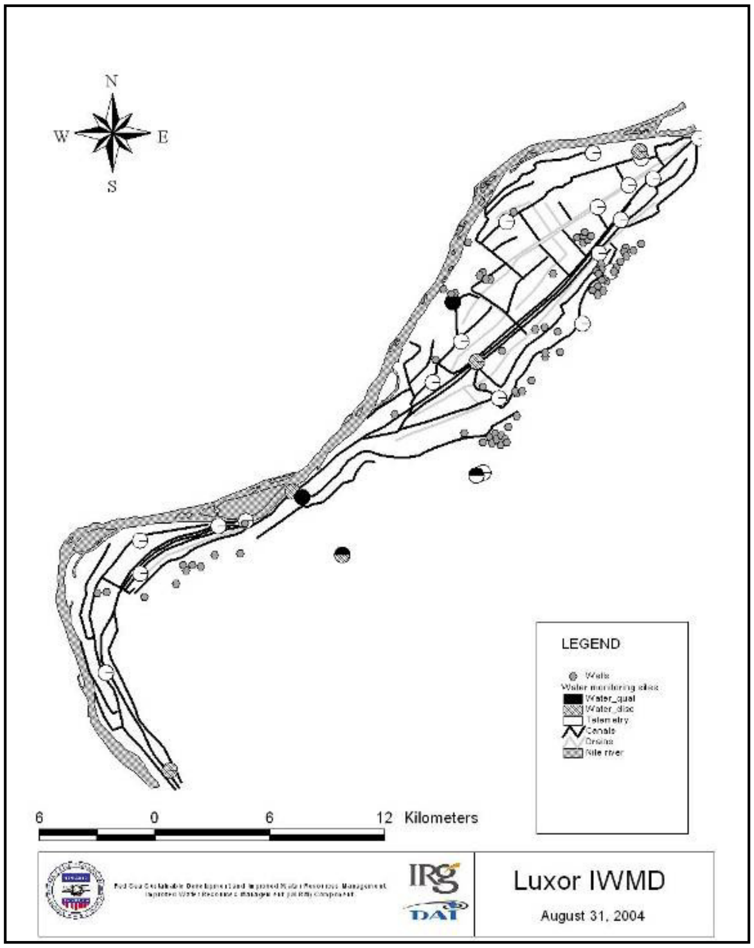
The Groundwater Database was originally developed by the Groundwater Sector within the MWRI. It was then customized for IWMDs based on a request from the IWRM project.

The following table illustrates data found n the Groundwater Database:

1	Owner Name	12	Source Of Power
2	Well Construction Date	13	Operating Hours
3	Well Coordinate	14	Discharge
4	No. Of Wells	15	Type Of Pump
5	Well Use	16	Nearest Well Distance
6	Area Served	17	Nearest Water Way Distance
7	Well Diameter	18	Salinity
8	Type Of Pipes	19	Do
9	Total Depth	20	Ph
10	Screen Depth	21	Temperature
11	Sand Trap Length	22	Static Depth

The database can print standard and ad-hoc reports to meet IWMD requirements, and can also export groundwater data to an Excel worksheet. Additionally, the database can display the location of wells over a base map using Arc Explorer (which is free to download).

A sample of a map with GW wells shown for the Luxor IWMD is shown below:



Complaints Database

The Complaint Database is designed and constructed by MIC (the Ministry Information Center). A complaint can be stored in the Complaint Database based on weather if it is a technical or administrative complaint. All complaints should have specific fields, such as the name of complainer, date, and type of complaint. A tracking field should also be appended in order to track whether the complaint has been resolved how it was resolved.

Violation Database

MIC also provided the Violation Database, which is used for tracking and archiving violations. The database was designed to deals with Law No.12 - 1983, and Law No.48 - 1982. The system records proceedings in which the violations are written (responsible engineer’s name, location, day, date, subject, violator’s name, etc.). The system also tracks each violation with all its stages (warning, removal, court, Jurisdictional verdict). It generates various reports such as contraventions' statistics report and district name report.

Digital Mapping System

The digital mapping system development consists of four major activities: 1) Base map development; 2) Boundary demarcation; 3) Physical system delineation; 4) Branch canal delineation.

