INFORMATION TECHNIQUES FOR IRRIGATION SYSTEMS

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on

Information Techniques for Irrigation Systems

held in Alor Setar, Malaysia

15-17 June, 1996

Theme: Scheduling of Water Deliveries in Irrigation Systems

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1. INTRODUCTION

1. INTRODUCTION

What is ITIS?

In recent years, many computer-based models and tools have been developed to support irrigation managers in taking better decisions on issues related to irrigation management (operations, water scheduling, maintenance, ...). Often, however, these models/tools are not targeted towards the needs of irrigation managers, while managers are not aware of recent developments in irrigation technology. This has led to a disappointingly low contribution of computer-based tools to irrigation management. With this in mind, the International Irrigation Management Institute (IIMI) and the French Institute of Research on Engineering and Environment (CEMAGREF) launched a network that would bring together irrigation researchers and managers to work on **generating and using better information for decisions making:** Information Techniques for Irrigation Systems **(ITIS).** The ITIS Network has a light and flexible structure and consists of the following five elements:

1. A **newsletter** disseminating experiences with information techniques in irrigation systems
2. An annual **Network Meeting**
3. A **database of individuals and institutions**
4. A **database of experiences** with information techniques in irrigation systems
5. An **IIMI-CEMAGREF coordinating committee**

Third International ITIS Network Meeting

The Third International ITIS Network meeting was held from 15-17 June in Alor Setar, Malaysia and was jointly organized by the Department of Irrigation and Drainage of Malaysia, the Muda Agricultural Development Authority, Cemagref from France and the International Irrigation Management Institute.

The objective of the meeting was to **exchange experiences** obtained on the **application of information techniques in irrigation systems** and to obtain insights in the requirements for successful development and application of information techniques. The exchanges focused on this year's theme of the Network Meeting was **"Scheduling of water deliveries in irrigation systems".** The whole meeting was broadly divided into two sections; discussions on case studies in different countries and a **joint analysis or case study of requirements of information and tools for improved irrigation scheduling in the Muda irrigation scheme.**

Theme: Scheduling of Water Deliveries in Irrigation Systems

Information Systems for irrigation managers

Managers of irrigation systems have to perform a wide range of activities, such as maintenance, daily operations, scheduling of irrigation deliveries, communicating with irrigators, etc., which are all related to the project objectives. In all these activities different decisions have to be taken, which are based on information that is available with a manager. This information needs to be provided at the right time, at the right place and in the right format. Information can be obtained from dynamic data (e.g. current water levels), permanent data (e.g. structure dimensions),

experience (e.g. the manager knows what the hydraulic effect of a changed gate setting is) and information that is processed from more than one set of data (e.g. an actual discharge divided by the target discharge). Recent technological developments, such as the improved access to computers, have allowed researchers and irrigation managers to propose changes in the acquisition, transmission and processing of information in irrigation systems. Some successful examples of the introduction of new information techniques have affirmed the potential of these tools. However, it seems difficult to derive lessons from these isolated case studies, which would enable a transfer to other systems. A second problem that was identified in earlier sessions of the ITIS network meeting, was that techniques/tools developed by researchers do not necessarily match the needs of irrigation managers.

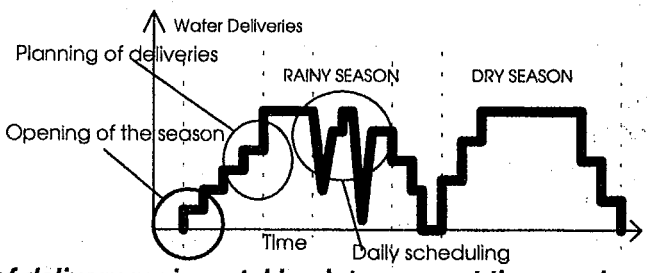
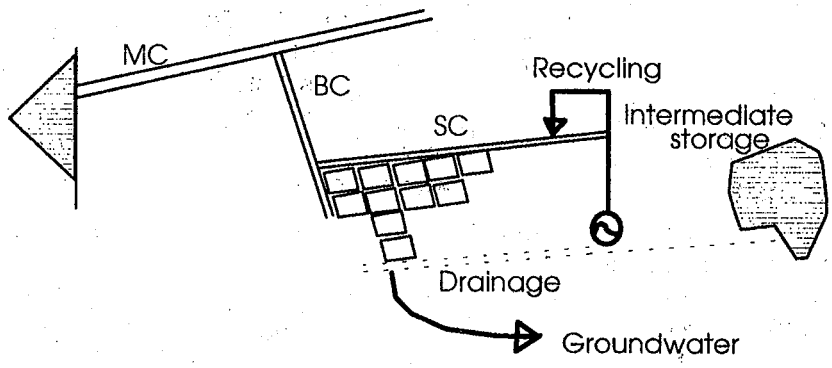
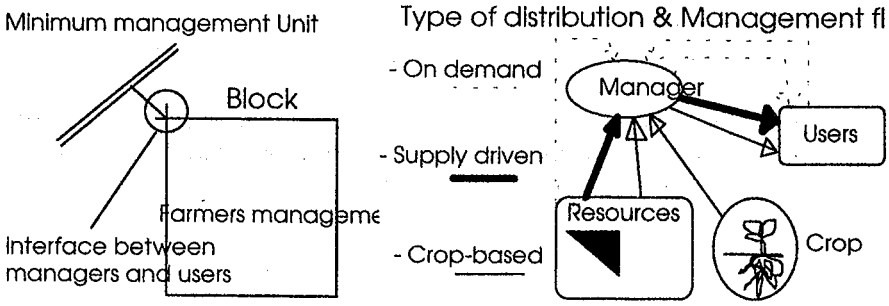
Scheduling of Water Deliveries in Irrigation Systems

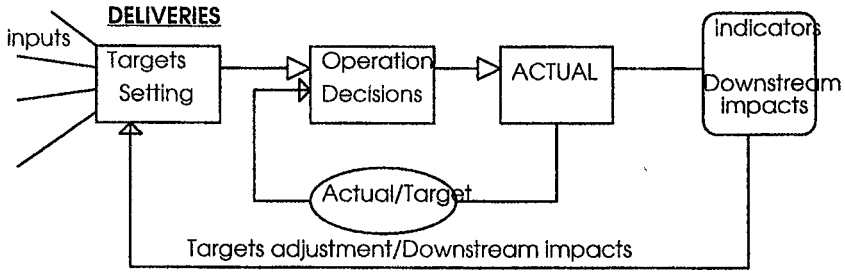
At the onset of an irrigation year/season, a planning is generally made on a schedule of water deliveries in an irrigation system. Decisions on the scheduling of water deliveries are based on information that is available for a number of parameters, such as expected availability of water resources (reservoir, river, ..), expected rainfall pattern, expected demand or cropped area, etc. A data acquisition, transmission and processing network is required to supply the required information. The planning is often subject to negotiations between (multiple) users and the irrigation managers, a process that varies in the different contexts. They each have their area of responsibility (e.g. main system versus tertiary unit), which needs to be well defined, but are often interacting in order to match supply with demand. Thus, a group of farmers that are not involved in the operation of the main system may very well be working with the managers on the seasonal planning of water deliveries.

Operational rules that govern the actual water deliveries will usually be defined both for the expected/projected situation as well as for changes therein (e.g., an exceptionally dry year). Operational rules are generally a function of the physical (hydrological, hydraulic, agronomic), social and political environment. These rules help irrigation managers in setting the operational targets during the season. An evaluation of the actual versus the projected performance may then give some good ideas on how well the targets were set, in addition to the daily adjustments that are made to better match actual with projected performance. Another aspect related more to the operational management rather than the seasonal planning is the reaction of managers to special events, such as rain showers (e.g., by shutting off the supplies).

In the following section an analytical grid is proposed with which the scheduling of water deliveries in an irrigation system can be analyzed. The grid is applied to the Muda irrigation scheme in order to test the grid and to give a practical example of the application of the grid.

Proposed Analytical Grid for Water delivery Scheduling

CONTEXT of the SYSTEM	**Hydrology** Rainfall, ET, Water abundancy, Shortage, Drainage, Different components of water for crops,... **Agriculture** Soil, Fields, crops, farmers' involments, land tenure,.... **Water resource share** water rights and rules for water allocation  ***Definition of delivery regimes taking into account the supply conditions as well as the demand (e.g., critical stages for crop)***
CHARACTERISTICS and **REPRESENTATION** of the **SYSTEM** in its **CONTEXT**	**Representation of the physic of the system**  **Representation of the Management system** 

OBJECTIVES	Global: • Increasing Yield • Flood and Drainage control • Providing supplemental water to agriculture • Improving water productivity • Diminishing environmental impacts • ..... Operational: • Decreasing irrigation costs • Decreasing operational costs (pumping) • Reducing Drainage • Minimizing withdrawals of fresh water • preventing salt intrusion or salinity problem • .....
DECISON PROCESSES	By whom What is the management unit considered What space scale to what extend the decision goes What is the interface (between users and managers) What time scale (daily to seasonal decision) What type of decision (seasonal planning, reaction to rainfall,...)
REPRESENTATION of the DECISION PROCESS	
PROCEDURES & IMPLEMENTATION	Tools and information requirements Information and communication

2. ITIS IN MALAYSIA

2. ITIS IN MALAYSIA

2.0 Keynote address Ir. Neo Tong Lee[1]

2.0.1 Introduction

Malaysia receives an annual average rainfall of more than 2500 mm mainly due to the Southwest and Northeast monsoons. The country is therefore rich in water resources when compared to other regions of the world. The annual average volume falling on the total land mass of 330,000 square kilometers amounts to 990 billion m^3. Out of this volume, 360 billion m^3 (36 percent) returns to the atmosphere as evaporation, 566 billion m^3 (57 percent) appear as surface runoff and the remaining 64 billion m^3 (7 percent) recharges the groundwater. Out of the total 566 billion m^3 of surface runoff, 147 billion m^3 occur in Peninsular Malaysia, 113 billion m^3 in Sabah and 306 billion m^3 in Sarawak. About 10 percent of surface runoff is readily available for consumption.

In spite of the apparent abundance of water supply compared with the demand, shortage of water has occurred in the country. This is because the occurrence of rainfall varies from region to region. Within regions also, the rainfall varies from season to season and from year to year. Because of this uneven distribution, the portion of water readily available the year round, without having to regulate river flows, is relatively low.

The growth in population and GDP has brought about heavy demand for water in Malaysia. Domestic and industrial water demand, which stood at 1.3 billion m^3 for 1980, has increased to 2.6 billion m^3 in 1990. It is expected to increase to 4.8 billion m^3 by year 2000. The share of industrial water demand has increased from 50 percent in 1980 to 56 percent in 1990. It is expected to increase to more than 60 percent in year 2000. Irrigation area has expanded from 329,000 ha in 1980 to 342,000 ha in 1990. There is no plan to expand the irrigation area further, but it is envisaged that the entire area will be double-cropped. Irrigation water demand will increase from 7.4 billion m^3 in 1980 to 9.0 billion m^3 in 1990. It will further increase to 10.4 billion m^3 in 2000. The aggregate total water demand is, therefore, estimated to be 15.2 billion m^3 by 2000 as compared with 8.7 billion m^3 for 1980 and 11.6 billion m^3 in 1990.

Currently, more than 80 percent of the country's water demand (12 billion m^3/year) is used by the irrigation sector (10 billion m^3/year). Irrigation is not only the largest water consumer in terms of volume, it is also associated with a comparatively low-economic-value, low efficiency and highly subsidized water user, the agriculture sector. Most of the irrigation schemes have system efficiencies of less than 60 percent and water productivity index of less than 0.2 kg/m^3. Investments in irrigation projects have been very large and these are funded by the public sector. Since 1960, the country has expended more than RM. 2200 million (RM 1 = US$ 2.43) for irrigation development projects. The figure does not include operation and maintenance expenditures.

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With the increased competition by non-agricultural sectors, water is increasingly seen as an economic good. Irrigated agriculture, while having to increase and sustain productivity, will have to reduce its water consumption at the same time. This needs to be achieved at low financial and environmental costs too. These challenges call for efforts involving both technological and management interventions. Regional and international co-operation is equally needed to ensure sustainability and global success.

2.0.2 Irrigation in Malaysia

Irrigation development in Malaysia dated from the end of the nineteenth century where the emphasis was to control and use the water resources. The Kerian Irrigation Scheme is the first of the large schemes to be constructed in 1892. Following the acute rice shortage after the great depression, the Department of Irrigation and Drainage was formed in 1932 and irrigated areas for paddy cultivation were progressively increased. By 1960, about 200,000 hectares were developed and the objective at that time was merely to supplement rainfall for single crop cultivation.

During the 1960's and early 1970's, the focus was shifted to increase production and income level of farmers through double cropping of rice. Development for adequate water resources for the off-season cultivation was the main strategy. To meet the additional irrigation requirements, large storage dams, major pumping installations and conveyance and distribution systems were constructed.

During the 1980's, the priority for irrigation took a new dimension with the need to rationalize rice cultivation with production cost and profit considerations. Since Malaysia does not have the comparative advantage in rice production due to high investment and production costs, there evolved a policy to confine irrigation development to the eight large irrigated areas designated as Granary Areas. Increasing efficiency, consolidations and increasing productivity are the thrust on the Granary Areas totaling 212,000 hectares comprising the irrigated areas of MADA, KADA, Seberang Perai, Trans Perak, North West Selangor, Kerian-Sg. Manik, Besut and Kemasin Semerak. Irrigation facilities were intensified and extended to the tertiary canal levels to provide good water control and management at the farm level. Paddy production from these Granary Areas has since then increased significantly.

Overall, Malaysia has over 600,000 hectares of paddy land comprising the eight Granary Areas (212,000 hectares) and 924 non-granary areas (130,000 hectares). The government has provided irrigation facilities in the non-granary areas at a lesser intensity. The remaining area of about 360,000 hectare is rainfed. Keeping with the government policy to focus rice production within the Granary Areas, the non- granary areas will gradually be phased out for more remunerative crops. To ensure at least 65 percent self sufficiency in rice, the granary areas target to produce an overall average yield of 4.5 tons per hectare with at least 180 percent cropping intensity by the year 2010. The current production statistics are shown in table 1.

PRODUCTION STATISTICS FOR GRANARY AREAS											
Granary Areas	Area (ha.)	Production									
		1990		1991		1992		1993		1994	
		Cl. (%)	yeild/ ha	Cl. (%)	yeild/ ha	Cl. (%)	yeild/ ha	Cl. (%)	yeild/ ha	Cl. (%)	yeild/ ha
1. MADA	97,000	196	3,821	196	3,969	195	4,031	195	4,162	200	4,363
2. KADA	31,477	147	3,534	155	3,657	167	3,832	185	3,426	174	3,446
3. Kerian Sungai Manik	30,058	170	2,520	172	2,803	181	2,816	174	3,250	150	2,557
4. Barat Laut Selangor	19,022	188	3,979	189	4,814	186	4,658	190	4,500	192	4,153
5. IADP, Pulau Pinang	13,000	168	1,645	172	2,221	184	2,627	157	2,919	145	3,108
6. Seberang Perak	9,150	180	4,116	180	3,933	163	3,145	175	3,538	178	3,698
7. KETARA (Besut)	5,100	156	3,200	159	3,061	156	2,319	182	3,405	174	3,257
8. Kemasin Semarak	7,330	53	1,669	60	3,071	72	2,894	103	2,998	125	2,680

Table 1 - Production Statistics for Granary Areas

A sum of RM 2,200 million has been spent on the irrigation development projects since 1960. This amount does not include the operation and maintenance expenditure. Federal funding will be confined to the eight Granary Areas with the emphasis on increasing the rice production. Infrastructure development such as the construction of dams, pumping installations and canal and farm-road development will continue. However, the emphasis will be on improving water management capabilities in general and improving the irrigation efficiency in particular.

2.0.3 Issues

The recent trends in investments suggest that it that the continuation of the high rates of irrigation development, as in the past, is unlikely. The main reason is the unfavorable economic outlook of new irrigation projects. Rising capital costs, low returns on capital, problems of operation and maintenance, low efficiency of water use, low level of water charges and revenues, environmental impacts of dams and degradation of natural resources are the reasons to forecast slower growth rate of irrigation development.

Constraints in land and water resources necessitate the present and future irrigation development be mainly targeted at exploiting the full potential of attainable cropping intensities and crop yields through rehabilitation, modernization and management review of existing irrigation systems. The current irrigation efficiency is around 35-40 percent with water productivity index of less than 0.2 kg/m^3. A program for Modernization of Irrigation System has been initiated with a view to improve irrigation performance and the farm productivity.

By the year 2010, the granary areas are expected to increase their production by 0.51 million tons above the production of 1990 (an increase of about 75 percent). The general strategy is to improve cropping intensity and yield from the granary areas as they are still well below their full potential. The task will stress on technological and management intervention for the production of paddy involves large volume of scarce resources (land, water, labor and capital). The main thrust is to increase the productivity in these areas totaling about 212,000 ha. The target is to produce an overall average yield of 4.5 tons per hectare with at least 180 percent cropping intensity by year 2010. These have to be achieved at reduced water consumption and lower financial and environmental costs. A comparison of national level paddy production and demand is shown in table 2.

PADDY PRODUCTION VERSES DEMAND					
Year	**1990**	**1991**	**1992**	**1993**	**1994**
MALAYSIA	1,850,542	1,926,574	2,021,177	2,080,754	2,155,521
8 GRANARIES	1,297,725	1,397,321	1,428,873	1,492,255	1,476,724
NON GRANARY	552,81	529,253	592,304	588,499	678,797
IMPORT	491,916	575.470	673,726	586,879	538,880
DEMAND	2,342,458	2,502,044	2,694,903	2,667,633	2,694,401
SUFFICIENCY LEVEL	79%	77%	75%	78%	80%

Table 2 - Paddy Production Verses Demand

2.0.4 Options

The challenges to increase productivity of irrigated agriculture call for efforts involving both technological and management interventions. One of the options is to improve irrigation management capacity by capitalizing on information techniques. Irrigation management constitutes a wide range of activities involving dynamic and real time information. The effectiveness of any decision or action made by the irrigation manager depends on data quality and availability. The dynamic nature of irrigation activities demands real-time information of parameters such as water resources, rainfall, water demand, farm activities, field conditions, water levels, canal flow and gate openings. Improved access to computers has allowed better management of this information.

Water allocation and on-demand real-time water distribution with supervisory local manual control have been initiated in MADA and the Kerian irrigation scheme in isolation to their specific needs. Basically, the aim is to optimize water resource available to the scheme by maximizing the effectiveness of rainfall and minimizing water released from the dams.

The computerized water control scheme was implemented in MADA since the 70's. The functions then were:

i. To assess the irrigation water requirement and storage capacity in the rice field.
ii. To estimate the available uncontrolled flow (in the rivers) and arrange reservoir releases only when required.
iii. To arrange the distribution of water to the irrigation blocks.
iv. To keep the management informed of water situation throughout the Muda area.

With advances in computer and telecommunication technology the system was further improvised in 1988. Various parameters such as hydrological data, irrigation data, cropping activities and crop yield can be monitored, processed and analyzed in a timely manner now. MADA is still in the process of improving the system to suit current needs and capabilities. The whole development of information management is a dynamic process.

The Kerian scheme has installed an elaborate data collection and communication system and has developed a computerized water allocation model. The management system was developed to optimize water resource available to the scheme by maximizing the effectiveness of rainfall and minimizing water released from the dams. The strategy is to collect, transmit, process and analyze the various irrigation data effortlessly and speedily. The system was initiated in the late 80's and is still going through an improvement process.

The mechanism of MADA water delivery scheduling will be addressed in detail in the key paper during this meeting while the Kerian system will be presented as one of other ITIS in the Field papers.

2.0.5 Conclusions

The development of these two communication systems serves as a starting ground for other schemes to develop their own specific information techniques. It is felt that a water distribution model based on real-time information is an appropriate tool to assist irrigation managers with seasonal scheduling and daily operating decisions. There is also a need to look into the possibility of fully automating certain important structures. This is necessary in the face of the labor shortage and the need to provide a flexible and efficient irrigation service in line with mechanization and progress in on-farm activities.

This forum undoubtedly provides the much needed platform for sharing experiences and would generate suggestions for improvement. A lot of opportunities exist for applying similar methodologies in other areas by adopting and improving these successful cases. The general idea is to develop a methodology to assist irrigation managers with seasonal scheduling and daily operating decisions that would provide proper control of the water distribution system based on real time information.

Thank you.

- Provision of a one-month fallow period in the dry months for pest and diseases control and regaining bearing capacity of soil.

2.1.4 Decision Processes

2.1.4.1 *Representation of the Decision Process*

There are three levels of decision process:

- **Seasonal Planning**
  - With the forecasted date of harvesting of the previous season's crop and the current 20-year hydrological record, a reservoir storage simulation program is run to assess the available water resources to irrigate the coming crop.
  - Alternate irrigation schedules will be put forward for the consideration of the agency/farmers joint committee. A final schedule will be decided and announced.
  - Once decided, various features in the schedule such as phasing (to reduce peak demand on system capacity and machinery), water stop dates, etc., have to be observed by the farmers.
  - Contingency plans will be put up in time of water shortage depending on the severity of the problem.

