



WATER MANAGEMENT INFORMATION SYSTEM (WMIS) FOR THE JORDAN VALLEY

Bruno Grawitz¹

ABSTRACT

The paper presents an example of design and implementation of an Information System dedicated to water management in the Jordan Valley. The Jordan Valley hydraulic scheme is described, followed by an analysis of the operation of such a scheme. The Information System designed is presented, as well as its integration within the Operator's organization. Based on personal experience the author provides recommendations for the design of such a system.

INTRODUCTION

In Jordan, water requirements are growing sharply, due to one of the world's highest population growths, associated to the industrialization and the development of the country. However, water resources are limited and subject to competitive use with neighboring countries. As a result, water is now a national issue in Jordan.

The Jordan Valley receives the larger amount of the country's renewable resources. It has undergone the development of a large and complex hydraulic scheme dedicated to the irrigation of 30 000 ha, and to the transfer of water to Amman (Jordan's capital) for domestic and industrial needs.

The Jordan Valley Authority (JVA) is in charge of this scheme operation, under severe constraints related to water quality and quantity. The Water Management Information System (WMIS) is an Information Technology tool developed to assist the JVA achieving optimal water management. WMIS is an integrated system, as it covers all tasks related to water management, from management of water resources, down to water distribution to the farmers, including billing and accounting.

Beyond the technical challenge related to the complexity of the scheme to be operated, the main difficulty when implementing such a system is to ensure proper integration of the tool within the existing chain of water management decision making.

JORDAN VALLEY HYDRAULIC SCHEME

Water Resources Layout

The Jordan River originates at the outlet of Lake Tiberias, and discharges into the Dead Sea. It forms the North-South axis of the valley. Several tributaries oriented east-west flow into the river. The water provided by these tributaries is used for irrigation and domestic purpose.

¹ Engineer at the Société du Canal de Provence (SCP)
Le Tholonet B.P. 100 13603 Aix en Provence Cedex 1 FRANCE
Tel (33) 4 42 66 70 00 Fax. (33) 4 42 66 70 87 E-mail SCPingenierie@wanadoo.fr

The Yarmouk River is the major Jordan River tributary. However its waters are shared with neighboring countries, namely Syria and Israel. The flow of the Yarmouk River is not regulated by a dam, and consequently it fluctuates significantly between the winter and summer seasons.

Further to the South, the Zarqa River, with a catchment basin entirely within Jordanian territory, is the second most important tributary. The King Talal Dam regulates the Zarqa River flow. The water quality of the Zarqa River is a concern as it receives treated return flow from Amman, and some saline springs.

The side wadis provide the remainder of surface resources. These small rivers are important for their floods, but have usually a low base flow.

Ground water resources are not negligible. In particular, the Mukheibeh Wells, to the North of the valley, represent an annual flow of 25 Mm³. This resource is of excellent quality, with a constant yield throughout the year. However, the production of these wells is decreasing, due to extensive depletion of surface water recharging the aquifer.

The King Abdullah Canal (KAC)

The King Abdullah Canal (KAC), running on the East bank of the Jordan River constitutes the backbone of the Jordan Valley hydraulic scheme. It is 110 km long with a head discharge capacity of 20 m³/s.

The KAC presents two main sections:

KAC North, 65 km long is fed by, the Yarmouk River, the Mukheibeh Wells, the KAC conveyer (water supplied from Lake Tiberias under the Peace Treaty since June 1995), and the side wadis whenever water is available, and provided that its quality is acceptable for domestic use.

KAC South, 45 km long. In winter, the Yarmouk River water is able to provide for all the valley's water requirements, and KAC South is therefore supplied by KAC North via a 12 m³/s siphon connecting the two sections. KAC South provides water to farmers, as well as to the newly constructed Karama Dam which stores winter water. In the summer the King Talal Dam and the Karama Dam supply KAC South.

The KAC is controlled by 37 cross regulators (check gates) consisting of radial gates with two weirs on each sides.

Storage Reservoirs

The following dams, described according to their location from North to South, have been constructed for storage of water:

- Wadi Arab Dam (17.1 Mm³) receives water from the Wadi Arab and from the Yarmouk through the KAC, by means of a pumping station.
- Wadi Ziglab Dam (3.9 Mm³) provides water to the NEG (NorthEast Ghor) irrigation project.

