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Decision Support System (DSS) for Water Distribution Management

Theory and Practice

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1. Introduction to DSS

THE IMPACT OF information techniques in all economic activities has been tremendous during the past decade. However, the potential of the multiple management methods and technologies derived from this field has not been fully realized in the irrigation sector. One area of application of information techniques concerns the design and installation of Decision Support Systems (DSS). This area, used for the particular activities relating to the management of water in irrigation schemes, constitutes the theoretical background of this paper. As an introduction to the concept of Decision Support Systems, three basic questions are briefly discussed below: What is a DSS? Why a DSS? How is a DSS installed?

a. WHAT IS A DSS?

Drawing on definitions commonly found in the literature, a DSS can be characterized as "a set of tools and procedures which, if used by the management of a particular system, would enhance the quality of the decision-making processes in this system."

In terms of tools, the main areas investigated for the design of DSS concern the fields of **measurements, data transmission** and **data processing**. The rapid expansion of electronics and microcomputer technology has opened new perspectives in these fields. Remote monitoring devices, though still at a prohibitive cost, have been developed for many applications. Commercially available software packages such as database management systems, spreadsheets and geographic information systems can be used to greatly improve the storage, retrieval and analysis of bulk amounts of data. Technologies and tools are thus available and need to be adapted and transformed into operational decision support systems to make them used widely by the decision makers of irrigation schemes.

b. WHY A DSS?

Many water management related problems diagnosed in gravity irrigation schemes are primarily due to a lack of *command* capability of the people managing them. Existing centralized *command* capabilities are often more administrative than responsive to needs, leading to a partial or total loss of control of the management over the physical process of water distribution occurring in the systems. Different types of strategies have been promoted to "reinject" control into system management.

The first category of interventions envisaged tend to upgrade the physical system by rehabilitating or modernizing its structures. A second type of intervention aims at modifying the management framework and transferring operational responsibilities of the system to the users. A third category tries to enhance the capability of the existing management by introducing or strengthening decision support activities. These various options have been tried in isolation or combined with more or less success in many irrigation schemes. The first and second approaches implemented in isolation often brought little improvement as far as the problems of *command* are concerned. Examples of underutilized sophisticated structures or chaotic management by unprepared user organizations are numerous. The third approach, alone or combined with the other two, potentially addresses the problem of *command* in a more straightforward manner. The nature of the intervention considered in this case (introduction of DSS) implies the use of better information by managers, which leads to a better understanding of their systems and, ultimately, to better decisions. In addition to enhancing the quality of the decisions taken, the use of a DSS is expected to increase the speed of the decision-making process. Typically, irrigation managers collect data, store data records in registers, and perform routine calculations. Often, these data and records are voluminous and trends or key information contained in the data are easily overlooked. In managing irrigation systems, the ability to make expedient decisions is of critical importance. **If data cannot be received and analyzed quickly, even important data or information may prove to be useless** (Sheng and Molden 1993).

c. HOW IS A DSS INSTALLED?

The successful introduction of a DSS requires the consideration of a performance oriented diagnosis and a management intervention package.

Do a performance oriented diagnosis

Blindly increasing the amount of data collected and stored, even in an organized way, is obviously not likely to solve vaguely identified management problems. Steps prerequisite to seeking ways of improving the functioning of any system are:

* Identification of a limited number of *key issues* influencing the overall performance of the system (i.e., water use efficiency, salinity, etc.)

* Identification of specific *management activities* playing a critical role in the process leading to poor or good performance relating to the key issues.

* Identification of the *performance drivers* likely to be studied and used for an improved achievement of these activities.

Often, a very powerful performance driver is behind a better use of certain available data by the manager or the collection and analysis of additional, specific data. The process of designing and implementing a DSS can be fruitfully envisaged only at this stage.

Think in terms of a management intervention package

Data do not come naturally in an accurate and reliable way to the office of the decision maker who is supposed to make use of them. The introduction of a DSS usually implies the design of a *management intervention package* which includes the consideration of problems of measurements, communication, and hardware instead of the recommendation of a single isolated tool. A real problem that remains is the gap which usually exists between the communication and measurement facilities (or the incentives to keep them functioning accurately) and the data requirements of many decision support tools. The three basic successive steps to be studied are:

* *Communication* requirements (list of "messages" from the field to the manager).

* Information expected from *data processing* (list of computational modules to be interfaced with the database to provide adequate support to the decision-making process of the manager).

* *Data* organization (optimal set of data to be put in the database).

The answers to the three basic questions raised in this introduction can be summarized as follows:

. "What?" For the scope of this paper, a DSS is intended to consist of a set of measuring devices, transmission facilities and a database interfaced with computer modules dedicated to the processing of specific information.

. "Why?" The primary purpose of a DSS is to improve the quality and speed up the chain from raw data to management information, and finally to decisions.

. "How?" The installation of an effective DSS has to be done in close collaboration with the end user, to avoid any discrepancies between the tools proposed and the practical facilities available in the system considered.

2. DSS for Water Distribution Management: Needs Assessment

A PROPER DIAGNOSIS of the weaknesses of the decision-making processes is a prerequisite to any intervention. This diagnosis cannot be confined to water distribution activities alone and has to be conducted in a broader perspective including other areas of water management. Following the development of a generic model for this purpose (Rey et al. 1993), the two main steps of the diagnosis consist of a global performance evaluation of the irrigation scheme followed by performance evaluations concentrating on critical activities.

a. IDENTIFICATION OF CRITICAL ACTIVITIES

The broad output/impact oriented evaluation (first step) permits the identification of *key issues* determining the actual performance of the scheme. It is argued that, in 90 percent of the cases, the three main issues relating to water management coming out of this type of evaluation are:

1. Water conservation.
2. Responsiveness of the distribution system to farmers needs.
3. Environmental impact of irrigation practices.

All of these issues can be characterized by an output objective and a performance objective.

Table 2.1. Key issues (output and performance objectives).

Issue	Output Objective	Performance Objective
1	Water use efficiency	External standards
2	Quality of distribution	Farmer satisfaction External standards
3	Quality of soil, water, etc.	External standards

The identification of a key issue leads to the consideration of *the management activities* involved in the production of the related output.

Table 2.2. Activities/tasks involved in the production of the outputs corresponding to three key performance issues.

Management activities	Key issues		
	1	2	3
. Seasonal land and water allocation	**		**
. Water scheduling	**	**	*
. Acquisition of water	*	*	**
. Operation of distribution network	**	**	*
. Maintenance of irrigation network	*	*	*
. Operation of drainage network			**
. On-farm irrigation techniques	**	**	

* Activities to be considered

** Common critical activities to be considered

While considering this list of activities/tasks, a first prioritization has to be done in order to identify *critical activities/tasks* which have the greatest influence on the production of the considered outputs. As an example, common critical activities are highlighted with two asterisk (**) in Table 2.2.

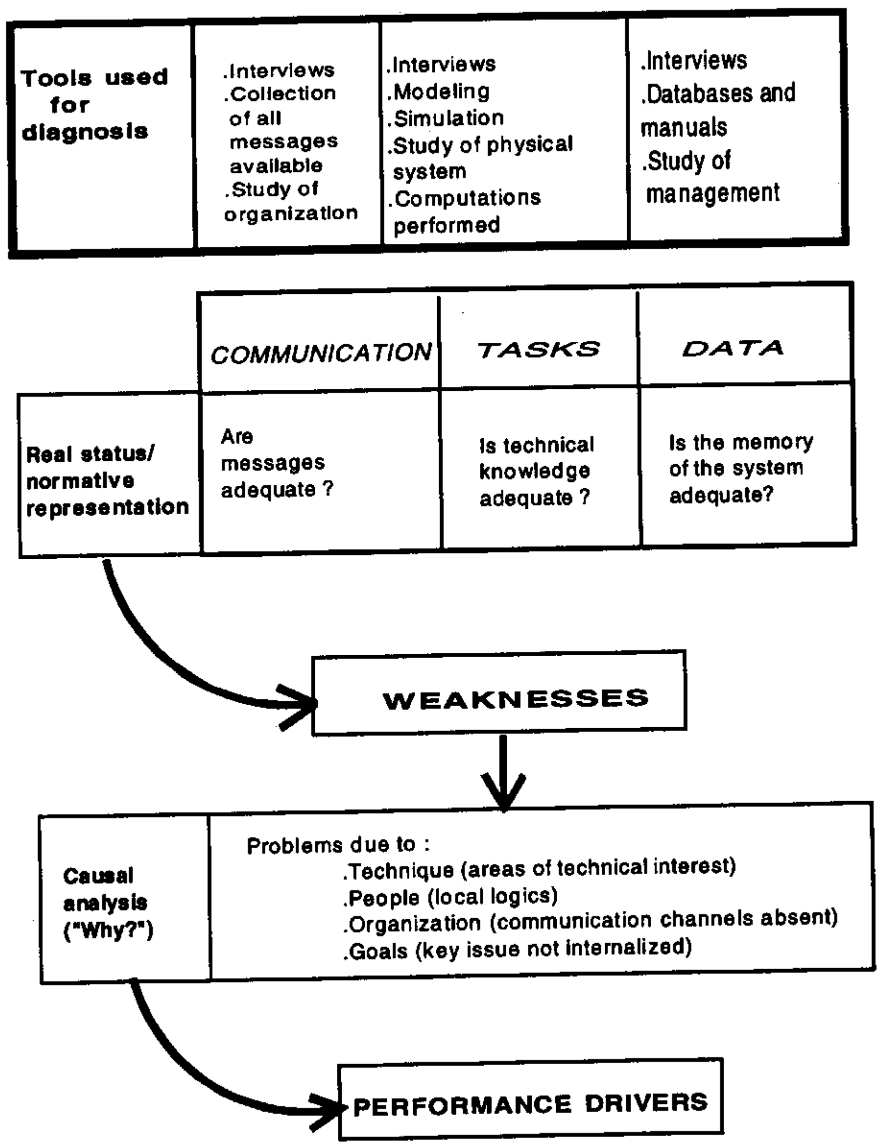
b. IDENTIFICATION OF PERFORMANCE DRIVERS

Being aware of potential sources of "non-performance" among the management activities (critical activities), a second type of performance evaluation focusing on these critical activities has then to be carried out.