- **Daily Operation Process**
  - A water balance model is applied to each irrigation block (the smallest entity in the water management system) to assess the water requirement. Irrigation water will be allocated accordingly. The quantum of water allocated will then be summed up for each canal system to determine the total requirement for the irrigation scheme. This process is executed centrally at the Engineering Headquarters using data fed back from the field.
  - In times when uncontrolled flow exceeds the field water requirement, the computer program automatically optimizes the distribution of the excess water over the project area. The main arteries of the irrigation canal system are used to discharge any excess water to the sea.

- Implementation and evaluation of **Long Term management intervention**
  - Over the years, several management interventions have been introduced such as tertiary development, installation of telemetry system and dry-seeding crop establishment method.
  - These management interventions have been evaluated using various performance indicators. The outcome from these evaluations may be utilized to improve the operation of the scheme.

2.1.4.2 *Information Requirement*

- An extensive **data-feedback system** forms the backbone of these decision processes. Parameters monitored are hydrological data, irrigation data, cropping activities, yield, etc.

- **Timeliness** of data acquisition is a key issue in improving the system efficiency. The telemetric hydrological network and VHF voice communication system installed in MADA provide real-time data.

2.1.4.3 *Targets/Strategies*

- Since the primary targets of water scheduling in MADA's context is to **optimize** the usage of available **water resources** without jeopardizing the potential crop yield, a crop-based supply system is found to be most suitable.

- At the field level, it means maximizing the effective use of direct rainfall and uncontrolled river flow and minimizing dam release.

- Recycled water is preferred to dam release due to water scarcity.

2.1.5 Procedures and Implementation

- **Management Tools** available in MADA for the implementation of water scheduling can be generalized into three major components as follows:-
  - Data feed back system
  - Decision support system
  - Enforcement of the decision

- The main tasks in **enforcing the scheduling** is to keep the farmers adhere to the planned irrigation schedule, and take only the amount of water allocated. This will minimize conflict of interests among themselves and with the agency. Cooperation of the farmers will result in smooth canal operations and higher system efficiency.

- **Future problems** anticipated and solutions:
  - As the Muda Scheme is water-deficit, additional water resources would be required to meet the needs of the region.
  - The potential uncontrolled river flow has not been fully exploited. Installation of telemetry stations in the catchment areas coupled with rainfall-runoff models will provide real-time data for optimizing its usage. Construction of regulating/storage reservoirs to store the excess 'uncontrolled' flow would mitigate the water deficit problem in the scheme.
  - WMCS needs to be continuously modified to accommodate the changes in the crop establishment methods.
  - Mixed cultural practices within a block causes difficulties in water management. Establishment of effective water user groups would improve water management.

2.2 Group discussions: Synthesis of Results

Group discussions had been organized during the second day of the workshop on the following topics:

1. Water scheduling for irrigation agriculture
2. Water delivery scheduling - irrigation agency and farmers
3. Tools for improving water delivery scheduling
4. Performance indicators for water delivery scheduling
5. Implementation of information techniques for water delivery scheduling
6. Dissemination of experiences

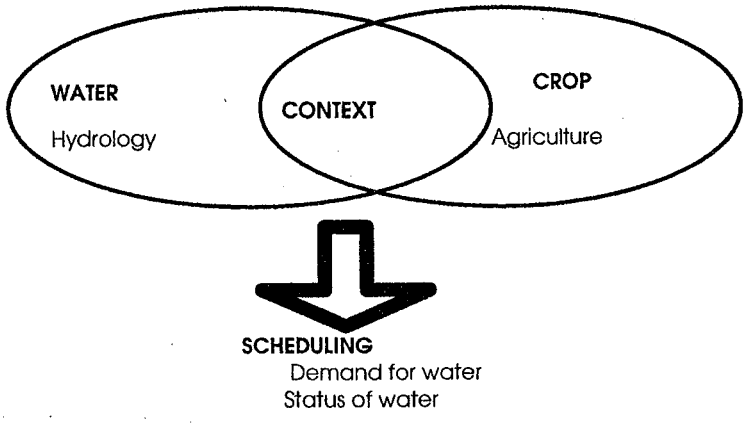
It was expected that each group addressed the given topics in two directions:

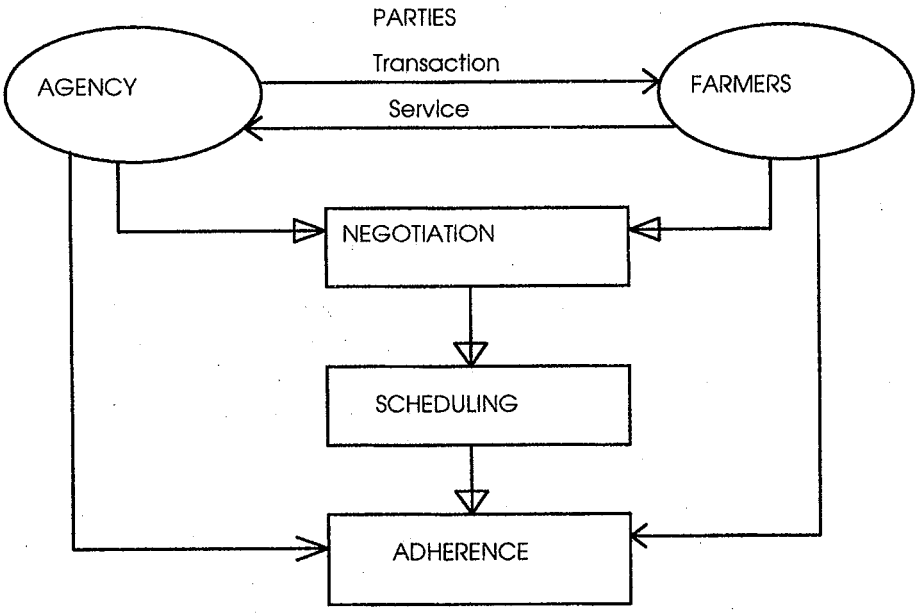
i) application to Muda scheme to identify specific issues
ii) application to other cases to derive generic issues

Although the mandate was twofold, most of the groups had focused only on the MUDA scheme due to lack of time. Presentations of each work group and a general discussion was the second part of the exercise. It appears to be successful in underlining some important features regarding water scheduling in the Muda scheme.

The outputs of the groups' findings, highlighted following key points. The context is the first step to consider in seasonal planning exercise. Agricultural context including crop requirements from which we can derive the demand for water, and hydrological context specifying the status of water resources, must be taken into account.

Scheduling is an operation dealing with the allocation of resources and identified requirements. It is a forecasting activity based on fixed and flexible variables. This operation can be considered as the main transaction between two parties (actors), the agency on one hand and the farmers on the other hand. The implementation of the whole operation basically take place in two phases. The first is the negotiation phase during which each parties defines demands, their requirements, to finalize a good compromise. The second is the implementation phase, delivering of water and plantation. During the latter phase, "adherence" to the scheduling must be monitored to avoid deviation (see diagram overleaf).





Important factors to be considered regarding the scheduling in MUDA are:

1. the agricultural techniques, that greatly influences the water demand schedule. Transplanting, dry seeding or wet seeding, does not lead to the same seasonal planning and to the same water demand as well.

2. the tertiary network availability. Where tertiary network had been built, water can be made available directly and in a rather flexible pattern to the paddy field through the network. in the absence of tertiary facilities, water is flowing from upstream field to downstream field and thus land preparation had to be realized in a sequence (flexibility very limited).

3. The social demand of farmers towards more flexibility. The constraints of the collective organization of land preparation and crop establishment is something that will have to be alleviated on a long term basis. Appropriate ways and means to ease the work of farmers and make farming more attractive is primarily important in a situation where urban jobs are appealing.

Having identified a general framework for the scheduling process, and the influencing factors, the discussions had then focused on two broad aspects: Information and knowledge; Adherence to the schedule.

Information and knowledge

Information is important for the management of irrigation systems. Particularly information on water resources and on water demand is of interest for the scheduling process. However, information must be cost effective. Accuracy of data and the use of information in the decision making process must meet the required level of confidence of managers and farmers.

Knowledge of farmer's expectations regarding the water service is felt as an area for improvement in the scheduling process.

Adherence to the schedule

Enlarging the consultative group on scheduling to district level (so far negotiations have been conducted at scheme level) is felt as a means to favor flexibility for the farmers.

Adherence to the planned schedule is considered as important both ways: agency in following the water delivery schedule, and farmers in preparing land and establishing crop accordingly. This adherence is important to ensure an even crop development per block. Thereby conflicts during the drying period towards the end of the season and during the harvesting period could be avoided.

Indicators on adherence can consist of mapping water progress within the scheme. At this point, participants suggest that the use of GIS capabilities in monitoring the progress.

Several points for further investigation have been outlined during the group discussions:

⇒ farmer's perception of the water service
⇒ gain and cost of flexibility in scheduling
⇒ gain and cost of tertiary systems
⇒ developments of spatial analysis tools like GIS

In general, the Muda scheme is well organized in terms of hardware, software and liveware aspects for the information collection and processes to meet management objectives. Hence, the last question tackled during the discussion was "how to formalize the MUDA experience and disseminate it?"

3. ITIS IN THE FIELD

MALAYSIA: KERIAN SCHEME

Teoh Boon Pin
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Abstract

The Kerian Irrigation Scheme is the third largest granary of Malaysia with a net paddy area of 23,559 ha. The scheme consumes more than 90 percent of the water utilization in the Kerian basin. With the current fast rate of economic and population growth, the competition for water from non-agricultural sectors is increasing. The continuous siltation of the Bukit Merah Reservoir, which is the main water source of the scheme (61 percent), adds to the problem. In order to stay tenable with the other rapidly expanding sectors, the Kerian Irrigation Scheme must improve the water use efficiency and productivity. Various procedures and methodologies are planned and adopted for optimization of water delivery scheduling. A computer program for irrigation management is proposed to access and analyze the relevant information from the main server and then provide outputs to guide seasonal planning in irrigation scheduling and daily allocation and also to carry out performance assessment.

1. Introduction

The Kerian Irrigation Scheme is the third largest granary in Malaysia with a net paddy area of 23,559 ha. It is located in the North West corner of the state of Perak. The tools used for irrigation management include a telemetry system for data feedback and a set of computer software used as a decision support system. Since 1995, steps are being taken to upgrade both the telemetry system and software concerned. There are proposed plans to install client-server Wide Area Network (WAN) system to collect field information for operation and management purposes. The irrigation management software being proposed is capable of accessing the information collected in the server and provides outputs, which help in seasonal planning of the water schedules, daily water allocation and performance assessment.

2. Context of the System

2.1 Hydrology

In the Kerian Irrigation Scheme, water utilized for irrigation and other requirements are from the following sources (based on 1989 to 1994 data).

1. Controlled supply from Bukit Merah Reservoir (61 percent).
2. Recycled drainage water from Sg. Bogak Pump House (13.6 percent)
3. Rainfall (25.4 percent)

The average annual rainfall in the Kerian Irrigation Scheme is about 2500 mm. The North-East Monsoon brings the highest amount of rainfall each year from September to December. The average pan evaporation is about 5-6 mm per day. Presently there are three class A pans distributed in the scheme area. The pan readings are taken daily by the operation staffs stationed in the locality offices (Farmers' Development Centers) near the pan stations.

After the completion of the upgrading of the Kerian Irrigation Scheme in 1990, the Kerian Irrigation had generally sufficient water to cater for double-cropping of paddy except in some occasional drought seasons like the off season of 1994.

2.1 Agricultural Aspects

Good water management is essential from the land preparation stage until the harvesting stage so that the appropriate agronomic practices and technologies could be effectively applied. Appropriate water depths need to be maintained during the various stages of the cropping season not only to cater for the basic crop water requirements but also for the control of weeds, pests and diseases.

Proper water depth control will reduce or eliminate weed growth. The most critical period is 10 to 30 days after transplanting or 0 to 30 days after direct seeding. Adequate water depths will retard weed growth and facilitate the effective application of weedicides. Good Water Management is also needed from nursery or seeding stage to harvesting stage to enable effective pests and diseases control program to be carried out. Shortage of water during the nursery stage or just after seeding will encourage attacks of trips (a bug), sheath blight (caused by a fungus called *Rhizoctonia Solari)* and blast. Shortage of water in the later stages will encourage attacks by *Spadoptera Litura* (a worm) and a rice bug called *Scotinophora Coarctata.* On the other hand, attacks by brown hopper *(Nilaparwato Lugens)* can be reduced by draining the field for 3-4 weeks. Further, a fallow period of 18 days is proposed after each season for the control of pests and diseases.

2.2 Socio-Economic Aspects

The majority of the farmers (about 90 percent) are members of the Area Farmers' Organization Authority (FOA). The farmers usually channelled their problems through the FOAs or JKKK (Village Security and Development Committee). There are six Area Coordination Committees consisting of the field staffs from the various agencies at the six Farmers' Development Centers. These locality offices provide the communication channels between the irrigation agencies and the farmers.

3. Characteristics and Representation of the System

3.1 System Characteristics

The Kerian Irrigation Scheme is located in the North West corner of the State of Perak. It is the third largest granary area in Malaysia with 23,559 hectares. The scheme is divided into eight compartments as shown in Fig. 1. The main source of water is from the Bukit Merah Reservoir (about 61%). The present maximum operational level is 8.69 m with a total storage of 75 million m^3 of which 19 Million m^3 is the dead storage. The source of irrigation is supplemented by the pumping station at Sg. Bogak Pump house with four electrical pumps of 5.1 m^3/s each. The water is recycled from Kerian River into the Main Canal.

3.2 Representation of the Existing Management System

3.2.1 *Organization Setup*

The Kerian Irrigation Scheme is managed by the Department of Irrigation and Drainage, District of Kerian, Perak Darul Ridzuan. There are two units involved in the operation and maintenance of the scheme, i.e., the Control Unit and the Irrigation Unit. The Control Unit is responsible for the operation of The Bukit Merah Reservoir and the primary canal systems. The Irrigation Unit is responsible for the operation of the irrigation system downstream of the primary system.

3.2.2 *Existing Water Management System*

The telemetric system of the Kerian Irrigation Scheme was installed in 1990. The system consists of 23 rainfall or rainfall cum water level stations throughout the scheme. A supervisory computer interfaces with a Front End Processor which scans the stations at selected intervals for field data and then transmits those data to the computer for storage in the hard disk. The water levels monitored are at strategic points of main canals near the headworks and regulators, inside the reservoir as well as at critical points of rivers upstream and downstream of the reservoir.

In 1989, an operation procedure for irrigation scheduling based on weekly water budgeting was adopted. The water budgeting exercise was carried out from the first day of the season and provided guidelines for seasonal planning in planting schedule, weekly pumping schedule and daily allocation and operation. The following procedures are followed.

i) *Planting Schedules*

New schedules committed for irrigation supplies are added to the on-going schedules.

ii) *Water Demand*

Weekly water demands are determined for individual command areas of the scheme based on the irrigation duties. Demands for domestic and social purposes are also allowed for.

iii) *Effective Rainfall*

Weekly contributions of effective rainfall are predicted at 70%, 80% and 90% confidence levels for effectiveness of 50%, 40% and 30% respectively.

iv) *Water Resource from Bukit Merah Reservoir*

Based on 25 years of dam inflow records, weekly inflow probability curves are prepared for confidential levels of 70%, 80% and 90%. The available water resources are dependent on the initial storage and the projected inflows.

v) *Sg. Bogak Pumphouse*

Whenever possible, the supply from Bukit Merah Reservoir will be the first choice. Any deficit, measured in terms of the quantity of water required to keep the reservoir above the critical level is to be met by pumping diversion subject to the limitations of the capacity of the Pumphouse and available low flow in Kerian River.

vi) *Determination of New Cropping Schedules*

Any new cropping schedule will be allowed if it is possible to keep the reservoir level above the critical level at 80% confidence level. If a new cropping schedule can be supported only with a confidence level between 70% and 80%, consultation with farmer leaders is made and the risks made known before any commitment is made.

vii) *Pumping Required*

The pumping schedule is based on the amount of pumping to keep the reservoir above the critical level at 90% confidence level.

viii) *Irrigation Management Based on Supply - Demand Position*

The supply-demand position is dependent on the water resource confidence level and the pump-weeks required. A confidence level of more than 80% together with a required pump-weeks of less than 25 is considered normal. Otherwise, the supply-demand condition is deemed to be alert or critical depending on the severity.

Supply is cut as the assumed irrigation efficiencies and effectiveness of rainfall are raised in steps of 5% and 10% respectively depending on the severity of the situation. At the same time, the operation and monitoring efforts at various levels of water delivery will be stepped up to achieve higher water use efficiency.

4. Objectives of Water Scheduling

The objectives of water scheduling are as follows:

i) To increase yield to 5 ton/ha before year 2005.
ii) To increase the cropping intensity to 190%
iii) To optimize the effectiveness of rainfall to at least 50%.
iv) To increase the overall irrigation efficiency above 70%.
v) To lower overall operational costs by reducing pumping required.

5. Representation of the Decision Process

There are three level of decision process in water delivery scheduling which are dealt with in the following paragraphs.

5.1 Seasonal Planning

There are three schedules staggered at one month apart, i.e. schedule 1 for compartments A, B & C, schedule 2 for compartments D, E & F and schedule 3 for compartments G & H. The cropping schedules are designed to enable the optimum use of rainfall in both seasons, harvesting to be done during the drier months and reducing the peak demand for supply during the pre-saturation periods.

Before the start of a new cropping schedule, a meeting of the Committee On the Determination of cropping Schedule consisting of the various, agencies and farmer leader is held. The DID is also a member of this committee and provides advice on the expected adequacy of water supply for the forthcoming season. A water budgeting exercise is carried out first before such meeting as discussed in paragraph 3.2.2. The proposed cropping schedule will be supported if the water resource confidence level is more than 80 percent.

5.2 Daily Operation Process and Information Requirements

5.2.1 *The Proposed New Water Management System*

There is a proposed project to implement a Real Time Water Management and Control System by upgrading the present telemetry system and development of a new irrigation management software for daily monitoring and operation purposes. The layout cum flow chart schematic for the data collection and communication system is shown in Fig. 2

A new telemetry system to collect hydrological and field data is proposed together with a computer system linked in a Wide Area Network (WAN) for communication purposes. The advent of cheap and yet powerful desktop servers has made possible the communication of information or data between the computers linked in a Local Area Network (LAN) in the District Engineer's Office with the computers at the Farmer's Development Centers where the operation staffs are stationed.

5.2.2 *Data Collection and Communication*

The types of data collected and their modes of communication are discussed below:

a) *Rainfall Data /Water Levels*

Beside the existing 23 rainfall or rainfall cum water level telemetric stations in the Kerian Irrigation Area, another 16 manual rainfall stations are proposed to be converted to the telemetric type with automatic rainfall recorders. The daily rainfall is scanned at 8:00 a.m. every morning by the monitoring software and stored in the server in the control Center. The water levels are scanned hourly and similarly stored.

b) *Evaporation*

Presently, there are three manual pan evaporation stations in the project area. It is proposed to be upgraded with automatic evaporation recorders which can transmit daily pan evaporation data directly back to the monitoring computer and stored in the server.

c) *Flow Rates Through Dam Offtakes and Main Canal Regulators*

Presently, the flow rates through the dam offtake and main canal regulators are obtained by manual readings of the gate openings and water levels concerned daily. New telemetric stations are proposed for these main structures so that the water levels upstream and downstream of the gates. The gate openings are to be monitored hourly and the data transmitted back to the monitoring computer and then stored in the server.

d) *Flow Rates Through Constant Head Orifices (CHO)*

The daily flows through the CHO along the main canals are to be obtained from two sets of water levels and gate opening readings taken at 8:00 a.m. and 4:00 p.m. The Irrigation Technicians/ Inspectors are required to input these flow data at the computers in their locality offices whereby the data are transmitted to the District Engineer's Office.

e) *Supply From Sg. Bogak Pumphouse*

At the Sg. Bogak Pumphouse, the pump operator is required to key in hourly the numbers of pump currently running and the pumping rate via the computer in the pumphouse. These data will be transmitted and stored in the server at the District Engineer's Office.

f) *Data on the Progress of Supply and Field Activity*

Every Tuesday, the Irrigation Technicians/ Inspectors are required to collect data on the progress of supply and field activity. They are expected to key in the data for their respective blocks at the computers in the locality offices, every Wednesday before 9:00 a.m..

An average of about 10 - 20 stick gauges are proposed at random sites for each sub-block (200-400 hectares) irrigated by a secondary canal. The stick gauges are to monitor field water depths weekly.

g) *JBA and Other Social Water Demand*

The domestic water demand by JBA (The Water Authority) and other social water demands from the Selinsing Canal (a main canal) are input into the computer running the irrigation management software.

5.2.3 *The Water Optimization Model*

The main purpose of the Water Optimization Model is to maximize the use of rainfall and minimizing the release from the dam and pumping while ensuring that the dam operational levels are always in the permissible range. Basically, the irrigation management software at a work-station will access the hydrological data, dam release, flow rates of regulators, field activity progress data, CHO flow rates and pumping data from the main server. From these data, and the supply allocation for each sub-block commanded by a secondary canal will then be computed. It is important to note the water balance is done separately for each of the sub-blocks normally irrigated and drained by a secondary canal and drain respectively.

a) *The Water Demand at Each Irrigation Sub-block*

In this model, the supply strategy will be such that the irrigation rates will be based on the water depths so as to maximize the storage capacity of the field at any one time while not allowing any water stress situation to occur.