- King Talal Dam (75 Mm³) stores water from the Zarqa River including Amman M&I treated return flow. This water is then released into the Zarqa River for further diversion, to irrigation carriers or KAC South.
- Karama Dam (55 Mm³), is used for the storage of some Yarmouk winter water via the KAC.
- Shueib Dam (1.4 Mm³) collects water from Wadi Shueib.
- Kafrein Dam (8.4 Mm³) collects water from Wadi Kafrein.

Water Users

Agriculture is the main water user in the Jordan Valley, with an average consumption of 220 MCM per year, for around 30 000 ha irrigated.

Farms are organized in *farm unit* supplied in water by a *farm turnout assembly* (f.t.a.). The average size of a farm unit is around 35 dunums (3.5 ha), and there are around 8000 farm units in the Jordan Valley.

All irrigation networks in the Jordan Valley are pressurized. Open channel irrigation networks have been converted to pressurized networks. These networks are supplied either by the KAC, or by the storage reservoirs via irrigation carriers, and in some instances by both. Irrigation networks are classified into different projects, represented in Figure 1.

The downstream end of KAC North supplies the city of Amman, via a chain of 5 pumping station which lift the water from an elevation of -280 m to an elevation of +1150 m. The pumping capacity is 45MCM per year, to be increased in the near future.

Water quality is a critical concern when operating the scheme. The water provided by the King Talal Dam, via the Zarqa River is of poor quality with a high level of salinity. As a result it must be mixed with fresh water supplied by KAC North in order to be acceptable for irrigation use.