This focused, process-oriented, evaluations permit identification of the real *performance drivers* on which improvement efforts can be concentrated. A method of evaluation based on the normative functional representation developed in part 3.a of this paper can be used if the operation of the distribution network has been identified as a critical activity. The information perspective used in part 3.a suggests that the process performance evaluation should be conducted considering the three facets, communication, tasks, and data.

For each of these facets, one must proceed by assessing the real status, comparing it with the normative representation, identifying gaps and exploring the causes of detected weaknesses. Indications for the evaluation process are given in Figure 2.1.

Figure 2.1. From critical activity to performance drivers (information system perspective).



The end product of this second performance evaluation should clearly highlight *the scope for DSS introduction* and pave the way for a well-targeted intervention at the water distribution management level or any other level identified as critical for the performance of the scheme.

3. DSS for Water Distribution Management: Generic Design

THE MANAGEMENT OF water in irrigation schemes implies decisions at different levels as listed in Table 2.2. A representation of the multiple and hierarchical management activities supporting these decisions can be developed. However, even though scheduling decisions will be evoked, this paper will concentrate on one type of activity: the operation of the distribution network and, more precisely, the operation of the main canal.

a. FRAMEWORK FOR DSS DEVELOPMENT

The designing of a DSS has to include **a careful analysis of the decision-making process considered** and specification, a priori, of the data that should be handled for making the decisions, the communication channels by which these data are transmitted and the different processes they are sequentially used for.

A Functional Representation of the System

As far as the management of water distribution at the main-canal level is concerned, a simple representation has been derived through system analysis and is briefly outlined below. The way by which this representation at the main-canal level fits in a broader representation of the management of the whole irrigation system is detailed in another paper (Rey et al. 1993).

As illustrated in Figure 3.1, we have distinguished three main *levels* to represent the managerial context relating to the main canal:

L_1 : People (or machines) in charge of decision making and data analysis.
L_2 : People (or machines) in charge of implementation and data collection.
L_3 : The physical system encompassing the canal, control structures and irrigation water.

We have also identified three main functions, *command*, *observation* and *evaluation*, each of which is subdivided into various activities.

Command Function:

C_1 : Decision making regarding operational strategies (planning, including target setting and overall control).
C_2 : Routine implementation of instructions and local control.

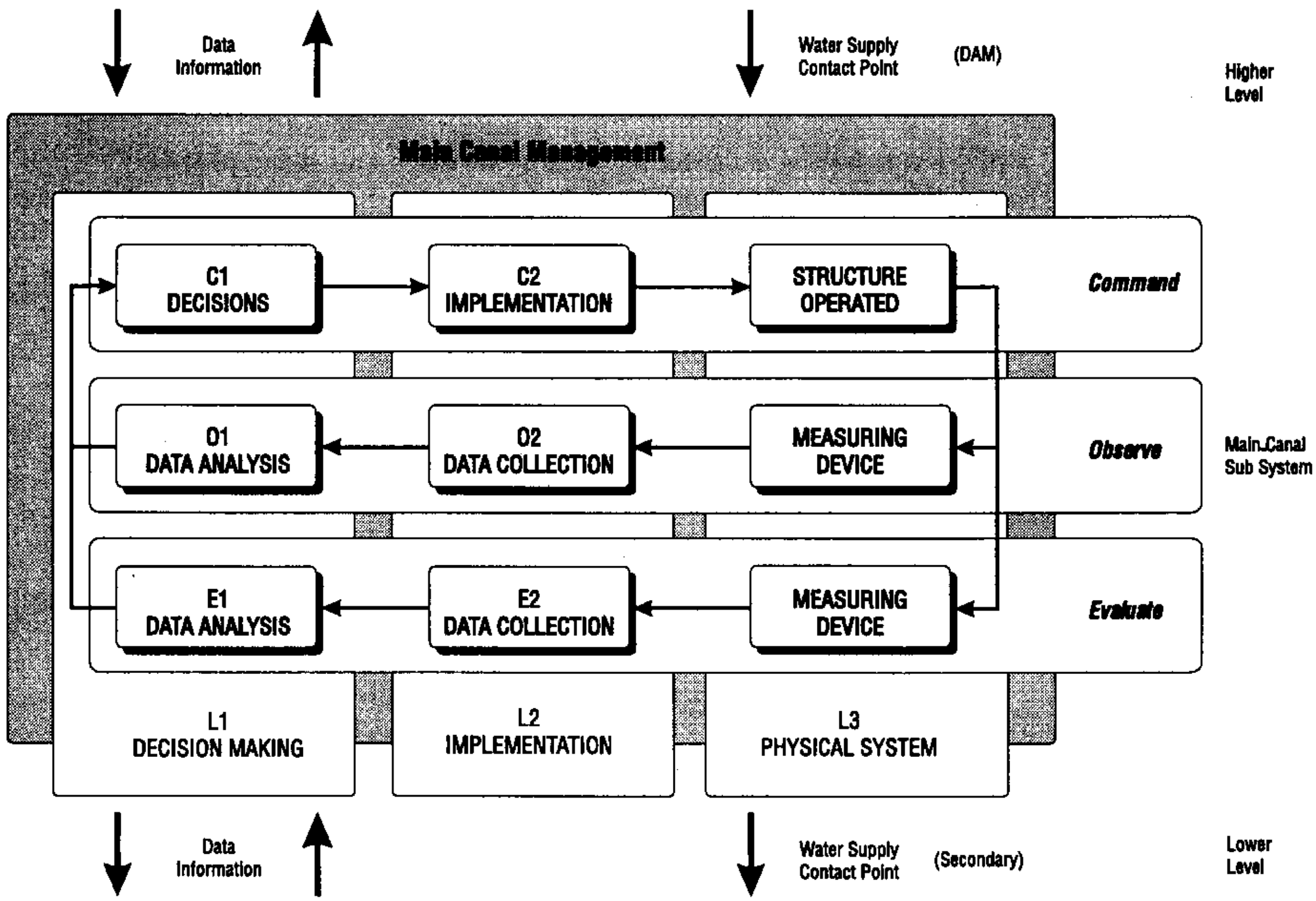
Observation Function:

O_1 : Observation of the hydraulic state and behavior of the system in order to fulfil the activity C_1.
O_2 : Collection of data (water levels, gate settings).

Evaluation Function:

E_1 : Analysis of water delivery performance, study of system functioning in order to improve the activity C_1.
E_2 : Collection of data (time and magnitude of operations implemented).

Figure 3.1. Functional representation of the main canal management.



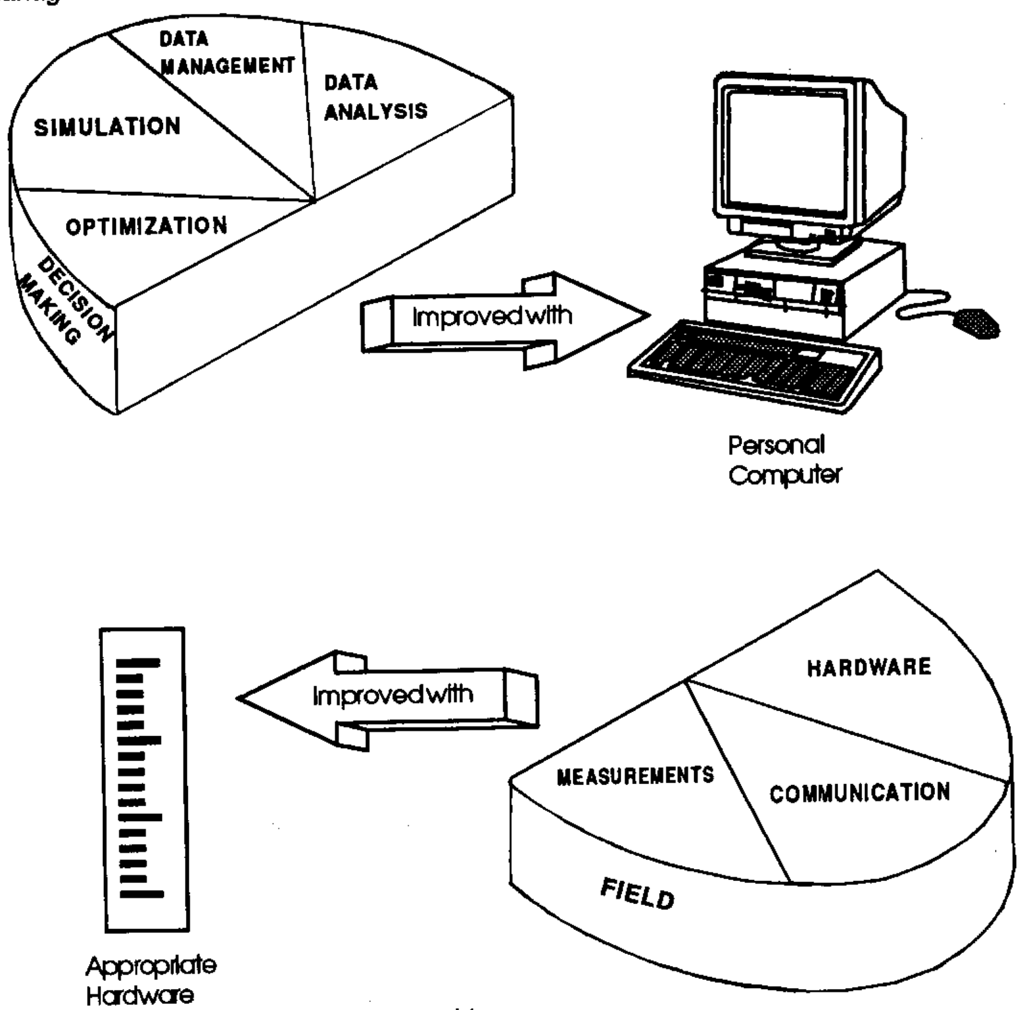
Any attempt to improve system management must take into consideration the complete sequence of activities involved and should lead to appropriate interventions where they are most needed. By further analyzing the functional representation, we can identify the main technical areas likely to require investigation prior to such interventions.

