JOURNAL OF
ENVIRONMENTAL HYDROLOGY
The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com
VOLUME 8 2000

APPLYING A DECISION SUPPORT SYSTEM TO OPTIMIZE WATER MOVEMENTS: THE KING ABDALLAH CANAL AT THE JORDAN VALLEY

Mahmoud Hasan College of Hydrology and Water Resources Engineering, Hohai University, Nanjing, China
Iyad Hussein Water Resources Department, Jordanian Consulting Engineers (JCE), Amman, Jordan
Suhail Wahshah Jordan Valley Authority (JVA), Ministry of Water and Irrigation, Amman, Jordan

A Decision Support System (DSS) is one of the essential tools that help decision makers, professionals and managers operate, control and take decisions on a sound and integral basis. Applications of a DSS are not limited to a certain sector or field, they reach most sectors, including the water management and planning field. This paper elaborates on the application of a DSS in Jordan, specifically to manage and operate the irrigation water demand and supply of the main water carrier in the Jordan Valley, the King Abdallah Canal (KAC). This canal extends from the upper part of the valley at Adasiya down to the Dead Sea with a total length of 110 km, connecting one of the most complicated irrigation and conveyance systems in the region. At present the Jordan Valley Authority (JVA), which is responsible for all the activities in the Jordan Valley, is operating and managing the water of KAC using the JVA Water Management Information System and JVA Hydraulic Model. After one year of implementing this project, there should be feedback and results that need to be analyzed and evaluated. This paper will focus more on the results and recommendations that will improve using the present DSS and make it a successful example for the country and the region.

INTRODUCTION

The main purpose of this paper is to present the application of a Decision Support System (DSS) as a management and operation tool for the King Abdallah Canal (KAC) in the Jordan Valley. This canal extends from the upper part of the valley at Adasiya south to the Dead Sea with a total length of 110 km, connecting one of the most complicated irrigation and conveyance systems in the region as shown in the map in Figure 1. At present the Jordan Valley Authority (JVA) which is responsible for all the activities in the Jordan Valley, is operating and managing the water of KAC using the JVA Water Management Information System and JVA Hydraulic Model. After one year of implementing this project, there should be feedback and results that need to be analyzed and evaluated. This paper will focus more on the results and recommendations that will improve using the present DSS and make it a successful example for the country and the region. Using the DSS in Jordan and in many developing countries is still a short experience that requires more analysis, evaluation and improvements to really achieve the established goals.

THE DECISION SUPPORT SYSTEM FOR WATER SUPPLY AND DEMAND MANAGEMENT

Expert System Applications in Water Resources

Decision making in water resources is a difficult and challenging task involving numerous parameters. Computer-aided decision making has been used extensively to solve many problems in the past decade. However, these systems are not used to replace the professionals and experts, but to support them, so the decisions still have to be made by the experts in the area. Recently, expert systems have wide applications in water resources and in the water industry, because problem resolution in these fields involves significant judgment and experience.

The general architecture of expert systems consists of four parts.

1. Interactive user interface.
2. Control and interface structure.
3. Data base.
4. Knowledge base.

An expert system is used in many water resources applications. They include:

1. Operation and management of water supply systems.
2. Complex hydrologic hydraulic models.
3. Urban drainage.
4. Operation and control of activated sludge plants.
5. Crisis and disaster management.

The Decision Support System

The DSS, which is part of an expert system, has been defined as a system to support managerial decision makers in unstructured or semi-structured decision situations. Bonczek and Holsapple (1980) defined a DSS as a computer based system consisting of three interacting components. These components are:

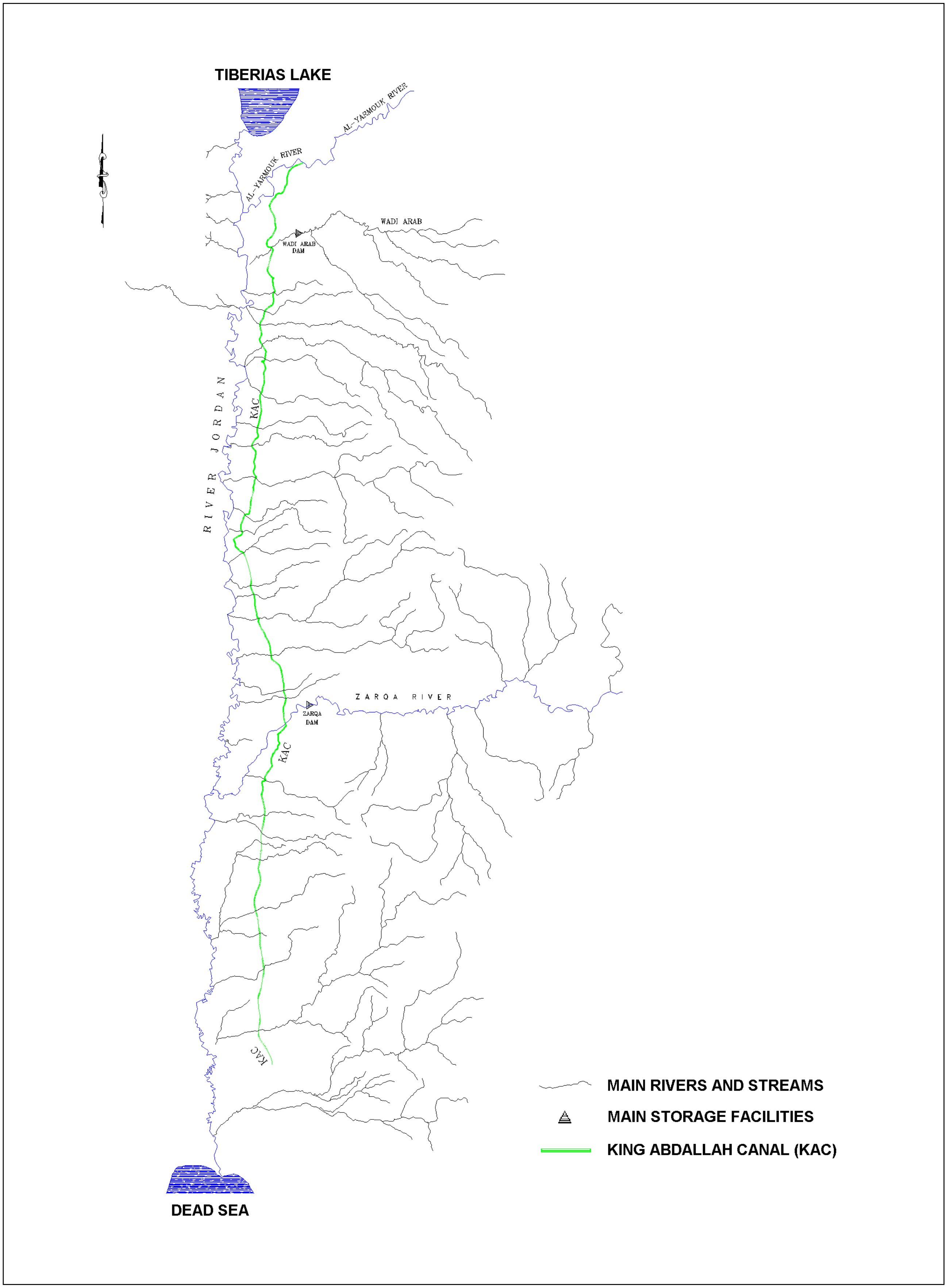

Figure 1. Map of the The King Abdallah Canal (KAC) in the Jordan Valley.

1. The language system, a mechanism to provide communication between the user and other components of the DSS;

2. The knowledge system, the problem domain knowledge embodied in the DSS, either as data or procedures; and

3. The processing system, the link between the other two components, containing one or more of the general problem manipulation capabilities required by decision-making.

The DSSs described in the literature show examples of support for all phases, such as intelligence or problem definition, design of alternative solutions, evaluation of and choice among the alternatives, as well as monitoring and control of implementation of the chosen solution. A final question about DSS usage patterns concerns purpose of use. By far the bulk of the DSS literature views the purpose of DSS as enhancing an individual decision maker's cognitive capabilities. This view ignores the fact that DSSs are used in organizational settings, and do not simply support lone decision makers. Other researchers describe the "offensive use" of a DSS as "tools to bolster an individuals position on a contested issue, and to provide the weight of evidence and to enable him to prevail." It has been noted that a DSS is often used to coordinate decision making activities among multiple, interdependent participants in a decision. In general, DSSs are used to exert control or influence, provide active coordination, and enhance cognitive capabilities.