For a typical irrigation sub-block, three depths are defined for the purpose of computation of effective rainfall and irrigation rate. The three depths are:

(i) Minimum Water Depth (MNWD) - This is the minimum water depth to be maintained in an irrigation sub-block so as not to cause any water stress of the paddy plants.
(ii) Desirable Water Depth (DWD) - This is the water depth most desired by the farmers for steady plant growth.
(iii) Maximum Water Depth (MWD) - This is the maximum allowable storage depth as determine by the ridge/bund height or the drainage outlet setting related to the height of the plants.

In order to optimize the effectiveness of rainfall, the irrigation rates will be calculated according to the following rules:

(i) When the field water depth is below MNWD, the full pre-saturation irrigation module (IM_p) will be supplied either from the dam or the pumphouse.
(ii) When the field water depth is between MNWD and DWD, the full supplementary irrigation module (IM_s) will be supplied either from the dam or the pumphouse.
(iii) When the field water depth is above DWD, only partial supplementary irrigation module (IM_s) will be supplied with priority from the dam and supplemented by pumphouse. Let ER_d and ER_w be the percentage of average effective rainfall contribution to total supply for the dry months (usually from January to March and July to August) and wet months respectively (to be calibrated). The duties will then be $(1-ER_d)X\ IM_s$ and $(1-ER_w)X\ IM_s$ for the dry and wet months respectively.
(iv) When the field water depth is above or equal to MWD, no irrigation will be given.

b) *Effective Rainfall*

The daily effective rainfall (R_e) is assumed to be dependent on three parameters namely:

(i) the existing field water depth (D1)
(ii) the amount of rainfall (R) for each sub-block that is based on the weighted average rainfall from the contributing stations.
(iii) Maximum allowable water depth (MWD).

An empirical storage model is proposed which uses a series of coefficients (C1, C2, ...) to evaluate effective rainfall for different ranges of D1 and R. The introduction of the coefficients is to account for any inaccurate assumption of certain parameters like MWD, seepage and percolation in the evaluation of effective rainfall and water balance computation. These coefficients are to be calibrated by the actual measurement of the ending depth (D2) at the end of each day over a period of time.

c) *Computation of Evapotranspiration*

let, P_s be % of land pre-saturated
P_v be percent of land planted/seeded
P_u be % of land unsaturated
E_p be the pan evaporation of the nearest pan station (mm/day)
E_t be the evapotranspiration (mm/day)
E_u be the average evaporation loss from unsaturated surface (mm/day)
E_s be the average evaporation loss from saturated surface (mm/day)
K_p be pan factor
K_c be the crop factor

The daily evapotranspiration is computed as:

$$E_T = P_u \times E_u + (P_s - P_v) \times E_s + P_v \times K_c K_p E_p$$

d) *Seepage and Percolation*

Three sets of percolation tanks have been purchased for installation and measurement purposes. Presently, the sum of seepage and percolation is assumed to vary from 0.5 mm/day to 2 mm/day depending on the soil types.

e) *Daily Water Balance for an Irrigation Sub-block*

The daily water balance is assumed to be governed by the following equation.

$$D2_{ji} = D1_{ji} + I_{ji} + Re_{ji} - ET_{ji} - SP_{ji} \quad \ldots (1)$$

where,

j is the irrigation sub-block subscript
i is the number of days from the start of the season
$D2_{ji}$ is the final water depth at day i
$D1_{ji}$ is the starting water depth at day i
I_{ji} is the amount of irrigation (mm)
Re_{ji} is the daily effective rainfall
ET_{ji} is the evapotranspiration (mm/day)
SP_{ji} is the sum of daily seepage and percolation (mm/day)

Re_{ji} is evaluated by the formulations as shown in paragraph 5.2.3 (b). Then $D2_{ji}$ can be computed daily based on equation (1). Any error in the computation of $D2_{ji}$ due to the assumptions made in this model is corrected by setting the water depth equal to the measured value once a week.

The irrigation management software should be run every morning at about 10:00 a.m. After accessing the input data from the server, the daily water balance will be carried to compute the allocation of water to all the secondary Constant Head orifice offtakes, primary offtakes and the amount of pumping required.

The gate operators can reset the gates once a day at about 3:00 p.m. to 4:00 p.m. During the other inspection in the morning at about 8:00 a.m. to 9:00 a.m., readjustment of the gates to the setting of previous day can be carried out if necessary. At each inspection/adjustment, gate opening and relevant water levels are taken for performance assessment purpose.

5.3 Performance Assessment and Management Intervention

Mohtadullah (1993) defined performance as 'the degree of achievement of desired objectives'. Each irrigation scheme should define the desired objectives and then formulate operational plans to achieve them. Upon execution, monitoring and evaluation in the form of performance assessment should be carried out to check the attainment of the objectives set. Any weaknesses in the operation and management of the irrigation system should then be identified and appropriate management intervention be implemented to address the relevant problems.

5.3.1 *Performance Assessment*

The Kerian Irrigation Scheme started to carry out performance assessment in the late eighties. The three indicators evaluated are:

i) Relative Water Supply (RWS)= $\frac{\text{(Supply + Potential Effective Rainfall)}}{\text{Water Requirement}}$

ii) Cropping Intensity (CI)

iii) Water Productivity Index (WPI) = $\frac{\text{Specific Yield (ton/ha)}}{\text{Specific Supply (cu.m./ha)}}$

5.3.2 *The Performance Of The Irrigation Scheme- Some Selected Results*

i) *Cropping Intensity (CI)*

After peaking on 1992, CI dropped to 169.12% and 140.88% in 1993 and 1994 respectively. The drop could be attributed to the shift of labor to other more lucrative sectors of the economy and the declining interest of the farmers due to low productivity and profitability.

ii) *Effective Rainfall*

Effective rainfall can be evaluated by weekly measurement of field water depths. Since no measurements of these water depths have been carried yet, a storage model is need to evaluate effective rainfall. Potential effective rainfall is the portion of the rainfall that is stored temporarily in the field. Whatever that is more than the maximum storage capacity is considered spilled-over from this potential effective rainfall. The part which is actually used up by the paddy plants or contributed to the losses is called actual effective rainfall. The balance contributes to the drainage.

The average potential effective rainfall is about 72%. On the other hand, using the same storage model, the actual effective rainfall is only about 25%. This is rather low due to general owner-supply conditions and lack of response to rainfall in allocation of supply.

iii) *Relative Water Supply (RWS)*

The average value of RWS is 1.42 indicating a general adequacy of supply. The lower values of RWS in compartment A, B, & C could be due to `back irrigation' (unaccounted for) and very late planting where farmers planted just a few weeks before stopping of supply. If the 'back irrigation' is assumed to contribute about 15% of the total irrigation, then the overall irrigation efficiency is about 60% (approximately the inverse of RWS).

iv) *Water Productivity Index (WPI)*

The average WPI in the Kerian Irrigation Scheme is only 0.15 Kg/m^3 which is quite low as compared to the targets of 0.3 - 0.6 Kg/m^3. The low WPI is a result of low yield of 3.12 ton/ha and high specific supply of 2,173 mm/season.

6. Procedures and Implementation

6.1 Management Tools

The management tools required for the implementation of efficient water scheduling can be classified into three general components as given below:

a) *Management Information System*

For irrigation managers to manage the Kerian Scheme effectively, there must be able to access all information relevant to decision making and management easily, preferably on line. The information concerned are of two types, firstly the real time data like hydrological data and secondly a database constituting information on the scheme like the parameters on the infrastructures and system characteristics. The real time information can be accessed through the proposed Wide Area Network (WAN) client server systems in which data are collected by the telemetry system or keyed in at the remote locality offices.

The second type of information required a relational database to be maintained at the main server of the `WAN'. A multi-table relational databases for the Kerian Irrigation Project have been designed to contain information on the basic system characteristics, canal and drain details and structure parameters.

b) *Decision Support System*

An irrigation management software capable of seasonal planning based on projection of water balance, daily water allocation based on actual field water requirements and also performance assessment can provide decision supports for the irrigation managers.

c) *Enforcement of the Decision*

The main tasks in enforcing irrigation scheduling are firstly to ensure that the farmers adhere to the planned schedule and secondly take only the amount of water allocated. In order to carry out the enforcement effectively, the prerequisites are institutional reformation which include changing farm management structure, culture, knowledge and attitude of both the farmers and the operation staffs. Policies and legislation must also provide support for enforcement of irrigation scheduling. Towards that objective, The Department of Irrigation and Drainage is currently engaging in a program to reformulate the country's Irrigation and Drainage Act.

7. Conclusion

In this age of information technology, the information system plays a very crucial role in helping irrigation managers in decision making and managing irrigation system. With the help of real time data feedback and on line access of relevant information, an effective water management and control system can be implemented to optimize the use of water resources.

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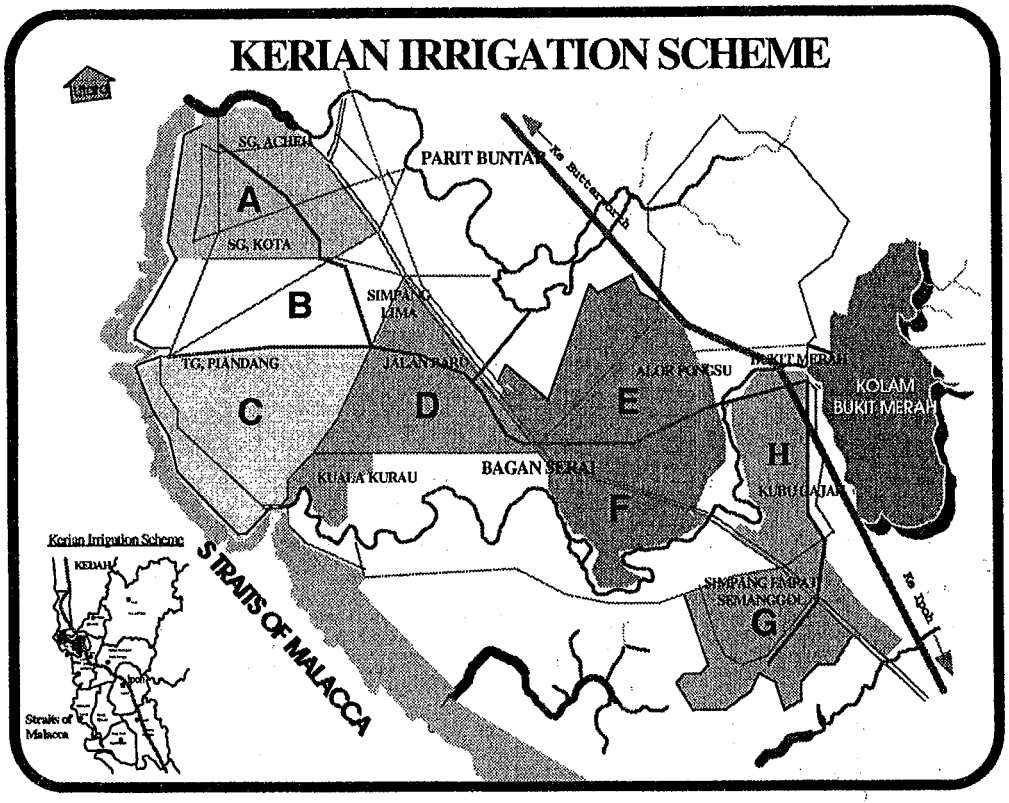

Fig. 1 Layout Plan of Kerian Irrigation Scheme

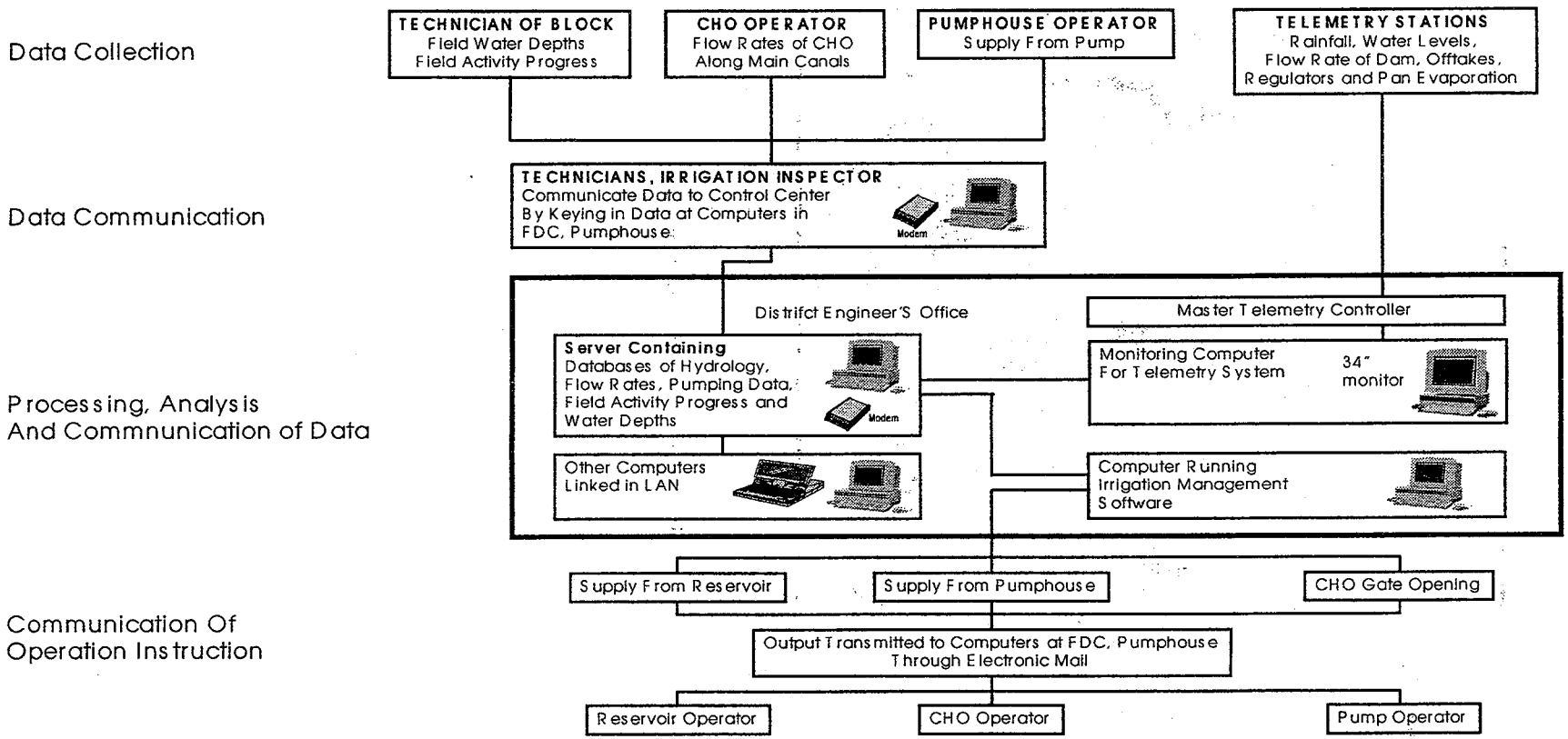

Fig. 2 - Schematic Layout for the Proposed Water Management and Control System

COMPUTER AIDED WATER MANAGEMENT EXPERIENCES FROM GALOYA IRRIGATION SCHEME IN SRI LANKA

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Abstract

Galoya Irrigation scheme is the largest irrigation scheme managed by the Irrigation Department of Sri Lanka. It provides irrigation facilities to 49,500 ha of mainly paddy land in the Eastern province. The irrigation system can be divided into three sub-systems: Right-Bank system, Left-Bank system and River System Division. A computer-aided water delivery scheduling system (decision support system) and improved communication network was implemented in mid 1980s in a section on the Left-Bank system, covering an area of 16,215 ha. The monitoring system links all the diversion points and offtake structures from the main canal with the Central Control Center at the Irrigation Engineer's office through a telephone system. Irrigation requirement Model (IRM) and System Operation Model (SOM) are the most important tools of the decision support system implemented in Galoya Left-Bank system.

The seasonal planning is done using the Irrigation Requirement Model (IRM). A cropping calendar is prepared specifying the percentage of irrigated area which falls into each category and the percentage of land that remain idle during each week of rotation. Five different cropping calendars can be input to the model to accommodate the variation of farming activities in the five management units. An important feature of the IRM is flexibility in making different schedules for each offtake, accommodating spatial variations in land soaking, land preparation and crop growth periods. The model can be used for both wet and dry seasons to calculate the irrigation requirements. The System Operation Model (SOM) uses the weekly irrigation requirements computed by IRM and estimates the flow rates at diversion points of the main canal and branch canals to maintain the required flows at offtakes. The flow measurements are conveyed every morning to the telephone stations by messengers riding push-bicycles. Similarly, evaporation and rainfall data are also collected and transmitted to the Control Center.

The computerized decision support system and the communication system have helped the management to smoothen the operation of the irrigation system throughout the cultivation season. The reliability of the irrigation supply has also improved. As a result, all the farmers have faith in the water delivery plan. Another benefit is the increase in the application of fertilizer, weedicides and pesticides, leading to an increase in the yield. The records show that irrigated area has increased and use of water from the reservoir has decreased after the new system was implemented.

1. Context of the System

Galoya Irrigation scheme is the largest irrigation scheme managed by the Irrigation Department of Sri Lanka. It provides irrigation facilities to 49,500 ha of mainly paddy land in the Eastern province. The infrastructure was built in early 1950s. The irrigation system can be divided into three sub-systems: Right-Bank system, Left-Bank system and River System Division.

The major water resources of the Galoya irrigation scheme are as follows:

a) Controlled supply from Galoya reservoir
b) Rainfall
c) Recycled drainage water from the left bank and right bank areas

The main crop cultivated is paddy. A part of the area under Right Bank is cultivated with sugar cane. At present, the farmers in the tail end of Right Bank command area practice dry-seeding In other areas wet seeding is practiced. There are two cultivation seasons: maha season falling between October and March when rainfall is abundant and yala season falling between comparatively dry April and September.

The farm size varies from 2 ha to 5 ha. However, in the older River System, the farm size varies from 25 to 50 ha.

2. Characteristics and Representation of the System

A computer-aided water scheduling and improved communication network was implemented in mid 1980s in a section on the Left Bank system, covering an area of 16,215 ha. The physical infrastructure in this area was rehabilitated in late 1980s, with improved canal profiles, gated control structures and flow measuring devices.

Main components of the infrastructure in the area concerned include, a 33 km long main canal, five branch canals having a total length of 53 km, 170 distributary and field canals taking off the main canal, and five intermediate reservoirs.

2.1 The Management System

The irrigation schemes coming under the Irrigation Department of Sri Lanka are managed as Divisions. An irrigation engineer is in charge of each Division. The Irrigation Engineer - Ampara Division manages the Galoya Left-Bank system. This is further divided into five units, which are separated by clear physical boundaries. A technical officer is responsible for the operation and maintenance of each unit. The Unit is divided into sections of approximately 200 ha. A Work Supervisor and a group of laborers are assigned to these sub-units to assist the technical officer in his duties.

In the main, branch and distributary canals, the flow is continuous. In principle, rotational water distribution is observed by the farmer organizations who operate the field channels.

3. Objectives of Computer-Aided Irrigation Scheduling

The overall objective of the computer-aided irrigation scheduling is to develop programs that could be run on a micro computer to meet the following requirements:

⇒ Assess weekly irrigation requirement at each offtake in the system. The assessment process should incorporate all factors that influence irrigation requirement such as rainfall, soil type and irrigated area.

⇒ Accumulate weekly irrigation requirements throughout the system and estimate the required flow in main and branch canals. In this process, factors such as canal losses, reservoir operations and drainage inflow should be included in the analysis.

⇒ Record weekly measurements of canal inflows and create a database documenting the actual system operation for the season. Compare the planned canal flow and measured flow and identify the areas for improvement.

4. Decision Process

4.1 Seasonal Planning

The seasonal planning is done using the Irrigation Requirement Model (IRM). This model uses the norms and equations used by the Irrigation Department for land soaking, land preparation and water requirements during crop growth.

Land Soaking Irrigation Requirement (LSIR) $= S_n/t + P + E_v - R_e$
Land Preparation Irrigation Requirement (LPIR) $= S_d + P + E_v - R_e$
Field Crop Irrigation Requirement (FCIR) $= P + Et_c - R_e$

where,

S_n - saturation requirement
t - time for saturation
P - percolation
E_v - evaporation
R_e - effective rainfall
S_d - submergence depth
Et_c - crop evapotranspiration

Total Water Requirement (TWR) $= LSIR * A_{ls} + LPIR * A_{lf} + FCIR * A_{ci}$

where,

A_{ls} - Area under land soaking
A_{lf} - Area under land preparation
A_{ci} - Area under crop irrigation

The above farming activities are monitored weekly during the season.

A cropping calendar is prepared specifying the percentage of irrigated area that falls into each category and the percentage of land that remain idle during each week of rotation. Five different cropping calendars can be input to the model to accommodate the variation of farming activities in the five management units.

The irrigation requirements calculated in this manner are compared with the design canal capacity. After making adjustments if necessary, the cropping plan and irrigation schedule are implemented.

⇒ Accumulate weekly irrigation requirements throughout the system and estimate the required flow in main and branch canals. In this process, factors such as canal losses, reservoir operations and drainage inflow should be included in the analysis.

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4.2 Daily Operation Process

The System Operation Model (SOM) uses the weekly irrigation requirements computed by IRM and estimates the flow rates at diversion points of the main canal and branch canals to maintain the required flows at offtakes. The conveyance losses, reservoir losses and drainage inflows are accounted for in this process.

The flow measurements are conveyed every morning to the telephone stations by messengers riding push-bicycles. Similarly, evaporation and rainfall data are also collected and transmitted to the Control Center.