It appears that, at the *field level* (L_2 and L_3), the most important issues are the establishment and sustainment of a reliable data collection network and the ensuring of timely communications between the field staff and the decision-making center. The main areas of technical interest at this level are COMMUNICATION, MEASUREMENT and HARDWARE.

At the *decision-making level* (L_1), the most important issue is the development of an integrated tool to support the command, observation and evaluation functions of the decision maker. This tool could be derived from a partial computerization of the activities C_1, O_1, E_1, and should comprise an efficient data-storage and retrieval system as well as a quick and systematic procedure for analyzing this data. The main areas of technical interest at this level are DATA MANAGEMENT, DATA ANALYSIS, OPTIMIZATION, and SIMULATION.

The potential technical areas likely to be studied while considering the development of a DSS are summarized in Figure 3.2.

Figure 3.2. Areas of technical interest related to the functional representation of main canal management.



The Three Facets of the Analysis: Communication, Tasks and Data

Study of the communication flows, the tasks carried out under the functions of command, observation and evaluation as well as the data used for performing these tasks can lead to a fairly systematic analysis of the decision-making level L_1. The output of this analysis conducted in an information system perspective consists of a list of *messages* to be received and sent by L_1, a list of *computations* (related to DATA MANAGEMENT, DATA ANALYSIS, SIMULATION or OPTIMIZATION) to be performed by L_1 and the subsequent layout of the *database* to be maintained at the level L_1. A summary of the main steps of the analysis is given hereafter followed by the details.

Facets of the Analysis

1. **Communication**

 * Identify the *activities* carried out at the decision-making level.

 * Identify the *messages* exchanged between the different activities and between the activities and the external partners of the decision-making component.

 * Identify the *information* in the messages.

2. **Tasks:**

 * Identify *management rules* (sequences of activities).

 * Identify specific *tasks* carried out under each activity.

3. **Data:**

 * Split the information conveyed into individual data.

 * Group sets of data into "objects" in order to build an image of the system which is as efficient as possible with regard to manager's activities.

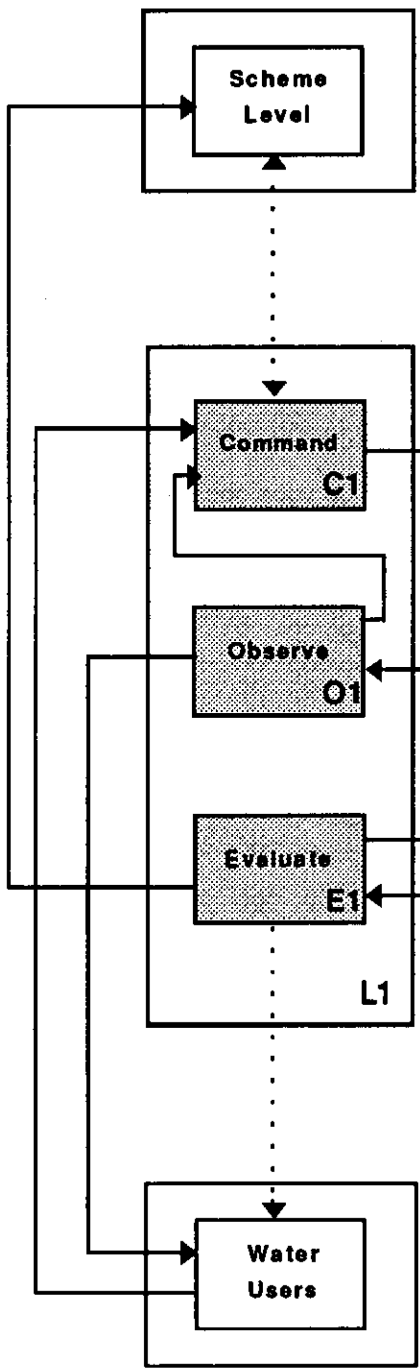
 * Check the coherence of the data organization with tasks and communication.

Facet 1 refers to the notion of messages, facet 2 highlights the operations or tasks undertaken after receiving or before sending these messages, and facet 3 aims at rationalizing the structure of the information conveyed by these messages in order to build an efficient memory or database for the decision-making component. These three components are studied from the perspective of the water distribution management at the main-canal level.

1. *The Communication System*

- *Communication Flows.* We obviously build on the representation presented earlier. The basic layout of activities and links with external partners is again made explicit in Figure 3.3.

Figure 3.3. Communication flows between activities.



The basic communication flows are described in Table 3.1.

Table 3.1. Basic communication flows.

OUTPUTS OF ACTIVITIES
■ Sharing of command outputs with field staff. ■ Sharing of observation outputs with water users and use of the detection of gaps between observation and targets to elaborate control commands. ■ Sharing of evaluation outputs with the scheme-level manager and the operational field staff.
INPUTS OF ACTIVITIES
■ Messages (from water users for fixing or revising of targets, from scheme managers for external constraints and procedures, rainfall measurements, etc.). ■ Data collected by the field staff regarding water and canal status.

In order to describe the whole dynamic of management activities, another type of input, the "Management Clock," has to be considered. Apart from "message-driven interventions," the manager obviously has routine activities of command, observation and evaluation to fulfil at regular intervals as illustrated in Figure 3.4. Adding this dimension and desegregating inputs, outputs and Management Clock signals, we can make explicit the communication flows (Figure 3.5).

* *Information.* This step aims at clarifying the contents of the different messages and implies, therefore, the obtaining of further details about the messages mentioned in Figure 3.5. The set of messages identified should be considered as an example and adapted while working on a particular system (time scales are obviously site-specific, other messages can be considered). Refined descriptions are given in Tables 3.2, 3.3 and 3.4 where the various messages are indexed by the numbers introduced in Figure 3.5.

Figure 3.4. The Management Clock.

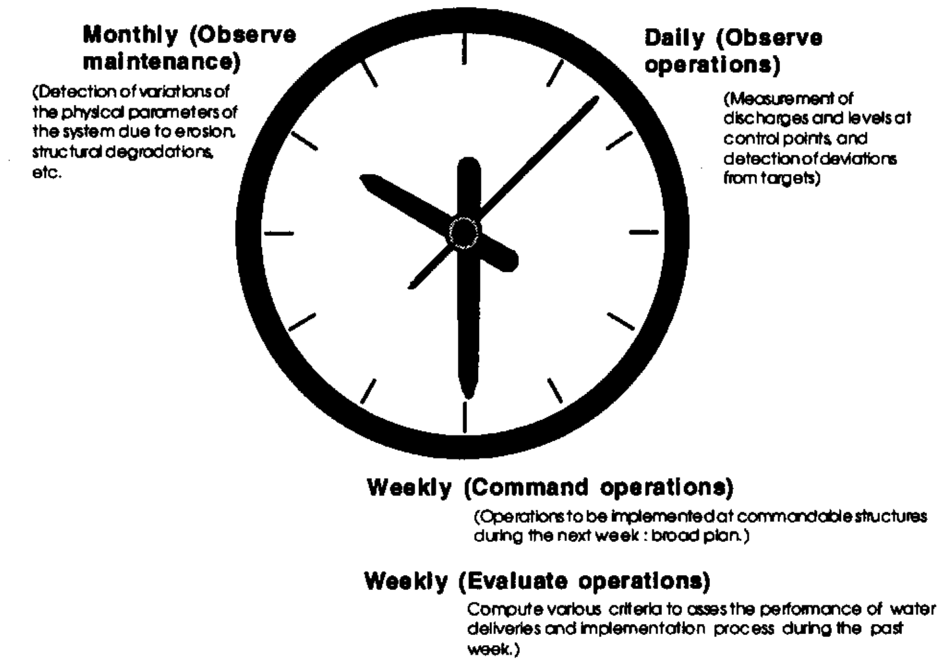


Figure 3.5. Management signals.

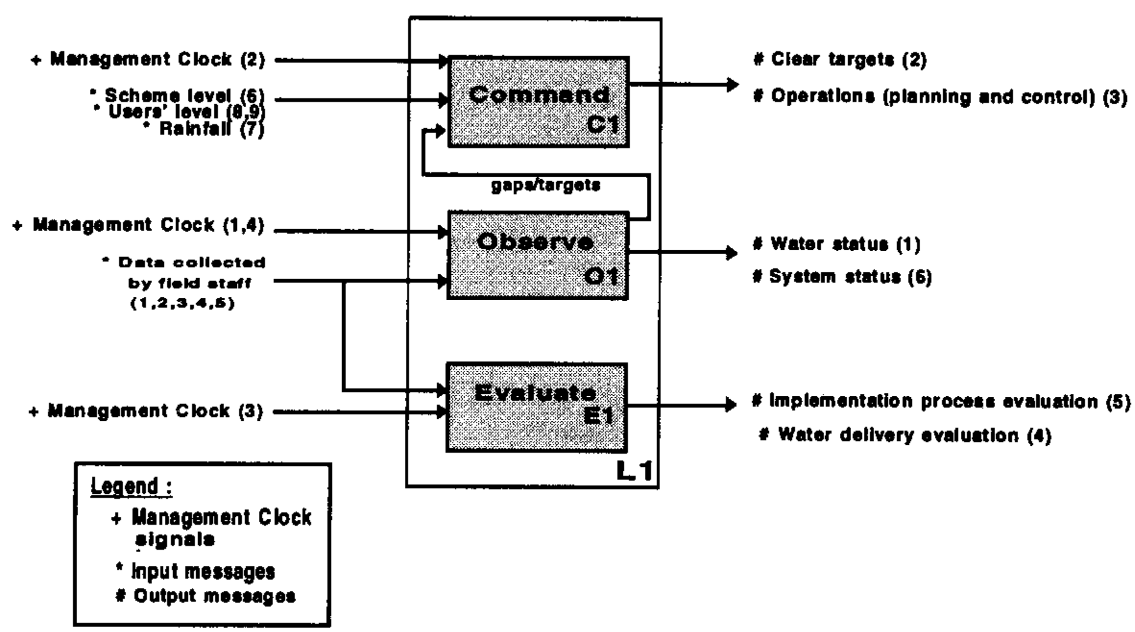


Table 3.2. Descriptions of input messages.