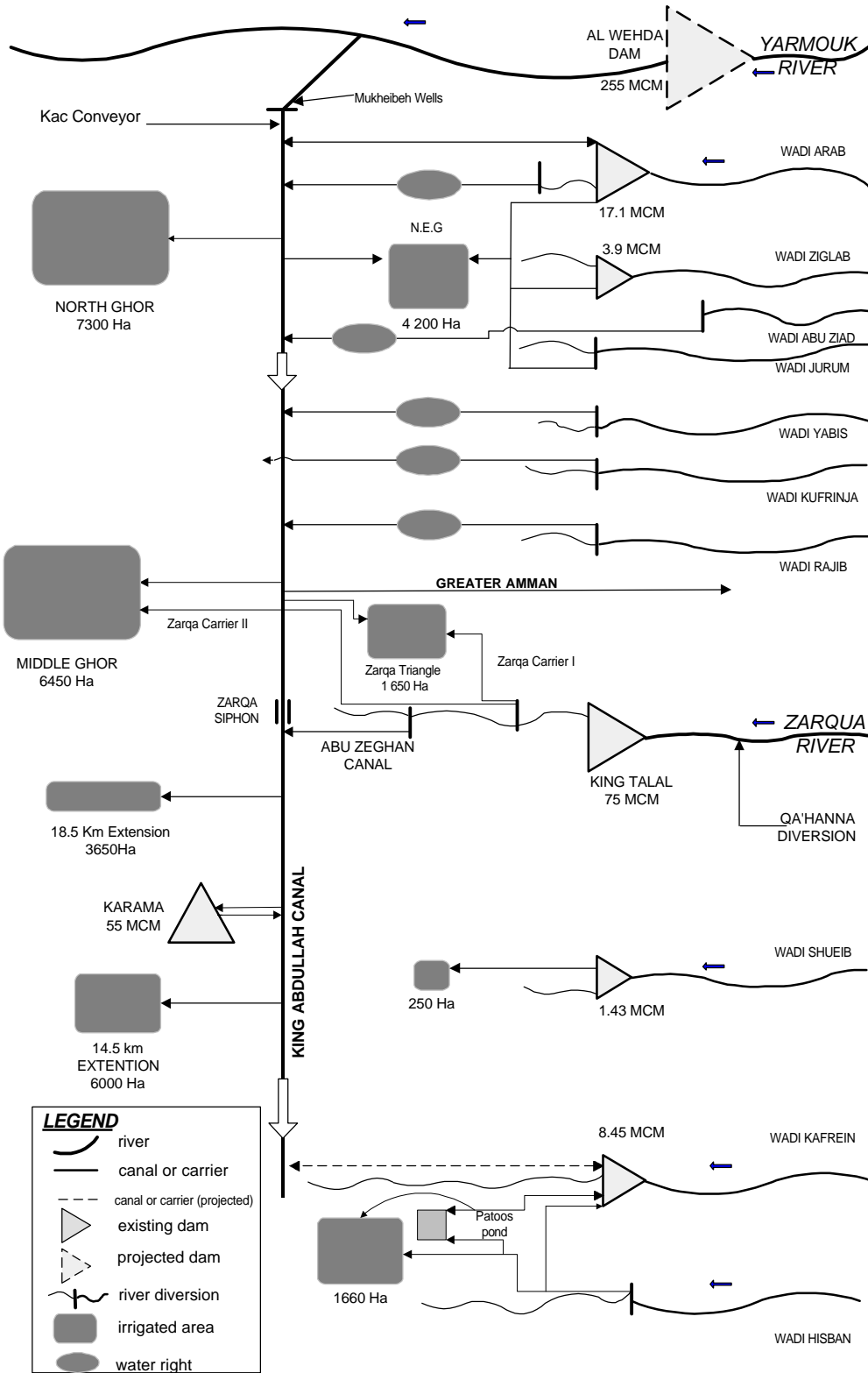


Figure 1. Jordan Valley Hydraulic Scheme

WATER MANAGEMENT AND DECISION MAKING

The Jordan Valley Authority is in charge of the operation and maintenance of the scheme represented in Figure 1. This requires adjusting on a daily basis a number of control infrastructures (gates, control valves, pumping station, etc.), which are set according to decisions made by different JVA Divisions. However, all these decisions, related to water management, are strongly interrelated, and request an efficient information system, in order to reach consistent and optimal operation of the scheme.

Such tools must be based firstly on an analysis of the various tasks to be performed. Three main activities can be found:

- Management of water resources, or *Water Supply*, which includes the management of all infrastructures related to delivery of bulk water to a group of water users (i.e. irrigation network head structures).
- *Water Distribution* related to the distribution of water to single users (i.e. farm turnouts).
- *Water Management Strategy*, which includes periodical cross-checking between water demand and water resources, in order to ensure the water balance for the coming months, and to decide whenever necessary upon water allocation between competitive requirements.

Water Management Strategy

The water management strategy is defined at the beginning of the irrigation season (October), and is refined on a monthly basis. At the end of the winter, when water demand starts to exceed water resources, establishing this strategy becomes crucial and requests relevant decision-making.

The strategy relies on and takes in account the water availability (water level in reservoirs, expected surface flows), the water demand (irrigation, municipal, Industrial), the water quality, and external constraints such as the Jordan/Israel Peace Treaty water agreement.

The strategy results in the following major decisions:

- Diversion of water from water resources,
- Allocation of water quota to the various consumers,
- Definition of a reservoir strategy (monthly target levels)

Water Supply

Water Supply is related to delivery of bulk water to a group of water consumers. It may be divided into four tasks:

Water Supply Management. Water Supply Management consists in applying on daily basis results of the Water Management Strategy, taking into account the actual water situation. The objective is to ensure that each consumer receives his share of water. Except for crisis situations, it does not require strategic decisions.

Operation of Infrastructures. This task consists in physically adjusting gates, opening and closing valves, and starting pumping stations, according to the output of the Water Supply Management activities.

System Monitoring. The objective of this task is to monitor the operation of the system, and to check that daily water management decisions have been correctly implemented in the field. It relies on hydraulic measurements (flow, water level, and water quality).

Water Supply Control. This task consists in analyzing field measurements in order to establish statistics. The objective is to follow-up and control the implementation of the water management strategy, and to provide statistics for future water management planning.

Water Distribution

Water Distribution consists in the management of the irrigation networks. It involves the operation of the network head structure, and the farm turnouts.

Water Distribution activities may be divided into four tasks:

Organization of Irrigation Schedule. The output of the task is a weekly calendar (or bi-weekly) which schedules the days and hours during which each farmer is entitled to receive water. This schedule takes into account the water quota resulting from the water management strategy, the crop water requirements, and the irrigation network physical constraints.