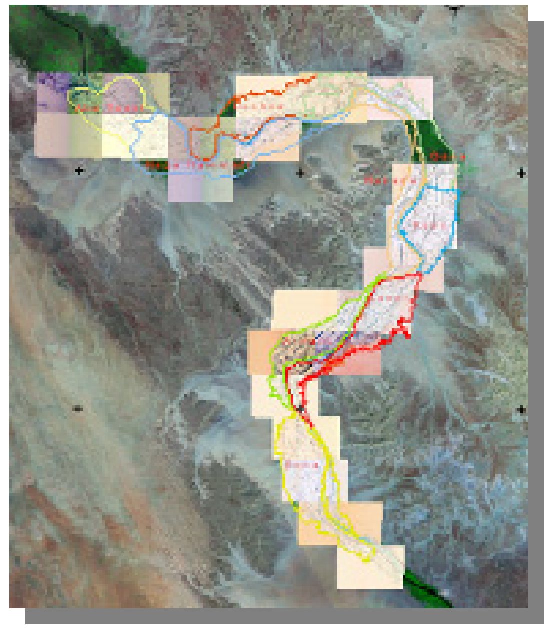
The following presents a brief description of each activity:

Base Map Development

A set of 1:25,000 and 1:50,000 scale paper maps covering each IWMD area were purchased from the ESA and distributed to the IWMDs. The 1:25,000 maps were scanned and geo-referenced using ArcGIS (The Egypt Red Belt is the coordinate system used for the NSA. WGS 1984 UTM 36 N is another commonly used coordinate system for Egypt), producing a set of raster images (geo-tiff format) for each IWMD. AutoCAD MAP is commonly used in Egypt by engineers. With it, a process of choosing a geographic coordinate system and importing both the geo-tiff 1:25,000 maps and the clipped satellite imagery were carried out to create the base map for each IWMD.

Boundary Demarcation

A ministerial decree was issued to define the IWMD boundaries based primarily on hydrological boundaries and satellite imagery (NASA Landsat 7 ETM+). Boundary delineations are based on ministerial decree and the well knowledge of the water distribution engineers in each IWMD. A team from each district consists of the staff members who are most familiar with the districts and villages that have sketched the new ministerial decree boundaries for their districts on the 1:25,000 paper maps. The new sketches were scanned, geo-referenced, and traced on-screen to create a district boundary file for each IWMD via ArcGIS. The IWMD boundary shapefiles containing the new boundary information were sent to the IWMDs for verification and revision, and then the final IWMD boundaries were delineated.



Physical System Delineation

The physical system of each IWMD consists of canals, drains, district boundary, water flow monitoring sites, water quality monitoring sites, groundwater wells, water structures (regulators, Weirs, Pump stations…etc.), and BCWUA locations

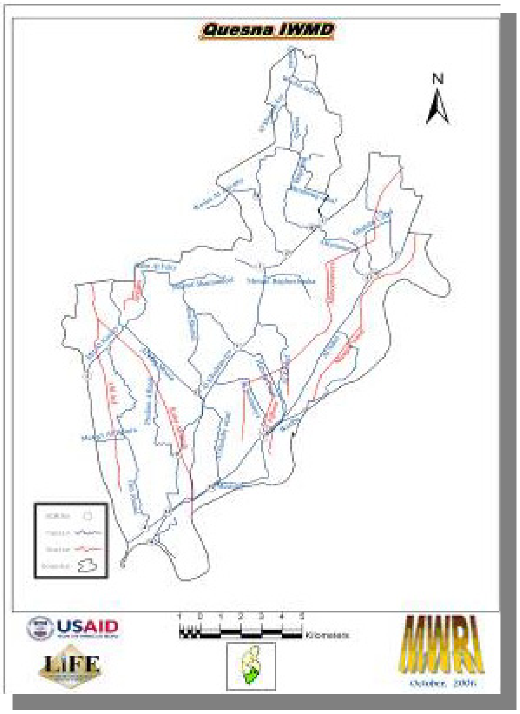
The shape files for the IWMD boundary were imported to AutoCAD Map. Using the technique of on-screen digitizing using the base map layer, all waterways (canals and drains) were delineated. Using a GPS device all the locations of the water monitoring sites (quality and quantity) were captured, downloaded to a PC using free DNR Garmin software then imported to AutoCAD MAP.