INPUT MESSAGES		
No.	**Type**	**Description**
1.	Flow measurements	Water levels at control points and state of commandable structures.
2.	Operations	Operations implemented on commandable structures: time and amplitude.
3.	Calibrations	Discharge directly measured in the field.
4.	Structure survey	Modification of geometric parameters.
5.	Canal bed survey	Evolution of topography.
6.	Information needed for target fixing	Can be imposed as a fixed schedule by the scheme level or cultivated area, cultivation stages, crop plan, etc.
7.	Rainfall	Rainfall measurements.
8.	Requests from users	Requests for modification of water delivery patterns for various reasons: problems due to maintenance, tail end, etc.
9.	Emergency	Overtopping, breaching of bunds, breaking of structures.

All these messages are conveyed *on adequate formats* to the canal manager at adequate frequencies.

Table 3.3. Descriptions of output messages.

OUTPUT MESSAGES		
No.	**Type**	**Description**
1.	Water delivery pattern	Set of discharges and levels at the control points, displayed on boards at field level to allow a joint monitoring by users and the agency.
2.	New targets	Set of targeted discharges transmitted to water users and field staff.
3.	New operations	Planning for the next week transmitted to field staff or correction of deviation by modifying the plan on a daily basis transmitted to field staff.
4.	Evaluation report	Synthetic evaluation of main-canal functioning during the past week: volume issued, difficulties at implementation stages transmitted at scheme level.
5.	Evaluation report	Synthetic evaluation of achievements of implementation staff during the past week.
6.	Maintenance report	Trend in variation of physical parameters, and proposals for maintenance submitted at scheme level.

Table 3.4. Management Clock activities.

MANAGEMENT CLOCK			
No.	**Frequency**	**Activities**	**Description**
1.	Daily	Observe operations	Measurement of discharges and levels at control points, and detection of deviations from targets.
2.	Weekly	Command operations	Operations to be implemented at commandable structures during the next week: broad plan.
3.	Weekly	Evaluate operations	Computation of various criteria to assess the performance of water deliveries and implementation process during the past week.
4.	Monthly	Observe maintenance	Detection of variations of the physical parameters of the system due to erosion, structural degradations, etc.

2. *The Tasks Carried Out*

A number of tasks are needed to analyze the input messages and generate the outputs. Each function (COMMAND, OBSERVE, EVALUATE) contains a "submenu" of individual activities which can be carried out by a succession of tasks. Since the development of these tasks implies careful analysis and raises generic problems of canal hydraulics and performance estimation, separate indications will be given in part 3.b. Nevertheless, the basic succession of tasks to be carried out after receiving any message (9 messages are mentioned) or considering the Management Clock (4 activities are mentioned) is presented hereafter without real descriptions of the calculations to be undertaken to fulfil them.

Table 3.5. Tasks to be carried out after receiving a message.

No.	Message	Basic tasks involved	Optional tasks
1.	Flow measurements	-Update operations -Update water levels -*Compute discharges* -Update discharges	-Activity: observe operations
2.	Operations	-Update operations -Update water levels	-Activity: evaluate operations
3.	Calibrations	-Update, consult discharges -Update, consult operations -Update, consult water levels -Consult hydraulic structure status -*Compute discharge coefficient* -Update discharge coefficient	-Activity: observe maintenance
4	Structure survey	-Update hydraulic structure status	-Activity: observe maintenance
5.	Canal bed survey	-Update hydraulic structure status	-Activity: observe maintenance
6.	Target fixing	-Update target fixing information -*Compute targets* -Update targeted discharge	-Activity: command operations
7.	Rainfall	-Update, consult rainfall records	-Activity: command operations (control)
8.	Requests from users	-Update, consult user request records	-Activity: command operations (control)
9.	Emergency	-Update, consult emergency records -Activity: command operations (control)	

Table 3.6. Basic tasks involved in Management Clock activities.

No.	Frequency	Activity	Basic tasks involved	Optional tasks
1.	Daily	Observe Operations	-Consult targets -Consult discharges -Consult water levels -Assess deviations -Produce output #1	-Activity: command operations (control)
2.	Weekly	Command Operations	-Consult hydraulic structure status -Consult targets -Consult library of water distribution plans -*Compute operations* -Produce output #2, #3	-Compute targets -Consult performance -Consult water levels -Consult discharges -Update library of water distribution plans
3.	Weekly	Evaluate Operations	-Consult hydraulic structure status -Consult targets -Consult water levels -Consult operations -Consult discharges -*Compute indicators* -Update indicators -Produce output #4, #5	
4.	Monthly	Observe Maintenance	-Consult operations -Consult discharges -Consult water levels -*Compute Strickler* -Update Strickler -*Compute seepage* -Update seepage -Consult discharge coefficient -Consult hydraulic structure status -Assess deviations -Produce output #6	- Compute maintenance action

3. *The Database Maintained*

The data obtained by analyzing the information conveyed through the different messages received or sent by the level L_1 should be organized in an efficient and systematic way by aggregating them in different objects.

An object is used by the manager to organize his knowledge about his activities and the system he has to deal with. An object is characterized by an identifier, usually has several occurrences and is described by a given set of data. The occurrences can be mainly of two types:

- Spatial -- (Example: the object "offtake" has several occurrences along a canal).
- Temporal -- (Example: the object "opening at a particular gate" has several occurrences in time and thus has historical records).

A generic classification of the objects related to main-canal management is proposed in Table 3.7.

Table 3.7. List of objects.

Type of object	Type of occurrence	Object description
1. Basic hydraulic "structures"	Spatial	Regulation structure, distribution structure, conveyance structure
2. Basic hydraulic "devices"	Spatial	Gate, weir, syphon, cross section, etc.
3. Operation of "devices"	Temporal	Gate opening, etc.
4. Hydraulic parameters	Temporal	* Measurements: water levels upstream and downstream, discharge, discharge coefficient, seepage, Strickler coefficient * Reference values or targets (historic): discharge, admissible Strickler
5. Context messages	Temporal	Emergency, user, rainfall, command area status, cultivation stage, etc.
6. Performance indicators	Temporal	Performance of hydraulic structures
7. Scenarios	Contextual	"Typical canal configuration," "typical water distribution plan"

A coherent "image" of the system usable by the level L_1 can be obtained by considering these objects. The coherence is ensured by the main concepts of structures and devices (Figure 3.6) and a network of relations between them and the historical records (Figure 3.7).

Figure 3.6. Data organization by object.