Water Delivery to the Farmers. This task consists in opening and closing farm turnouts in order to provide water according to the irrigation schedule. The schedule may be modified one day prior to irrigation: either according to farmer's requests in case of unexpected events

Billing & Accounting. This task consists in computing on a monthly basis the amount of water consumed by each farm, establishing and sending the invoices accordingly, receiving and registering payments.

Water Demand Assessment. This task consists in checking farm crops, in order to establish a Planting Register. The Planting Register is used to compute present and future water needs, and farm quotas.

Flow of information

Figure 2 provides the top-down flow of information: from establishing a water management strategy, down to field implementation.

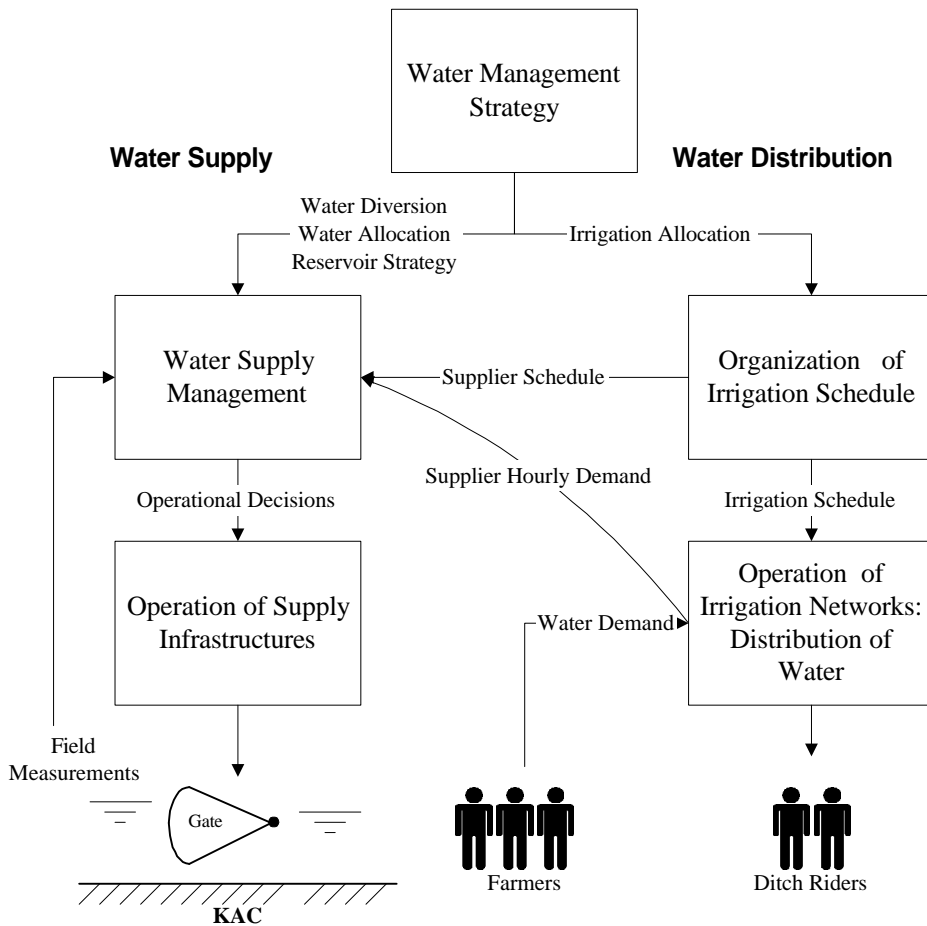


Figure 2. Water Management Top-Down Flow of Information

Figure 2 illustrates that Water Supply and Water Distribution are not completely independent. The supplier² schedule and supplier hourly demand must be provided to the canal operators in order to establish the daily water balance, and operate the KAC.

To ensure the quality of water management, field information is required in order to assess the actual water situation, to control the implementation of decisions, and further, to analyze the effects of these decisions (feed-back). Figure 3 completes Figure 2 with field monitoring and data analysis tasks, as well as the associated back-flow information.