THE JORDAN VALLEY AUTHORITY (JVA)

Role of the JVA

The JVA is a governmental organization responsible for the social and economic development of the Jordan Rift Valley. Originally established in 1972 as the Jordan Valley Commission, it was renamed JVA in 1977, when a development law for the Jordan Rift Valley had been approved. This law was modified in 1988, after the creation of the Ministry of Water and Irrigation.

The area of responsibility of JVA extends from the Yarmouk River in the north to the Red Sea in the south. The eastern extension of the area is limited by the 400 m contour line above sea level.

Duties and Responsibilities of the JVA

Duties and responsibilities of the JVA are as follows:

a - The development of the water resources of the valley for the purposes of irrigated farming, domestic and municipal uses, industry, generating hydroelectric power and other beneficial uses; also their protection and conservation and the carrying out of all the works related to the development, utilization, protection and conservation of these resources.

b - Develop and improve the environment and living conditions in the valley and carry out related works.

c - Planning, design and construction of road networks including highways, village and farm roads.

d - Development of tourism in the valley, delineation of areas having special features which can be developed for tourist and recreational purposes, the development of these, and the construction of tourist and recreational facilities on these areas.

e - Development of the social status of the valley inhabitants including the establishment of private local institutions in order to help them to actually contribute to the development of the valley andthe achievement of the objectives sought from its projects.

THE WATER MANAGEMENT INFORMATION SYSTEM (WMIS)

The scarcity of water and the ever-increasing requirement to meet the needs of irrigated agriculture, the rapidly growing population, urbanization and expanding industries requires efficient management of available water, which has now become one of the national priorities of Jordan .

In the Jordan Valley, water management faces several difficulties:

1. a general deficit of water compared with the demand, which imposes setting priorities among the various water users and continuous adaptation between water distribution and water supply,

2. a partial control of the water resources, particularly with the Yarmouk River, which leads to unexpected deficits in summer, or to high risk of flash floods in winter,

3. different water resources having varying water quality and high salinity in some cases, and

4. complex hydraulic schemes with numerous projects, each of which has the possibility of receiving water supply from different resources.

The WMIS is a decision support tool which has been developed to assist the JVA to overcome these difficulties. The objective of this tool is to collect and process all the available and relevant information related to water management and then feed it to the JVA Hydraulic Model to start the simulation and optimization processes. This provides the Hydraulic Manager support to select the most rational strategy for water use over the upcoming season, to implement this strategy on a daily basis, and to have the opportunity to react quickly and appropriately to unexpected events.

THE JORDAN VALLEY HYDRAULIC SCHEME

Water Resources in the Jordan Valley

The Jordan River, starting at Lake Tiberias and terminating at the Dead Sea, constitutes the north-south axis of the valley as shown in Figure 1. It is fed on the right bank by several tributaries which are oriented east-west and constitute the surface water resources of the valley, to the north, the Yarmouk River is the main tributary. Further to the south, the Zarqa River whose catchment is entirely on Jordanian territory constitutes the second important tributary resource. The remainder of the resources in surface water are supplied by the wadis. These are subject to flood flows but have very low base flows, and consequently are difficult to use without storage facilities.

It must however be noted that the resources are not regularly distributed throughout the year but present a peak at the start of the spring and a substantial drop in the summer period which corresponds to the highest irrigation water demand.