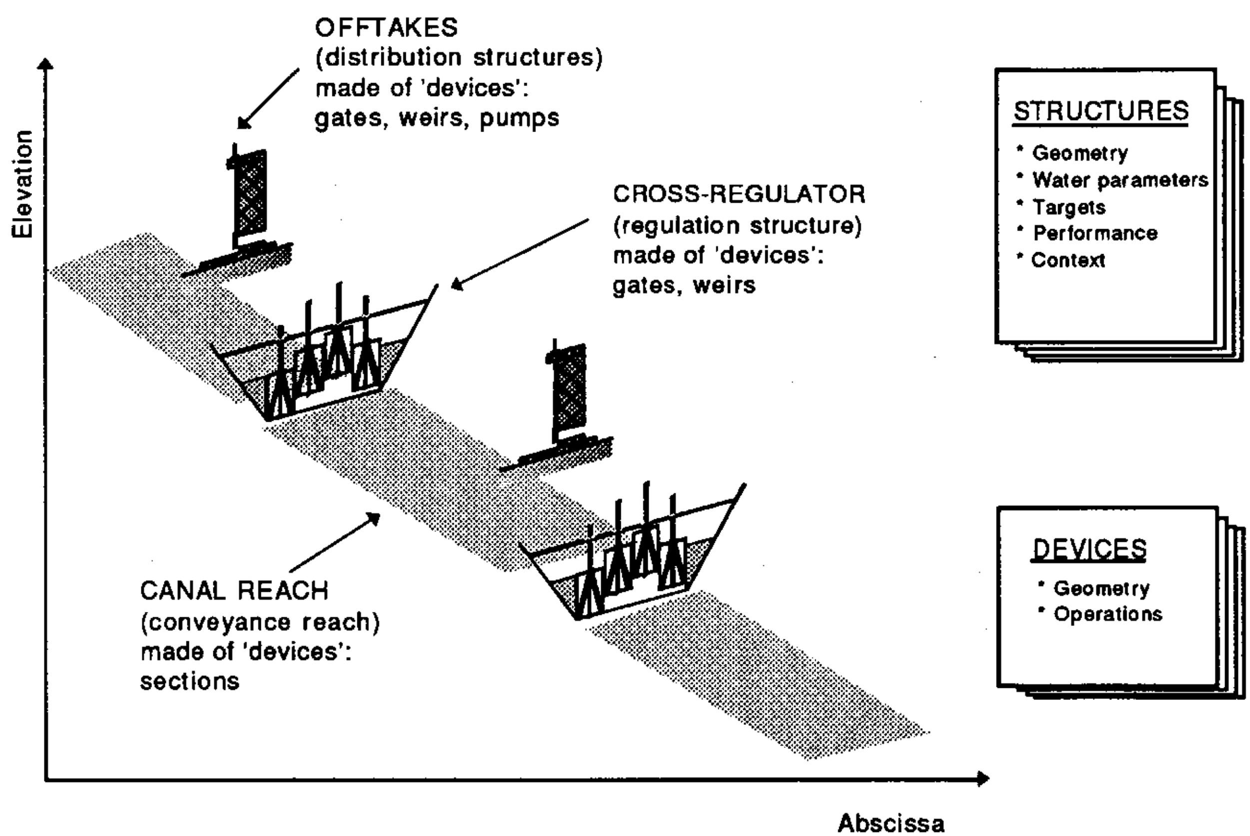
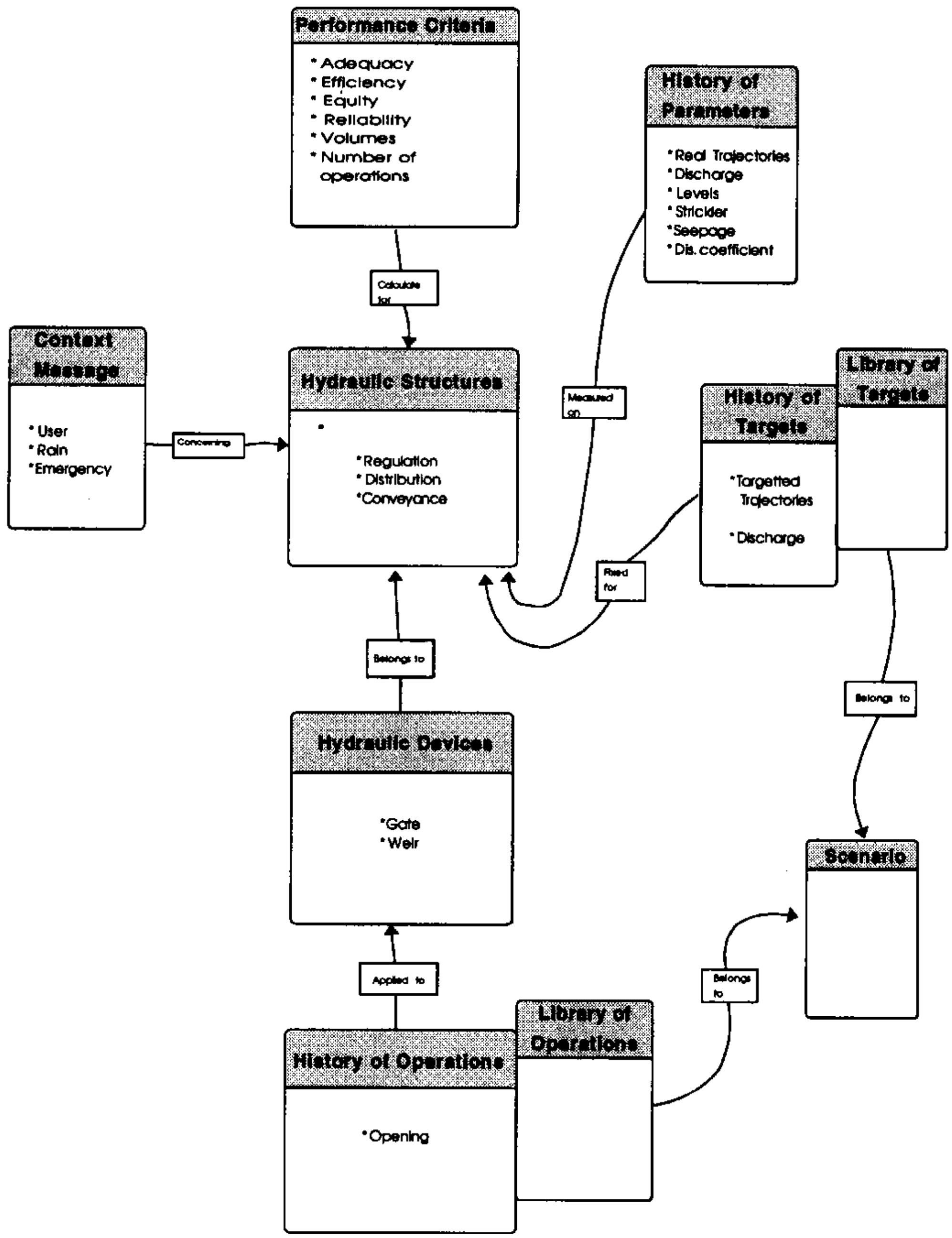


Figure 3.7. Relations between objects.



At this stage, messages, tasks and data have been broadly described. They are interacting according to the matrix given in Fig. 3.8.

Figure 3.8. Messages, tasks and data.

INPUTS MESSAGES + [DATA PROCESSINGS (tasks)] * [DATA] = OUTPUTS MESSAGES

INPUTS MESSAGES	struct.	op.	lev.	dis.	Cd	seep.	K	tar.	rain.	user.	emerg.	perf.	lib.	DATA	OUTPUTS MESSAGES
*1. (forms)		U	U	C,U										hydraulic structures	+1?
*2		U	U											operations	+3?
*3	L	U,L	U,L	U,L	C,U									water levels	+4?
*4	U													discharges	+4?
*5	U													Cd	+4?
*6								C,U						seepage	+2?
*7									U,L					strickler	+2?
*8										U,L				target discharges	+2?
*9											U,L			rainfall	+2
+1. (activities)			L,G	L,G				L						users requests	D,#1,+2?
+2	L	C	L^	L^				C^,L				L^	L,U^	emergency	D,#2,#3
+3	L	L	L	L				L				C,U		performance indicat.	D,#4,#5
+4	L,G	L	L	L	L,G	C,U,G	C,U,G							library	D,#6

*1.Flow measurements
*2.Operations
*3.Calibrations
*4.Structure survey
*5.Canal bed survey
*6.Target fixing
*7.Rainfall
*8.Requests from users
*9.Emergency
+1.Observe operations
+2.Command operations
+3.Evaluate operations
+4.Observe maintenance

U: Update
L: Look or consult
C: Compute or process
G: Assess deviation

(^): optional

#1.Water delivery pattern
#2.New targets
#3.New operations (plan/control)
#4.Evaluation report (up)
#5.Evaluation report (down)
#6.Maintenance report
D.Display

Every object is created (U) and consulted (L) at least during one of the management activities (following one of the 13 inputs). The shades relate to computation tasks undertaken through the COMMAND function (target and operation computations) or through the functions, OBSERVE and EVALUATE (discharge, discharge coefficient, Strickler coefficient, seepage, and performance indicator computation).

The main objective of this detailed analysis was to propose a systematic approach leading to a comprehensive understanding of the notions of functions (command, observe, evaluate), communication (messages), tasks (data processings) and data (database). Based on this framework and some technical considerations (part 3.b), the practical design of tools can be envisaged for a given canal in a given management context.

b. TECHNICAL KNOWLEDGE INVOLVED

Knowledge for the COMMAND Function

The computations identified for the function of COMMAND are the computation of water delivery targets (water allocation plan) and the computation of operations (water distribution plan). Using the terminology of Figure 3.2, the main areas of technical interest involved in these two computations are optimization and simulation. Envisaged separately, the technical knowledge required to perform these two computations can be specified:

- The computation of water delivery targets has been extensively discussed in the literature and various water allocation models are available (Van der Krogt 1993; Makin 1993). It is worth mentioning that the fixing of targets at the main-canal level goes beyond the assessment of crop or soil water requirements and also addresses the questions of conveyance efficiency and rotational scheduling. Computation of targets under specific conditions like water shortage can require additional considerations for optimizing the allocation. Management simulation models are useful in assessing the feasibility of given water allocation plans in terms of monitoring and operational implications (Murray-Rust 1994).

- The computation of a sequence of operations enabling a canal manager to supply water according to fixed and known water delivery targets involves mainly hydraulic considerations and a good knowledge of the system facilities (storage capacity of the reaches, lagtimes, manageability of structures, safety, etc.). Hydraulic simulation models are useful tools to assess the efficiency of water distribution plans (Baume et al. 1993).

  Problems arise while realizing that these two computations should actually be considered as linked through a global optimization process. It is indeed not possible to work out an optimal water distribution plan without having water delivery targets and, similarly, it is also not possible to work out optimal targets without assessing the managerial cost of the associated water distribution plan (Rey et al. 1993).

Knowledge for the OBSERVATION Function

The computations identified in this process are all related to hydraulic parameters: discharges, discharge coefficients (calibration of structures), seepage, and Strickler coefficient. The ability to compute discharges with a reasonable accuracy at various control points (including regulation and distribution points of interest) is a key data analysis issue. Methods of computation (structure formulas, rating curves) are available and need careful consideration. Sensitivity studies with regard to input data (water levels, openings) might be required to work out the most suitable computation method at a particular structure. The determination of seepage and Strickler coefficients can be computerized provided that historical hydraulic data can be analyzed in order to identify periods of steady flow along the canal studied (Male 1992).

Knowledge for the EVALUATION Function

The computations required relate to the definition of performance indicators and involve mainly data analysis through statistics. Difficulties usually do not arise at the technical computation stage but they arise in choosing a set of indicators relevant and meaningful to the decision maker considered. Classical indicators are derived from means and standard deviations of the ratio of the real and targeted deliveries at the different distribution points of a canal (Molden and Gates 1990; Rao 1993).

Based on the analytical framework and previous technical considerations, the practical design of a prototype tool to assist the management of a given canal in a given context can then be envisaged.

c. DESIGN OF COMPUTER TOOLS

As far as the computer-based decision support tools are concerned, the growing library of software provides numerous examples of technical standards. The choice of a type of tool is of primary importance. In most cases, the computer tool itself while being only one element of the "action package" acts as a real and essential catalyst in the intervention process.

- Structure of software: The information system approach tends to emphasize the role of a core, database-management software (DBMS) linking the *database* to *specific applications* via a model-based management software (MBMS) which performs tasks on the available data and provides outputs to the user through an interactive *interface* generated by a dialog-generation management software (DGMS), as represented in Figure 3.9.

  Usual links between the three types of packages (DBMS, MBMS and DGMS) to be selected and the areas of technical interest identified in Figure 3.2 while studying the management functions are made explicit in Figure 3.10.

- Required characteristics: Beyond the choice of a proper structure, the degree of acceptance of a particular software and ultimately its usefulness are conditioned by many characteristics. The characteristics listed by various authors (Jurriens 1993; Murray Rust 1994) can be referred to for the design of computerized decision support tools in general. The key factors presented are user friendliness, flexibility and relation of the tool to the practices of the user before the introduction of the tool. It is imperative that these factors be taken into account at the design stage.

