PERFORMANCE ASSESSMENT DIAGNOSIS

Final Report

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Preface

The project has been undertaken jointly by the International Irrigation Management Institute (IIMI) based in Colombo, Sri Lanka, and the International Institute for Land Reclamation and Improvement (ILRI) in Wageningen, the Netherlands. Planning and advisory support has also been provided by the International Institute for Hydraulic and Environmental Engineering (IHE), based in Delft, the Netherlands.

Staff from both IIMI and ILRI were fully involved in the planning and implementation of the project, including extended periods of direct collaboration in both Colombo and Wageningen. The project started in September 1990 and was completed by the end of February 1991. A draft of the Final Report was sent to members of the ICID Working Committees on Irrigation Performance Assessment and Operations, Maintenance and Management of Irrigation and Drainage Projects which met at the Executive Council Meeting of ICID in Beijing in April, 1991.

Many useful comments and contributions resulted from this meeting, and these have been incorporated into the final text.

The output from this project, and any further activities in the general subject area, will form part of a presentation to the 15th. Congress of the International Commission on Irrigation and Drainage to be held in the Hague, the Netherlands, in September 1993.

Acknowledgements

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The initial design of the project was undertaken by Ir. Ernst Schulze of IIMI, and Mr. Bart Schultz of the Dutch National Committee of ICID.

From IIMI, substantive contributions were made to the final text by Dr. Douglas J. Merrey, Mr. Charles Nijman, and Dr. Marian Fuchs-Carsch.

We would like to recognize the substantial contributions to the discussions on design environments and performance indicators made by Ir. Wouter Wolters of ILRI. Additional comments and suggestions were also received from Ir. Paul van Hofwegen of IHE.

Following the presentation of the first draft of the report at the ICID Executive Council in Beijing in April many additional comments were received. We are particularly indebted to Dr. R.S. Varshney for his extensive comments.

We would also like to thank the members of the Steering Committee for their advice and assistance: Charles Abernethy of IIMI, Dr. Rien Bos of ILRI, and Ir. Jan Luijendijk of IHE.

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Section 1

Performance Assessment Diagnosis

1.1 Description of the Project and its Objectives

The objective of this project was to develop a set of hypotheses concerning the interrelationships between physical design, management strategies and performance and sustainability of irrigation systems. To this end a number of case studies from Asia, Africa, and South America were selected from the existing literature, backed with personal experiences of the authors and their colleagues in the collaborating institutions, that were anticipated to reveal whether it is possible to diagnose different levels of performance, and relate this to the physical design of the systems.

The overall principle underlying this project is that while performance of an irrigation and/or drainage system reflects the qualities of the organizations and individuals responsible for the management of the system, it is greatly influenced by the physical design of the water delivery system. A good manager will ensure that the appropriate management strategies are adopted that are compatible with both the physical and management qualities.

During the first part of the project it became clear that there was no effective definition of performance, and no clear process by which a diagnosis could be made of performance other than on highly subjective grounds. It therefore became necessary to look at the process by which performance can be defined and assessed before a diagnosis could be made of conditions that might foster or constrain high performance.

1.2 Project Contents

This report is divided into seven sections as follows:

Section 1 introduces the project objectives, describes the format of the report and presents the primary hypotheses that have been developed. These hypotheses are not justified in this section.

Section 2 addresses the issue of why performance needs to be evaluated. By drawing parallels between the world of business management and irrigation management it is possible to understand where there are similar conditions that allow the types of assessment undertaken in commercial enterprises to be adopted in irrigation performance assessment. It is also possible to determine where conditions are sufficiently different that irrigation management has to develop its own criteria and standards of performance.

Section 3 provides a broad classification of the main design types, and how they affect management decisions. For each design environment a description is provided of the primary characteristics of the physical irrigation infrastructure, typical water allocation principles that are appropriate to those designs, and the types of institutional arrangements that are found. It also addresses issues of system objectives and the interrelationships between design and the management of operations and maintenance.

Section 4 provides details of performance from 15 case studies that represent typical examples of different design environments. For each environment a description is provided of the performance of the system in achieving its stated objectives, including aspects such as water distribution equity, reliability and adequacy, and the impact of achieved water delivery patterns on agriculture.

Section 5 examines the extent to which the case studies show evidence of performance in respect of non-agricultural conditions including sustainability of physical resources, health, and income distribution. It also addresses issues of how well systems respond to external changes such as changing agricultural targets and increased competition for water, land and labor resources.

Section 6 provides a discussion of a process by which it is possible to diagnose performance in irrigation systems. This process looks at a set of pathways that address whether objectives were fulfilled, whether secondary targets were met, and the relative importance of constraints to improved performance. These constraints include implementation aspects of both operations and maintenance, physical constraints that require redesign or rehabilitation, and institutional constraints.

Section 7 looks at a set of hypotheses that if followed provide the basis for performance-oriented management. It addresses four groups of concerns that were identified from the case studies: the process by which objectives are identified, the implementation of work plans to meet those objectives, the information gathering and feedback process that forms part of the management control function, and the institutional arrangements that provide the basis for management of the system.

1.3 Hypotheses on the Process of Performance Assessment

During project implementation the need for a more logical approach to the process of performance assessment became quite clear. The proposals for such a process are presented in Section 6, but a summary of the major conditions required for a proper assessment of performance are given below.

If, and only if, the appropriate data is available is it possible to undertake a logical and analytical process of performance assessment.

Target and Objective Achievement

The ideal level of performance can only be achieved when targets were achieved, objectives were fulfilled, and there was an efficient use of available resources.

If targets and objectives are met but resource use is not efficient, then performance can be improved by institutional modifications that lead to better resource use: this can lead either to a reduction in resource utilization or definition of a more ambitious set of objectives to make use of the spare resource capacity.

Target and Objective Mismatches

If targets are not met but objectives are, then there is a target-objective mismatch: because the targets are short term efforts to fulfill wider objectives, the targets are more likely to require modification in the first stage of managerial intervention.

If targets are met but objectives are not, then there is a target-objective mismatch. A review of both objectives and targets is required to determine whether it is the objectives or the targets that must be modified before performance can be improved.

Assessment of Implementation.

Where neither targets nor objectives are fully satisfied, then the most likely way to obtain long term improvements of performance is to focus on setting and achieving shorter term targets; once this basic management condition has been achieved it may be possible to broaden the scope of management improvements.

Only when shorter term targets have been fulfilled is it possible to make an evaluation of the utility of these targets in achieving the overall objectives laid down, and determine if the objectives are realistic.

If targets are both feasible and appropriate then the primary cause of poor water delivery performance is through poor implementation in respect of either operations, maintenance or both:

- if the condition of physical infrastructure is not a primary constraint, then operational procedures merit greater attention; however,

- if the condition of physical infrastructure is the primary constraint, then maintenance procedures should be assessed first before addressing operational change.

Where targets are appropriate but not feasible due to design or construction constraints, then improvements will have to be made to physical infrastructure if targets are to be met: any redesign of existing systems must be undertaken not only on technical criteria but also in relation to the probable management capacity and interest in operating and maintaining the physical infrastructure following reconstruction.

A major cause of poor performance is a mismatch between targets and the availability of financial and human resources: targets must be set that are realistic given resource availability even though this may result in more modest expectations of output from the system.

1.4 Hypotheses Relating to Management Conditions

Based on the diagnosis process described in section 6, it is possible to come to some tentative hypotheses that describe the management environment conducive to high performance. The details and some supporting arguments are presented in detail in Section 7, but the hypotheses themselves are listed below.

(a) Objective Setting

Objectives must be simple and clearly expressed, and the responsibilities for achieving them clearly defined.

Objectives must be based either on past experience from that system, or from systems facing similar design and management conditions, rather than on assumptions about what ought to be achieved.

Performance of irrigation managers must initially be based on their fulfillment of a specified set of objectives. At the same time, there must be a parallel process of evaluation and reviews the impacts of current management actions.

Higher levels of performance appear easier to obtain when the objective set is simple. Management for complex objective sets, particularly where different objectives require different actions over different time frames, is extremely difficult unless there is an explicit recognition of their relative priorities.

Objectives must reflect the needs of all participants: policy-makers, planners, managers and users, rather than only one or two groups. Strengthening farmer participation in the annual or seasonal planning process and the development of operational plans and targets is one way of improving performance.

Performance assessment requires an evaluation not just of output but of the setting of objectives and of the management of available resources in attempting to fulfill those objectives

(b) Operationalization

Each objective has to be transformed into a set of operational targets that match the responsibilities of each participant in the management process.

It is unrealistic to expect managers at system level to develop or modify operational targets unilaterally that will meet objectives developed in the external environment.

Targets must be quantified to facilitate monitoring, and a set of standards developed to enable evaluation to be undertaken.

(c) Information Feedback and Management Control

Without good and accurate information there can be no progress towards performance-oriented management.

Management cannot operate as a black box when either the internal or external environmental conditions are changing: it is essential that managers understand how to achieve particular targets under one set of conditions so that they can make appropriate operational changes when other conditions change.

The common tendency to report that targets have been achieved when in reality they were not is completely alien to the concept of performance-oriented management.

Information on the levels of target achievement and the consequences for agricultural output must be directly integrated into the management structure.

(d) Institutional and other Management Conditions

Performance-oriented management requires a set of incentives and commensurate accountability throughout the management structure.