Hydraulic Scheme

To meet the peak demand during the summer which coincides with a surface water shortage, a considerable hydraulic development program has been carried out over the last forty years. This development comprises storage, transport and water distribution structures. The Jordan Valley Hydraulic Scheme consists of the following components:

a. Storage structures

The King Talal Dam situated on the Zarqa River is the main storage structure and the Wadi Arab reservoir is the second largest structure. The Ziglab reservoir, the Wadi Shueib and Wadi Kafrein reservoirs contribute reasonable water quantities for irrigation uses. However, it is worth noting that at present, only the King Talal and Wadi Arab dams are connected to King Abdullah Canal and can be integrated into the overall management of resources in the valley.

b. Transport structures

The King Abdullah Canal (KAC) forms the backbone of the scheme along the Jordan River for a length of 110 km and constitutes the main valley conveyance structure. It is supplied from the north by the Yarmouk River and the Mukheibeh wells. The canal section between the Yarmouk and the Zarqa siphon is called KAC North. The section south of the Zarqa siphon is called KAC South. The KAC is currently operated by 36 cross-check gates numbered from 2 to 37. The other main conveyance structures are:

1. The Zarqa Carriers I and II, which take water from the Zarqa River downstream of the King Talal reservoir, before the Abu Zeghan canal intake and the saline springs.

2. The connection between the KAC and the Wadi Arab dam, comprised of a pumping station associated with a 5 km long pipe. This assembly has a capacity of 1.2 m^3/s and the water can be pumped back to the Wadi Arab Dam. Before being released into the canal, the water is used to generate electricity.

3. A pipe and a series of pumping stations to supply water to the city of Amman from the KAC at Deir Alla.

c. Future projects

The need to meet an ever-increasing demand throughout the year involves the construction of storage structures for impounding the water when in oversupply and distributing it during shortages. Several structures are being planned to increase current storage capacities. These are:

1. The Karameh Dam, under construction, is situated in the lower section of the valley to the south of the Zarqa river and is supplied only by the KAC.

2. Improvements on the Yarmouk River, which would provide a reasonable annual volume of the Yarmouk River for domestic and irrigation purposes to the Jordan Valley.

3. A connection from the Kafrein Dam to the KAC, and raising its banks to increase capacity. Located at the end of the canal, the junction with the KAC will enable the unused water to be recovered and stored in the Kafrein reservoir for redistribution later during shortage periods.

Finally, dams might be proposed for construction on Wadi Jurum, Kufrinja and other wadis.

General Water Management Strategy

In the winter season, all projects are supplied with water coming from the Yarmouk River and the side Wadis. In addition, water is pumped from the KAC into the Wadi Arab reservoir. In the summer season, the King Talal Reservoir, through the Zarqa River, provides water to KAC South and its connected projects, as well as the Middle Ghor project. The projects connected to the North KAC, including Amman, are supplied with water coming from:

a. The Yarmouk River and the side wadis,

b. The KAC North conveyor,

c. The Mukheibeh wells and the Adasiya wells,

d. The Wadi Arab reservoir in case of shortage.

During the intermediate season (spring or fall), or whenever the daily water balance indicates that there is a surplus in KAC North, the surplus goes to either KAC South or its connected reservoirs.

Operational Organization

The management of the hydraulic structures in the Jordan Valley is performed by the JVA according to four organizational levels. The WMIS is an integrated system and involves all the levels of this organization.

These levels are:

1. The central O&M Director and JVA High Management are involved in the consideration and approval of seasonal water management strategy.

2. The Water Management Division, located at the Dirar Center, is in charge of the daily water resources management according to the adopted strategy. The head of this division (Hydraulic Engineer) is responsible for the day to day decisions regarding the releases from dams or the back pumping into dams, transfer from the King Abdullah northern section into the southern section and management of shortage situations. Furthermore, he is responsible for the generation and presentation of seasonal planning scenarios to higher management.

3. The Nine Stage Offices located along the valley are in charge of water distribution. They are under the responsibilities of the Regional Directorates. These stage offices are responsible for processing demands from farmers, generation of irrigation orders, irrigation scheduling, billing and accounting and field reporting.