Figure 3.9. Components of computer-based decision-support tools (inspired by Sprague).

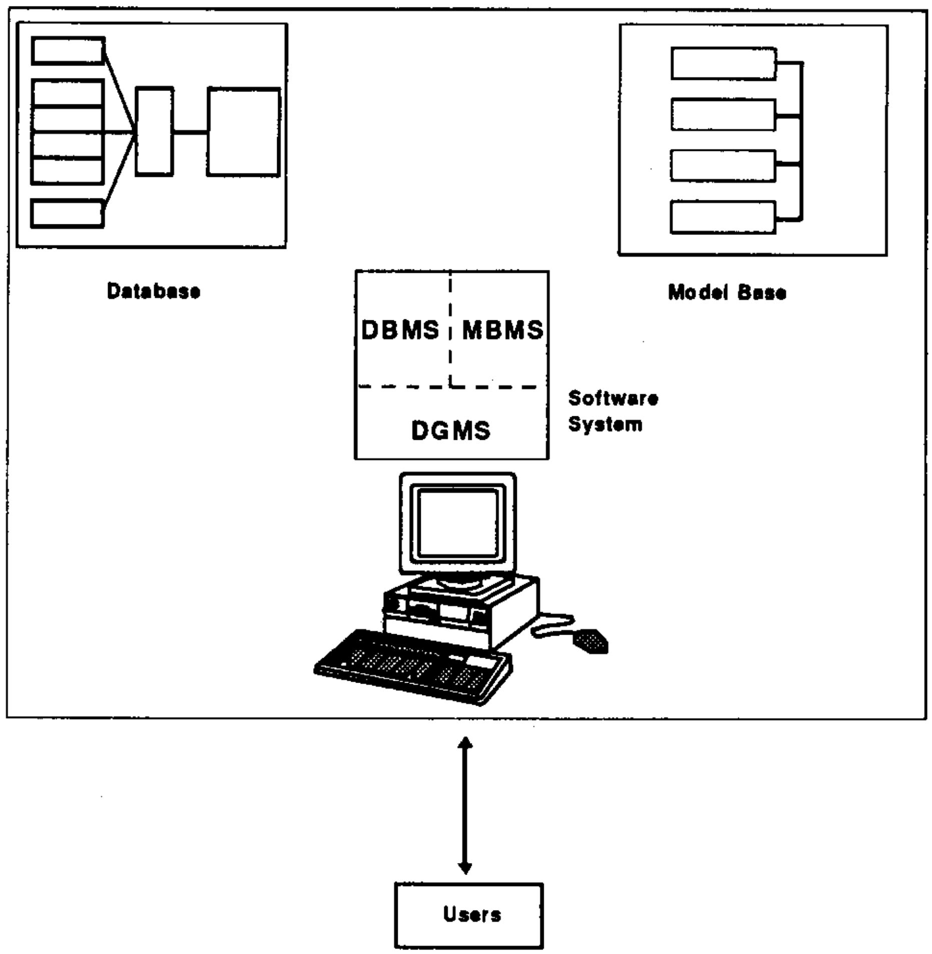
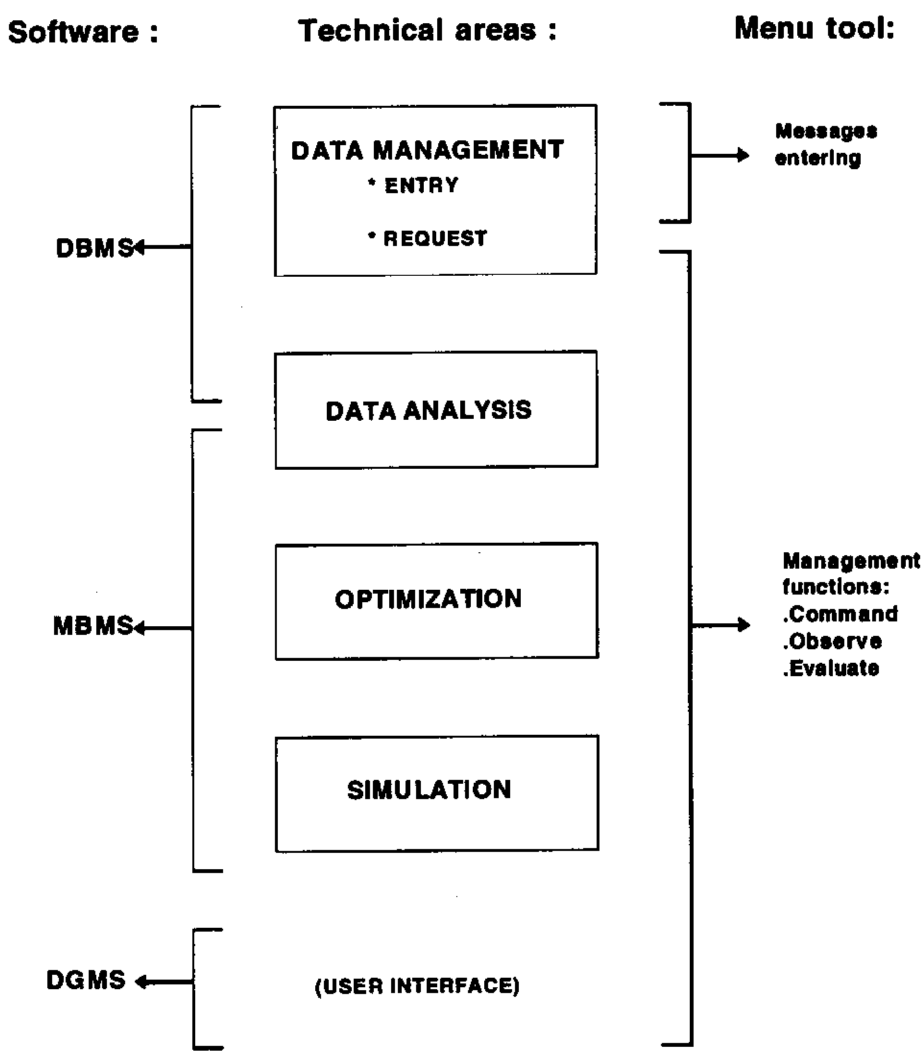


Figure 3.10. Link between software packages and technical areas for decision support.



4. DSS for Water Distribution Management: Field Installation

THE FIELD INSTALLATION of a DSS requires careful attention. Securing the interest and commitment of the user depends on his degree of participation in the installation process and in a proper sequencing of the installation steps in the field. These two aspects are briefly discussed here.

a. MODE OF INTERVENTION

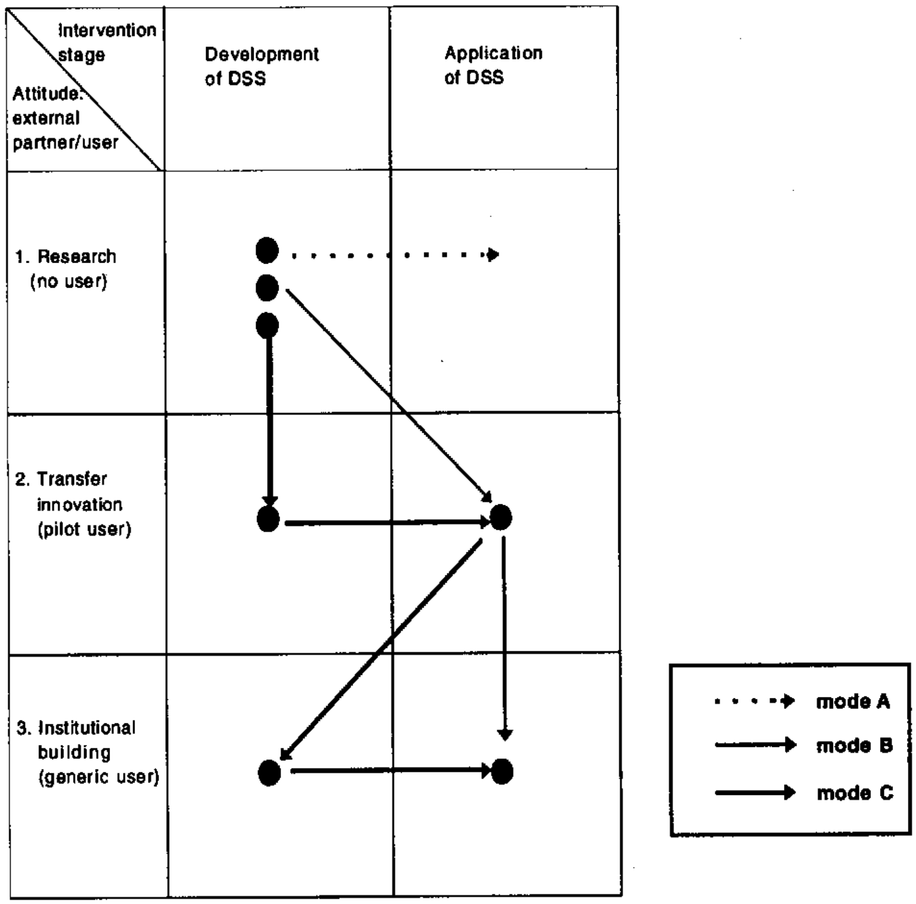
Different modes of intervention can be followed for installing a DSS. The choice of a particular intervention mode has to be carefully made as it impacts on the process of implementation, the time required for implementation, and on possible transfer of tools and methods to irrigation managers. In Figure 4.1, a typology of the modes of intervention is presented for determining the degree to which the users are involved in the design and development of the DSS.

Mode A : Problem-solving approach by an external partner, leading to the transfer of results but not of tools or methods.

Mode B : Semi-participatory or turnkey approach with an external partner leading to a transfer of ready-made tools and methods for application of tools (to a pilot and/or generic user).

Mode C : Participatory approach with an external partner leading to a transfer of methods for development and application of tools (to a pilot and/or generic user).