Evaluation of performance in respect of each objective requires an explicit statement of who is, and who is not, responsible for attaining that objective.

Failure to clearly define responsibilities for achieving objectives appears to lead almost inevitably to lower levels of performance.

Accountability requires that there be specified targets or contracts at points of transfer of management responsibility which enable all parties to determine whether the agreed level of service has actually been achieved and to assess causes of failures to meet the terms of this contract.

The transition from current practices to performance-oriented management will be difficult: it requires changes in planning, in operations, in control and in the institutional setting. The transition also requires that patience and understanding are present to tolerate false starts and mistakes during this process.

A more systematic evaluation of performance obtained through carefully controlled case studies is required both to verify the validity of these hypotheses, and whether additional conditions need to be added. The limitations of using secondary data through completed case studies is clear, and it is essential that such follow on studies be conducted in live irrigation systems where information on management inputs can be added to the somewhat more common descriptions of output form irrigation systems.

Section 2

Why Do We Need Performance Indicators ?

2.1 Introduction

The exploitation and utilization of water for irrigation requires that there are periodic evaluations of its utility and efficiency of use. Although this concern with performance within the irrigation sector is increasing as pressure grows on water resources in all parts of the world, and concerns increase regarding the sustainability of irrigated agricultural systems, it is also essential that any enterprise requires feedback on the management of resources and the end result in terms of increased output.

During this century there has been a dramatic increase in the area irrigated. Most of this expansion has occurred through capital investments in infrastructure for the capture, storage and distribution of water, and in the conversion of rainfed areas into irrigable land. This type of development has created a number of groups who have a direct concern on the performance of the irrigation system: investors, policy makers, planners, managers and users.

Each of these groups has to be able to assess the effectiveness of the systems in which they have a stake. To do this they require not only basic information about the inputs and outputs of the system, but also a framework within which this information can be processed and evaluated. This framework has to be capable of allowing assessment of the performance in individual systems and permit comparisons with other systems and even other sectors of the economy to determine the relative utility of the initial investments and operational inputs.

Without such a framework and its associated set of indicators, performance assessment remains a subjective process that has little value for improving irrigation management. Yet, despite the frequently stated concerns with poor performance in the sector, there are few agreed indicators and no agreed framework for performance assessment.

2.1.1 Definitions of performance and performance indicators

Abernethy (1989) defines performance as :

> *" The performance of a system is represented by its measured levels of achievement in terms of one, or several, parameters which are chosen as indicators of the system's goals."*

This definition carries with it a number of implicit assumptions that are at the heart of the problem of performance assessment.

The first issue is that of scale and audience: the "system" can be at a number of different levels, from the water delivery system upwards through the individual irrigation system, the irrigated agriculture system and up to national level. Each level has a set of goals that may or may not coincide, each requires a different set of performance parameters.

A common problem in performance assessment is transference of goals from one level to another. This can best be illustrated by the difference in goals included in the design of an individual irrigation project (e.g. increased production over rainfed agriculture or efficient water distribution) compared to those at national level (e.g. foodgrain self-sufficiency or equitable distribution of benefits). While such different goals should not be incompatible, they require different indicators and require a different assessment time frame.

The second issue is the extent to which performance is represented by the outputs from the system as opposed to the performance achieved in managing available resources towards specified goals. The distinction could perhaps be better demonstrated by referring to output performance and managerial performance.

Output performance is the degree of fulfillment of a specific quantified output target, typified by such things as yield, water use efficiency, and cropping intensity. Ideally it is expressed as a dimensionless ratio, or percentage. Frequently the output itself is treated as a measure of performance, but this does not favor comparison because of a host of site specific influences.

Managerial performance is an entirely different phenomenon. It looks at the process by which available resources are utilized in order to fulfill the eventual outputs of the system, and involves assessment of the procedures by which targets are set in relation to available resources. This means that it includes evaluation of performance of individuals in matching goals and targets, in identifying and utilizing performance parameters that effectively reflect those goals, and responding to unexpected changes in resource availability. In this manner, assessment of managerial performance is less neutral than assessment of output performance but may more clearly identify ways in which performance can be improved.

The third issue arising from Abernethy's definition is that of change in performance expectations over time. The system has to adjust to changes both in the external environment and internal within the system, and have a capacity to modify goals and targets as a consequence. The danger of developing and using a specific set of output parameters is that they will continue to be used even though they no longer adequately reflect the changed conditions affecting the system, or changed objective themselves.

This approach to performance assessment for irrigation has roots in the ways in which business assesses its management. Ansoff (1979) states that from the viewpoint of society, the effectiveness of an organization's activities, whether profit or non-profit, can be measured by two complementary criteria:

(1) "The degree to which the organizations' products/services respond to the needs of its customers; and
(2) the efficiency with which the organization uses resources in supplying these needs."

To paraphrase this, the performance of an organization (the effectiveness of its activities) is a measure both of the degree of fulfillment of the output objectives (customer satisfaction) and the management of available resources (efficiency) in accomplishing this.

Further, a manager must select a set of parameters to measure and describe performance. Performance indicators, by providing information on past activities and their results, help in making informed judgments which may guide our decision-making about future activities.

This approach clearly distinguishes between output (the results) and management (past activities); the ultimate utility of a particular set of performance parameters is that they guide managers into better performance in the future because they facilitate judgement as to the level of performance actually achieved, and the underlying causes of that level of performance.

2.2 Standards of comparison

Judgement of performance requires some standard of comparison. Within the field of irrigation management two approaches adopted so far have been :

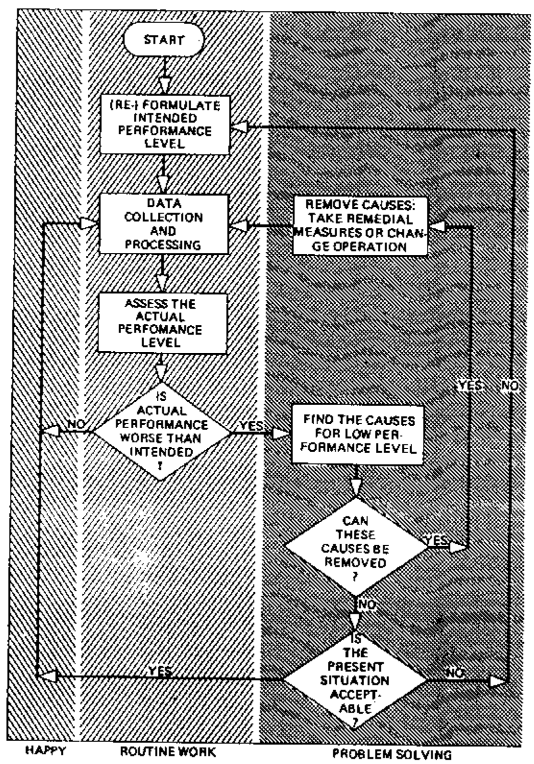
1. Development of performance indicators that can be applied to irrigation systems worldwide. The performance of a particular system can then be compared with performance of similar systems elsewhere.

Bos & Nugteren (1974) followed this approach for irrigation efficiencies, using qualitative and quantitative data. Small & Svendsen (1991) produced a framework for assessing irrigation performance that in principle is applicable worldwide, but thus far it is only qualitative. Abernethy (1989) also made recommendations for a limited set of indicators which might be adopted as standard (Refer to glossary in Annex 1 for description) of some selected indicators. While this approach allows a comparison of the outputs or achievements of a particular system with some universal standard, it provides little or no information on what caused that level of achievement: the resources used in obtaining the results are not considered, and managerial inputs are not assessed.

2. Comparison of actual results with what was planned. Figure 2.1, from Wolters & Bos (1990), shows how comparison of actual with intended results provides information on the need for corrective action. While the flow chart is drawn up for irrigation water management, the same procedure can be followed for any of the tasks in an irrigation system. This approach is clearly process-based. It is also flexible in that it is not tied to any given set of performance indicators: as long as the indicators clearly reflect the targets laid down, the process will be effective.

Figure 2.1

A simple flow chart of irrigation water management



The second approach provides guidance for corrective action, which the first approach does not always give. The first approach allows comparison of irrigated agriculture systems worldwide, which the second does not.

Ideally, what we want is a procedure that effectively utilizes both kinds of performance indicators. Because the use of these two sets of indicators is not yet common in the irrigation world, we shall first explore their use in the business world.

Commercial companies worldwide have been using more or less universally applicable performance indicators for over 400 years. In the last century, an applied science called *management accounting* was developed, which Anthony & Reece (1983) describe as

> *"the process within an organization that provides information used by an organization's managers in planning, coordinating and controlling the organization's activities."*

After having seen why and how the business world uses performance indicators, we shall further investigate their potential use in irrigation.

2.3 Performance indicators in business

2.3.1 Overall performance

From Ansoff's definition, we can immediately derive an indicator that is used all over the world for expressing the overall performance of a particular business. The Return on Investment (ROI) is calculated as:

$$ROI = \frac{\text{(Income from transactions) - (Costs incurred)}}{\text{Resources Employed}}$$

We can do this by expressing everything in money : *the degree to which the organizations' products/services respond to the needs of its customers* is simply replaced by *revenues from sales*, which is indeed an objective measure for customers' appreciation of the products or services. Also, all of the costs incurred and resources employed are expressed in money terms, according to accounting principles that are basically the same all over the world.