4. The Field Operation staff is responsible for the implementation of the instructions generated by the WMIS.

WMIS DESCRIPTION

Architecture and Main Functions

The WMIS consists of the following components:

a. A database developed with the ORACLE relational database management system. This database is distributed between the main computer center, i.e. the WMCU (Water Management Computer Unit) located at the Dirar Control Center, and the other computers located at the Stage Offices. The data is replicated at the different sites according to a strict design rule that only the set of data that is absolutely necessary is maintained at the site. This allows storage to be optimized and performance to be improved. A master data set is maintained at the WMCU and any changes to the system data set, due to changes in the configuration, are made only at the WMCU. These changes are subsequently transmitted to the remote sites, thereby ensuring that data consistency is always maintained.

b. Database access inquiry procedures, and application programs which allow the data to be extracted, processed and displayed as information in meaningful forms. The Water Management Database contains:

* <u>Data maintained at the WMCU</u>

- Crop prices

- Socioeconomic data for land tenure and ownership

- Meteorological data by climatic zone
- Daily water inflows into the canal by source
- Total daily distribution by project, stage, farm
- Canal, crop, reservoir characteristics
- Farm unit characteristics and links to the distribution network
- Canal hydraulic data

* Data maintained at the WMCU and sent to the Stage Offices

- Cropping patterns by climatic zone (by stage and project)
- Water consumption per crop per period of the year
- Production by crop by climatic zone by planting season
- Water prices

* Data maintained at the Stage Office only

- Irrigation orders
- Daily field report
- Water dues and other dues by farm unit
- Details of payments by farm unit
- Details of planting by farm unit

The WMIS Main Functions can be classified into four main subsystems performing different functions:

a. The Seasonal Planning And Forecasting Subsystem which helps the decision maker to elaborate the best strategies for water management in the coming season.

b. The Daily Water Management Subsystem which helps the Hydraulic Engineer balance for the coming day the available water supply with the water demand.

c. The Hydraulic Subsystem that helps to manage the various hydraulic structures by continuous canal monitoring through a measurement network connected to a Hydraulic Model which computes the optimal gate settings and dam releases or back pumping schedule.

d. The Stage Office Subsystem that collects the farmers irrigation requests, checks the validity and feasibility of these requests with the water allocated at the stage by the Dirar Center, and issues irrigation orders for the Ditch Riders which are also sent to Dirar for canal management purposes. It also allows the Stage Office Manager to keep track of the water consumption of the different farms for billing purposes.

SYSTEM FUNCTIONING

Seasonal Planning and Forecasting Subsystem

This subsystem is an autonomous application software system whose main function is to calculate monthly reservoir target volumes. The monthly functions are a set of functions that allow the system operator to parameterize the system for the coming month, view key information that has been compiled at the stage and transmitted to the WMCU, e.g. planting records, billing information.

The most important function performed at the monthly level is the assignment of crop quotas at the WMCU. Simply stated, these functions allow the user to extract reference crop quotas (the amount of water a given crop needs for a given month for a unit area) from the system database. This result is fed forward into the Daily Water Management Subsystem and acts as a guideline in the release strategy of controlled water resources from the enabled reservoirs in the system on a daily basis. The system comprises the forecasting module and the planning module.

Daily Water Management Subsystem

The Daily Water Management Subsystem is an autonomous subsystem that performs the daily supply and demand water balance. The program is an essential prerequisite to run the hydraulic model effectively and is intrinsically linked with the hydraulic module. The program consists of:

1. An initialization process wherein the previous day's information is archived and copied as the initial data set for the current run of the balance.

2. A number of interactive data entry screens which allow the user to enter daily information, e.g. uncontrolled inflows, actual consumer demand, M&I demand.

3. Data entry screens to distribute the available water on a resource to projects basis and on a project to consumer basis.

4. Options to produce hard copy results on a daily, schematic and cumulative basis.

Hydraulic Subsystem

The Hydraulic subsystem consists of the following:

a. The Measurement Network

The objective of the measurement network is to provide information concerning the canal status to the Hydraulic Engineer in charge of the operation of the KAC, such as water levels upstream and downstream of check gates, water levels at the main inflow points for the computation of the discharges coming from these points.