² A *Supplier* is the head structure of an irrigation network

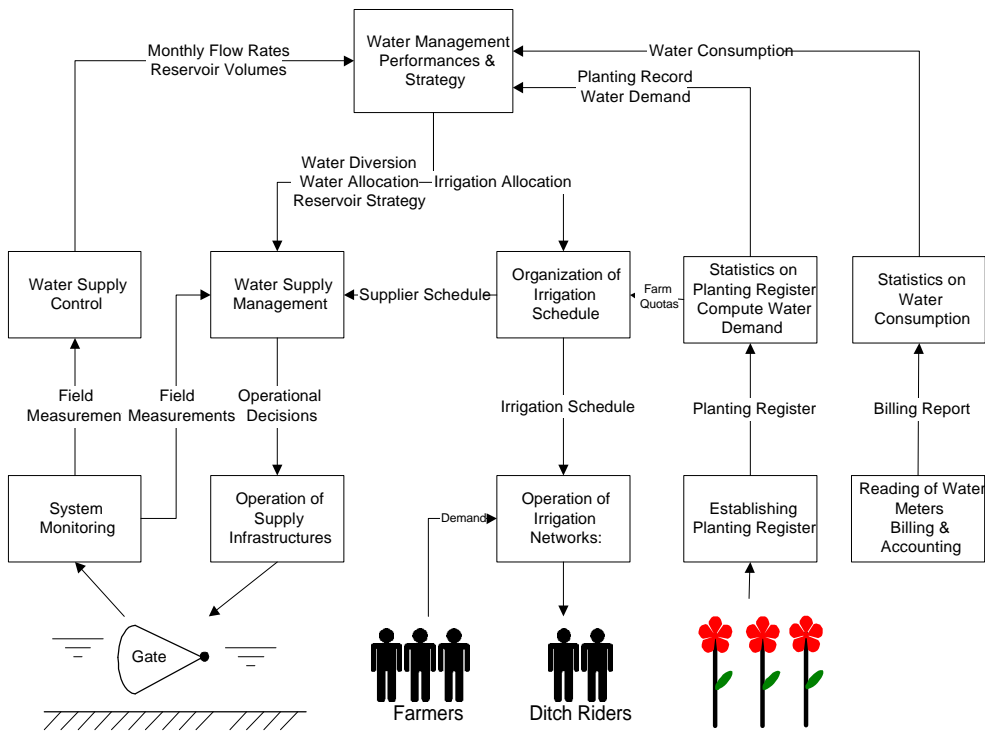


Figure 3. Water Management Flow of Information

THE WATER MANAGEMENT INFORMATION SYSTEM

The Water Management Information System (WMIS) is designed in order to optimize water management in the Jordan Valley, by providing all involved with the relevant information and decision support tools. The system consists of a dynamic and distributed database, where all relevant information related to water management is gathered, and application modules, which process the information and provide decision support.

WMIS Database

The database is divided into three sections:

Static Data

The Static Database contains data related to the Jordan Valley hydraulic infrastructures (layout, reservoir characteristics, irrigation network characteristics, and farm characteristics), and general water management policy (crop reference quotas, evaporation rate in reservoirs, project efficiency, water prices)

The infrastructure layout is described according to *nodes* and *links*. Nodes are either:

- Resource Nodes, which only provide water (rivers, wadis, rainfall, wells, springs, external resources)
- Buffer Nodes, which can either receive water from other nodes or provide water to other nodes (reservoirs, canals, river course, carrier)
- Consumer Nodes, which only consume water (irrigation network, municipalities, waste)

Links represent the connections between nodes. They are either virtual (i.e. connection between rainfall and a reservoir), or they represent a physical infrastructure (i.e. pipe, pumping station...)

Historical Data

The Historical Database contains field measurements: rivers daily flow rates, reservoirs levels, reservoirs daily inflows and outflows, KAC daily inflows and outflows, farm consumption & accounting data, monthly planting register.

The Water Management Data

The Water Management Database contains water management planning data: forecasted water resources, reservoir target volumes, consumer monthly water requirements and quotas, suppliers monthly and daily quotas, irrigation schedule, irrigation orders.

WMIS Application Modules

To each water management task represented in Figure 3 corresponds a WMIS Application module.