The decision process is illustrated in Figure 1.

5. Irrigation Management Procedures and Implementation.

5.1 Management Tools

Irrigation requirement Model (IRM) and System Operation Model (SOM) are the most important tools of the decision support system implemented in Galoya Left-Bank system. These programs are written in BASIC language, to suit the configuration of Galoya system. Therefore, they are not generic models directly applicable to other systems.

An important feature of the IRM is flexibility in making different schedules for each offtake, accommodating spatial variations in land soaking, land preparation and crop growth periods. The model can be used for both wet and dry seasons.

The hardware include Radio Shack model 16-B micro-computer installed in 1984.

The monitoring system links all the diversion points and offtakes from the main canal with the Central Control Center at the Irrigation Engineer's office through a telephone system. While Parshall flumes and rated concrete sections measure the flow in main and branch canals, the flow measuring devices located in the distributary and field channels are broad-crested weirs (BCW) and trapezoidal flat bottom flumes

5.2 Achievements of the Computer Aided Irrigation Management System

The computerized decision support system and the communication system has helped the management to smoothen the operation of the irrigation system throughout the cultivation season. The reliability of the irrigation supply has also improved. As a result, all the farmers have faith in the water delivery plan. Another benefit is the increase in the application of fertilizer, weedicides and pesticides, leading to an increase in the yield. The records show that irrigated area has increased and use of water from the reservoir has decreased after the new system was implemented. Figure 2 shows the change of the amount of irrigated area. Figure 3 indicates the trend of water use.

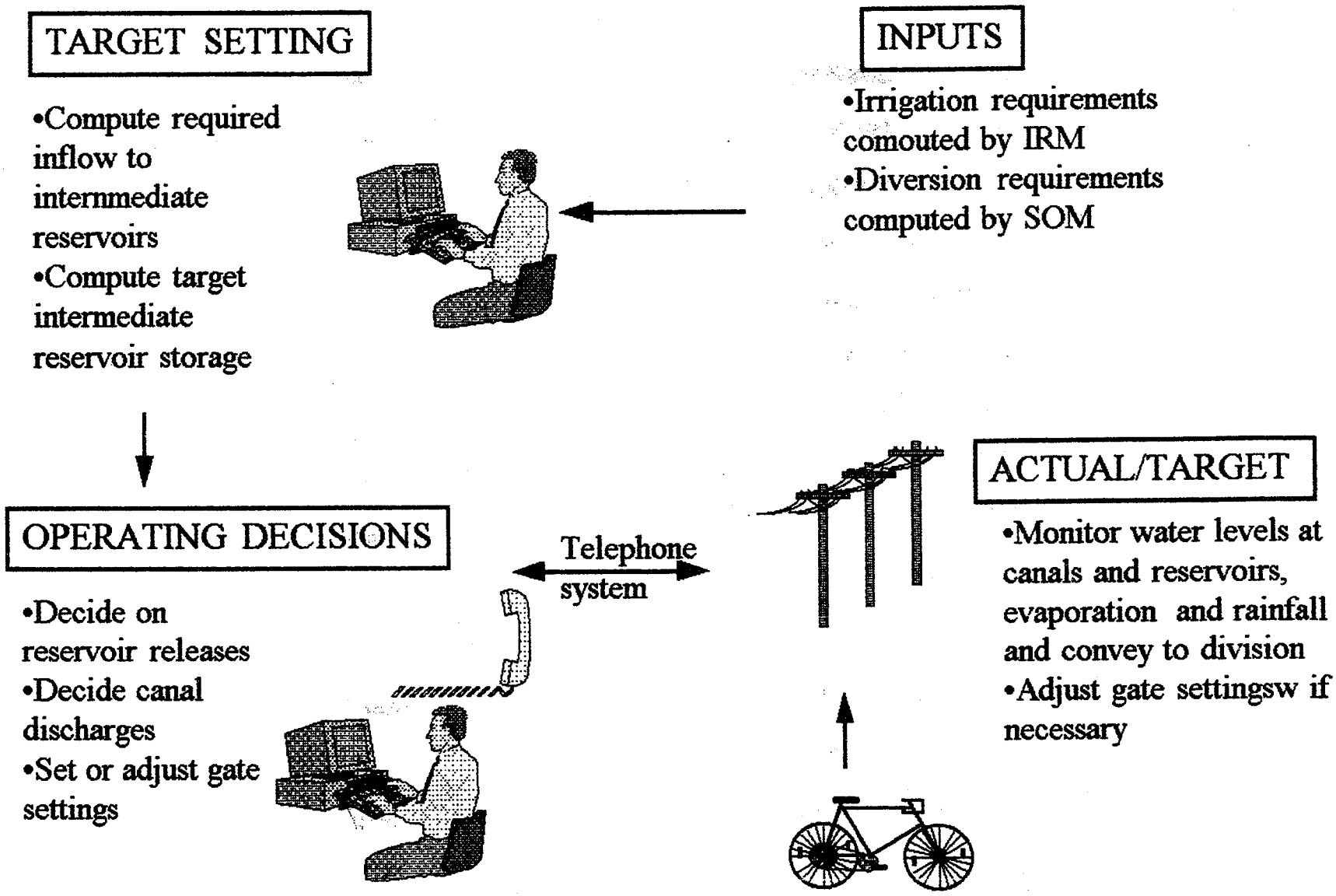
TARGET SETTING
•Compute required inflow to intermmediate reservoirs
•Compute target intermediate reservoir storage
INPUTS
•Irrigation requirements comouted by IRM
•Diversion requirements computed by SOM
OPERATING DECISIONS
•Decide on reservoir releases
•Decide canal discharges
•Set or adjust gate settings
Telephone system
ACTUAL/TARGET
•Monitor water levels at canals and reservoirs, evaporation and rainfall and convey to division
•Adjust gate settingsw if necessary

Figure 1

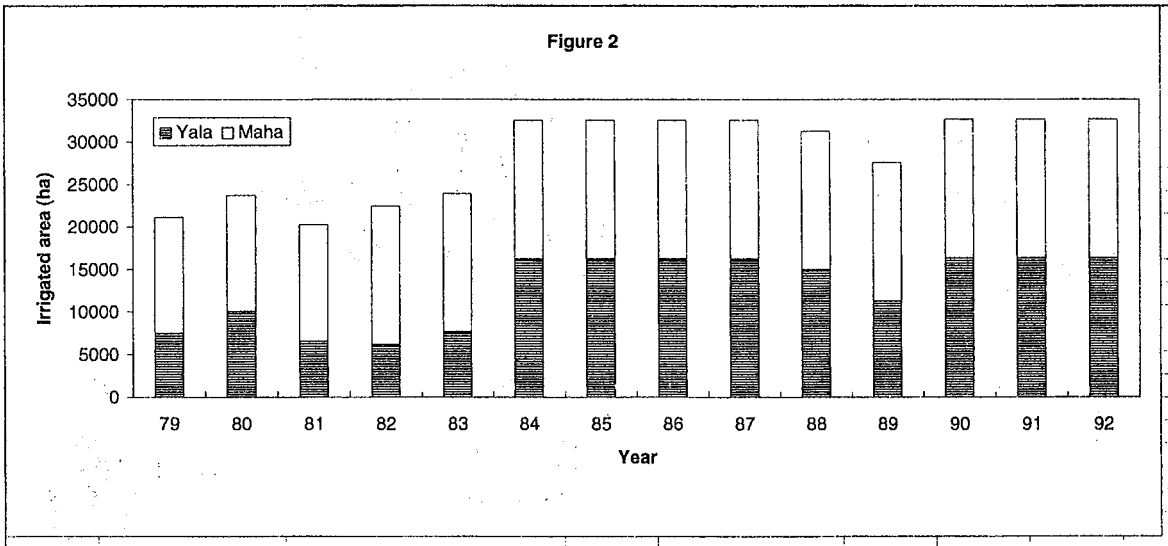
Figure 2
Yala
Maha
Irrigated area (ha)
35000
30000
25000
20000
15000
10000
5000
0
79
80
81
82
83
84
85
86
87
88
89
90
91
92
Year

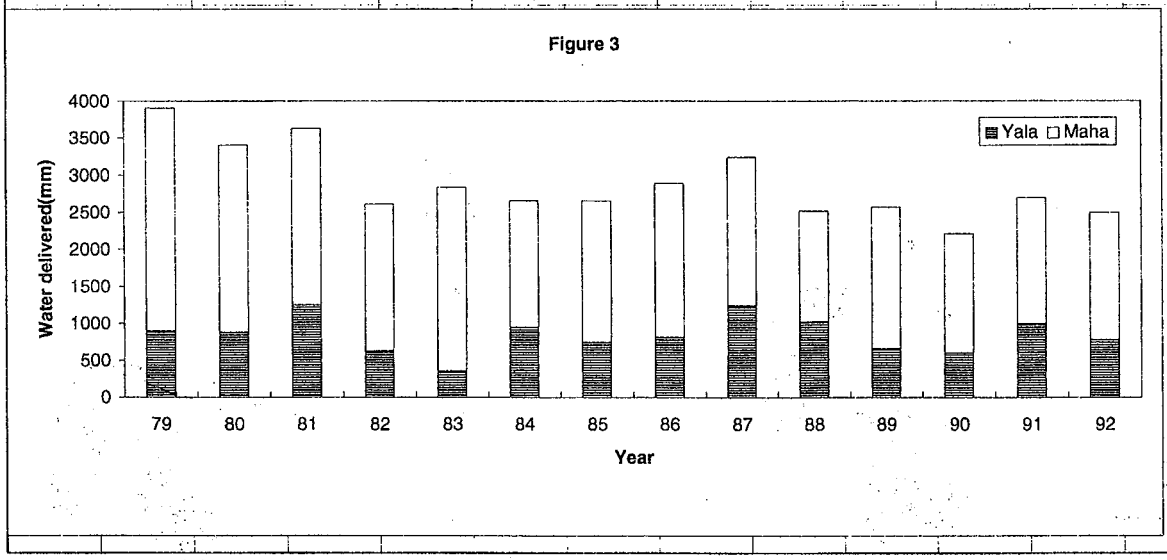
Figure 3
Yala
Maha
Water delivered(mm)
4000
3500
3000
2500
2000
1500
1000
500
0
79
80
81
82
83
84
85
86
87
88
89
90
91
92
Year

NEW SYSTEM OPERATION TOWARDS MORE FLEXIBILITY: ON-GOING STUDY FROM THE MAHAWELI SYSTEM B IN SRI LANKA

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Abstract

The System B irrigation scheme is the largest of the development areas under Mahaweli Development Project. Out of the designed irrigable area of 42,000 ha under System B, 28,000 ha lying on the left bank of Maduru Oya are in operation now. The remaining area on the right bank is yet to be developed. Although adequate water availability was assumed at the design stage, water deficits are predicted for the future due to the high water consumption in the developed area and the future water requirements of the area to be developed.

The constraints to smooth canal operation include transport and communication problems and manual canal operations which result in water level fluctuations in the main canal. Due to the recent trend of cultivation shifting from single-crop type to multiple crops, there is a need for the canal operation strategy to be made more flexible to cater for varying water demands of different crops. It is perceived that a management tool such as a computer-aided hydraulic simulation system could be useful to improve the efficiency of canal operations. A research has been implemented to study the possibility of developing computer-based tools to strengthen the canal manager's decision making power. The study will be implemented in three different phases. The first phase involves developing methodologies for the improving of present information system. The second phase deals with making a better understanding of the main canal behavior with the use of SIC hydraulic simulation model. Feedback on the findings of the second phase and the development of new operational guidelines will be planned during the third phase.

1. Context of the System

The Mahaweli Development Project is the largest single integrated regional development project ever undertaken by the Government of Sri Lanka. The project encompasses the construction of a series of reservoirs with facilities to generate 600 mega-Watt of hydro-power, providing about 365,000 ha of downstream land with irrigation facilities, establishing new farmer settlements and improving the agricultural production in newly developed areas.

The System B irrigation scheme is the largest of the development areas under Mahaweli Development Project. Out of the designed irrigable area of 42,000 ha under System B, 28,000 ha lying on the left bank of Maduru Oya are in operation now (see figure 1). The remaining area on the right bank is yet to be developed. The major soil group is Non-Calcic Brown Soil, which occupies about 41 percent of the area.

The irrigation scheme is located in the dry zone of Sri Lanka. The average annual rainfall is about 1700 mm. The major portion (75 percent) of this occurs during North-East monsoon from October to February. The remaining falls between April and September. The two cultivation seasons correspond with the rainfall pattern. Maha season cultivation is done during North-East monsoon period when irrigation supplements rainfall. During the yala season, which falls between April and September, the crops heavily depend on irrigation.

The designers of the irrigation scheme assumed that the System B would have a reliable and adequate water supply for two crops per year. This assumption was mainly based on the fact that the system lies downstream of the major storage and power generating facilities. Therefore, flexible water delivery scheduling based on crop water requirements, leading to high productivity was envisaged at that stage. However, water deficits are predicted for the future due to the high water consumption in the developed area and water requirements of the area to be developed.

2. Characteristics and Representation of the System

The major source of irrigation water is the Maduru Oya reservoir, which is supplemented by Mahaweli river through a trans-basin canal. The distribution network consists of a 53 km long LB main canal, 24 branch canals with a total length of 71 km, and several secondary canals taking off the main canal. The main and branch canals are concrete-lined. The offtake structures from the main canal are gated and of undershot type. Sixteen gated-cross-regulators control the water levels of main canal. All the regulator gates, including those which are radial gated, are manually operated. The design discharge in the main canal is 65 m^3 per second. A tertiary canal (field channel) irrigates about 16 ha.

2.1 The Management System

The Resident Project Manager (RPM) heads the management structure in System B. He is assisted by several Deputy Resident Project Managers (DRPMs), who handle specialized subjects such as land administration, agriculture, water management and community development. The scheme is divided into nine administrative blocks, which are managed by Block Managers. Each block covers about 2,000 to 2,500 ha with 2,500 to 3,000 farmer-families. A block is further divided into units managed by Unit Managers. Each unit provides water for about 250 to 300 ha with 300 to 350 farmer-families. The Unit Manager acts as the interface between the users and the management. While the agency manages the main, branch and distributary canal system, the farmers have the authority for the operation and maintenance of the field channels.

The average flow in a field channel is 28 liters per second (one cusec). Flow measuring facilities are available at all diversion points up to the field channel head gate.

3. Objectives of the Research Study to Improve Irrigation Management

A research has been implemented to study the possibility of using computer based tools to strengthen the canal manager's decision making power. The main objective of this study is to develop methodologies to provide a better service to farmers whilst maintaining reliability and flexibility of the irrigation supply. This will be achieved by strengthening the canal manager's

decision making power with the use of appropriate computer assisted tools. The study also envisages developing operational guidelines for the management of main canals with a variable weekly or daily flow pattern.

4. Decision Process

4.1 Seasonal Planning

The proposals for the each cultivation season are prepared by the Project's Seasonal Agricultural Planning Committee, in consultation with farmers. Usually the proposal is prepared well ahead of time, and forwarded to the Mahaweli Secretariat in Colombo. The proposal is examined there, and the general guideline for the season is formulated as the Seasonal Operation Plan(SOP). These guidelines contain the total extent to be cultivated, monthly allocation of water and the first and last dates of water issues.

The policy decisions for the seasonal agricultural program are made with due consideration given to the availability of water, climatic conditions, market potential and other socio-economic factors. These decisions are conveyed to, and discussed with the farmer leaders at the pre-cultivation meeting. As a result the farmers have the opportunity to consult the fellow farmers and express their ideas at the cultivation meeting. Any adjustments to the proposed plan could be made at this stage, provided the changes are within the SOP.

4.2 Canal Operations During the Cultivation Season

Irrigation staff attached to each block office is responsible for making irrigation schedules and implementing them. The turnout irrigation schedule for the coming week is prepared before 12:00 hr.s each Saturday. Irrigation schedules are prepared considering the field irrigation requirements, which are estimated with respect to the following:

- The agricultural plan set up by the field channel farmer organization
- The limits set by the agricultural program decided at the project level
- The recommended water allocations for average soil conditions, and
- The allowances for canal losses.

In preparation of the schedule, the data related to the cultivation program planned for the each week will be considered with the other relevant information such as total extent recommended for the season, extent ready for land preparation, extent cultivated, extents under different cropping stages. This enables the management to quantify the water requirements, based on the recommended water allocations for different phases of the cultivation, with a reasonable accuracy.

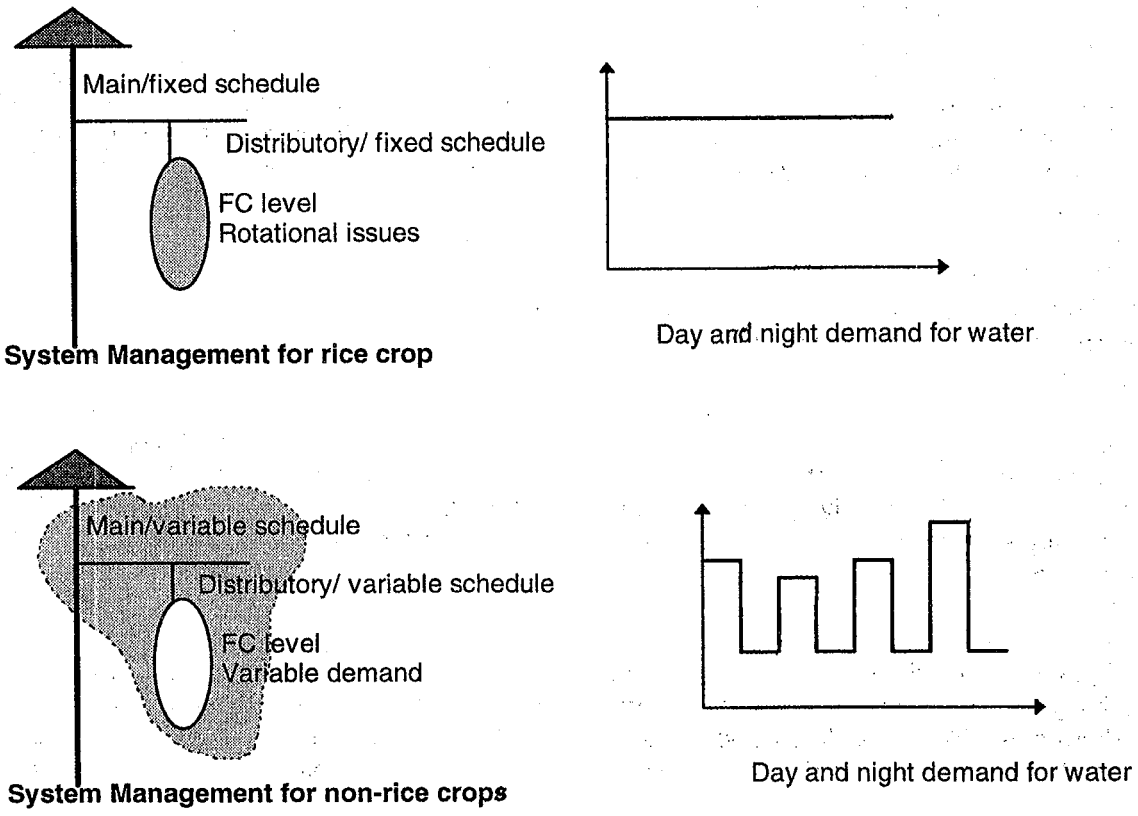
The irrigation schedule indicates the volume of water needed at all the turnouts for the forthcoming week. These volumes are expressed as flow rates to be delivered to the head of the field channels for a specified period of time. The turnout schedules prepared in this manner are the building blocks of the D-canal weekly operation plan, and those in turn are the basis for daily water orders.

The guidance for canal operations is provided by the Project Operation & Maintenance (O&M) Manual. The Block level staff furnish water orders following these guidelines. In response to these orders the Project level staff operate the main canal.

The constraints to smooth canal operation include transport and communication problems. As a result, water orders are not placed daily or at pre-arranged times. In the absence of an order, the main canal operator assumes that the block order for the present day is as same as the previous day. Manual canal operations are another constraint. A considerable amount of water level fluctuations in the main canal has been observed due to this, making it difficult for the staff of the Block Manager to provide a reliable water supply to the farmers.

Farmers in System B are now shifting from paddy cultivation to the cultivation of other crops and no-traditional crops such as gherkins, sweet melon and baby corn. Therefore, there is a need for the canal operation strategy to be made more flexible to cater for varying water demands of different crops. The ability to change the flow rapidly, while keeping fluctuation of flow in the main canal to a minimum, is the key to flexible canal operation without excessive water use.

In order to move towards a more demand driven operational system, many trial-and-error attempts have been made so far. However, the achievements to date are not very satisfactory. As shown by Figure 1, when moving from rice based systems to multi-cropped systems, there is a need for changing targets even on a day to day basis.



It is perceived that the use of a management tool such as a computer-aided hydraulic simulation system could be useful to improve the efficiency of canal operations, by providing a better understanding of the irrigation system and by facilitating the decision making process.

5. Implementation of the Study

The study will be implemented in three different phases. The first phase involves developing methodologies for the strengthening of present information system. This includes installation of gauges for gated cross regulators, more systematic data collection, storing and processing system. IMIS, a software developed by IIMI-ITIS Unit will be used to store and process the data.