The network also allows the canal manager to remotely control from the Dirar Center some specific check gates. The measurement network is based on 14 Remote Transmission Units (RTU) located along the KAC which transmit the data to the Dirar Center every 1 minute. Each is composed of sensors (water level, gate opening), a gate actuator when the gate is remotely controlled (RTU 70; 80; 100; 110) and a building sheltering the transmission equipment such as electrical cabinet with local indicators, PLC, modem charger and batteries in case of power breakdown. The information displayed includes:

* the measured water levels,

* the computed discharges at inflow points (weirs) or through the check gates,

* various alarms: high water level, unauthorized entrance into RTU building, gate closed, communication failure etc.

b. The Hydraulic Module

The Hydraulic Module comprises essentially two parts:

1. The Hydraulic Table Generator

The Hydraulic Table Generator is a program which precomputes hydraulic characteristics of the KAC in a table format according to its geometry. These tables are then read by the HydraulicModel. The canal is divided into reaches. A reach corresponds to the portion of canal comprisedbetween two check gates. Each reach is composed of different subreaches for which thecharacteristics of the canal (cross-section, slope, friction loss coefficient) remain constant.

2. The Hydraulic Model

The Hydraulic Model is a program which is run at least three times a day: presently at 7:00 am, 11:00 am, and 3:00 pm. The information provided to the hydraulic model are:

* the water levels in the canal upstream and downstream of the check gates connected to the measurement network, as well as the openings of the check gates,

* the expected inflows into the canal for the coming period,

* the program of outflows from the canal.

The information provided by the Hydraulic Model are:

- for the first run of the day only, the balance between inflows and outflows into the canal for the coming day,

- the volume in the canal according to the water level measurements at the time of the run. This volume is compared to a reference volume, chosen by the user (first run of the day only at 7:00 am), and to a forecasted volume computed during the previous run. This allows the canal manager to determine if the canal is in a deficit or surplus situation.

- forecasted volumes in each reach of the canal for the subsequent hours until the following day at 7:00 am. The 7:00 am set of values are summed up and compared to a reference value called the target volume. This allows a forecast of any deficit or surplus in the canal for the following day.

- the optimum check gate settings for the coming period, as well as the openings of gated spillways if water spillage is necessary,

- the optimum schedule for releases from reservoirs and/or back pumping into reservoirs, if any,

- the forecasted water levels upstream and downstream of each check gate for the subsequent hours until the following day at 7:00 am, as well as the forecast average discharges. This forecast is loaded to the measurement network monitoring system and can be compared at any time with thereal values measured on the field.

Stage Office Subsystem

The Stage Office subsystem is the organizational unit associated with a group of adjacent or near adjacent farm units. There are currently 9 stage offices at various sites in the Jordan Valley. The Stage Offices have execution level authority for the collection and calculation of stage water demand based on farmers demand, as well as the execution level authority to distribute the allocated water to the farm units within stage. The distribution of water bills as well as the collection of those bills is the responsibility of the stage office. The main tasks of the Stage office are :

a. Daily Functions, such as

1. Irrigation request processing

2. Calculation of stage demand and communicating with the WMCU central control unit at Dirar.

3. Irrigation orders processing

4. Water consumption processing

b. Monthly functions, such as

1. Water quota and irrigation processing

2. Water quota and irrigation cycle processing

3. Billing and accounting

4. Suspensions processing

c. Reports

The following reports can be produced by the module:

- Irrigation requests.
- Daily check capacities report.
- Supplier flows at 24 hours.
- Irrigation orders.
- Detailed consumption.
- Water bills.
- Irrigation cycle.

EVALUATION OF THE WMIS

Evaluation of the Water Management Information System considered the following subsystems:

- The Hydraulic Subsystem (The Measurement Network and the Hydraulic Model)

- The Daily Water Management Subsystem

- The Stage Office Software Subsystem

For each subsystem, four different indicators were evaluated and assessed. The indicators are as follows:

a. User-friendly

b. Benefits of the system

c. Difficulties

d. Improvements/developments

The results of the evaluation exercise are presented in Table 1.