Three modules cover the activities of water management strategy:

- Surface Flow Forecasting: the objective is to forecast monthly flow rates of rivers and wadis for the coming season.
- Water Management Strategy: the objective is to balance water resource with water demand for the coming months of the season and to set monthly reservoir target volumes
- The Water Management Performances: the objective is to monitor the application of the water management strategy, and compute the water balance, and water efficiency (water delivered/water received) of various parts of the hydraulic scheme (irrigation networks, reservoirs, KAC, carriers etc.)

Two WMIS application modules cover the water supply activity:

- Water Supply Management: the objective is to perform the water balance for the coming day, according to the water management strategy and the water situation. The program output are flows to be set at the water supply control structure.
- Historical Data Management: the objective is to transfer data from the SCADA³ to the WMIS or enter manually measured data. The module analyses and validates the data, perform simple statistics, and provides summary reports for the use of JVA management.

³ SCADA: Supervisory and Control Data Acquisition system

Six WMIS application modules cover the water distribution activity

- Irrigation Scheduling Program: the objective is to establish the irrigation schedule on a weekly or bi-weekly basis.
- Irrigation Orders Processing: the objective is to produce irrigation orders: list of farm turnouts to be opened, and timing of openings
- Billing & Accounting Program: the objective is to enter water consumption, compute water bills, establish invoices, and enter payments.
- Planting Register Processing: the objective is to enter the Planting Register provided by the field reports.
- Water Consumption Statistics: the objective is to establish monthly statistics concerning farm water consumption, water billed, and water provided at the head of the irrigation network.
- Planting Record & Water Demand: the objective is to validate, and aggregate the Planting Register by irrigation network, and compute the corresponding water demand for the coming months.

Telemetry System and Automation of the KAC

For the specific tasks of *System Monitoring and Operation of Water Supply Infrastructures* (c.f. Figure 3) a telemetry and remote control system has been installed on the main hydraulic infrastructures. The telemetry system gathers the following measurements:

- all KAC inflows, either through level sensors associated to thin plate weirs, or through flowmeters
- all KAC outflows (through flowmeters), and status of pumping station
- upstream and downstream level, gate opening of 28 KAC check gates
- water salinity in various part of the KAC
- water levels and flow release at the main reservoirs
- flow at main carriers

The measured data is transferred through a 30 pair private cable to JVA Control Center where it is displayed by a SCADA software. From the Dirar Center, the operator can assess the global status of the King Abdullah Canal. In addition the operator can remotely control the KAC tunnel entrance gate (Yarmouk River), and the 28 measured cross-check gates.

The system is connected to SCP designed *Dynamic Regulation* software, which automatically set the remote controlled KAC cross-check gates. *Dynamic Regulation* relies on the program of outflow (provided by the WMIS) and on the measured KAC water levels and inflows. Based on this data, target volumes and flows are computed in each canal reach. The results are updated every 2 hours. The gates are set accordingly, and their position is corrected every 15 minutes through a PID controller.

INTEGRATION OF WMIS TO THE JVA

JVA Organization

Activities related to Water Distribution are well identified within the JVA: operation and maintenance of the irrigation networks is under the responsibility of three *Directorates*. The Directorates depend on Stage Offices to organize water distribution among farmers, open and close farm turnouts, and follow up billing and accounting operations.

Originally the organization of Water Supply was scattered between different JVA Divisions: the Central Directorate was in charge of the KAC operation, while the dams were operated by the Dam Directorate, and the main carriers either by the North, Middle or South Directorates, depending upon their location.

With the implementation of the WMIS, and specifically the telemetry system, the Central Directorate became the Control Center for all JVA water supply infrastructures. The operation of the dams is still under the responsibility of the Dam Directorate, but dam releases are performed upon instructions provided by the Control Center.

The office of the Director of Operation Maintenance establishes the Water Management Strategy. This strategy is proposed to JVA upper management (Secretary General) and to the Minister of Water and Irrigation for approval.

WMIS Architecture

As a result of JVA organization, The WMIS is distributed between four types of sites:

- O&M Director Office (1 site)
- Directorates (3 sites)
- Control Center (1 site)
- Stage Offices (10 sites)

The distribution of the system concerns the database (except for JVA headquarters), as well as the application programs. The system is also connected to the telemetry and KAC remote control system. Figure 4 illustrates WMIS architecture, and communication links between the different sites.