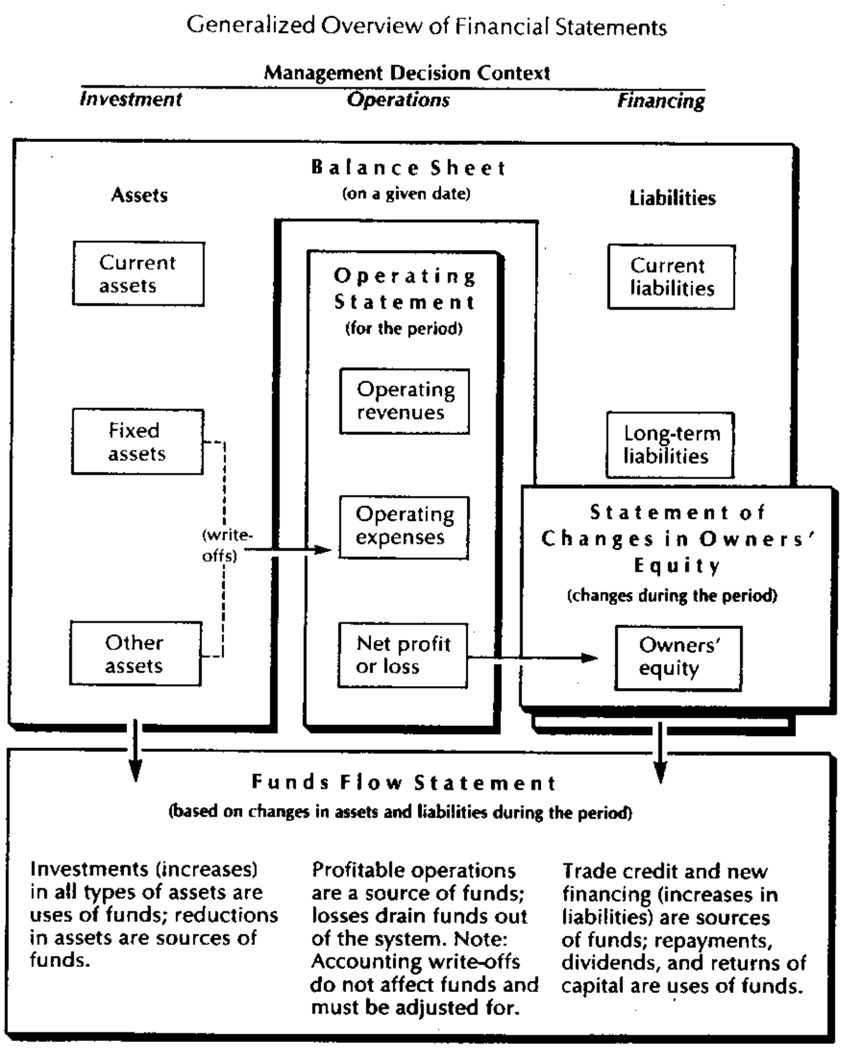
All companies that have issued shares are required by law to issue annual, independently audited financial statements from which shareholders and other interested parties can readily obtain the ROI, which allows them to compare this years' overall performance of the business they have invested in with that in other years, or that of other companies. Individual shareholders who are not satisfied with the ROI achieved by the company may, on the basis of the information provided, decide to sell their share and invest in another company. Shareholders can also get together as a group and consider the need for changes in the company's management.

Within the irrigation sector, the parallel is in terms of overall sector performance. An objective such as foodgrain self-sufficiency can be easily determined, the investment in irrigation compared to the costs incurred, and a decision made as to whether to promote or discourage further foodgrain production. However, it does not immediately identify the causes of shortfall: for this, a more detailed evaluation of performance of the individual components of the sector is necessary.

In business this is done using the company's financial statement (Figure 2.2) that gives a more detailed picture of profit and loss of each component, and the managerial decisions that are associated with each broad activity.

The operating statement reflects the effects of management's operating decisions on business performance and the resulting profit or loss. It lists the revenues for a specific period, and the costs and expenses. Revenues and costs involve such elements as sales, purchases of goods and services for resale or manufacturing, payment of wages, interest expenses, research & development, etc. By expressing these various items as a percentage of revenues, the analyst obtains a dimensionless ratio which, like ROI, can be compared with ratios obtained in other years, or with ratios of other companies in the same type of business. Any abnormalities draw the attention of the analyst and pinpoint the issues that need to be clarified by the company's management.

Figure 2.2 Generalized Overview of Financial Statements (From Helfert 1987)



2.3.2 Operational performance

The financial statements provide information that allows the company management and stakeholders to assess business performance. But they are not detailed enough for operational decision making. This requires performance standards which are specific to the particular type of business.

Managers make plans for providing products or services that will contribute a net profit to the business. In order to evaluate the profit potential of each of these plans they prepare an income statement for the next budget period, including all of the estimated costs related to producing and selling that product or service, the probable output, and the expected revenue. In drawing up these estimates, planners make use of data on past performance and must make assessments of likely conditions in the future.

Each part of this income statement is identified with the executive or group responsible for carrying out that part. For each operation, performance standards are set in such a way that performance according to standard will produce the estimated profit. During implementation of the selected plans, management control consists of comparing actual performance with the standard, and taking corrective action as required. This process is essentially the same as the one in Figure 2.1 which depicts the irrigation water management process.

Drawing up operational performance standards, therefore, serves several purposes (after: Anthony & Reece, 1983):

1. As an aid in making and coordinating plans,
2. As a device for communicating to managers and employees within the organization what is expected of them,
3. As a way of motivating these managers and employees to achieve the targets set for them,
4. As a benchmark for controlling ongoing activities,
5. As a basis for evaluating performance of individual managers and employees,
6. As a way to develop insights into the detailed workings of the various parts of the organization and their interrelationships.

2.3.3 Strategic control

The process described above provides the basis for developing operational targets and assessing the degree to which they have been accomplished. However, this may be insufficient for achieving long term, sustained performance.

Targets are quantified expressions of broader objectives. In many cases objectives are qualitative and it is a matter of judgement as to how well component targets actually fulfill the overall objective. Meeting short term targets, a measure of successful operational performance, says little or nothing about the utility of those targets in actually achieving overall objectives. This requires a parallel process of strategic review and decision-making that examines whether the fulfillment of targets is actually fulfilling the overall objectives.
Put in another way, the process of strategic control asks two questions:

> *"Am I doing things right?"* (did I meet the targets?), and
>
> *"Am I doing the right thing?"* (does this also fulfill my objectives?)

It is the answer to both these questions at the same time that determines overall performance in respect both of output and management.

Meeting the performance standards in all of the manufacturing operations for a given product or service only tells us that things are done right; this is no guarantee that the product will contribute to the company's ROI as expected. To achieve this, it is essential that the company is doing the right thing: offering products or services that respond to customers' needs and at a price they are willing to pay. Not only do customers' needs change, but there are changes in the external environment. If they are ignored, the company may well go bankrupt.

This forces the company's top-level management to periodically examine whether the products or services that it is offering are well matched to the opportunities offered by a constantly changing demand environment.

An obvious parallel can be drawn from irrigation: assuming that national objectives for the irrigation sector include productive, equitable and sustainable agriculture, a set of water delivery targets can be drawn up for each system. It may be that the targets achieve only one or two of these objectives at any given time, and a set of priorities must be drawn up for each time period. Many irrigation societies have stressed short term production and equity objectives, but have paid a much larger cost in terms of long term degradation of the physical environment.

2.3.4 Summary of uses of performance indicators in business

Although it is obvious that there cannot be a direct transfer of business principles to irrigation management, it is worth reflecting briefly on what performance indicators do for the business environment:

1. They fulfill a legal obligation to demonstrate performance (in the form of annual financial statements) for use by shareholders and other investors.

2. They require businesses to maintain a detailed and accurate record of day-to-day transactions, both for reporting but also for evaluation purposes.

3. They provide the basis for performance standards for planning, operating and controlling the business; operational performance indicators can be viewed as critical variables in a model that describes the contribution of individual activities to the overall result:

    - In the planning stage, such models provide guidance in selecting among potentially profitable activities; performance standards used in these models are based on projections of historical data from the company itself or from available data from other firms in same type of business.
    - During implementation, the model is tested and refined, through constant monitoring of operational performance and measurement of its contribution to the overall result.
    - Control consists of taking corrective action when performance standards are not met. If achieving some of the performance standard proves unfeasible, more resources may be allocated or performance standards lowered, but in either case the resulting ROI must remain acceptable.

4. In a competitive commercial environment, precise and accurate performance indicators are required to:

    a. detect deviations between actual and planned performance at all levels and taking corrective action because not doing so jeopardizes profitability, and to
    b. improve on existing standards, in order to stay ahead of competition, but not to the point where standards are unprofitably high.

While these conditions are clearly oriented to the profitability of particular concerns, they also apply to monopolistic enterprises where one of the primary clients is the government system of regulation and control.

Where a government decides that a monopoly is an acceptable basis for industry it must, to maintain as much efficiency as possible, provide both a set of standards which the industry must achieve, and regulate the industry to ensure that it is doing so within a predetermined set of conditions. Thus, although the driving mechanism is not profitability per se, there is still a process of accountability built into the system.

Irrigated agriculture, especially large scale irrigation developed using capital from central governments, and operated and maintained with the assistance of government subsidies is more closely allied to a monopoly than a profit motivated concern. The accountability is not only to the users but also to the government. It is therefore possible to transfer at least some of the lessons from business to irrigation management.