The second phase deals with making a better understanding of the main canal behavior with the use of SIC hydraulic simulation model. The different steps of this phase are as follows:

- Building of SIC model: This task is completed already.
- Calibration of the model: Initial calibrations are completed.
- Sensitivity analysis: It is expected to conduct a comprehensive study to identify the more sensitive regulating devices to formulate proper operating guidelines.
- Studying the wave propagation pattern: to assess the time lag between the discharge change at the main sluice, and the reaching of a new steady state along the main canal. Wave propagation under various conditions will be recorded at site and compared with the SIC simulations.

During the third phase emphasis will be given to feedback the findings of the previous phases. Information collected and stored in the information system IMIS, will be initially used for improved understanding of the irrigation system behavior and its response to different hydraulic conditions. It is also expected to continue the current studies to evaluate the system performance with the Simulated impact (SIC outputs) and Real impact on sites (actual data).

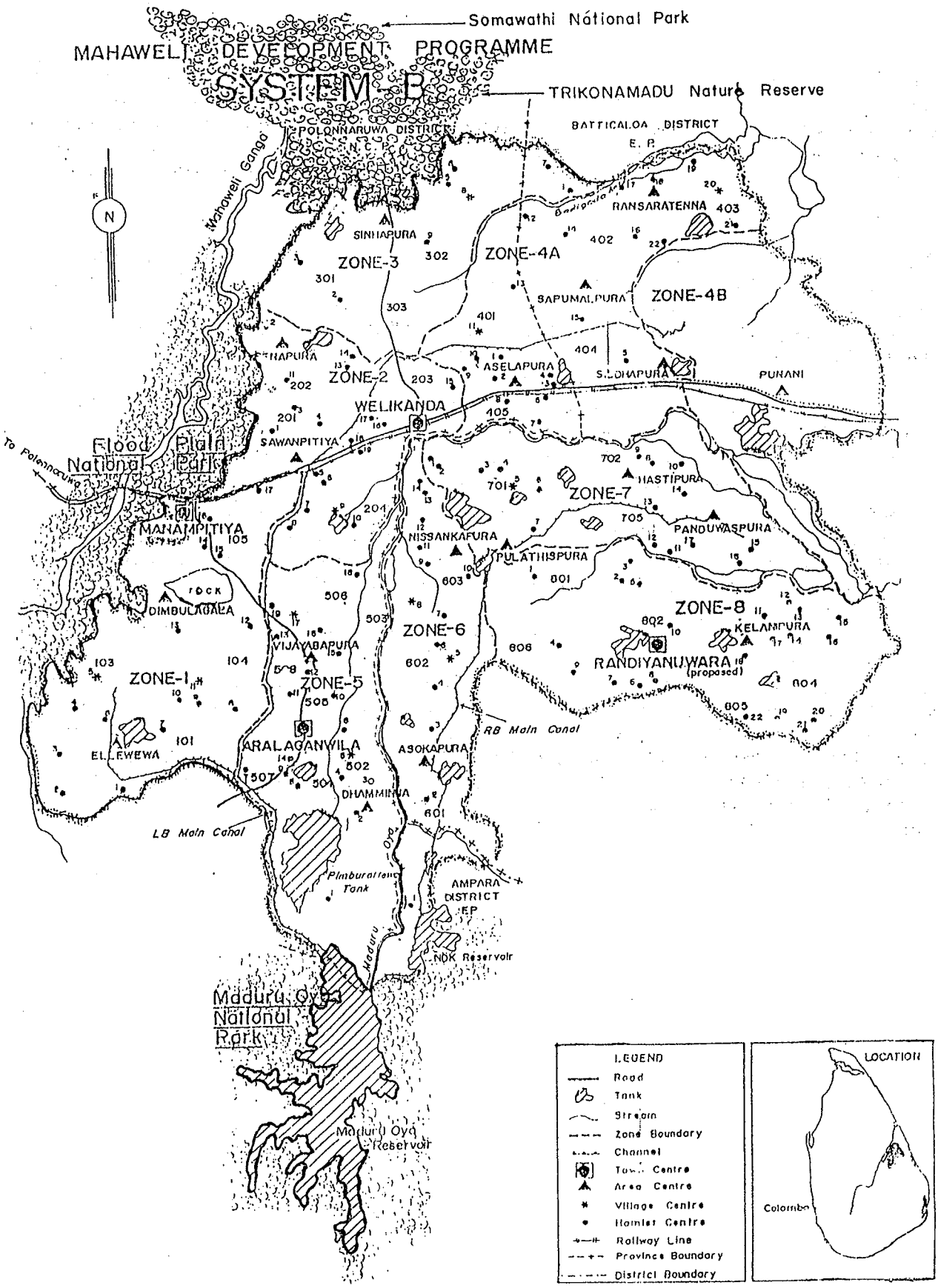


Figure 1: Mahaweli Development Program: System 'B'

WATER SCHEDULING IN THAILAND'S IRRIGATION PROJECTS: THE CASE OF WASAM PROGRAM IN THE MEKLONG PROJECT

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Abstract

The Greater Chao Pharya Project in the Central Plain of Thailand was constructed in 1960s. The project was expanded to provide irrigation facilities for the Western part of the delta in 1970s after the construction of the Greater Meklong Project. The Western part of the delta receives water from the Meklong basin. This area can be considered as water-abundant compared with the Chao Pharya project. A part of the waters of Meklong area is diverted to the lower Chao-Pharya area.

The improved infrastructure facilities have allowed the management of the Greater Meklong Project to computerize the canal operation and management, using a software called WASAM. which helps to calculate the required discharges at the regulators. The output is conveyed to the field staff to adjust the gates accordingly. During the weekly canal operations, there is a regular monitoring and feedback process between the field staff and the computer center. The water allocation is demand-based in principle. However, the quantities can be modified according to the availability of water resources.

Among the problems experienced in the application of WASAM computer model is the difficulty of accurate data collection, due to the large number of crops cultivated and inadequacy of staff. Another constraint is that the amount of water drawn from other water sources is not known accurately. The lack of a benefit or a reward for matching the water deliveries to the requirements is also absent. This has led to the monitoring and feedback system to operate in a routine manner, and threatens the viability of the process too. However, the water demands from the other competing sectors are on the increase. Therefore, the water management in the Meklong project needs to be improved in the near future.

1. Context of the System

About 4.5 million ha of the cultivated area of Thailand are irrigated. The Thai irrigation projects can be divided into two categories: people's irrigation projects managed by the farmers and the projects initiated and managed by Royal Irrigation Department. The first category is found mostly in the Northern region. The second includes large, medium and small scale projects, such as dams constructed for irrigation in North-East and the extensive river diversion network in the Central Plain.

The Greater Chao Pharya Project in the Central Plain was constructed in 1960s. It covers a gross area of 1.4 million ha. The project was expanded to provide irrigation facilities for the Western part of the delta in 1970s, after the construction of the Greater Meklong Project. The locations of the two projects are shown by the Figure 1.

The Western part of the delta receives water from the Meklong basin. This area can be considered as water-abundant compared with Chao Pharya project. A part of the waters of Meklong area is diverted to the lower Chao-Pharya area.

During the rainy season, the water management in the Chao Pharya Project concerns dealing with the excess water. But the overall water availability is not sufficient to meet the demand. As a result, the seasonal irrigation scheduling is supply oriented. The quantity of water released is based on the dam storage.

2. Characteristics and representation of the System

The primary and secondary canals in the Greater Meklong Project are lined. The canals, which are equipped with regulating devices, have adequate design capacities to supply water to fulfill the crop demands. These facilities have allowed the management to computerize the canal operation and management, using a software called WASAM (Water Allocation, Scheduling and Monitoring). The Software was developed by Euroconsult.

Four levels can be identified in the management structure of the Greater Meklong Project. Starting from the bottom, the first is the tertiary or the farm level, where the farm ditches are managed by the farmers. The secondary canal system is managed by the Zonemen employed by the irrigation agency. The main office of the sub-project manages the primary canal system. Finally, the management responsibilities of the feeder canals rest with the Regional Office.

In the Chao Pharya Project, the available water is allocated among the six main canals and rivers, which distribute water over the delta. The distribution is based on the cropping activities of the corresponding areas. However, the water requirements of the lower delta, for such needs as salinity intrusion control, transportation and renewal of polluted waters also have to be considered when allocating water. Therefore, the experience of the agency staff plays a key role in the irrigation management in this project.

3. The Decision Process

The command area of Greater Meklong Project is divided into several hydraulic units called Sections to facilitate the application of WASAM model. The water requirement for each Section is calculated using the parameters such as crop coefficients, effetive rainfall and evapotranspiration. They are updated each week with respect to the observed field wetness. The required discharges at the regulators are calculated using these water requirements. The output is conveyed to the Zonemen and the Gate Keepers to adjust the gates accordingly.

During the weekly canal operations, there is a regular monitoring and feedback process between the Zonemen and the computer center. The output of this process is produced as monitoring reports, which include comparisons between theoretical and actual water requirements and effective water supply. The water allocation is demand-based in principle, although the quantities can be modified according to the availability of water resources.

4. Constraints and Limitations of the Present Irrigation Management Process

The WASAM computer model requires a substantial amount of field data to be operated. The Zoneman is expected to collect the data such as crop progress, cropping pattern and field wetness in an area of about 2000 ha. Due to the large number of crops cultivated and inadequacy of staff, the data collection has become a very tedious task. This affetcs the accuracy and precision of the data.

Due to the unreliable water supply from the canal system, farmers depend substantially on other water resources such as tube wells. However, the amount of water drawn from other sources is not known accurately. It is suspected that the actual use of canal water can be as low as 70 percent of the present estimate. This also complicates the use of the computer model.

Effective water management should respond to the changes of local crop water demands. A feature of the four-tier management structure in this irrigation scheme is, unless a substantial water shortage is experienced, a request for the adjustment of flow is not conveyed from one level to the next upper level. As a result, when little or no water shortage is experienced, any change of the flow rate is unlikely. Further to this, a certain amount of water is intentionally transferred from the Meklong Project to the Chao Pharya System as drainage water. Therefore, there is no benefit or reward for matching the water deliveries to the requirements.

These conditions affect the accuracy of data collected and timely transmission, because the Zonemen perceive that the data are not effectively used for canal operations. This has led to the monitoring and feedback system to operate in a routine manner, and the viability of the process is also threatened.

However, the situation does not allow complacency because the water demands from the other competing sectors are on the increase. An example is the increased abstraction of water for the city of Bangkok, upstream of the project area. Therefore, the water management in the Meklong project needs to be improved in the near future.

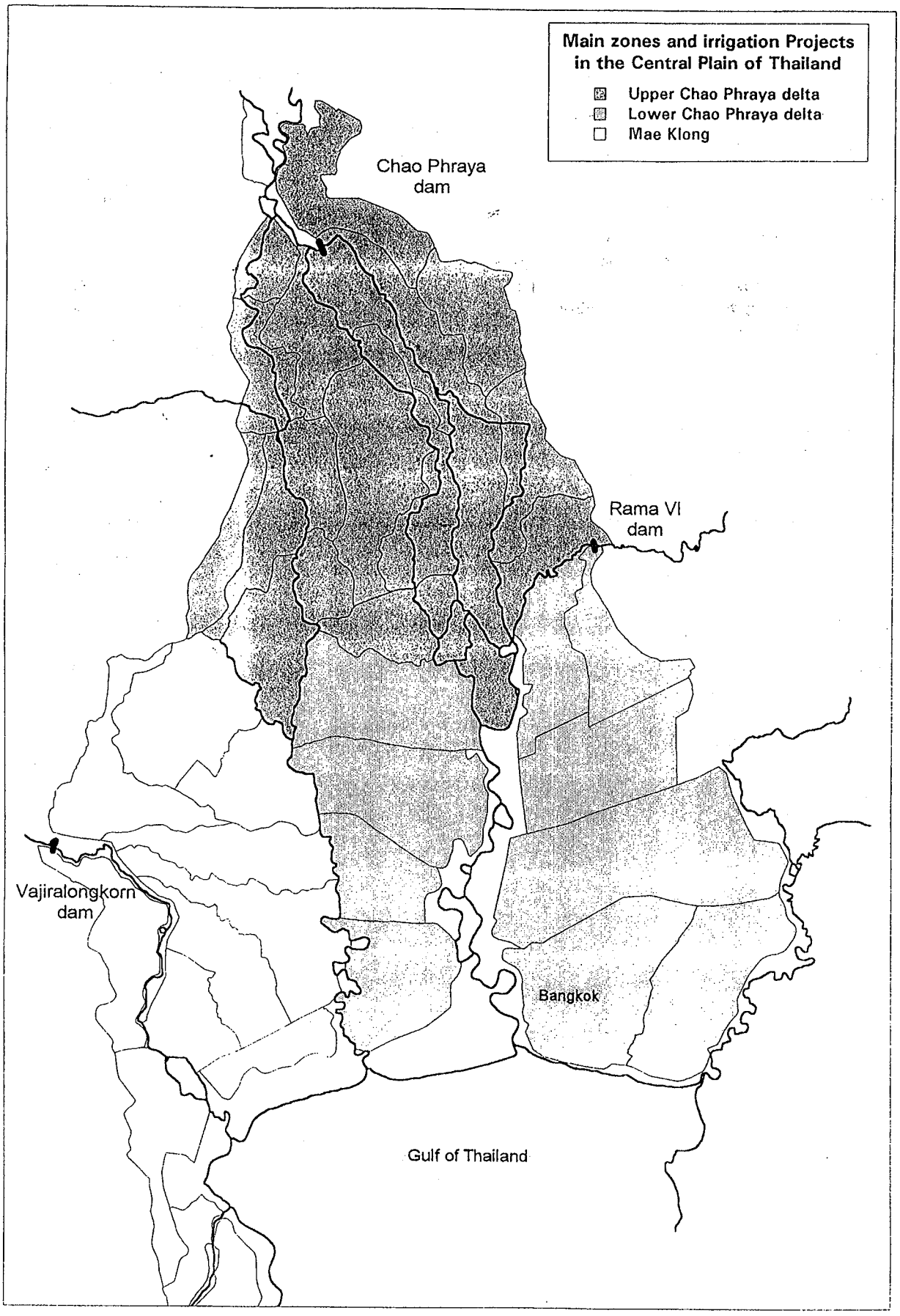
Main zones and irrigation Projects in the Central Plain of Thailand
Upper Chao Phraya delta
Lower Chao Phraya delta
Mae Klong
Chao Phraya dam
Rama VI dam
Vajiralongkorn dam
Bangkok
Gulf of Thailand

Figure 1

CANAL CONTROL AND COMMUNICATION PILOT PROJECT, KHADAKWASLA IRRIGATION SCHEME

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Abstract

Khadakwasla irrigation scheme is located in the State of Maharashtra, India. The principal components of the irrigation infrastructure are two storage reservoirs, a pick-up dam, a 170 km long main canal, and an irrigation distributary system consisting of two branch canals and sixty distributaries and direct outlets taking off from main canal. About two-thirds of the designed irrigable area of 62,146 ha under this main canal are in operation now, while the remaining is under development.

The main objective of providing irrigation facilities is to provide water for cultivation in the rabi and hot weather seasons, which are dry. Water resources are planned to ensure proper utilization of reservoir storage at the end of rainy (Kharif) season through rest of the irrigation year. However, manual operations and irrigation scheduling hinder efficient, timely and reliable distribution of water along this substantially long main canal. To alleviate these problems, a computer-assisted irrigation management system is being introduced now, as a pilot project.

The main objectives of this pilot project are to optimize the exploitation of available water resources and to facilitate decision making for effective canal management, and minimize the variation of demand at the main canal by computerized scheduling. Canal Irrigation Management System (CIMS) which is being implemented now, is the first phase of implementation. The decision support system produces irrigation schedules for each rotation, for individual offtakes, using an optimization technique. It also simulates water levels and flows in the main canal and computes gate settings of control structures. These targets are based on crop water requirements. The telemetry sub-system monitors the water levels at target locations and feeds back to the Controlling Division. As a result, real-time monitoring of flow conditions is possible. The data are transmitted to the central computer system through the telemetry system.

In the phases to follow, it is envisaged to increase the number of real-time canal monitoring locations and to simulate canal flow under non-steady flow conditions in order to evolve a control strategy for the main canal. It is also planned to develop a revenue information and billing system.

1. Context of the System

Khadakwasla irrigation scheme, located in the State of Maharashtra, India, was originally designed in 1873 to irrigate a small area in Pune district. This irrigation system was subsequently enlarged and developed in stages to the present state.

Annual rainfall in the command area varies between 500 mm to 750 mm, average annual rainfall being 610 mm. Over 90 percent of this occurs between June and September. The terrain gently slopes towards Mutha-Bhima river, which forms one boundary of the command area. The drainage water flows to the river. A few patches of high ground are irrigated by pumping.

Major soil type in the area is black cotton soil. The crops grown include wheat, sorghum, sugarcane, cotton, gram, pulses, pearl millet, maize and sunflower. They are grown in three cultivation seasons: kharif (June to Mid October), rabi (mid October to February) and hot weather season (March to June).

The priority order for allocating water in the decreasing order is as follows:

i. domestic water supply
ii. irrigation of perennial crops under long-term sanctions
iii. irrigation of seasonal crops

The planning for rabi and hot weather irrigation is carried out at least a month before the starting of rabi. No prior planning is done for kharif irrigation supplies. The practice is to release the amount of water likely to spill over during the rainy season, for irrigation. However, in a dry year, 2o percent of the storage can be utilized for irrigation in kharif season.

2. Characteristics and Representation of the System

The principal components of the present irrigation infrastructure are as follows:

- Two storage reservoirs and a pick-up dam.
- A 170 km long main canal that serves both the irrigation needs of the command area and water supply needs of Pune city.
- Two branch canals and sixty distributaries and direct outlets taking off from main canal.

A new main canal called New Mutha Right Bank Canal (NMRBC) was constructed in the 1960s. Out of the originally designed irrigable area of 62,146 ha under this canal, about two-thirds are in operation now. The remaining is under development.

2.1 The Management System

Planning for water distribution is essentially crop-based. However, daily operations are of on-demand type, constrained by the available storage. Farmers participate in the seasonal planning by making applications for irrigation water, based on areas to be cultivated under each crop. They forward their applications to the Section Office, which is the interface between the users and the officers. The principle of canal operation followed in the scheme is called Shejpali, which is a demand based system.

The canal system is divided into several Sub-Divisions, which are controlled by Sub-Division offices. The Division office controls the water releases to the main canal. The periods during which the canals are supplied with water are called "turns" or "rotations".

Information techniques are being introduced as a pilot project, to plan, schedule and monitor irrigation in the scheme. The Canal Irrigation Management System (CIMS) which is being implemented now, is the first phase of the project. It comprises of installing two sub systems: a decision support system for planning and scheduling and a telemetry system for monitoring and feedback.

3. Objectives

The main objective of providing irrigation facilities is to provide water for cultivation and other purposes in the rabi and hot weather seasons. Water resources are planned to ensure proper utilization of reservoir storage at the end of the rainy (Kharif) season through the rest of the irrigation year.

4. Decision Process

4.1 Seasonal Planning

The objective of seasonal planning (also called Preliminary Irrigation Scheduling) is to quantify the anticipated demand and available supply at the project level for rabi and hot weather seasons. During this process, water requirements for proposed crop areas and water requirements for non-agricultural uses are added together to arrive at the total volume of water required for the two seasons.

The seasonal planning process begins with the farmers' requests for water being forwarded with the areas to be cultivated under each crop. The Irrigation Department accords sanction for irrigation after considering available storage, established priorities and other relevant factors.

Using the irrigation supply norms expressed in area irrigated per day-cusec (AIDC), an irrigation schedule for each outlet is prepared at the Section Office and communicated to farmers.

4.2 Daily Operation Process

For each turn or rotation, water allocations for Sub-Divisions are made according to the indents generated at the Section Offices. These indents, which are based on supply norms, are conveyed to the Controlling Division via Sub-Divisions. Following this, the Executive Engineer in charge of the Controlling Division decides the water allocation schedule to Sub-Divisions. Changes to water demand due to events such as rainfall are also accommodated. The finalized schedule of main canal operation is communicated daily to the Sub-Divisions, during the rotation.

The irrigation schedule prepared in this manner contains the number of days for each turn. The time at which water supply to each distributary should start is decided at the individual Section Offices. Before implementing, this is reviewed at the Sub-Division to minimize the fluctuation of daily demand in the main canal.

The canal flow is monitored at distributary and main canal levels. The canal flow levels at the head of the distributaries are measured by Section Office staff and the data were communicated to the Division office twice a day. Main canal flow is measured at the boundaries of Sub-Divisions, and the data are conveyed to the Division office.

The communication network, which is being replaced by an information technology based system, is composed of three tiers. The primary network connects all the important dams to respective administration centers of the Irrigation Department. The secondary network provides communication among Sub-Divisions and links them with the Division office. The tertiary network supports voice communication between Section Offices and Sub-Divisions. The data are transmitted through VHF voice communication links.

The previous system of decision making can be represented by the Figure 1.