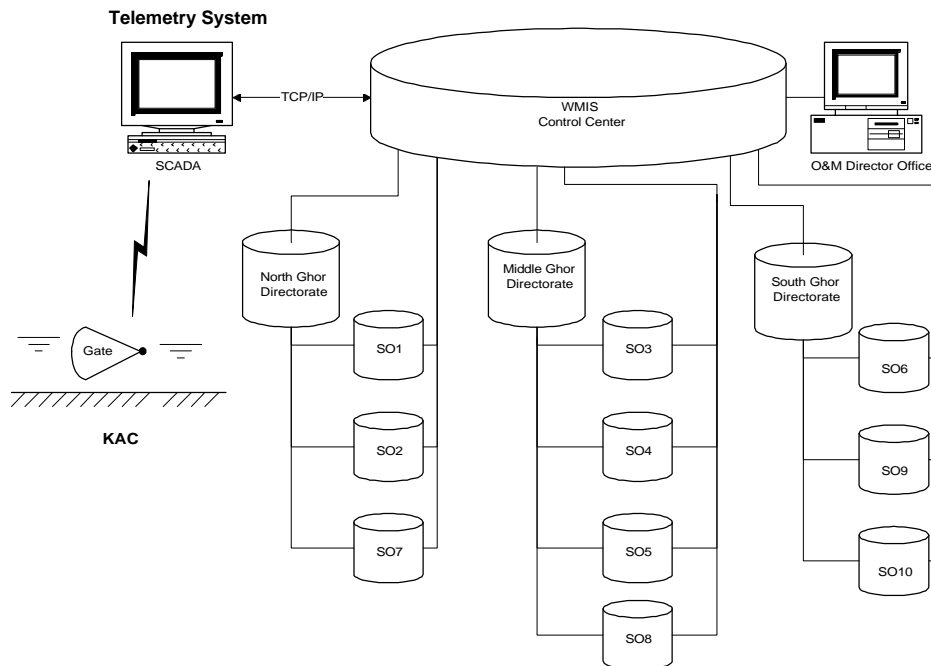


Figure 4. WMIS Architecture

One of the main difficulties encountered when implementing the WMIS, was integrating the system in the JVA decision-making chain. Application modules requesting low-level or no decision-making were used once the staff was properly trained. These modules were design mainly to assist the staff in performing their daily tasks more efficiently, through the use of computers. On the other hand, application modules requesting a medium level of decision-making (i.e. Water Supply Management), were sometimes run, but rarely used for the benefit of water management. This was due to the way the scheme was operated: skilled field operators were adjusting control infrastructures on a daily basis with little instructions and no control from their management.

The implementation of the WMIS, and specifically the telemetry and remote control system were an incentive to remedy this lack of central decision-making and control, which would eventually lead to inefficient water management.

On the other hand, the system itself had to be partially redesigned. Decision-making application modules have been simplified by focusing primarily on relevant decisions. Furthermore, the flexibility of the system has been improved in order to implement the modules at the appropriate location. For instance, depending on the organization of a Water Distribution Directorate a given module may be installed at the Stage Offices or at the Directorate.

CONCLUSION

Operation of hydraulic schemes dedicated to irrigation is being analyzed with an increasing acuity. Faced with various constraints such as water scarcity, environmental issues, or pumping costs, the Operators are being asked to improve their management of water resources. The use of Information Technology tools, is certainly a way to achieve this objective.

However, the implementation of such tools, is often challenged by the Operator's existing organization and practices, which are the result of tradition, but are often proved to be detrimental to the efficiency of water management. Such shortcomings are usually pointed out in the process of designing a Management Information System, provided that this task is performed with sufficient care.

The system designer must take into account these practices in order to ensure the integration of the system in the chain of decision-making. Indeed, a system designed only according to water management logic will be faced with serious difficulties at the stage of implementation, and eventually may not be used by the Operator. On the other hand, a system which only reproduce the existing procedures may help to reduce the Operator staff but will certainly not improve water management.

The art of the engineer, when designing a Management Information System, is to define the fine line between process logic, and integration to existing practices. The system must be flexible enough to adapt to its environment, and yet remain faithful to the logic of water management. If this challenge is successfully tackled, the system may actually help the Operator to improve operational organization procedures, and tend toward optimal water management.

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