Figure 4.1. Different modes of intervention.



b. STEP-BY-STEP INSTALLATION

Nine generic steps can be identified for the installation of a DSS following a participatory mode of intervention (mode C). These steps are implemented in sequence but are generally overlapping. Some of the activities have to be repeated in part in later stages of the implementation (e.g., physical survey). The case of a DSS for water distribution management is made explicit below.

1 *Define the prototype.* Researchers and the system managers have to agree on a tentative configuration of the decision support tool and the expected outputs through in-depth discussions of the various options available (simulation or not, choice of indicators, etc.).

2 *Survey of the physical system.* All basic, permanent data required to carry out selected computations (descriptions of control structures, topography of the canal, etc.) have to be collected.

3 *Build awareness among staff members.* Staff members involved in or affected by the installation of the DSS have to be integrated into the implementation process. The proposed activity has to be presented to all staff members, after which they participate in the implementation of the DSS.

4 *Set up a data collection and transmission network.* Once the set of permanent information relating to the physical configuration of the system is stored in the DBMS, it is critical to review, organize and systemize the information flows of dynamic data between the field and the decision-making level. Specific data collection formats have to be designed and specific training of staff responsible for measurements, data recording, data transmission and data entry has to be carried out.

5 *Introduce data analysis activities.* The first by-product of flow-monitoring activities is a record of water distribution patterns in the irrigation system. Being aware of actual water deliveries, assessing trends, and doing simple water balance computations in real time can contribute to analysis of management practices and discussion of problems of water distribution. The computation of other indicators can then be progressively introduced. The use of display boards is a very valuable support at this stage.

6 *Investigate the validity of water delivery targets.* The rules underlying the fixing of targets, expressed in terms of discharges at the control points, may be evaluated by comparing water delivery targets with the real water distribution pattern. Steps to improve or revise the rules can thus be initiated if necessary.

7 *Initiate control activities.* The frequency and magnitude of control operations is very much related to the accuracy of the water delivery targets. Control operations are needed only if gaps between measured and targeted discharges are detected. Except in the case of strong perturbations in the system, control instructions can usually be transmitted in a fairly qualitative manner and be limited to adjustments at certain gated structures.

8 *Optimize operational decisions.* In the event of strong perturbations, as well as for a limited number of difficult management phases (rotations, starting water issues), more complicated procedures involving the regulation structures may have to be determined and possibly tested via a simulation model prior to implementation.

9 *Work out a mechanism for evaluation.* A seasonal evaluation of the impact of the use of the decision support system on the management organization and, ultimately, on the water delivery performance, together with an assessment of possible improvements to the system, is essential.

5. Example of Application

THE PURPOSE OF this section is not to provide a detailed case study of the interventions conducted by IIMI in a particular scheme. The case of the Kirindi Oya irrigation system (in the south of Sri Lanka) is rather used as a support for illustrating the various notions and methods introduced earlier. Background information on this irrigation system can be found in Sally et al. 1988 and Rey et al. 1992. The main canal considered is a 24 km long earthen canal commanding an irrigated area of 4,000 ha. The climatic conditions in the area and the characteristics of the scheme are such that the water available in the reservoir serving the scheme is insufficient for growing rice during the two traditional Sri Lankan cultivation seasons, *maha* and *yala*.

a. A DSS FOR THE MANAGEMENT OF THE KIRINDI OYA MAIN CANAL

Needs Assessment

Which Management Intervention?

In Kirindi Oya, the key issue of performance improvement was clearly identified as the need for efficient management of an extremely scarce water resource. Under such conditions, key areas of potential improvements concern both the planning stage (choice of crops and cultivation calendar) and the operational stage (water application methods at the field level, water conveyance, and distribution management). Among these, water distribution at the main-canal level was identified as a critical activity.

Identification of Performance Drivers

To study the decision-making process at the main-canal level, the quality of the communication system between the field staff and the canal managers, the indicators used as management signals, and the decision-making rules and procedures had to be assessed. The indications given in Figure 2.1 for identifying the weaknesses in the decision-making process were used for articulating the process-evaluation around three main questions:

Adequacy of messages: Are management decisions based on reality? The actual deliveries at the head of the secondary canals were insufficiently controlled by the manager, due to the lack of measurements and **communication** along the canal, and water wastage occurred due to the high reaction-time lag. Thus, providing him with a timely and reliable "picture" of his system was identified as a prerequisite of management improvement.

Adequacy of system memory: Are management decisions based on performance analysis? Under water-scarce conditions, a key indicator is the volume delivered to the different secondary canals, computed at regular intervals. The maintenance of a small **database** permitting easy access to this indicator (and potentially others) appeared as an interactive means of promoting an optimization attitude at the decision-making stage.

Adequacy of technical knowledge: Is the logic of management decisions technically sound? The hydraulic behavior of open-channel systems with cross-regulators is sometimes far from intuitive and requires a fairly long experience to be completely mastered. In order to be performed efficiently, critical **tasks** of water distribution management (during phases implying changes of the main discharge) required additional procedures. The study of water distribution plans, created with simple decision support modules and tested with a hydraulic simulation model, was proposed.

This diagnosis phase did not address the issue of suitability of the hardware (modernization and rehabilitation) and deliberately concentrated on potential improvements by a better management of the existing system.

Suggested DSS and Installation

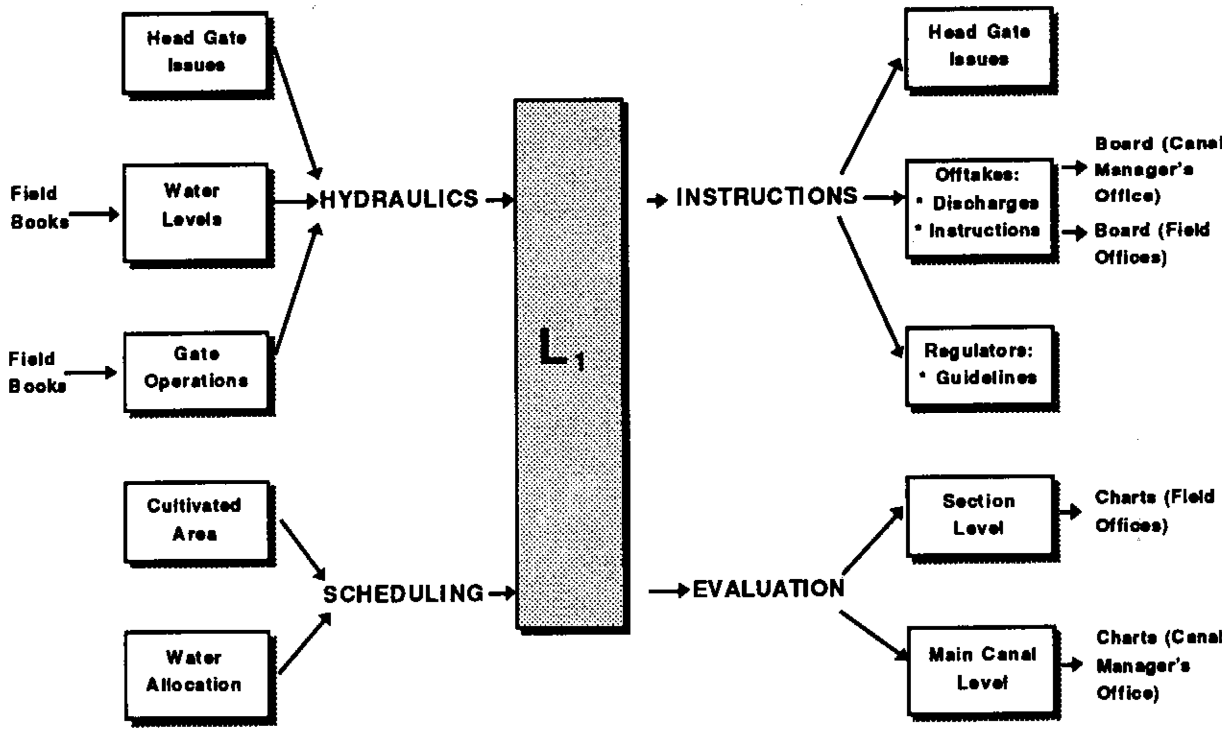
Following the previous recommendations, a frequent data collection system and communication network were created and are currently being used. Essentially, basic data of water levels and gate openings are collected at all structures operated along the main canal, including gated regulators and offtakes. These data are recorded twice a day by the gate keepers and summarized in a standard format which is handed over, on the same day, to the canal manager. These new data are converted into discharges, displayed in the manager's office on a board and stored in a computerized database.

The complete set of messages introduced in Kirindi Oya is presented in Figure 5.1. The boards display the discharges at the offtakes stimulating timely control of deliveries. The charts summarize the cumulative volumes issued at the offtakes, per section of the canal and for the whole canal, focusing the attention of the manager on the key strategic objective of water use efficiency.

The database created reflects the information conveyed by the messages and comprises data on canal structures and topography, hydraulic trajectories at the structures (levels, openings, discharges), and some contextual information (areas cultivated, rainfall).

Parallel to this first set of activities, interfaces between the previous database, simple hydraulic modules (spreadsheets) and an hydraulic simulation model (CEMAGREF 1992) were developed to allow further improvements in the decision-making process. This combination of tools provides the manager with guidelines for a better understanding the hydraulic functioning of the canal, in order to prepare coordinated operations at the cross-regulators when needed (rotations among different sections of the canal, start of issues) and test these operations prior to implementation.

Figure 5.1. Management Information System messages.



b. UTILIZATION OF THE DSS IN KIRINDI OYA

Tracing the Water Consumption

Interesting results have been obtained regarding the key performance issue of water conservation. A decreasing trend in water consumption was observed as made explicit in Table 5.1. This trend is the result of a combination of factors but is definitely linked, as confirmed by the two successive managers of the Kirindi Oya Right Bank Main Canal, to the enhancement of the control capability of the management resulting from the introduction of the DSS. As a result of the systematic introduction of monitoring activities, the water delivered at the heads of the distributaries was looked into by the managers throughout the seasons and water was saved whenever possible.