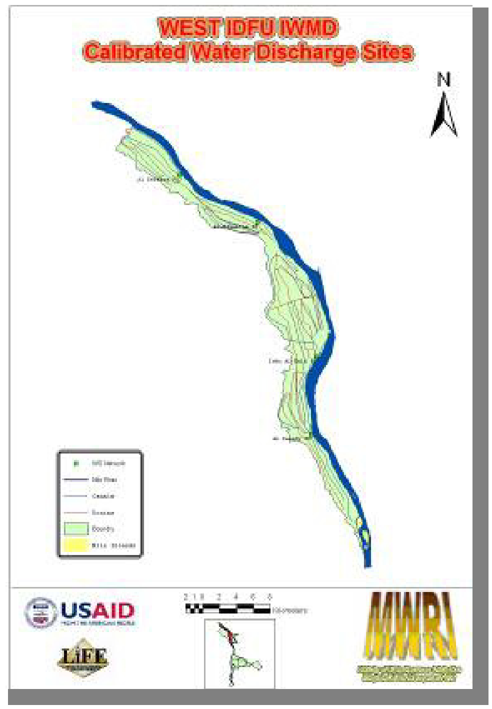
For groundwater well locations, the Groundwater Database creates shapefiles automatically and imports them as the GW layer in AutoCAD MAP.

Additionally, a set of processes were made to link the features drawn in AutoCAD MAP to a tabular table using the database connection in AutoCAD MAP to Microsoft Excel, Access, or txt files.

A set of standard map layouts was set for all the IWMD maps including the legend, north direction, title bar, scale bar and frame.

Two IWMD maps using one of the standard layouts are shown below.





Branch Canal Boundary Delineation

A discrepancy was detected between the gross area served by each IWMD in the ministerial decree and the calculated area based on its digital IWMD boundary using ArcGIS. The calculated areas ranged from 10% less to 160% more than the decree areas. Some of the main issues with the differences between the decree and GIS areas are:

- Urban, industrial and other non-agricultural areas were included.
- Unofficial, hilly/out of command, and underdeveloped/new lands were included.

To obtain with good accuracy of agricultural area served by branch canal will help improve the calculation of crop water requirements and the distribution of water resources. Ultimately this will also improve the matching between irrigation demand and supply.

In order to determine the exact irrigable area for each IWMD, a survey of branch canal irrigable area was carried out. For each branch canal, the area served was defined as the total land that is officially registered with the MALR with water supplied from the same branch canal for crop production. Fallow lands (i.e. lands not irrigated this year or this season but irrigated the year before) were included.

Pre-Survey. With branch canals from the digital map and handout based on knowledge of the districts to draw the branch canal boundaries, canals, drains, boundaries, and landmarks were downloaded to the GPS units and used as guide during the field work.

Field Work. Visited the questionable locations, asked farmers to verify which plot is irrigated by which canal when there is a doubt. Correct the boundaries on the map.

Once sure of the boundaries, used the GPS track function and circle around the boundary area. Went back to the starting point to close the boundary line, and saved the track on the GPS device. Then, GPS built-in area function calculated the track area to provide a first estimate of the branch gross command area. The detailed methodology used by the IWMD mapping teams is discussed below.

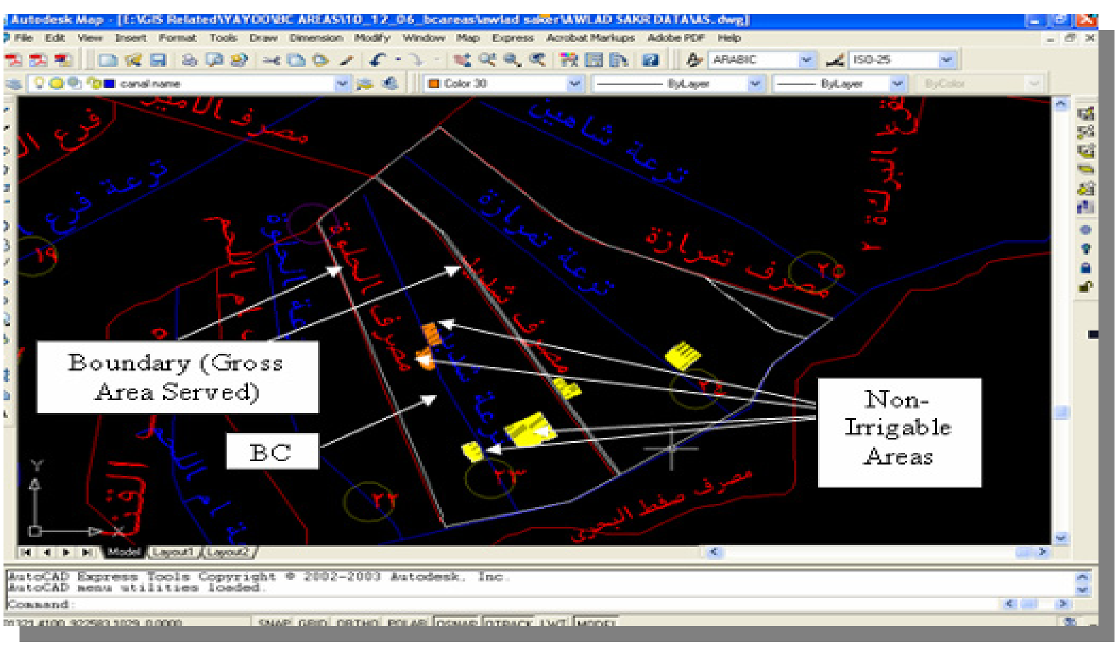
Post-Survey. Connected the GPS device to the computer with the DNR Garmin software, import the tracks to AutoCAD Map from the GPS devise via the Garmin software and saved these tracks as shapefiles.