CONCLUSIONS

The situation following twelve months of Pilot Project Operation can be summarized as follows:

* the Stage Office software is operational and used at all stages,

* the Measurement Network is operational and used,

* the Hydraulic Model is operational and used in the north KAC,

Table 1. Evaluation of Water Management Information System (WMIS)

WMIS Subsystems	User-Friendly	Benefits of the System	Difficulties	Improvements/Developments
1. The Hydraulic Subsystem				
* Measurements Network	- Simple functions are regularly used. - Trends and scaling function are rarely used	-Unique way to visualize the situation in the canal. - Reaction of the canal - Computer water volumes	- Sediment problem - Highly trained technicians	- Converting manually measured CG into remotely controlled CG. - Extension of the measurement network.
* Hydraulic Model	- Entering data and running the program are relatively easy. - Understanding the concept of regulation, performing a critical analysis, analyzing the results are more difficult.	- Quick reaction - Regain a centralized control of the canal	- Field operation (Adjusting all CGS three times a day at fixed time is not an easy task). - Timing problem (Hyd. Eng. duty schedule should be implemented in order to overcome this difficulty).	- Improvement of calibration and printed reports. - Strict checking procedure must be installed. - Adding one more operation period in the evening is required.
2. The Daily Water Management Subsystem	- The system should be operated by the Hyd. Manager.	- Full potential of the system has not been fully realized.	- Time consuming (computer).	- Reports should be improved.
3. The Stage Office Software Subsystem	- Since the generation of the irrigation request is automatic volume and data entry time were reduced.	- Auto generation of irrigation requests and field consumption reports. - Producing the flow per supplier for 24 hrs.	- Computer performances are not up to the system.	- Additional queries and reports. - Speeding up the respones time of queries and reports.

* the Daily Water Balance is operational and used in parallel with the previous JVA water balance,

* the SPF is operational but has not yet been used,

* the system as a whole is partially used in an integrated mode.

The Pilot Project was indeed a key factor in these achievements. The Pilot Project provided opportunities to the JVA to obtain on-the-job training and to adapt procedures to the new system.

Some additional efforts must be made in order to utilize the full potential of the system. These efforts concern mainly the application software, involving upper level management, the Daily Water Management subsystem, and the Seasonal Planning and Forecasting subsystem. Extensive on-the-job training must be provided to the user of these applications: The Hydraulic Engineer and his assistants, and the Technical Hydraulic Manager and his assistant.

With regard to the measurement network, the Pilot Project was clearly a success. The JVA Water Management Division, with the help of the consultant and the contractor, were able to solve most of the problems that were encountered. The project demonstrated the difficulty for the JVA to perform some of the maintenance tasks. In order to minimize the duration of failures and to guarantee the accuracy of the measurements, it is necessary to subcontract some activities. Provided that the maintenance is well secured, the expansion of the network will be a key factor for improving the water management and raising the efficiency of the whole hydraulic scheme.

REFERENCES AND BIBLIOGRAPHY

Dyck, S.; "Integrated Planning and Management of Water Resources", Technische Universitaet Dresden, Dresden, Germany, 1990.

Gorry, G.A., and M.S. Morton; "A Framework for Management Information Systems", Sloan Mgt. Review, Vol. 13, No.1, Fall 1971.

Bonczek, R.H., C.W. Holsapple, and A.B. Whinston; "The Evolving Roles of Models in DSS", Decision Sciences, Vol. 11, No.2, 1980.

Labadie, J.; “Decision Support System in Water Resources”, NATO-ASI Conference, Sept. 1989, Spain.

Labadie, J., C. Sullivan; “Computerized DSS for Water Managers”, Journal of Water Plg. and Mgt., ASCE, 112(3), pp. 299-307.

Jordan Valley Authority Law; Amman, Jordan, 1989.

Moore, J.H., M.G. Chang; “Design of DSS”, Data Base, Vol. 12, Nos. 1 and 2, Fall 1980.

Jordan Valley Authority, ERNO/GERSAR Project Report; “Management Information System, Hydraulic Model, Operating Instructions Manual”, December, 1995.

Jordan Valley Authority, Information Directorate, ERNO/GERSAR, Technical Report; ”Water Management Information System, General Description”, December, 1995.

Weshah, A., Z. Elias; “The Jordan Valley: An Integrated Development Experience”, Proceedings of the International Symposium on Water Resources in the Middle East, Champaign, Illinois, 1993.

Jordan Valley Authority; “ The Jordan Valley development. The plans, the achievements, the future.”, 1987.

ADDRESS FOR CORRESPONDENCE
Mahmoud Hasan
College of Hydrology and Water Resources Engineering
Hohai University
Nanjing 210098
P. R. China

E-mail: mihasan1@hotmail.com