2.4 Performance in irrigated agriculture

2.4.1 Overall performance

As discussed earlier, Ansoff stated that the effectiveness of an organization can be measured by two complementary criteria :

(1) *" The degree to which the organizations' products/services respond to the needs of its customers; and*
(2) *the efficiency with which the organization uses resources in supplying these needs."*

If we want to apply Ansoff's definition to irrigated agriculture, a clearer understanding of both "organization" and "customer" is required.

1. Who is *the organization* ?
2. Who are *its customers* ?

The irrigated agriculture system is frequently divided hierarchically by basic functions required at each level. At the highest level, that frequently referred to as the irrigation sector, the primary constituents are policy makers who are concerned with the overall performance of the sector vis-a-vis other sectors. This may well affect decisions as to the annual appropriations for operation and maintenance, strategies for food self-sufficiency, import substitution, poverty alleviation, or the relative share of water and land resources to be devoted to agriculture rather than industry or urban growth. These sector level planners should have a concern for long term sustainability of the physical, financial and social systems that support sector viability. They work directly with investors who are willing to provide capital for the sector.

Below the sector is the agency level, where various institutions share responsibility for management of inputs and services that support the farming community. In some cases, there are multipurpose agencies charged with greater coordination, although internally they often are divided up as if they were effectively different groups. There is an increasing trend to allow such activities to be undertaken by the private sector. Included in this level of the hierarchy are those responsible for allocation of resources between irrigation managers in different districts and systems: within the government hierarchy, this is the irrigation agency which will be charged with the task of translating overall government or national objectives into regional and district targets.

The third level is that of the irrigation system. Normally this is defined hydrologically because the primary function of irrigation at this level is the allocation and distribution of water. Frequently this is viewed as the task of the system level engineers within the irrigation agency, although a significant percentage of total irrigated area in many countries is operated and maintained by farmers. Management of larger systems is normally geared towards fulfillment of specific targets that reflect the objectives laid down at agency level.

This hierarchical distinction is of great importance. If the level which is being assessed is not clearly specified there is a risk of confusing the objectives of one level with the targets of another. A typical example might be to blame a system manager for inequitable water deliveries when the objectives laid down by the agency refer only to production.

2.4.2. Effects of investment subsidy

Most large scale irrigation systems have a considerable element of subsidy. Yudelman (1985) stated that : *"annual investments in irrigation in developing countries now stands close to $ 15 billion."* These investments largely come from public funds, either from the countries themselves or as subsidized loans from international development banks or agencies. A few have been outright grants.

While irrigation investments largely come from public funds, helping to spend is an attractive proposition for private enterprises such as contractors and consultants. Investments in irrigation are also attractive from the point of view of the development banks and agencies, because it provides the opportunity to disburse a large amount of money in a relatively short time. This helps these agencies to meet their spending targets, which for them is an important measure of success. The national irrigation agencies also generally welcome new investments in irrigation, because it brings in new funds and increases their sphere of influence. The process of getting the project may be far more important than the actual purpose of the project itself.

The key that opens the door to all of the above benefits for the various parties concerned is a favorable interpretation of the feasibility study, which assesses the viability of the system from various perspectives: technical, social, economic, or any perspective that potential donors or lending agencies consider important (environment, sustainability, role of women, etc).

Because the instruction to conduct a feasibility study, the study itself, and the interpretation of its results are all done within the group of interested parties mentioned earlier, there is reason to assume that in the feasibility study the estimates of benefits arising from irrigation development tend to be optimistic. This means that performance expectations are high even before the project starts, based not so much on experience in comparable sites but in order to justify a favorable benefit stream. Typically, cropping intensities, yields, and water use efficiencies are predicted to be far higher than is commonly found in practice. At the same time, potential negative effects (salinization, health) tend to be downplayed.

For the same reason, there appears to be a tendency to underestimate development costs, or perhaps even reduce costs by selecting less expensive designs and using low values for recurrent costs for operation, management and maintenance of the irrigation system. Experience shows that inflation rates are frequently higher than assumed, thereby increasing actual recurrent costs.

Yudelman, a former Director of the World Bank's Agriculture and Rural Development Program, confirms that irrigation projects often defy planners expectations :

> *"A recent survey undertaken by the author of 12 irrigation projects showed that these projects together cost almost twice their expected cost of $800 million and provided water enough to irrigate only two thirds as much acreage as projected."*

And on the same page :

> *"Many of the irrigation projects funded by the Bank have suffered from faulty design. Behind design failures are poor preparation and the difficulties of bringing engineers and agriculturists together."*

We have seen earlier that in a business environment nothing is obtained by setting standards higher than what can realistically be achieved. And also, that setting unrealistic standards in the planning stage may lead to wrong investment decisions, which undermines the company's long-term profitability and even its survival.

Yet, in the case of investments in irrigation development, there are organizations that seem to be able to get away with unrealistic planning assumptions: by the time the construction of the irrigation system is completed, most of these organizations' own objectives are already achieved and their direct involvement with the system comes to an end. In other words, long term performance is far less important than generating the next cycle of projects.

In our perception, the above conditions present a serious constraint in achieving a performance-oriented attitude in irrigation system management: if the expectations are perceived as unrealistic by managers at the very outset, then there is little likelihood that they will make a serious effort to achieve them.

2.4.3 Effects of subsidy of operational costs

The higher the subsidy of operational cost, the less important it becomes for system managers to ensure that the services provided are adequate, both in an operational sense (implementation according to plans) and in a strategic sense (services well adapted to needs of customers). Rather than managing for system outputs, the attention of the system's operators focusses on obtaining and administrating inputs.

It is in this respect that many irrigation agencies show some of the negative symptoms of monopolistic enterprises. Job security, salaries and other rewards are not linked to output performance or efficiency of resource utilization by agency staff. If customers are not happy, there has traditionally been little they can do about it directly, and frequently resort to political channels to obtain more water. While this may be successful some of the time, it undermines the basis of effective management.

2.5 **Main System Performance**

This study is not a full evaluation of performance at all levels of the irrigation sector. It focusses instead on the issue of management of the main system: the allocation and distribution of water from the source of the system to the point where individuals or farmer groups take over responsibility for these tasks.

In this document, *the organization* will be the managers of the main irrigation system, who are responsible for supplying irrigation water and perhaps other services to farmers, who we consider as *their customers*. The way we distinguish between main system managers and their customers differs from the role distinctions made by Small & Svendsen (1991):

> *"First, our definition of an irrigation system includes farmers acting in their role as irrigators, while excluding their parallel role in other aspects of crop husbandry. This distinction is necessary to establish a clear analytic separation between the irrigation system and the agricultural system. Second, in the case of public authorities responsible for both irrigation activities and other services such as agricultural extension, only the irrigation-related roles are considered to be part of the irrigation system."*

While we sympathize with the need for *"a clear analytic separation"*, our perception of performance requires us to divide the world into *organizations* on the one hand and *their customers* on the other. A major advantage of making this division is that it makes very clear who is responsible for the overall process of water allocation and distribution. This does not exclude farmers from certain important processes: identification of seasonal or annual objectives, determination of concepts of equity, and concurrence with proposals for scheduling of deliveries.

There are, of course, also farmer managed irrigation systems. This does not present a major conceptual difficulty: in those cases farmers are the managers of the main system and at the same time they are their own customers. The management of water at system level is undertaken as a collective activity, leaving individuals the choice of how to use their share on their own farm.

Now we are ready to give a definition of the overall performance of main system management:

The overall performance of main system managers depends on two complementary criteria :

(1) **The degree to which the services offered by the main system managers respond to farmers' needs, within the limitations imposed by national policies and objectives; and**
(2) **the efficiency with which the irrigation system uses resources in providing these services.**

It should be noted that the requirement to use resources efficiently is not limited to resources that have an economic cost: efficient, or at least responsible, use of water is also called for, even when water is free.

The lack of a direct economic linkage between managers' performance and the needs and requirements of farmers means that a rather different set of linkages needs to be established that provides the motivation and regulation of the performance of the managers.

To ensure adequate performance of the irrigation system managers, therefore, it needs to be clearly established what services the irrigation system will provide and what resources it will have at its disposal. The process by which these are established is essentially one of negotiation. We shall not attempt to give general guidelines on how this negotiation needs to be conducted and by whom. It would seem that water users, system managers, the irrigation agency, and those agencies who are providing other services to support irrigated agriculture all need to take part.

The general statement that we wish to make, however, does not refer to the negotiation process, but to its outcome. We insist that whatever the services decided upon, these must be expressed in the form of an agreed contract, which includes a definitive statement of:

- the performance indicators that will be used to measure the adequacy of the services provided by the irrigation system managers,
- the methods that will be used for obtaining these indicators, the frequency of measurement, the method and frequency of reporting the results, and to whom the results will be reported,
- the consequences of not meeting the agreed upon performance standards.

However, there is not an infinite degree of flexibility for either managers or water users:

the level of service that can be provided by the irrigation system managers and the appropriate performance standards for a particular system are greatly influenced by the design of that system.

The services that can be provided by irrigation system managers will depend in large measure on the flexibility or rigidities built into the design of the physical infrastructure of the system and the accompanying management system.

Before proceeding to performance from selected case studies, presented in sections 4 and 5, the next section looks at different design environments in terms of their potential for managers to provide different types of service, and which in turn will affect the level of performance that can be achieved.