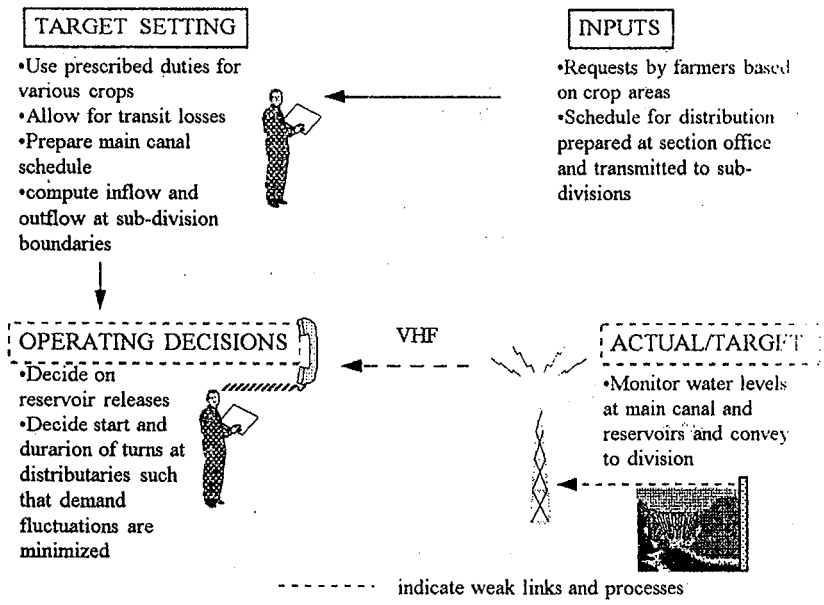


Figure 1 - A Schematic Representation of the Decision Process Without the Proposed IT Based Canal Management System

4.3 Constraints and Limitations of the Previous System

One of the principles followed in preparing the irrigation schedule is to ensure minimum fluctuation in daily water demand in the main canal. The experience shows that this is a difficult task when done manually.

Another observation is that it takes about 24 hours for a tail-end distributary, to feel the effect of a change of water supply in the main canal. Therefore, accommodating the daily changes of water demand in the irrigation schedule is a very complicated exercise with the present irrigation management system.

During the reservoir-filling period, a maximum permissible level of storage is maintained to ensure the safety of the dams and control the floods. The present method of observing this is mainly based on the experience of the Irrigation Department. It is questionable whether this method is competent enough to ensure that the reservoirs are filled up by the end of monsoon period, at an acceptable level of probability.

Some limitations to transmit data from remote locations are imposed by the VHF system. Repeater stations have been set up to overcome this. Further, the system covers only the field offices and flow observation and control points along the main canal were not linked with the Sub-Divisions or Controlling Divisions. As a result, timely monitoring of canal flow conditions and comparing them with planned schedule was not possible. Occurrence of rainfall or an emergency situation is conveyed with a time lag.

5. Irrigation Management Procedures and Implementation.

5.1 Management Tools

A pilot project has been launched in Khadakwasla irrigation system to improve the efficiency of irrigation system management using information techniques. This is implemented in three phases. During the first phase, a decision support system and facilities for real time monitoring are developed and established.

The main objectives of information technology (IT) based management system are as follows:

- optimize the exploitation of available water resources to improve the efficiency of canal operation.
- facilitate decision making for effective canal management and minimize the variation of demand at the main canal by scheduling canal operations with a computer model.
- facilitate acquisition, storage and transmission of canal flow data to the central computer system using a telemetry system.

The Canal Irrigation Management System (CIMS) developed under phase one is comprised of the following two sub-systems:

- telemetry sub-system which acquires real-time canal flow, river flow, reservoir storage and agro-meteorological data from various remote locations. The collected data are processed and stored in the computers.
- irrigation management sub-system which performs as a decision support system (DSS). It helps the management in planning and monitoring irrigation system operations. This sub-system consists of the following seven modules:

    - Data Transfer and Processing Module
    - Configuration Data Maintenance Module
    - Reservoir Operation Module
    - Irrigation Planning Module
    - Canal Scheduling Module
    - Flow Simulation Module
    - Management Reports Module

The decision support system produces irrigation schedules for each rotation, for individual offtakes, using an optimization technique. It also simulates water levels and flows in the main canal and computes gate settings of control structures. These targets are based on crop water requirements.

The telemetry sub-system monitors the water levels at target locations and feeds back to the Controlling Division. Under the new system, real-time monitoring of flow conditions is possible. The data are transmitted to the central computer system through the telemetry system.

Hardware configuration of CIMS is as follows:

- A Front-End System to acquire data from remote locations and to transmit them to the main system. This is a DOS operated 286 computer, connected to the main system through an RS 232-C communication link.
- A main system for running the irrigation management sub-system. This is a UNIX based, 486 computer system with two terminals.

In the phases to follow, it is envisaged to increase the number of real-time canal monitoring locations and to simulate canal flow under non-steady flow conditions in order to evolve a control strategy for the main canal. It is also planned to develop a revenue information and billing system.

Representation of the decision process after the new communication system and decision support system are installed is illustrated by Figure 2.

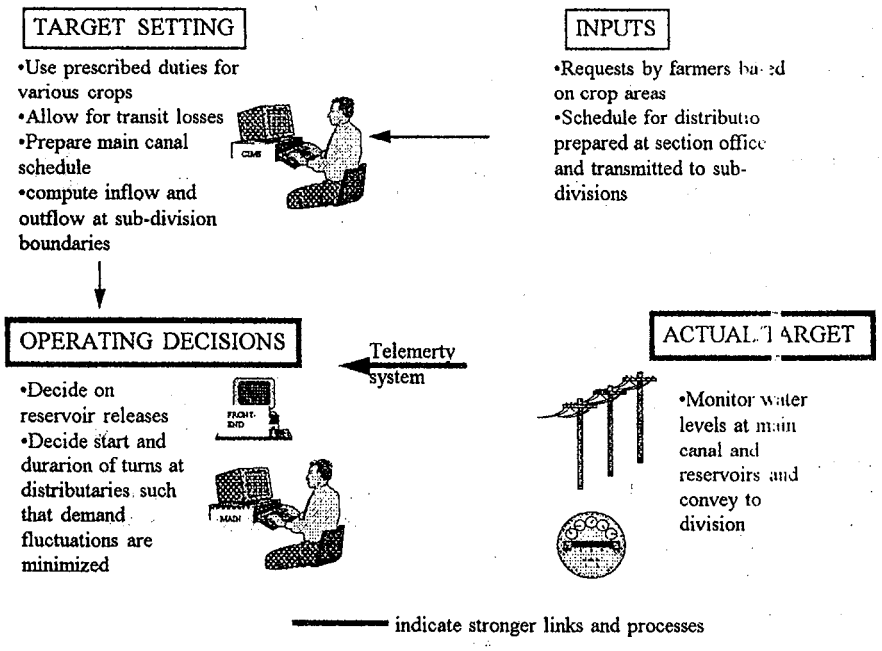


Figure 2 - A Schematic Representation of the Decision Process After the Introduction of CIMS

5.2 Expected Advantages of the System

Reservoir operation module produces a set of 'rule curves' which facilitate the operation of reservoirs. It is expected that this will help to increase the possibility of full reservoirs at the end of the rainy season. Seasonal planning and scheduling of canal operations are also expected to improve when CIMS is fully implemented. Real-time monitoring of reservoir and canal flow conditions are possible with the new telemetry system. Before its implementation, communication system extended down to the field offices only.

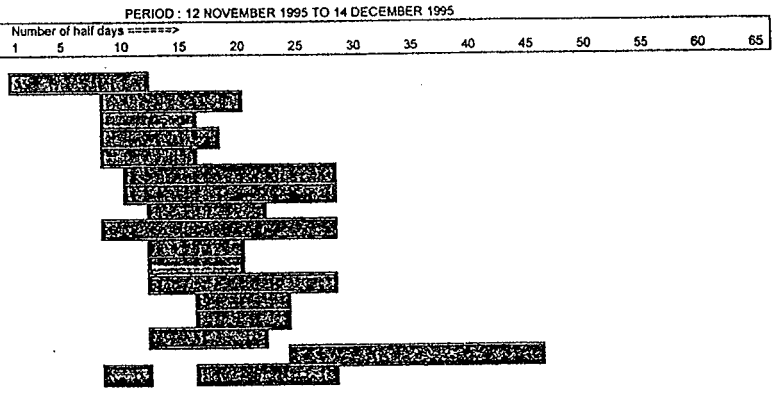
A comparison of the irrigation schedules made in 1995-96 rabi season produced encouraging results for the advocates of CIMS. The results show that the maximum discharge required in the main canal reduced by about 8 percent. The duration of canal waterings were also reduced considerably. For example, in Daund Sub-Division, the duration reduced from 14 days with manual scheduling to 10 days with CIMS-assisted scheduling. The net effect was a reduction in total canal losses by about 7 percent. Some of these features are illustrated by the Figure 3, which uses the Daund Sub-Division as a sample.

CANAL OPERATION SCHEDULE OF NEW MUTHA RIGHT BANK CANAL

CROP SEASON : RABI, ROTATION NUMBER : 1, MANUALLY PREPARED SCHEDULE

PERIOD : 12 NOVEMBER 1995 TO 14 DECEMBER 1995

DAUND SUB-DIVISION	CAPACIT (cfs)	DEMAND (day-cfs)	SUPPLY (day-cfs)
BELOW KM.172	160	1212	1212
Dist. - 46	10	60	60
Dist. - 45	20	75	75
Dist. - 44	20	90	90
Dist. - 43	10	39	39
Dist. - 41	25	210	210
Dist. - 40	12	91	91
Dist. - 39	6	26	26
Dist. - 38	1	10	10
Dist. - 37	3	12	12
Dist. - 36	10	40	40
Dist. - 35	25	200	200
Dist. - 34	3	10	10
Dist. - 33	3	7	7
Dist. - 32	25	135	135
BIGWAN BRANCH	190	1600	1600
LIFT-DAUND	10	100	100



NOTE : Offtakes are operated with variable flow.

CANAL OPERATION SCHEDULE OF NEW MUTHA RIGHT BANK CANAL

CROP SEASON : RABI, ROTATION NUMBER : 1, SCHEDULE PREPARED USING CIMS

PERIOD : 12 NOVEMBER 1995 TO 13 DECEMBER 1995

DAUND SUB-DIVISION	CAPACITY (cfs)	DEMAND (day-cfs)	SUPPLY (day-cfs)
BELOW KM.172	160	1212	1212
Dist. - 46	10	60	60
Dist. - 45	20	75	80
Dist. - 44	20	90	90
Dist. - 43	10	39	40
Dist. - 41	25	210	2123.5
Dist. - 40	12	91	90
Dist. - 39	6	26	27
Dist. - 38	1	10	10
Dist. - 37	3	12	12
Dist. - 36	10	40	40
Dist. - 35	25	200	200
Dist. - 34	3	10	10.5
Dist. - 33	3	7	7.5
Dist. - 32	25	135	137.5
BIGWAN BRANCH	190	1600	1620
LIFT-DAUND	10	100	100

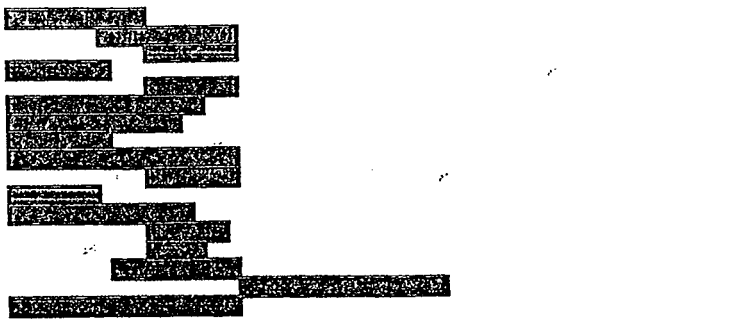


Figure 3

It is estimated that improved irrigation planning and scheduling have the potential of saving 5 to 10 percent of the total live storage per year. The savings are mainly related to the duration of canal waterings. The managers have also found that the identification of the improvement needs of the physical system, which would result in cost effective enhancement of system operation, can be achieved through the new management system.

5.3 Implementation Problems and Challenges

The irrigation managers faced several difficulties and challenges during the installation of communication facilities. VHF transceivers had to be tuned to the limited range of frequencies allocated by the government. This resulted in certain problems at the installation stage of the telemetry system. Construction of shelters for the equipment in remote locations, such as dam sites situated in hilly terrain, impeded the progress of work. Providing a reliable power supply to some locations continues to hinder smooth operation of the system.

WATER ALLOCATION IN EGYPT: AN OVERVIEW

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[2]

Abstract

The 6,825 km long Nile river is reputed as the longest one in the world. It is the main water resource of Egypt. About 99 percent of the population lives in small patch of land centered around Nile valley and Nile delta. The other water resources are rainfall, drainage water reuse and ground water. The irrigated land in Egypt is divided into five regions. The Upper and Middle Egypt regions are located in the Nile valley. The East, Middle and West Delta regions are located in the Nile Delta. Five levels can be identified in the irrigation management structure. They are the Central (Irrigation Sector), Directorate, Inspectorate, District and the Farmer levels.

The water duties for Upper, Middle and lower Egypt are calculated at the Central Level of the agency using the Nile Water Management Model. A mathematical model called DIRECT compiles the crop pattern data and compute the canal flow rates in a District.

Several modifications of the existing management system, which are needed to improve the irrigation efficiency are identified. The regulators that separate neighboring General Directorates need to be calibrated. A proper monitoring system would reveal the constraints for water allocation. The continuous consultation among the government agencies is required facilitate the modification of the plan of releases, quantification of the sufficient amount of water, and the timing of the deliveries. Among the challenges the irrigation managers are likely to meet in the future are the pollution of drainage water, which may affect the chances of its reuse.

1. Context of the System

The Nile river is the main water resource of Egypt and supplies all the irrigation water requirements of the country. This 6,825 km long river is reputed as the longest river in the world. Although the country spreads over about one million square kilo meters, about 99 percent of the population lives in small patch of land centered around Nile valley and Nile delta. The Nile valley has a length of about 940 km between Aswan and Cairo. Thereafter, the river forms a delta and runs through two main branches to the sea at a distance of about 200 km from the bifurcation.

Nine other African countries, namely Tanzania, Burundi, Rwanda, Zaire, Kenya, Uganda, Ethiopia, Aritria and Sudan, share the waters of Nile river with Egypt. The sharing of water between Egypt and Sudan is governed by Nile water agreement of 1959. The agreement stipulates that, when the evaporation from Lake Nasser is excluded, 75 percent of the remaining inflow to be diverted to Egypt. The rest is allocated to Sudan.

Annual rainfall in Egypt is about 200 mm. The rains are mostly confined to coastal areas. The crops are grown in two seasons: winter and summer. The major winter crops are wheat and clover. Cotton, rice and maize are the major summer crops.

As previously mentioned, the Nile is the main water source catering the water demands described above. The drainage reuse is practiced at some locations along the canal network where the good quality drainage water is available to be mixed with canal water. The ground water is also extracted either from deep or shallow aquifers to meet a part of the demand. As a result of this conjunctive use policy of the Ministry of Public Water and Water Resources (MPWWR), many projects such as installing pump stations and digging wells have been executed in Egypt. The main objective of increasing the conjunctive use of water is to raise the water use efficiency.

2. Characteristics and representation of the System

2.1 The Physical System

Several large scale control works have been constructed across the river for water storage and diversion purposes. As shown in Figure 1, there are eight large-scale diversion barrages downstream of the Aswan Dam. These barrages divide the river into seven reaches and constitute the major structures of an intensive irrigation network. The total length of the canal system is about 31,000 km. Groundwater wells are dug in the tail-end areas of the canal system to augment the canal flow. Apart from this there is a drainage canal network with a total length of about 17,000 km. The drainage from upper and middle Egypt is conveyed to the river. A part of this is reused in the lower reaches. The drainage from lower Egypt flows to the Mediterranean sea and helps to prevent the sea water intrusion in the delta.

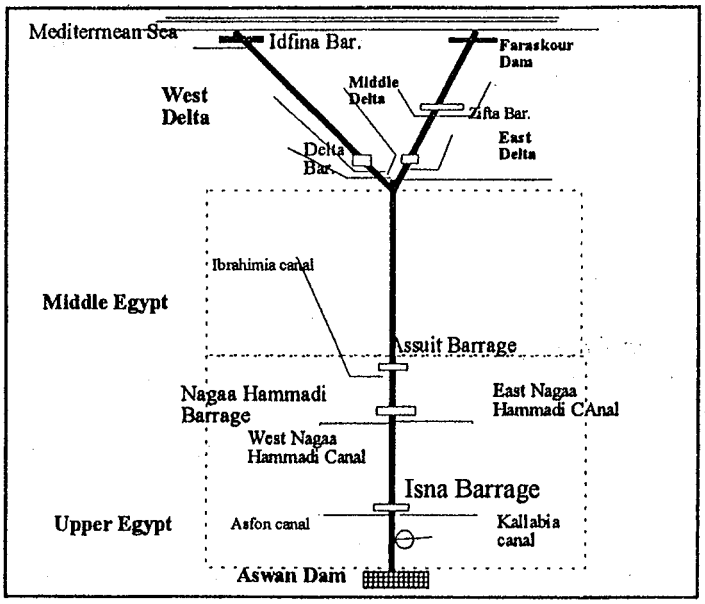

Figure 1

The total irrigated area is about 7.5 million feddans (3.15 million ha). About 20 percent of the area is irrigated by pumping from the river to the canal system.

2.2 The Management System

The irrigated land in Egypt is divided into five regions. The Upper and Middle Egypt regions are located in the Nile valley. The East, Middle and West Delta regions are located in the Nile Delta. Five levels can be identified in the irrigation management structure. They are the Central (Irrigation Sector), Directorate, Inspectorate, District and the Farmer levels. The structure is illustrated by the Figure 2.

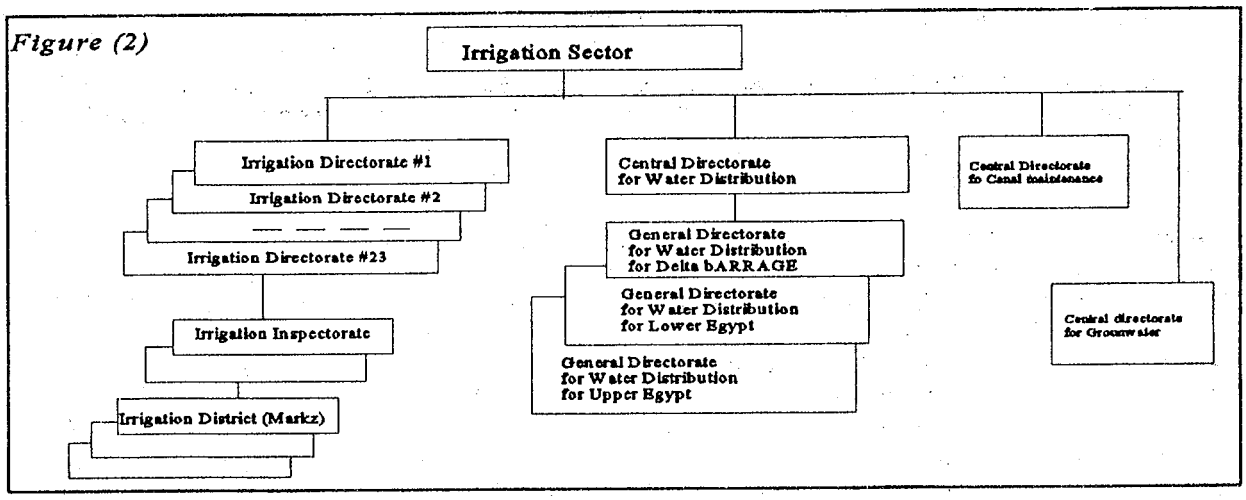

Figure 2

The Central level management of the (MPWWR) is responsible for the operation and maintenance of the irrigation system. It consists of the Central Directorate for of Water Distribution, the Central Directorate of Canal Maintenance, and the Central Directorate of Ground Water. Twenty three Directorates handle the operation and maintenance of the branch and distributary canal system. There are two to three Inspectorates under each Directorate, and each Inspectorate consists of about four Districts. The District, which is the smallest administrative unit, manages about 30,000 feddans. The management set-up in a district is headed by a civil engineer, who operates the canal system (branches) down to the level of Mesqa (farm ditch). The farm ditches are maintained and operated by the farmers under supervision of the Ministry of Agriculture (MoA). The farmers also prepare the irrigation schedule for the farm ditch. Under the Irrigation Improvement Project (IIP), water user associations are created to operate the farm ditches. This association has a chief and the members. They collect the required funds for ditch operation and maintenance.

Within the district (Markaz) there are many villages served by the district canal system. The MoA has established Agriculture cooperatives in each village. The Agricultural Cooperatives are responsible for providing the farmers with the agricultural inputs such as seeds and fertilizers. Therefore, the Cooperative needs to have accurate information of the cropping pattern. Each cooperative serves one village, representing an area ranging between 500 to 2000 ha.

3. Water Allocation and Operation Principles

The first priority is given to municipal and industrial water requirements even during water shortages. The Egyptian National Authority for Municipalities determines these requirements based on the standards set for each region. The results are sent to the MPWWR to be considered in water allocation plan. Other requirements such as navigation or compensation flows for some canals are also considered. Compensation flow is the water used to improve the water quality or raise the canal water levels particularly during the low water level period.

The Water Distribution Directorates in Lower and Upper Egypt are responsible for measuring the water levels and discharges at the key points along the irrigation network. The objective is to ensure equal distribution of water among irrigation Directorates based on their pre-set water requirements. Water shortages will redistributed according to the requirements of each Directorate. Since the Municipal requirements need to be met first, re-allocation of water will be based on the agriculture requirements.