The IWMD staff added the boundaries/tracks on the 1:25,000 base maps. On the screen, the branch canal boundaries were checked for their accuracy, i.e. that they matched with known landmarks. Then, the staff used the 'list' command to calculate the branch canal gross command area.

Using the clipped satellite image, Google Earth image, and the GPS device, the IWMD team determinates the non-irrigable areas. Then the net area for each branch canal can be calculated based on the following table:

Feeder canal	Branch canal	Main boundaries	Gross area (fed)	Non-agricultural areas (fed)	Net irrigable area (fed)

An example of the branch canal command area survey is shown below.



The irrigable area for Sheded canal is calculated based on the GPS survey results as show below.

Feeder canal	Branch canal	Main boundaries	Gross area (fed)	Non-agricultural areas (fed)	Net irrigable area (fed)
Deffan	Sheded	Mosque at village 8 Al Hamra	1693.47	65.54(residential) + 29.16 (water way)	1598.77

LESSONS LEARNED

Identification of lessons learned from any endeavor is an extremely valuable exercise, and is imperative n this instance considering IWMD activities will be continued by the MWRI. The following lessons learned are the result of an attempt to objectively identify items worthy of consideration when establishing and implementing information systems at the MWRI district and directorate levels.

1. Introducing central-level MWRI databases at the district is a way to get the district information systems up and running quickly.
2. The IWMDs were a bit overloaded with six databases in the initial stage of the project. In the future, a phased approach should be implemented to introduce two or three of these databases every four to six months.
3. A database management system is appropriate for the IWMDs and has provided them with the essential tools to store, analyze, and report water resource data in a timely fashion. The District managers are now able to make water management decisions based on “real” data.
4. A digital mapping system has produced up-to-date high-quality maps including boundary, canals, drains, water monitoring points, water quality sampling points, wells, BCWUA locations, and branch canal command areas for each District. With GPS units and AutoCAD Map, the Districts have inexpensive tools to measure irrigable areas accurately.
5. IT technical support was weak from each of the Directorates. All future training courses should include the Directorate staff members.
6. Interactions between MWRI central offices and the IWMDs were useful, and have provided an exchange of experience and ideas as well as a better understanding of district information system needs.
7. Output results of the MISD database (i.e., biweekly water demands) are questionable in some cases because the database contains a hardwired system target efficiency factor of 70% and is not calibrated for each IWMD.

RECOMMENDATIONS

The objectives of the IWMD program in the Egyptian water sector were to modernize water management systems and decentralize parts of the system, while developing capacity to manage new authorities at lower levels. These objectives were well served as a result of the IWRM achieving a great deal of success in the information systems at the 27 districts and five directorates.

Data collection and management are the foundation of all aspects of water management. Applications range from resource availability assessment to the allocation of water to productive activities in various sectors as mandated in the IWMD program. Integrated water management at the district level is a critical and important empowerment and devolution process. This process not only informs national and regional decision makers regarding key water management issues at the districts, but it empowers the district staff, water users, and other local stakeholders to actively participate in the improvement of water management in their immediate surroundings.

Robust systems of information management have been started and data are being entered into modern information systems to support district-level management decision making and routine data communications with higher MWRI levels. The momentum built under the IWRM should be maintained and expanded, and the information systems and procedures that have been developed and implemented by the IWRM project should be extended to all 204 districts and 22 directorates to facilitate devolution of centralized authority from the national level.

The information systems need to be introduced and implemented at the directorate to consolidate district data via direct PC modem communications or Internet in the near future. To prepare for this recommended distributed information management approach, all the information systems at the directorates should have the functionality to access, append, and consolidate data/information from the remote computers in the districts, and to provide district data and information to MWRI in Cairo. A majority of the IWMD databases can be implemented by the directorates with some minor modifications. Under the IWRM project, the information system development work should be mainly focused on the five directorates to establish the distributed information system over the next 24 months.