Section 3

Design Environments and Their Relation to Management Objectives

3.1 Introduction

The primary concern of the irrigation manager at system level is the delivery of water throughout the canal system in accordance with plans designed to facilitate the productive use of this water for agricultural production. Depending on the nature of the agency, this overall objective may be supplemented with others that relate to such aspects as income generation, environmental concerns, or the general social well-being of farmers and their families. These will all affect the water allocation decisions required at an annual or seasonal time frame.

However, on a day-to-day basis the manager is mostly concerned with the appropriate distribution of water within the water conveyance system. There is much less concern for how that water is actually utilized or distributed between adjacent farmers or farmer groups because the main system manager has little direct control over these aspects of irrigated agriculture.

The way in which the manager can achieve the proper and efficient distribution of water is affected by a set of conditions which cannot be changed in the short run. These conditions include:

- the design of the physical infrastructure of the system and its layout which determines the locations at which water can be controlled and distributed, based on assumptions at the design stage concerning probable agricultural patterns and climatic conditions;

- the principles of water allocation between water user groups or individuals, and the strategies to be adopted when there are changes in overall water availability at the head of the system;

- the organizational and institutional environment which determines operational procedures, staffing levels, financial resources for operations and maintenance, monitoring and evaluation processes, and the legal environment within which the system will be managed.

These combination of these conditions is the design-management environment within which irrigation performance at system level has to be assessed. A basic hypothesis underlying the entire study is that if the physical design, the water allocation principle, and the supporting institutional and organizational arrangements are not carefully matched, it will be difficult if not impossible to attain high levels of performance.

This section provides a broad classification of the main design and water allocation environments: for each environment a description is provided of the primary characteristics of the physical design of the irrigation infrastructure and the types of water allocation principles that can be supported by that design.

3.2 Basic Components of Design-Management Environments

Variations in each of the components of the design-management environment have significant impacts of the subsequent performance of the system. This subsection provides an overall description of the main variants that are found, while the following subsection examines some of the interrelationships between them.

3.2.1 Physical Design for Water Flow Regulation

Upstream Control Systems comprise the vast majority of irrigation systems in the world. A distinction has to be made between systems that achieve water division by using fixed division structures and those that have gates at offtakes along the canal.

a) Fixed Division Systems are those where water can only be managed at the head of the canal; division between subsidiary canals or offtakes along the canal is achieved through fixed division structures that do not have gates.

Because of different principles of allocation of water between users or user groups, two design variations exist within this class of systems:

- **fixed overflow weirs**, where the width of each section of the weir is in proportion to water rights based on a percentage share of available water; and

- **submerged orifices** that are designed to deliver a relatively constant discharge over a range of different operating heads.

b) Gated Division Systems where gates are constructed at each offtake along the canal, allowing water to be managed at every bifurcation in the system. Three variations in the basic design that directly affect management potential exist, based on the degree to which it is possible to manage the water surface elevation on the upstream side of each offtake gate:

- **no canal cross-regulation**, where water surface along the entire canal is determined by open channel hydraulic relationships between discharge and head;

- **fixed cross-regulation**, utilizing weirs or other structures that result in stable head-discharge conditions on the upstream side of each offtake gate; and

- **gated cross-regulation**, where gates in the canal itself can be used to manage water levels irrespective of the instantaneous discharge being delivered to the structure. In the vast majority of systems gates are controlled manually but more modern technologies utilize hydraulically controlled automatic gates that maintain an almost constant water level irrespective of discharge. These are predominantly found in Francophone countries. There are also a few systems where automatic operation of gates based on sensors that monitor water levels and/or discharges at different points along the canal.

Downstream Control Systems are designed to permit instantaneous response to changes in demand by automatic operation of gates throughout the system. Most downstream control systems use balanced gates that open or close in direct response to changes in water level on the downstream side of the gate, although there are also systems that have electronic sensors that respond to water level changes and send signals to electrically operated gates. The choice of technology adopted does not affect the purpose of the system.

3.2.2 Water Allocation Principles

An essential component of the design phase is the consideration of the principle by which water will be allocated between individuals or groups of water users. Knowledge of this is essential both at the time the system is designed and for assessment of the performance of managers in selecting appropriate discharge targets during the operational phase.

Water allocation is normally defined by two sets of rules. The first set of rules determine the principles by which water will be shared between individuals, and form the basis of water rights. The second is the degree of conditionality of the right, normally based on a determination of actual water availability at the head of the system. It is the combination of these two sets of rules that determine the overall right to water in each system, and the rules have to be clearly known before any assessment can be made of performance related to water distribution.

a) Water Rights. Every system has to have a known principle by which individuals or groups have an established right to water: the principle is normally permanent and may have a legal basis.

There are several different types of rights that have significant implications for how systems can be operated to achieve the expected water distribution pattern. These include:

- **Share per unit area**, where available water is divided on a percentage basis determined by the potential irrigable area: shares of this nature do not guarantee a specific discharge because the percentage is independent of total water availability;

- **Share per person or household**, an uncommon right where each individual or family group is entitled to a share of available water irrespective of size of landholding (and in some cases may include landless households);

- **Fixed Discharge per unit area**, where water is delivered volumetrically in proportion to the potential irrigable area;

- **Fixed volume**, where each water user is entitled to a maximum volume of water during an irrigation season, although the right may vary between individual water users based on precedence or purchase of the water right: timing of water delivery is normally based on an indent or request system to system managers to allow for ease of scheduling, but does not affect the total right for the season;

- **Instantaneous demand**, where there are no restrictions imposed and individual water users can take as much or as little water as they wish at given moment in time: this requires a parallel set of institutional mechanisms to regulate demand, normally water pricing based on actual volume used; and

- **Informal or undefined rights**, where access to water varies in time depending on local power structures: in some cases it may be anarchic, in others it may rely on a process of frequent negotiations that reestablish or reaffirm traditional rights.

b) Conditionality of Water Rights. When there is insufficient water to meet all demand, or where there is a specific effort to control cropping patterns at system level, some mechanism is required that can modify or suspend access to water on a seasonal or annual basis. For this to be effective there has to be some clearly understood planning process before the start of each season that determines whether all rights will be met or whether some rights will be suspended or modified. Variations in conditionality include:

- **suspension of rights**, where specified portions of the command area are scheduled or programmed for irrigation, the remainder not being permitted to irrigate at all;

- **priority of access**, where some areas receive their full right and others receive a reduced share: this may be associated with a regular and predictable imposition of crop production programs such as those of Sudan and Egypt that regulate demand at system level, or by a set of individual cropping decisions based on whether they have a high or low priority for obtaining water.

- **temporary rotational irrigation**, where access to water by groups of users is regulated by time. This may or may not result in a change in right, depending on the way in which water is normally shared between users.

3.2.3 Institutional and Organizational Aspects

As discussed in subsection 3.1 the design-management environment includes the institutional and organizational conditions that directly affect the capacity of managers to achieve the water allocation targets that have been established.

Unfortunately, the use of secondary data employed in this report is limited in its assessment of these conditions because these conditions are not described in the original literature. It is therefore difficult to make a specific categorization of these aspects because there is considerable diversity between different countries and even within countries, and there is a greater degree of variability over time than in either the physical design of the system or in water allocation principles.

a) Staffing Levels and Skills. Each combination of design and water allocation principle requires a particular staffing pattern: the more gates that are present in the system the more staff are required. The canal layout and the physical environment also directly affect maintenance requirements. However, staffing levels are influenced by the degree of mobility and the extent to which some gate operation and maintenance activities are the responsibility of water users.

   The physical infrastructure may also determine the required skill level of operational staff, particular where more sophisticated infrastructure is involved. Maintenance requirements for automated or hydraulically controlled gates are significantly higher than for simpler control facilities.

b) Financial Resources. The annual allocation of financial resources for operations and maintenance has an immediate impact on likely staffing levels, and the balance between establishment costs and the resources available for maintenance and repairs to infrastructure. Where most of the resources are used for paying salaries and benefits there is a greater likelihood that physical infrastructure will not be maintained effectively.

c) Implementation Responsibility. The institutional environment determines the relative importance of direct and indirect responsibilities of each agency for provision of inputs. In many countries government agencies have full responsibility for operation and maintenance down to a specific level of the system, at which point full responsibility is turned over to water users. In others there are areas where there is joint responsibility for operations or maintenance between government agencies and water users.

   Agricultural inputs may or may not be the direct responsibility of a single agency, and even within a single multi-input agency each subdivision may or may not act in a coordinated fashion. The consequence is that coordination across these responsibility boundaries may be difficult, and have a direct impact on performance in the agricultural, economic and social sectors. In some cases they are the full responsibility of the private sector, thus reducing further the influence of government agencies in affecting overall performance.

   Boundaries for implementation responsibilities may not be the same as for monitoring responsibilities. In these cases there must be proper coordination and flow of information between agencies.

d) Planning Functions. The way in which objectives are defined, at system and agency level and for wider sectoral objectives, also directly affects the extent to which managers can accommodate performance responsiveness into normal procedures.

e) Internal Procedures. Within each agency, whether or not it is single-input or multi-input oriented, there is a set of internal procedures and policies that influence the capacity of the agency to achieve a particular level of performance. These may be expressed as straightforward rules in operational manuals that determine how specific tasks are to be undertaken, and include reporting procedures for inputs and outputs.

f) Incentives and Accountability. Perhaps the most important aspect of all of the institutional ones is the extent to which agencies have built-in incentives to be responsive to actual performance. If salaries or promotion are closely linked to individual performance, then it is likely that the system as a whole will perform better than one where personal ambitions are not linked to performance but to other criteria such as length of service or seniority. In some societies concepts of prestige or shame are used as ways of assuring high performance by individuals. In either case, performance improvement will only come about if individual performance is directly linked to opportunities to make improvements in the quality of management applied by those individuals.