The canal system within a district is operated according to a rotation principle. There are two systems of rotation; two turn rotation and three turn rotation. Under the two-turn rotation system, the canal system is divided into two groups. Each canal group will be opened for 7 days and closed for another 7 days resulting in a length of irrigation interval of 14 days. Under the three-turn rotation, the canal system is divided into three groups. Each group of canals will be opened for flow for 5 days and closed for another 10 days giving an irrigation interval of 15 days. The rotation system for rice is usually two-turn rotation with 4 days on and 4 days off. During the winter closure period the rotation is different. First, the whole canal system is opened for 10 days to help the farmers to build up the soil moisture to the maximum level to ensure no crop stress during the closure period. The canal system is then gradually closed within 3 days, and is kept closed for 15 days to execute the annual maintenance and construction works. After the end of full closure period, the canal system is gradually opened within 3 days and an irrigation application of 10 days is given to the whole canal to rebuild up the soil moisture which has been lost during the winter closure. Then the winter rotation continue till the start of summer season. Based on this rotational table, the water requirements is calculated for each branch canal at the district.

The water managers in Egypt try to make the maximum use of the available space for storage upstream of the main barrages along the Nile. Their conventional wisdom is to keep the water levels upstream of the main barrages at the minimum levels so as to accommodate any excess flow in case of delayed of planting or rain. The stored water also helps to meet part of the unexpected water withdrawals till the Aswan releases reach the barrage.

4. The Decision Process

4.1 The Annual Plan for Water Allocation

An annual plan for water allocation is prepared at the Central level of the MPWWR. This plan is based on the anticipated cropping pattern. It is discussed with the Directorates every three months. Changes in climatic conditions, cropping pattern or the time of plantation can result in a modification of the plan.

The District Engineer collects the cropping pattern from each cooperative and sends the data to the Directorate, where the District water requirement is assessed. The MPWWR, in cooperation with Mott-Macdonald consultants, has developed a mathematical model called DIRECT to compile the data from crop pattern in each cooperative and converting them into required flow rates in the canal system. Using the Rotation table set by the irrigation directorate, the software can produce the irrigation schedule for each branch canal for one year.

4.2 The Methodology for the Computation of Water Requirements

The crop water requirements are calculated in several steps. The first step is to calculate the available water for the crop using soil conditions and rooting depth.

Available water for the crop, AWR = (FC-WP) * RZD * C

Where,
- FC = Field Capacity
- WP = Wilting Point
- RZD = Root Zone Depth
- C = A factor to multiply water holding capacity (FC-WP) to get the available water for the crop

Crop evapotranspiration (ET_{crop}) is calculated based on factors such as climatic conditions and crop growth stage:

$$ET_{crop} = K * ET_0$$

ET_0 is the potential evapotranspiration calculated for a reference crop and K is the crop coefficient. The modified Penman equation is used to estimate the ET.

The next step is to calculate the Water Duty, defined as the amount of water needed to be applied for one feddan for a certain period. This can be calculated at the farm level or at the canal intake. The irrigation efficiency (Eff) is used to account for farm, distribution or conveyance losses, depending on the location at which the Duty is calculated. The following equation is used to calculate the Water Duty:

$$\textbf{Water Duty} = \frac{\textbf{Et}_{\textbf{crop}}}{\textbf{Eff}}$$

Leaching requirement is included in this Water Duty by suitably modifying the irrigation efficiency. The overall irrigation efficiency for the Egyptian system ranges from 60 -70 percent depending on the soil and state of canal and its structures.

The water duties for Upper, Middle and lower Egypt are calculated at the Central Level of the MPWWR using the Nile Water Management Model. The input data required for this model are evapotranspiration, crop coefficients, irrigation efficiency and crop-staggering. Crop-staggering is the percentage of crop area that is planted in a certain period. The model uses the following formula:

$$\textbf{Water requirements for crops at period (j)} = \sum_{i=1}^{n} \textbf{S area of crop (i)* Water Duty (i,j)}$$

Where Water Duty (i,j) is the Water Duty for crop (i) during the period (j) which is usually 10 days.

Usually the crop area in one region in Egypt is planted during 20 - 30 days. A pre-planting irrigation is given to the land to be cultivated to prepare it for crop establishment. This application is about 420 m^3/feddan and 220 m^3/feddan for summer and winter crops respectively. The water duties calculated from the Nile Water Management Model are used for the water allocation in the regions and the main canals.

To calculate the required supply from Nile to a main canal, the following equation is used :

Canal supply = Agriculture water Demand + Municipal and Industrial water Demand + Other requirements + losses - Drainage reuse - Groundwater use

Water requirements for the Directorate is the sum of the Districts requirements. Two Directorates are separated by a regulator in the main canal. The Central Directorate For Water Distribution calculates the water requirement at the key points or entrances to the Directorates. The Directorate is responsible for distributing this water allocation among its canal system based on the rotation system mentioned before.

The main canal is defined as a canal which serves more than one Directorate. As a result, the water allocation plan for a main canal stipulates the share of each Directorate. The share of the Directorate is expressed in quantity and percentage required in every 10-day-period. This helps to re-allocate the water deficit among the sharing Directorates.

4.3 Formulation of the Irrigation Schedule

A plan for the water releases from the Aswan Dam is drawn using the water requirements. The plan depends on the following factors:

- Water requirements downstream each main barrage along the Nile
- Expected gain or loss through the Nile reaches
- Lag time

Water requirements downstream a barrage is calculated by summing up the water requirements of the Directorates downstream of it. For example, water requirements downstream the Assuit barrage is the total water requirements for agriculture, Municipality and industry etc., for Lower Egypt region and small pump stations in Middle Egypt region. The expected gain and loss is subtracted or added to these water requirements to obtain the water releases downstream of the Assuit barrage.

The expected gain or loss is calculated from actual data for the previous year. It is assumed that the previous year figures will be appropriate during the current year since the changes in Aswan releases are normally slight. The water gains in the river reach is the result of the return flow to Nile from the cultivated areas, and the groundwater movement into Nile, which occurs when the water levels in the river are lowered. The loss of water from Nile is due to evaporation and seepage. The calculation of gain or loss is made by using the water balance method for the reach using the actual measurements. The following example explain this methodology:

A reach is defined as the stretch between to barrages as shown in Figure 3. Water balance for this reach involves measuring the following terms:

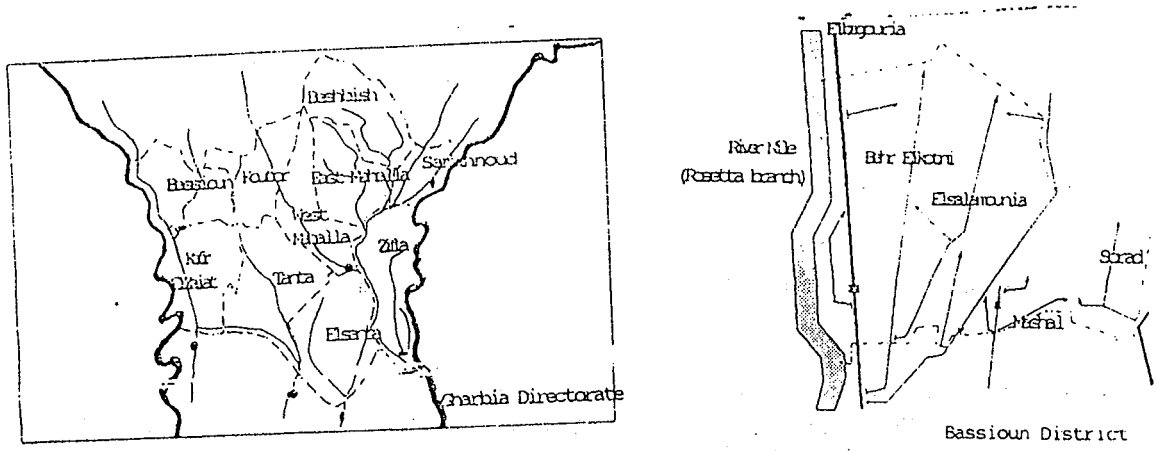

Figure 3

$Q1_i$: Inflow to the reach at the time i

$Q2_{i+t}$: Outflow of the reach at the time i+t, where t is the lag time for Q1 to reach barrage 2

P_{i+t1} : The withdrawal flow by pump station at time $i+t_1$, where t_1 is the lag time between barrage 1 and pump location.

C_{i+t2} : The withthdrawal by canal at time $i+t_2$, where t_2 is lag time between barrage 1 and canal location.

DS_{i+t} : The change in storage upstream the barrage 2. It is calculated by measuring the water levels at time i and at time i+t. The difference between these recorded levels is converted into volume using the barrage storage rating table which gives the volume (DV) of water corresponding to a one centimeter change in water level at different stages of upstream levels.

Thus, $\mathbf{DS_{i+t} = (L_{i+t} - L_i) * DV}$

The water balance for the reach can be written as follows:

$$\mathbf{Q1_i = Q2_{i+t} + P_{i+t1} + C_{i+t} + DS_{i+t} + LOSS_i - GAIN_i}$$

The terms of this equation are known except LOSS and GAIN. The total of the LOSS and GAIN can be determined as follows:

$$\mathbf{\{ LOSS - GAIN \} = Q1 - \{ Q2 + P + C + DS \}}$$

Lag time is an important factor in irrigation planning or operating the Nile system. The water released from Aswan takes a certain time to reach water user. This lag time varies according to the quantity of discharge. The following table shows lag time between Aswan Dam and main barrages along the Nile, and their relation to Aswan releases:

The drainage water reuse contribute to meet the crop water requirements and thereby raise the water use efficiency of Aswan releases. However, the pollution of drainage water may affect the chances of its reuse. The MPWWR and other concerned authorities are trying to minimize the pollution of water. The Drainage Research Institute, which monitors the quantity and quality of drainage water now, is one such organization. Pollution may result from sewage effluent disposed without treatment or from agriculture pesticides and fertilizers. Industrial effluents are very serious pollution sources due to presence of toxic materials. As a result, the water management concept need be changed to control both of quantity and quality of water.

SCHEDULING OF WATER DELIVERIES IN IRRIGATION SYSTEMS: CASE OF MOROCCO

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Abstract

The Haouz region, spreading over 663,000 ha, is a major agricultural area situated in the south-western part of Morocco. Low rainfall, large annual variations of temperature and high evaporation are the main climatic features in the region. The major crops include cereals, fruits and olives. The principal components of the irrigation and drainage infrastructure in Haouz Region include three barrages and a conveyance system comprising two main canals and a system of secondary and tertiary canals. The Rocade main canal is automatically operated from the Centre Général de Télécontrôle (CGTC) situated in Marrakech. The role of the CGTC is to manage the distribution of water and to supervise the daily behavior of the canal. An advanced automatic control technique called "Dynamic Regulation" is applied to the canal system through computer programs. The central computer is connected via VHF transceivers to the control terminal locations. The set point values are fed back to the regulation devices in order to automatically adjust the movable cross gates. The benefits of the present irrigation management system include saving water through improved agricultural planning and better monitoring of canal operations. However, the development of a non-steady state simulation model of the main canal flow, introduction of automatic regulation techniques, improving the planning and operational management at field level and solving the silting problem in the barrages and the canals are some of the requirements to improve the irrigation performance.

1. Introduction

The irrigation sector plays an important role in Moroccan economy. Since 1966, priority has been devoted to irrigation and 15 to 40 percent of the public investments was continually reserved for the development of hydro-agricultural infrastructure.

The area which can be used for agriculture in Morocco is estimated at about 8 millions ha. Out of this, 2.9 millions ha receive an annual rainfall exceeding 400 mm. The remaining 5.1 millions ha gets a lesser rainfall. As a result, Moroccan climate is generally semi-arid with the succession of rainy and dry years.

During the recent past, Moroccan governments had invested massively to develop new irrigation schemes and to rehabilitate old irrigation systems. The objective of the National Irrigation Programme is to mobilize and manage the available water resources for the irrigation of one million ha. Important hydraulic constructions have been erected during last decades. These include barrages, main and secondary canals, canal instrumentation including installation of measurement devices and manual and automatic control of main canals.

2. Context of the System

The Haouz region, which is a major agricultural area, is situated in the south-western part of Morocco. It is composed of 3 sectors: Tessaout amont, Haouz central and Tessaout aval. The total area is 663,000 ha. The climate is characterized by low annual rainfall (300-400 mm/year), large variations of temperature (37°C in summer and 5°C in winter) and high evaporation (2300 mm/year).

The major crops produced include cereals, fruits such as apricot, orange and apple and olives. An irrigation program was put in place in order to mobilize the available water resources and to arrange for the water deliveries to the irrigation sectors.

3. Characteristics and Representation of the System

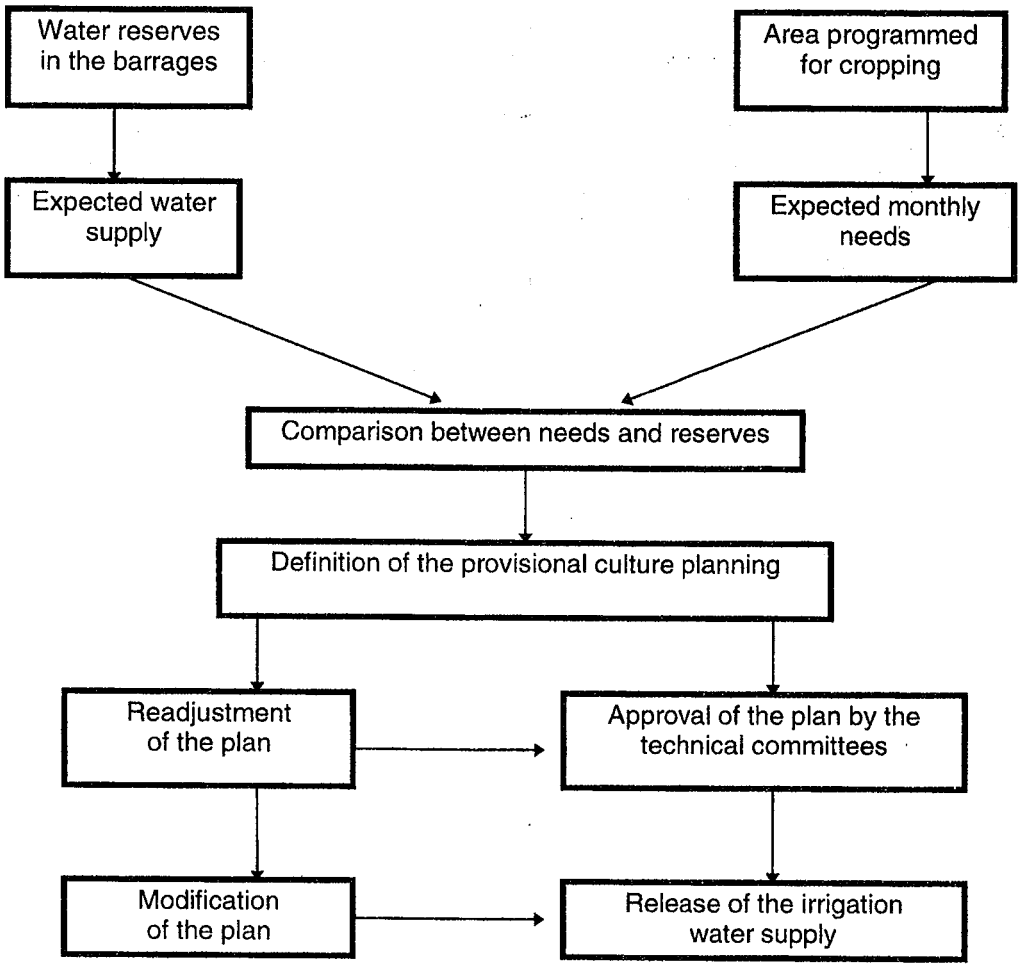
The principal components of the irrigation and drainage infrastructure in Haouz Region are as follows:

- Three barrages,
- A conveyance system comprising two main canals: Rocade canal (118 km) and T2 canal (93 km),
- An interconnected system of secondary and tertiary canals.

The Rocade canal is 118 km long and is designed for a flow rate of 20 m^3/s. The annual transferable water is around 300 MCM: 260 MCM for irrigation purpose and 40 MCM for drinking water supply of Marrakech city. The canal is automatically operated from the Centre Général de Télécontrôle (CGTC) situated in Marrakech. The role of the CGTC is to manage the distribution of water and to supervise the daily behavior of the canal. An advanced automatic control technique called "Dynamic Regulation" is applied to the canal system through computer programs. The central computer is connected via VHF transceivers to the control terminal locations. The parameters measured by sensors at various points along the canal are stored by the control terminal. The computer system communicates with the terminal site through the VHF communication network in order to acquire, to process and to store the data. The set point values are fed back to the regulation devices in order to automatically adjust the movable cross gates. These procedures and equipment constitute a decision support system which helps the Moroccan Irrigation Department in planning and monitoring seasonal as well as day-to-day canal operations.

4. The Decision Process

During the irrigation planning process the preliminary irrigation programme is prepared, taking into account the existing norms and priorities depending on whether the year is rainy or dry. The planning procedure is schematically presented as follows:



In order to ensure the planned irrigation operations and water distribution to be at an acceptable level of accuracy, both in terms of rate of flow and duration, the main Rocade canal is automatically operated. The flow rates vary at the canal head end and control points along the canal, owing to opening and closing of offtaking channels.

4. Conclusions

The benefits of the present irrigation management system used in Haouz region can be perceived in terms of water savings through improved agricultural planning and better monitoring of canal operations. However, some of the following enhancements are needed to be adopted in order to improve the efficiency of the system:

- Development of a non-steady state simulation model of the main canal for better understanding of flow and water level conditions throughout the canal operation and to provide adequate guidance for settings of gates.

- Introduction of automatic regulation techniques in order to circumvent the limitations of the present Dynamic Regulation system.

- Improving the planning and operational management at field level.

- Resolving the problem of silting in the barrages and in the canals

The general idea is to develop a methodology to assist irrigation managers with seasonal scheduling and daily operating decisions that provide efficient control of the water distribution system based on real time approach.

SCHEDULING OF WATER DELIVERIES IN THE IRRIGATION SYSTEM OF THE INDUS BASIN (PAKISTAN)

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Abstract

The irrigation network in Pakistan is considered as the largest contiguous gravity flow network in the world. It has been designed during the last two hundred years, mostly by the British Engineers. The original system was designed as run of the river without any reservoir, after partition with India three big reservoirs and a network of link canals were added. The system supplies water to the four provinces of Pakistan. Each province has a Provincial Irrigation Department (PID) and a Central Regulation Directorate. These directorates are responsible for water allocation and scheduling at the main canal level.

The main objective of the canal operations is to achieve as much equity as possible and to ensure the supplies of the tail-end farmers. Within the limitations set by surface water availability, the farmers have the authority t decide most matters related to crop production and cropping intensity. Exploitation of ground water is also managed by the farmers and they are free to share and manage this water. The state management ends at the secondary canal. A seven-day roster called "Warabandi" (to fix the turn) is formulated for all the farmers of a water course. The beneficiaries are expected to operate and maintain the water course and implement Warabandi system. In the case of a dispute, the state management intervenes and fixes the start and duration of the turn of each cultivator according to his land-holding size.

Within the Chishtian Sub-Division of the Fordwah-Eastern Saddiquia System, the Irrigation Department and the International Irrigation Management Institute (IIMI) conduct a joint pilot study to implement Irrigation Management Information System (IMIS) which enhances the decision making power of the manager. The IMIS monitors daily operations and analyzes the data.

1. Context of the system

The history of irrigation and civilization in Pakistan, which centers round the Indus valley, is as old as those in the Nile delta and the valley of Euphrates and Tigris. At present, about 27 percent (21 million ha) of the total area of Pakistan (79 million ha) is cultivated. The irrigated area totaling 16 million ha is about 77 percent of the cultivated area.

Six rivers, namely Sutlej, Bias, Ravi, Chenab, Jehlum and Indus, feed the irrigation system of Pakistan. The first five are tributaries of Indus, which join the main river at Panjand. The Indus river flows through the Sind province to the Arabian sea. All the rivers are snow-fed and their discharges vary with time and space. The alluvial planes of Pakistan built by these rivers are ideally suited for canal irrigation.

The climate of Pakistan is semi-arid. The maximum temperature rises to 40 to 44 degrees Celsius (105 to 112 degrees Fahrenheit) while the minimum temperature in the alluvial planes range between 27 to 32 degrees Celsius (80 to 90 degrees Fahrenheit). The rainfall varies between 4 to 40 inches (100 to 1000 mm) per year. The surface evaporation varies between 100 to 120 inches (1000 to 1500 mm) per year, resulting in a total loss of water amounting to 37,020 million m^3 (30 million acre-feet). The total storage capacity of the reservoirs is about 19,744 million m^3 (16 million acre-feet). A further 130,000 million m^3 (105 million acre-feet) is diverted to irrigation system.

The irrigated area in Pakistan is divided into nine agro-ecological regions. Although the area within an agro-ecological region is considered as homogeneous, variations environmental features such as water-logging, salinity and ground water quality exist within them. The major Crops in summer (kharif season) include rice, cotton, sugar cane and fodder. In the winter (rabi season), the crops are wheat, oil seeds and vegetables.

2. Characteristics and Representation of the System

2.1 The Physical System

The canal system in the four provinces of Pakistan comprises of three main reservoirs, 19 barrages, 12 inter-river link canals, 43 main canals and 107,000 outlets delivering water to the farmers. The aggregate length of the main canals is about 60,000 km. The system has been designed to benefit as large area as possible, and to ensure equitable distribution of water. The designed water allowance of a canal command varies from two to seven cusecs per 1000 acres per year for the Punjab canals. During the peak requirement period, surface water is not sufficient to meet the demand. A large quantity of ground water is used to compensate the deficit.