Table 5.1. Water deliveries in Kirindi Oya.

	Maha 90/91	Maha 91/92	Maha 92/93
Rice crop duration	3.5 months	3.5 months	3.5 months
Average duration of land preparation	6 weeks	6 weeks	6 weeks
Area cultivated	2,530 ha	2,980 ha	2,518 ha
Rainfall	1.01 m	0.70 m	0.30 m
Measured duty	2.53 m	2.35 m	2.52 m

Use of Indicators to Assess the Manageability of Structures

A second field of investigation in Kirindi Oya was the hydraulic functioning of the different structures (cross-regulators and offtakes) and their related achievements with regard to water delivery targets. For this purpose, a set of indicators was computed for all offtakes along the canal.

Three performance indicators, P1, P2, and P3. These indicators (see Molden and Gates 1990) explicitly take into account the targets formulated by the manager in terms of water deliveries.

P1: Measure of adequacy (indicative of the notion "enough supply").

P2: Measure of efficiency (indicative of the notion "no waste")..

P3: Dependability (indicative of the notion "timeliness of the deliveries").

Three descriptive indicators, D1, D2 and D3. These indicators aim at describing hydraulic behavior at the structures without explicit reference to managers' targets.

D1: Total number of gate adjustments performed at a given structure.

D2: Average submergence at the structure (ratio of the downstream level over the upstream level).

D3: Average level fluctuation upstream of the structure (standard deviation of the upstream level).

The set of performance indicators was first used to detect weaknesses in the water delivery process. The quality of water deliveries at one structure is highly dependent on its location along the canal and on the capabilities of field staff in charge of operating it. Discriminating amongst the different structures according to their achievements with regard to common objectives such as adequacy, efficiency and reliability of water deliveries is of great importance in ensuring proper management control. For each of the three performance indicators, structures were separated into three groups, values below the average, values equal to the average, and values above the average, and received, respectively, the flag numbers, -1, 0, and +1 (see Table 5.2 for examples of 5 structures). For further comparison, three main categories were finally created according to the value of the sum of the flags. Structures presenting a good water delivery profile could then be separated from those where problems occurred in meeting their targets during the season.

Following the same approach, structures were classified according to the values of their descriptive indicators (see Table 5.3 for examples of 6 structures). In the process of diagnosing the potential

Table 5.2. Flags according to performance indicators.

Tract	Structure	P1 (Adequacy)	P2 (Efficiency)	P3 (Dependability)	Summary
3	FC55	1	-1	-1	-1
3	DC1A	1	-1	0	0
3	DC1B	-1	1	1	1
1	DC1	0	1	1	2
1	FC6	1	1	1	3

Table 5.3. Flags according to descriptive indicators.

Tract	Structure	D1 (Number of operations)	D2 (Submergence)	D3 (Level fluctuations)	Summary
4	FC37	-1	-1	-1	-3
4	DC1	-1	-1	0	-2
1	F56	0	-1	0	-1
5	DC1	1	0	-1	0
2	DC9	1	-1	1	1
3	FC55	1	0	1	2

difficulties faced by field staff at the implementation stage, simple information concerning the hydraulic conditions at the structures is useful. A structure is considered as "operating well" if few operations are done, the degree of submergence is low, and few fluctuations of upstream water level occur.

This set of flags helped the manager to focus his attention on critical structures of his system and eased his diagnosis.

Working Out Water Distribution Plans

As mentioned earlier, a combination of simple hydraulic modules interfaced with a hydraulic simulation of flow was proposed for improving the quality of water distribution planning.

The first module proposed, based on the initial water levels in the canal and topographical data, gives information concerning the approximate time needed for filling the reaches in the parts of the canal where the water level appears to be too low. Rough information about adequate gate settings at the gated regulators to fill the reaches in a coordinated manner is also provided.

The second module, based on the consideration of the water delivery schedule and the use of linear transfer functions for rough modelling of the water propagation along the canal (diffusion and lag times), provides a first tentative plan for the water released at the head gate.

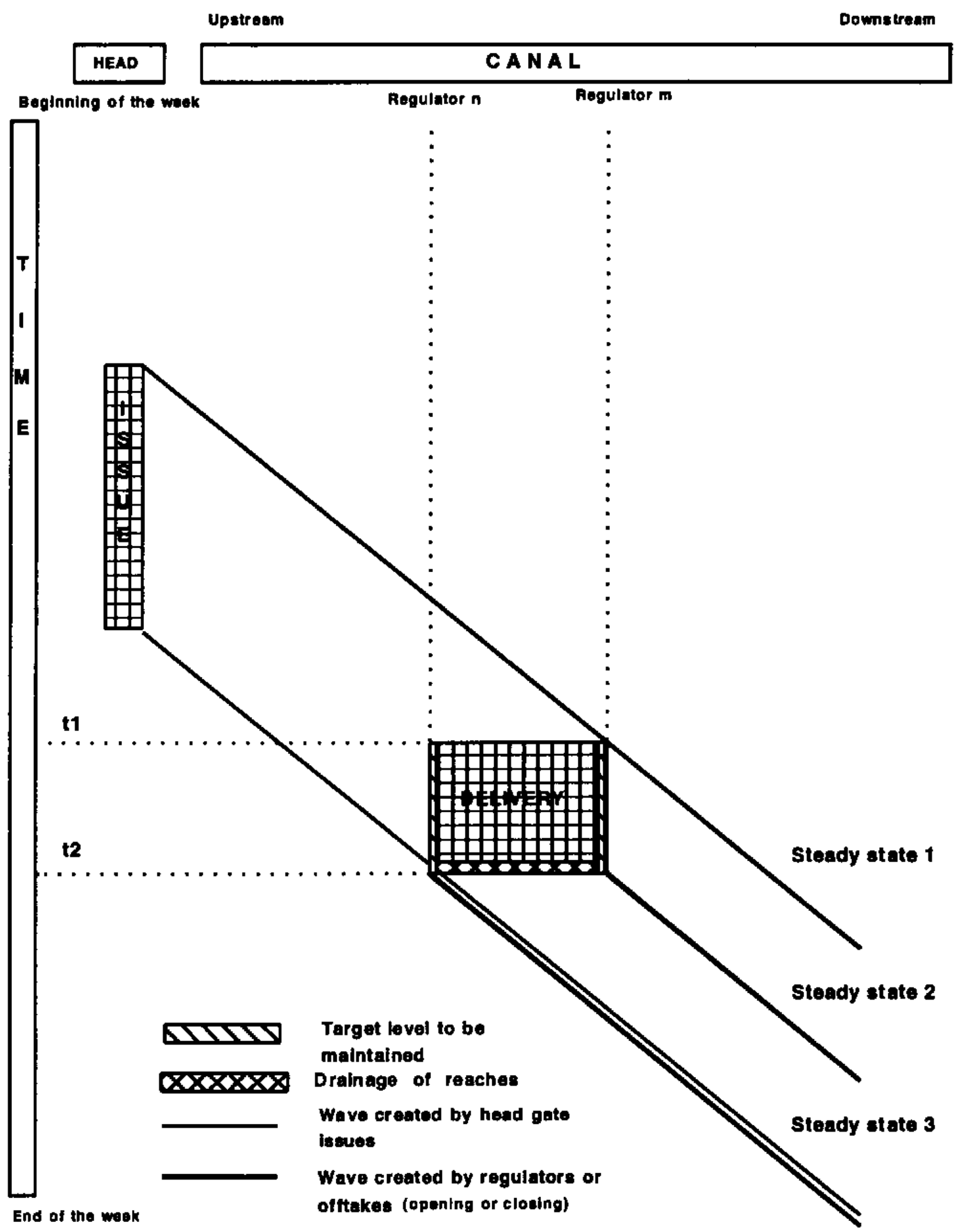
Based on the water issue pattern at the head gate and the water delivery schedule, the propagation of water along the canal is studied in order to provide some guidance concerning the time and amplitude of gate settings required to achieve the targets. This analysis is mainly done manually by studying a simple chart presenting a summary of the expected water delivery pattern. Some steady flow simulations are also used to generate indications about the optimal amplitude of gate openings during the different stabilized phases of the water issues (Figure 5.2).

Having followed these three steps, settings tentative for all the gates along the canal are then available to be tested and evaluated by means of an unsteady flow simulation. Water levels and discharges at any point of interest along the canal are computed by the model and the results are evaluated in terms of water deliveries achieved at the offtakes and water level fluctuations in the main canal.

If considered as satisfactory, the plan is proposed for implementation; if not, the decision maker can revise it according to the weaknesses detected by looking at the simulation results, and retest it.

This method has been used for bringing the canal on "regime" at the beginning of the water issues in the wet season, 92/93. Though the method was not followed perfectly by the field staff, the operations worked out allowed the stabilization of the canal at a faster rate than usual.

Figure 5.2. Study of the water distribution plan.



6. Conclusion

A ROBUST FRAMEWORK for understanding the needs of an irrigation manager in terms of decision support is essential for defining and installing a decision support system which fits his own capabilities and the physical and organizational features of his system.

As far as the computer tools are concerned, the generic analysis presented in this paper leads to the consideration of the value of simple DBMS shells interfaced with computational modules which can be either designed by the managers themselves (simple spreadsheets for water scheduling) or found in the growing library of specific computer applications (hydraulic simulation, for example).

IIMI's experience in Sri Lanka reveals that a willingness is emerging to reorient initiatives in the field of DSS from external supply-driven interventions to in-house developments based on skills and experiences of the irrigation managers themselves. This trend, which could be a step towards technical autonomy and sustainability, needs to be supported by institutional decisions and the strengthening of research and development capabilities within the irrigation agencies. The role of external partners would thus need to be partially redefined and adjusted--from a final product marketing perspective to focussing on reinforcing the agency's own capacity to develop and apply appropriate information techniques, and providing advice on needs-assessment techniques, modular development of tools, training programs and evaluation methods. This paper can be considered as a modest attempt in this direction.

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