3.3 Design-Management Interrelationships

The interrelationship between the physical design, the water allocation principle and the institutional and organizational aspects may have a major impact on the extent to which different objectives can be achieved. This section addresses some of the more important ways in which the design of the system interacts with management requirements.

3.3.1 Interrelationships between Design and Operational Objectives

In the context of the main system there is a wide range of potential objectives that can form the basis for the day-to-day tasks of water distribution. It is the choice of one or more of these objectives that will dictate the appropriate discharge or water level targets to be implemented in the field.

Despite this, very few of the case studies actually specify the operational objectives of the systems. It is unclear whether this is because it was not considered important, or because the system managers could not articulate these objectives clearly. In the cases where specific objectives are not stated, it has been assumed that system level objectives represent a combination of one or more of three basic principles that are frequently incorporated into the design and operational objectives of irrigation systems: adequacy, reliability and equity.

An indication of the potential of each type of design to fulfill these three broader objectives is suggested in Table 3.1.

Adequacy

Adequacy is the capacity of an irrigation system to meet demands of farmers. It can be managed in two ways: by matching cropping plans and calendars with estimated seasonal water availability before the start of the season, and by adjusting operational targets in response to actual demand during the season. A distinction must be made here between supply-based and demand-based systems. Supply-based systems do not attempt to make short term adjustments in discharge even though demand is varying; demand-based systems do.

Fixed Division Systems are supply-based because there is insufficient control capacity to permit discharges to be managed to meet changes in demand. Individual farmers or water user groups manage demand through careful selection of cropping patterns. Agencies may have an indirect role in providing advice on what cropping patterns may be most suited to the level of supply that is likely to be delivered, but the design provides no opportunity to manage supplies differently if demand exceeds supply. Actual deliveries will normally only exceed crop water requirements if farmers reduce seasonal demand by modifying cropping patterns, except for periods of low demand during harvest or rainfall.

Gated Division Systems allow for greater flexibility of water distribution to meet short term changes in demand, so that it is possible to manage for adequacy more closely. This does not preclude the necessity for an effective planning process that helps to set broader demand targets, based on assessment of previous performance and likely overall water availability. There are significant opportunities for actual deliveries to exceed crop water requirements in these systems either through untimely or ineffective gate operations, or because of deliberate disruption of the gate operation plan.

Instantaneous Demand Systems are specifically designed to achieve adequacy goals by ensuring that the capacity of the canal system at any location is sufficient to meet the maximum potential demand. There is therefore a permanent potential for actual deliveries to exceed crop water requirements, and mechanisms such as pricing are required to discourage individual users from taking more than they need or pay for.

Table 3.1

Potential System Managements Objectives for Different Designs

	Reliability	Adequacy	Equity
Ungated Overflow	*	–	**
Submerged Orifice	*	–	**
Gated, Little Cross-Regulation	*	*	*
Gated, Fixed Weir Cross-Regulation	*	*	*
Gated, Adjustable Cross-Regulation	**	**	**
Downstream Control	**	**	–

key to symbols : ** very important * important – no concern

Reliability

This is a more difficult objective to assess because it is subjective, dealing with the quality of irrigation service rather than the quantity. It covers both the reliability of discharges or water levels (stability) and the reliability of timing of deliveries (predictability). Depending on the water delivery mode adopted in the planning stage either variability or predictability or a combination of both may be important.

Fixed Division Systems have a high potential for both stability and predictability when they operate at or close to designed discharge. However, they are sensitive to fluctuations in discharge at the head of the canal, which cannot be compensated for through any downstream operational inputs.

Gated Division Systems have the potential to offer higher reliability in respect of both variability and predictability, particularly where there is a large amount of cross-regulation infrastructure. However, if managed poorly, there is a potential for very high unreliability.

Instantaneous Demand Systems are highly reliable because water is always present in the main canal system.

Equity

The mechanism for determining equity comes through the water allocation process. The design of the system has to be compatible with the water allocation principle: if it is not, then it is unlikely, if not impossible, to achieve the equity principle implicit in the water allocation plan.

Fixed division systems are particularly effective in meeting equity objectives based on a percentage share of available water (e.g. share per unit area, per person or per household) as long as the overall percentages stay the same. There is little capacity to respond to situations where the basis for the share changes, such as expansion of the irrigated area because then the design has to be modified at all locations within the system. The net result is a relatively static system that rarely, if ever, reassesses water allocation.

Fixed systems also provide limited opportunities for implementing rotations or other conditional aspects of water rights. Control over water is only possible at the head of a canal section, and rotations must be between secondary rather than between tertiary canals.

Gated Division Systems are essential to accommodate water allocation plans that are responsive to short term changes in demand. As the density of control infrastructure increases, so the potential for greater management in response to equity increases. Systems with gated cross-regulators provide a larger potential to manage for short term changes in equity than those with little or no cross-regulation capacity, especially those associated with conditional water rights when discharges are lower than the designed capacity of the canals.

Instantaneous Demand systems cannot be managed for equity within the main system. Individual demand has to be regulated by other mechanisms such as pricing. The system must be designed to ensure that each canal has sufficient capacity to meet the maximum instantaneous demand.

3.3.2 Design Implications for Operation

Management requirements for operation of the system are summarized in Table 3.2 This table states the obvious: whenever a design includes an adjustable structure, there is an operational input required.

Table 3.2

System Management Inputs Required for Each Design

	Operations			Maintenance	
	Discharge at Head of Canal	Offtake Gates	Regulator Gates	Canal Cross Section	Control Gates
Ungated Overflow	*	–	–	(*)	–
Submerged Orifice	*	–	–	**	–
Gated, Little Cross-Regulation	*	*	–	*	*
Gated, Fixed Weir Cross-Regulation	*	*	–	(*)	*
Gated. Adjustable Cross-Regulation	*	*	*	(*)	*
Downstream Control	–	–	–	(*)	**

Key to symbols: ** critical * important (*) to avoid losses – no input

More important is the recognition that if the design includes an adjustable structure that provides greater managerial opportunities to meet the different main system objectives, there is also the potential for mismanagement that results in failure to meet the objectives.

Fixed Division Systems can only be operated at the control locations provided at the head of each major canal section. Although this means that there is a relatively limited number of locations at which managerial inputs can be applied, the design requires very close attention to inputs at these locations because there are no further opportunities downstream to compensate for poor upstream management.

Ungated overflow systems will respond to water level or discharge variations equally throughout the entire system: equity is unaffected, unreliability is felt equally at all points, as is the shortfall in adequacy.

Submerged orifice systems respond in an entirely different manner to upstream fluctuations, although the extent of the response is highly dependent on design. The Adjustable Proportional Modules widely used in India and Pakistan show only small variations in discharges compared to simple pipe outlets. Orifices near the head of the system will have smaller fluctuations in discharge and smaller percent reductions in discharge than orifices near the tail of the canal. For these systems to function at designed levels of performance, it is essential that discharges into the ungated sections are kept as close as possible to designed discharge (typically between 70-100% of design), and fluctuations kept to a minimum.

Gated Division Systems require greater operational inputs. Operational inputs are required at every offtake structure, and increase further as the number of moveable cross-regulators increases. This does not, of course, imply that operations are the sole responsibility of any one agency: a number of different bodies, including water user groups, may have responsibility for part of the operation of the system. However, the total number of operational inputs remains the same irrespective of who is responsible.

Because such systems have the potential to meet a number of different demand conditions they also require a clear monitoring process. This monitoring has to be in two forms: checking of actual discharges or water levels and comparison with the targets laid down in operational plans; and monitoring of field level conditions that determine whether the targets themselves were appropriate or require modification for the next set of operational plans.

Systems of this design also require much greater attention to communication both between agency staff and between agency staff and farmers. Unilateral operation of any gate will have an effect on water levels or discharges at all downstream locations: gate operations must therefore be coordinated to meet hydraulic conditions and fulfill the different operational objectives. Operation of gates outside an agreed plan will result in great unreliability downstream, and it will become difficult to meet adequacy or equity objectives.

Instantaneous Demand Systems have few requirements for operational inputs unless there is some form of control required at the head of the system to ensure stability of discharge into the head of the canal.

At the design stage it is therefore possible to determine what operational requirements will be and thus define the operational staffing requirements. Similarly, in assessment of performance, it should not be difficult to determine whether current staffing patterns are compatible with the requirements dictated by the design.

Nevertheless, it is not uncommon to find cases where staffing patterns have been modified as a result of changes in financial or other institutional conditions without any consideration of whether these changed operational inputs are compatible with the requirements imposed by the existing design.

3.3.3 Design Implications for Maintenance

Maintenance requires a completely different pattern of management inputs from operations. This is illustrated in Table 3.2. There is a strong argument for disaggregation of "O&M" into "O" and "M" when considering performance of field staff.

Maintenance is required for three different purposes: minimization of conveyance losses, prevention of failure of moveable control structures, and sustaining the hydraulic conditions required by the design for effective water distribution. However, the relative balance between these three tasks is different for each design.