2.2 The Management System

Three main levels can be identified in the management set-up, with respect to the decision making. They are the provincial, system (the main and the secondary canal) and tertiary levels. The Figure 1 provides information about the factors which influence the decision making and scheduling.

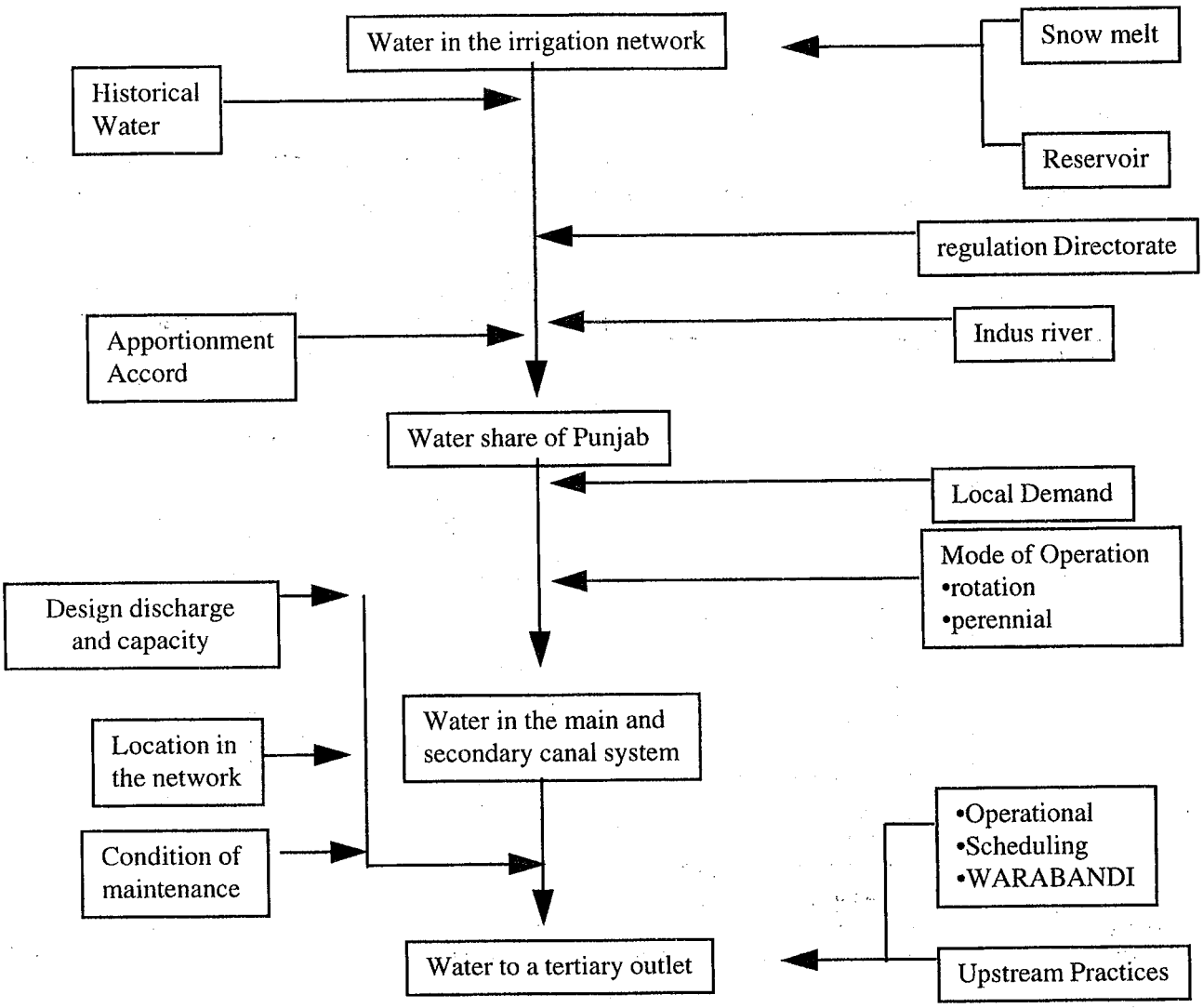

Figure 1

Within the limitations set by surface water availability, the farmers have the authority to decide most matters related to crop production and cropping intensity. Exploitation of ground water is also managed by the farmers and they are free to share and manage this water.

3. Objectives of Water Scheduling

The irrigation system is a run-of-the-river system. Therefore, variability and shortage of surface water supplies are expected. The result is that regulation and irrigation delivery scheduling are very important functions of the Irrigation Department. The main objective of the canal operations is to achieve as much equity as possible and to ensure the supplies to the tail-end farmers.

The objectives of the irrigation system can be categorized into two: global and operational. These objectives are described in detail in Table 1.

System Level	Global Objectives	Operational Objectives	Decision Making Authority
Main network and reservoirs	• Providing maximum water for agriculture and power generation. • Flood and drainage control • Sustainability of the network	• Matching the water demand of different systems. • Implementing the Water Apportionment Accord between the Provinces.	WAPDA ISRA
Main canals	• Deliver water to the secondary system according to the design discharge. • Maintenance of the main canals • Satisfy the demand of the secondary system.	• Distributing the water shortages or excesses Equitably. • Minimize the operational cost.	PID
Secondary canals	• Deliver water to the tertiary canal system according to the design rights. • Take care of the environmental impacts. • Increase productivity.	• Distributing the water shortages or excesses Equitably. • Minimize the operational cost.	PID
Tertiary system	• Providing water to all the cultivators on an equitable basis.	• Following the authorized scheduling.	Frequently the farmers, occasionally the PID

ISRA: Indus River Systems Authority
WAPDA: Water and Power Development Authority
PID : Provincial Irrigation Departments

Table 1 - Global and Operational Objectives of the System

4. Decision Process

4.1 The Planning Procedure

At the provincial level, Regulation program is prepared for each crop season separately (two seasons in a year) and for all canals. These programs are prepared on 10-daily basis and conveyed to the headworks from where one or more canals offtake. The main canal flows are monitored at the headworks and conveyed to the regulation directorate. The IRSA distributes the water according to the apportionment accord between the provinces. An account of the provincial-level canal flow for a five day period is recorded by the IRSA .

The quantity to be released to a canal is decided based on the allocation made by the Regulation Directorate, or the request by the canal management, whichever is less. This quantity is then released by the engineer in charge of the headworks. The engineer in-charge of headworks monitors the canal flow and informs about the variations from the schedule to the Central Regulation Directorate.

A sub-division is the basic administrative unit of the network and Sub-Divisional Officer (SDO) is the "Regulation Officer" of the sub-division; but in the case of shortage, scheduling follows a top to bottom pattern, first at the provincial level (usually three or four sub-divisions), and in the end at the sub-divisional level i.e. within the distributaries. Hence, mostly rotation programs are prepared at the divisional level.

Each SDO works out the requirement (indent) of the area under his supervision. The water requirement is conveyed from tail-end to head end through the respective SDOs. The SDO is expected to include the effects of events such as rainfall, canal breaches. When the supplies are less than the demands, a rotation program is implemented. A eight-day rotation is usually adopted. The tail-end of the distributary would run for seven days under this system.

The state management ends at the secondary canal. The farmer-managed water course receives water from the secondary canal through an outlet which is designed to deliver the authorized share of water. In Pakistan, the water rights related to the canal is linked with the proprietary rights of the agricultural land.

A seven-day roster called "Warabandi" (to fix the turn) is formulated for all the farmers of a water course. The beneficiaries are expected to operate and maintain the water course and implement Warabandi system. In the case of a dispute, the state management intervenes and fixes the start and duration of the turn of each cultivator according to his land-holding size.

5. Implementation Procedures

5.1 At the sub-divisional Level:

The water rights of the Chishtian sub-division distributaries are partly prenial and partly non-prenial, hence the authorized discharge at the head of sub-division is 38 m^3/sec in Kharif and 12 m^3/sec in Rabi. A rotational program is implemented among Chishtian and two upper sub-divisions.

According to this rotation Chishtian sub-division was at the second preference during the first week of the Kharif season starting from the April 16, 1994, at the third and the first preference in the followings weeks and so on; sub-div was at the second preference again during the last week of the season, 7-16th October 94. Other than this seasonal rotational plan, SDO Chishtian prepared a 10-daily water demand or emergency requests which have varied, for the same period, in the range of 0 to 1400 feet cube per second.

In the sub-division ID and IIMI have a joint pilot study to implement the Irrigation Management Information System (IMIS) which helps the manager in better decision making through the monitoring of daily operations and data analysis. The request of the manager (Indent) and the daily actual discharge at the head of the sub-division is shown in Figure-2 below. This discharge hydrograph indicates the relation between manager's demand, actual water received and the design discharge, briefly ;

i. In December and January there is one month official closure period for the annual maintenance, for this period demand and supply both are nil.

ii. In April and May farmer's demand of water increases steadily which is reflected in Indent, supplies follow the same pattern.

iii. There are rains in April, August and September, which are reflected in the periods of low demand and supply or short closure in these months.

iv. During maximum demand Indent is higher than the design discharge.

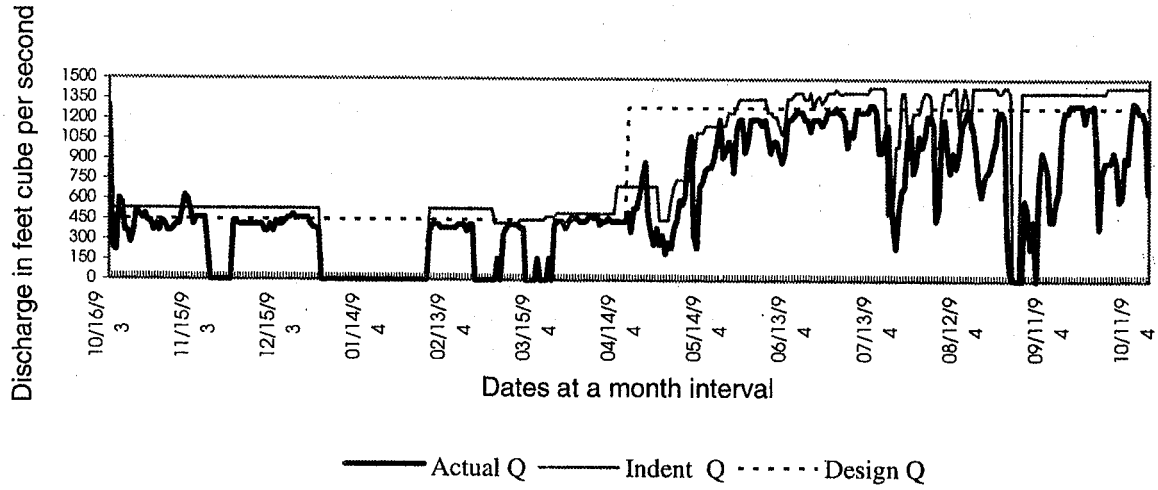

Figure 2 - Actual, Indent and Design Discharge in Rabi 1993-94 & Kharif 94 at RD199

5.2 At the Farm level (an example of WARABANDI):

An example of the re-adjustment of WARA BANDI on request of a cultivator is shown in Annexure-1. This type of adjustments are possible in case of changed circumstances such as division of land, new area brought into cultivation, alteration in water course etc. For any change in WARABANDI, suggestion of other water users are obtained and honored, if a user is still aggrieved, he can appeal to the Divisional Officer (XEN) and can finally go to the court of law for the final verdict.

WARABANDI is framed on a 7 days (168 hours) basis, the total time is divided by the total culturable area within the boundary of the outlet to work out the turn per unit area. The turn of each farmer is equivalent to his land holding. The operation of turn remain continuous irrespective of availability of water in the channel. The commencement of the turns is changed with an offset of 12 hours each year in a fixed month, so that a user who had been getting water at nights during the past year, would get water at day time in the current year.

4. SYNTHESIS

4. Synthesis

This section attempts to structure the outcome of discussions during the Network Meeting on ITIS in Muda and ITIS in the field. The meeting was especially targeted to address the issue of information techniques for water delivery scheduling. The discussions centered around five main themes:

1. Functions of an information system related to water delivery scheduling
2. Inputs of an information system
3. Outputs of an information system
4. Implementation of an information system
5. Future developments

4.1 Functions of an information system related to water delivery scheduling

Operating an irrigation system can be sub-divided in: the command level (transforming targets into decisions then implementing operations accordingly), the observation level (monitoring the actual implementation of the operation and the resulted system state) and the evaluation level (collecting and processing of information on real impacts of the operation). An information system was perceived to be the organization of observations to help the managers in fulfilling the functions of command and evaluation of water delivery scheduling.

The command function, which is on-line, deals with temporal decisions (when to start/stop delivering water) and with spatial decisions (staggering water delivery to different canal commands). The evaluation function is generally off-line and deals mainly with two questions: (i) are the targets the right ones and (ii) how did the actual water delivery match with the scheduled.

Water delivery scheduling can then be seen as a process that considers different relevant parameters. These parameters are examined in order to find out whether they are fixed (e.g., in the case of Muda the crop choice, paddy, is fixed) or dynamic (changing with time, e.g., the progress of land preparation, crop water requirements).

When parameters are dynamic they require monitoring and need to be incorporated in the information system in order to feed the command function. The data that are thus collected and transmitted need to be processed in the information system. The manner in which the dynamic parameters are integrated depends on the complexity and the responsiveness of the infrastructure. The fact, for instance, that in Egypt intermediate reservoirs are present in the system simplifies the information requirements somewhat. Inversely in Muda scheme, rainfall has been increasingly monitored in real time in order to improve the rainfall efficiency.

An important function of the information system is to apply a set of criteria on the values of various parameters that are obtained in order to help the irrigation manager to decide on the water delivery schedule. Ideally, an information system would be able to then test a number of scenarios to evaluate *a priori* the impact of these scenarios. Following that a few alternative scenarios can be proposed for implementation.

In Table 1, information characteristics (dynamic or fixed; considered in scheduling or not), relevant to the case studies presented in the Network Meeting, are examined. In the case of the Punjab and Egypt, the water availability are much more fixed (and therefore less considered). In the case of Egypt there is a fixed water quota taken from the Aswan reservoir, while in Pakistan the

For the command function the parameters that are changed differ for the various case studies (see Table 3). For the Sri Lankan irrigation systems, the area under cultivation can change from season to season depending on the water availability, whereas in Malaysia everybody or nobody gets water. Here managers sometimes succeed in working with the farmers to modify agricultural practices (e.g. direct seeding) in case of water shortage. In other systems the available water is shared amongst farmers, who will deal with the shortfall.

Irrigation system Parameters	Function	Parameters
Central Plains	Command	- discharge
Gal Oya	Command	- irrigated area - discharge - start date
Mahaweli	Command	- irrigated area - discharge - start date
Punjab	Command	- discharge
Nile Delta	Command	- discharge
Marrakesh	Command	- discharge
Khadakwasla	Command	- discharge
Kerian	Command Evaluation	- discharge - start/end date
Muda	Command	- discharge - start/end date

Table 3 - Outputs of an information system for water delivery scheduling

Another point raised during the meeting was whether all the data that are collected are really used for the water delivery scheduling. Is it possible to achieve a good water delivery scheduling with less or minimum level of information (e.g. for the fixed parameters)?

The Muda staff stressed the importance of the evolution of water delivery scheduling. Through an increased involvement of farmers in the planning of the schedule, the adherence has been dramatically improved leading to water saving.

4.4 Implementation of the information system

The scale at which the information system is targeted is for all the irrigation systems a choice that was made a long time ago, depending on the parameters (fixed, dynamic) that need to be captured, the interaction between farmers and system management, etc. The scale at which the information system is functional determines also the level of detail that is incorporated in the information system. Negotiation often takes place on those parameters that are dynamic.

In most of the irrigation systems there is a formalized method of sharing information between farmers and system management, usually in the negotiation process of water delivery scheduling. Horizontal sharing of information (e.g. between farmers or between gate operators) is something that has been tested only in a few cases. During the discussions an example from Pakistan was quoted where system operations were markedly improved through an information system between gate operators.

The impact of different measures (e.g. new hardware) is an issue that can be addressed through the evaluation function of an information system. Similarly, it was advocated to evaluate the impact of the information system itself.

Parameters	Scale	Farmers' involvement	Data collection	Transmission	Processing
Central Plains	?	?	Manual	Telephone Manual	Computer
Gal Oya	Tertiary unit	Negotiation at system level	Manual	Telephone Manual	Manual Computer
Mahaweli	Tertiary unit	Negotiation at system level	Manual	Manual	Manual[3] Computer
Punjab	Farm	Self-administered at tertiary level	Manual	Telegraph Manual	Manual[3]
Nile Delta	Region level	Negotiation at region level	Manual automated	Telemetry Manual	Computer
Marrakesh	System	-	Manual	Manual	Manual
Khadakwasla	Farm	Crop choice submitted to managers	Manual automated	Manual Telemetry	Computer
Kerian	Secondary block	Negotiation at system level	Manual automated	Telemetry	Computer
Muda	Secondary block	Negotiation at system level	Manual	Telemetry	Computer

Table 4 - Implementation of the information systems

[3] Both in the Mahaweli system in Sri Lanka as well in one of the irrigation systems in the Punjab, experiments are presently underway to implement a computer-based information system. Results are awaited and will hopefully be presented in next year's Network Meeting.

Over the last few years the information system has been upgraded in many schemes. It appears from the case studies that information systems are often a mixture of traditional and improved technology, which seem to work well and sustainable. In most cases the data collection is still carried out manually, while transmission of data has been upgraded as system managers want quick access to information. It was also mentioned a few times that manual override is a must in case of unexpected events.

4.5 Future developments

During the discussions a number of possibilities for future development related to information techniques were suggested by the participants. They are listed in Table 5. It is important to derive some more lessons from these individual case studies, perhaps through sustained information sharing, through common evaluation tools, etc.

Apart from the developments in the field, ITIS reported also on parallel developments in the databases of information techniques that are now available in the market. A book has been prepared by ILRI, The Netherlands, while the ICID has made a compilation on discette (LOGID). The latest development is an Internet database maintained by Thomas Stein of Kassel University (http://www.wiz.uni-kassel.de/kww/).

Parameters	Future Developments
Central Plains	spatial tool
Gal Oya	sustaining implemented information system
Mahaweli	enhancement of information system, development of modelling skills for improved operations
Punjab	enhancement of information processing
Nile Delta	automation
Marrakesh	possibility for enhanced information processing
Khadakwasla	adoption of advanced information techniques
Kerian	impact assessment of new information system
Muda	automation development of evaluation function

Table 5 - Future developments in the different case studies

ANNEXES

Annex I

Detailed Program of ITIS International Network Meeting

Saturday: 15 June 1996

08:00 am.	-	08:30 am.	Registration
08:30 am.	-	08:45 am.	Arrival of Invited Guests; Seating

Opening Ceremony

08.45 am.	-	09:00 am.	Welcome Speech by Dato' Syed Azizan Al-Idrus, General Manager of MADA.
09:00 am.	-	09:15 am.	Introductory Speech by Mr. Patrice Guerin, Deputy Head of Irrigation Division, Cemagref, France.
09:15 am.	-	09:30 am.	Introductory Speech by Prof. G.V. Skogerboe, Director of IIMI Pakistan
09:30 am.	-	09:35 am.	Presentation of Memento To General Manager of MADA Deputy Head of Irrigation Division, Cemagref and Director of IIMI Pakistan by Director General of JPS, Ir. Neo Tong Lee
09:35 am.	-	09:50 am.	Light Refreshments
09:50 am.	-	10:00 am.	Group Photograph at Main Entrance

Introductory Session — Chairman: Ir. Loke Kok Yan, Head of Engineering Division, MADA

10:00 am.	-	10:30 am.	Keynote Address by Ir. Neo Tong Lee, Director General of JPS Malaysia
10:30 am.	-	10:40 am.	Briefing of Meeting Procedures and Programme by Dr. Daniel Renault, IIMI

First Session: ***ITIS in MUDA*** — Chairman: Ir. The Siew Keat, Director of Irrigation, JPS Malaysia.

Repporteurs: Ir. Geh Yean Lean
Ir. Ch'ng Ban Seng

10:40 am.	-	11:30 am.	Introduction to The Muda Scheme by Ir. Lau Eng Lim, Senior Engineer of Water Management, MADA

11:45 am.	-	12:10 pm.	Pakistan
12:10 pm.	-	12:30 pm.	Questions/discussions
12:30 pm.	-	14:00 pm.	Lunch Break
14:00 pm.	-	14:45 pm.	Summary of ITIS in the field and guidelines for the discussion
14:45 pm.	-	15:00 pm.	Discussions on ITIS in the field
15:00 pm.	-	15:10 pm.	ITIS No.3: Outputs and future Dissemination of proceedings
15:10 pm.	-	15:20 pm.	Workshop on "Canal Control" Marrakech 97, Prof. A. Benhammou
15:20 pm.	-	15:30 pm.	Canal Operation GRID for ITIS No.4. Dr. Daniel Renault, IIMI
15:30 pm.	-	16:00 pm.	Discussions on Canal Operations
16:00 pm.	-	16:10 pm.	Vote of thanks from IIMI/CEMAGREF. Prof. G.V. Skogerboe, Director of IIMI, Pakistan
16:10 pm.	-	16:30 pm.	Closing Speech by Ir. Hj. Keizrul b. Abdullah, Deputy Director General I, Department of Irrigation and Drainage, Malaysia

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