Conveyance losses: all systems, irrespective of design, require maintenance to control conveyance losses as this directly affects objectives of adequacy and equity. Variations in the intensity of maintenance inputs come in the physical environment (notably soil type, climate and rates of weed growth) and the total length of canals. These inputs are more or less constant for each system, and can only be changed through lining, compaction, or other structural change. Determination of the actual rate of loss, and its change over time, requires monitoring: it is common to find that losses are estimated at the design stage but never checked in the field.

Prevention of failure of moveable control structures: maintenance intensities for prevention of failure of moveable control structures are also easy to quantify, and are constant for each system. The intensities increase as the number of control structures increase, although for automatic systems and instantaneous demand systems the maintenance is critical: if gates are not maintained properly and thus do not respond to changes in water levels, then the system objectives cannot be met.

Sustaining the hydraulic integrity of the conveyance system: maintenance requirements to sustain hydraulic integrity of the conveyance system are highly dependent on the system design. If the system relies on open channel hydraulic relationships to achieve the water distribution objectives then maintenance will be the critical management input. Failure to maintain the canal cross-section at or close to design specifications in submerged orifice systems or gated systems with little or no cross-regulation means that head-discharge relationships at offtakes will be different than those intended, and the result will be a lower than expected performance of water distribution.

In other types of design the control infrastructure can tolerate a wider range of canal cross-section variation because gates can be used to modify head-discharge relationships or because weirs across the canal reestablish the correct conditions irrespective of downstream changes in cross-section. However, this will only be true up to a point, because drastic changes in cross-section will ultimately have an impact on the hydraulic integrity of the system.

3.4 Assessing Performance in Different Design Environments

The discussion in this Section has provided the basis for defining the process by which performance in respect of water allocation and distribution can be assessed in each different design environment.

This process essentially asks three sets of questions:

Were the operational objectives (adequacy, reliability and equity) clearly defined, and were they compatible with the design of the system?

Were the operational targets (discharges or water levels) clearly specified, were they consistent with the stated objectives, were they compatible with the system design, and were they compatible with available resources?

Were the maintenance targets (level of losses, functionality of control structures and canal cross-section) clearly specified, were they compatible with operational targets, and were they compatible with available resources?

These questions form the basis for assessing the water allocation and distribution performance in each of the case studies examined in the following section. For obvious reasons not all questions could be satisfactorily answered because there was not always sufficient information provided.

Section 4

Irrigation Performance in Typical Design Environments

4.1 Introduction

This section describes selected examples of performance in the major design environments, roughly following the order of the classification described in Section 3. A few of the larger systems are hybrid, with different designs at main and secondary level; in such circumstances the case study is referred to in more than one location in the text.

It should be stressed that the selection of case studies was based on a combination of available literature and personal experience of the authors. The case studies are not intended to be representative of all systems of that design type. The intention was to see, based on a selection of examples from different parts of the world, whether it is possible to make some generalizations about design-management interactions and their potential to affect the performance of those systems.

Conspicuous by their absence are case studies of automatic upstream control or downstream control systems. This is explained by the comparative lack of data from such systems readily available in the contemporary literature. It is obvious that in any further continuation of this work this gap will have to be addressed and it is regretted that there has not been the time or the opportunity to include these types of design-management environments at this stage. There can be little doubt that the experiences of performance assessment in these systems employing higher technology needs to be documented, and the authors are aware of several on-going studies in Thailand, Malaysia, Morocco and elsewhere that will complement the information contained in this section of the report.

4.2 Fixed Division Systems

As described in Section 3, fixed division systems rely on a combination of water level and design of structures to control water distribution. Case study material from both the major categories in this design type, fixed overflow systems and submerged orifice systems, are discussed below.

4.2.1 Performance Examples in Fixed Overflow Systems

This type of design meets the two main sets of criteria viewed as important in farmer-managed systems, particularly in remote areas: simplicity of operation and maintenance, minimizing the daily requirements of users to keep the system functioning effectively, and quick and unambiguous monitoring of whether water is being distributed in accordance with the predetermined allocation rules.

Operational activities, except in instances where rotations have to be undertaken, are largely confined to management of water at the intake. Typically, however, intake structures are also simple, frequently with an overflow section at the head of the main canal to provide a stable discharge. With this type of design reliability of water deliveries is high, except when river discharges are less than the canal capacity.

Maintenance inputs are also straightforward. Because hydraulic control is only required at overflow structures there is no concern with head-discharge relationships at other locations along the canal system. As long as structures are kept reasonably clean canal maintenance does not directly affect water distribution performance. Typically, systems of this type are maintained by periodic inputs from all water users a few times a year, the intensity depending on sediment loads or rate of weed growth.

Because systems are essentially self-operating there is little scope for assessment of management inputs at system level, and agricultural benefits have to be assessed in the context of utilization of water by farmer groups and individuals. There are few detailed studies of this kind reported in the literature.

Three case studies fall into this category: six small systems in Nepal, a small system in West Java, Indonesia, and the secondary and tertiary system of the Fayoum Irrigation System in Egypt. Further details are provided in Appendix 2.

Water Distribution Equity

The case studies demonstrate the importance of clearly understanding what the users themselves feel to be equitable before an assessment can be made of distribution of water.

In the case of six small systems in Nepal (Case Study #1), the stated equity objective was an equal share of water per unit area of irrigable land. That this objective was achieved can be seen from Figure 4.1 a&b, which shows that there is little variation in average water availability between head and tail of the systems. In the largest system (Parwanipur) there was a slight but insignificant decline in Water Availability Index (WAI: for definitions of this and other terms, please see Glossary in Appendix 1) from head to tail of the system. In all other systems no difference existed in terms of WAI between head and tail of the system. The Interquartile Ratios for the nearest and furthest 25% of sample plots are remarkably low (Table 4.1).

By contrast, Cipasir System in West Java (Case Study #2) has a completely different definition of equity. Each farmer is entitled to a share of water that is based on the length of time the land has been developed: farmers in upper end areas whose ancestors built the original system are entitled to much more water than those in newer additions to the system. The water rights can only be determined by a detailed analysis of the size of proportional dividers and the diameter of bamboo pipes serving each subsection of the system. This is a good example of a system that does not provide equality but is still seen as equitable by water users.

An effective design resulting in good uniformity of water distribution is the Fayoum in Egypt (Case Study #3). Measurements along the Bahr Seila sub-command of the Bahr Wahby canal show that, apart from the head end section, the water distribution is almost uniform (Table 4.2). The upper 20% receives somewhat more than its fair share for the sub-command (but no more than the average for the entire Fayoum) both because of post-construction changes to fixed structures and the use of pumps from the canal that cannot be easily controlled by the irrigation agency. However, over the remaining 80% of the area water distribution is controlled by ungated division structures more or less in proportion to the commanded area. Tail end areas actually benefit slightly more than the middle, again partly the result of modifications to division structures to allow more water to pass along the canal than originally intended.

Adequacy

Adequacy at system and subsystem level in small systems can normally only be controlled at the offtake from the river. In the Nepal systems there are efforts to regulate discharges into the system to accommodate changes in both water availability and demand. Calculation of the Relative Water Supply (RWS) at the intake into each system (Figure 4.2 a&b) shows that supply and demand are well adjusted at system level, with weekly averages being normally in the range of 1.0 to 2.0. In none of the systems is RWS very high, suggesting that over time the farmers have learned to estimate how much land can be irrigated with reasonable safety in a normal year. Smaller systems in the Hills tend to have lower values of RWS, suggesting that farmers are able to work together well to share scarce water supplies. Although there is land available for potential expansion of the irrigated area the RWS levels suggest that farmers are unlikely to expand the total area for risk of water shortages in drier years.

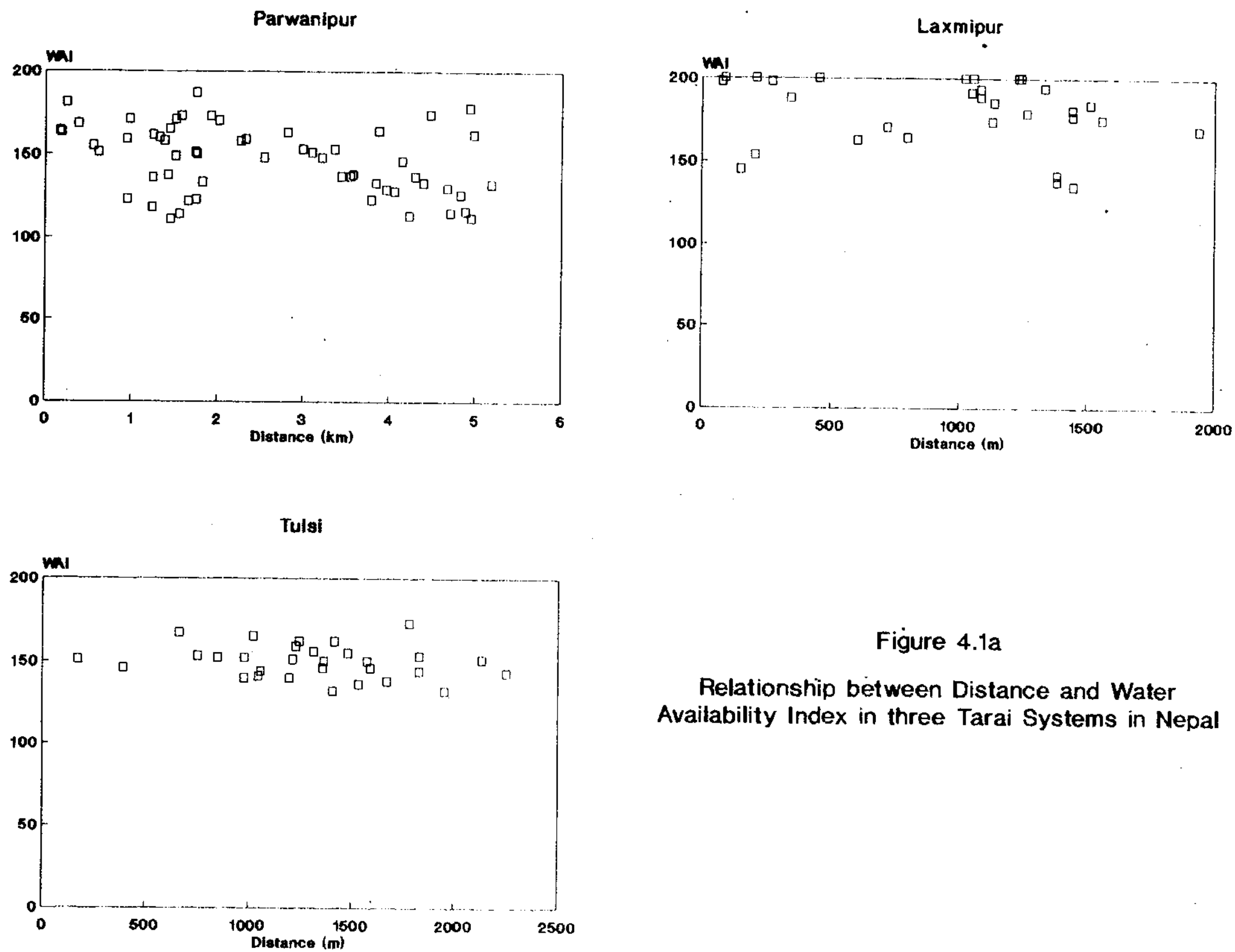
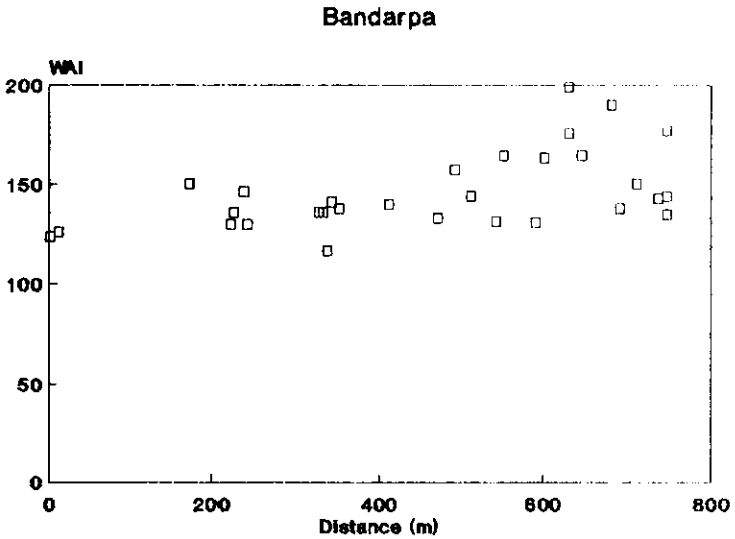
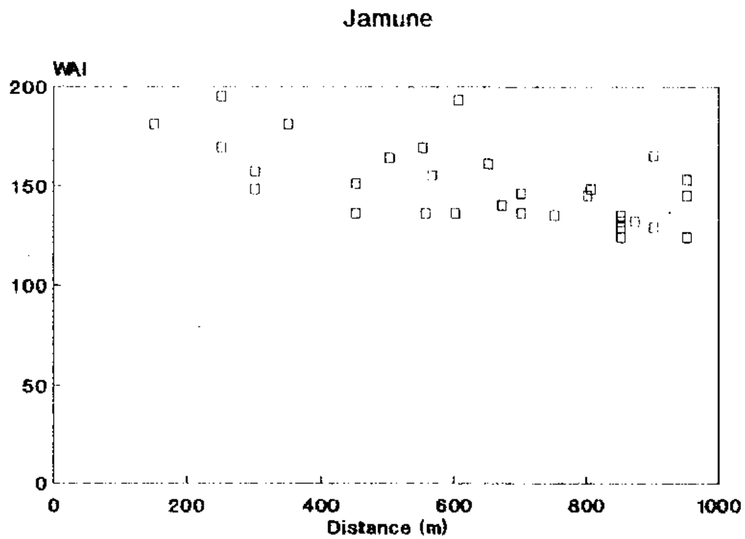


Figure 4.1a

Relationship between Distance and Water Availability Index in three Tarai Systems in Nepal





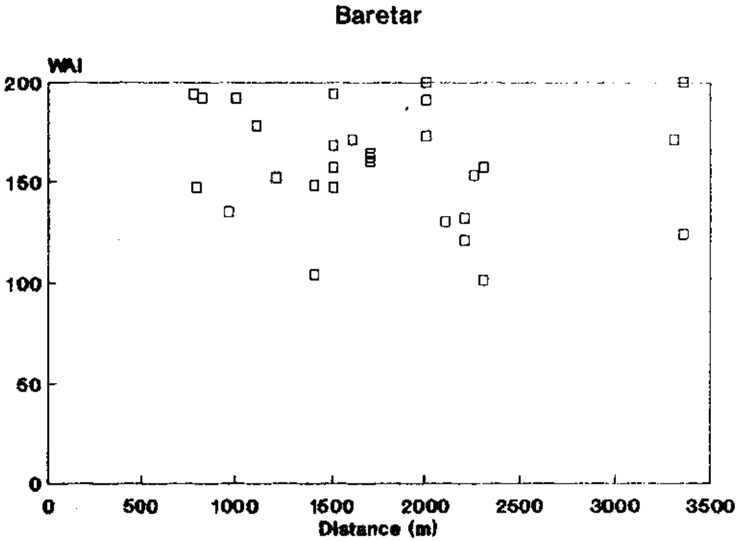


Figure 4.1b

Relationship between Distance and Water Availability Index in three Hill Systems in Nepal

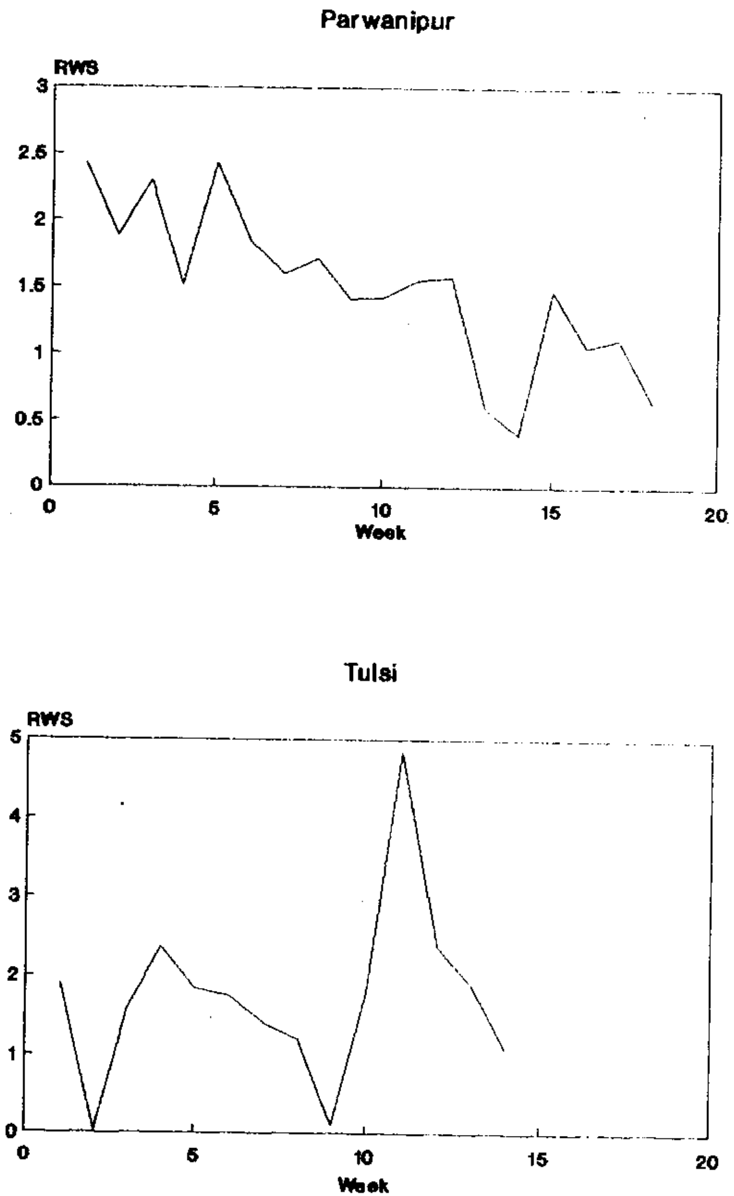


Figure 4.2a

Weekly Relative Water Supply
in three Tarai Systems in Nepal

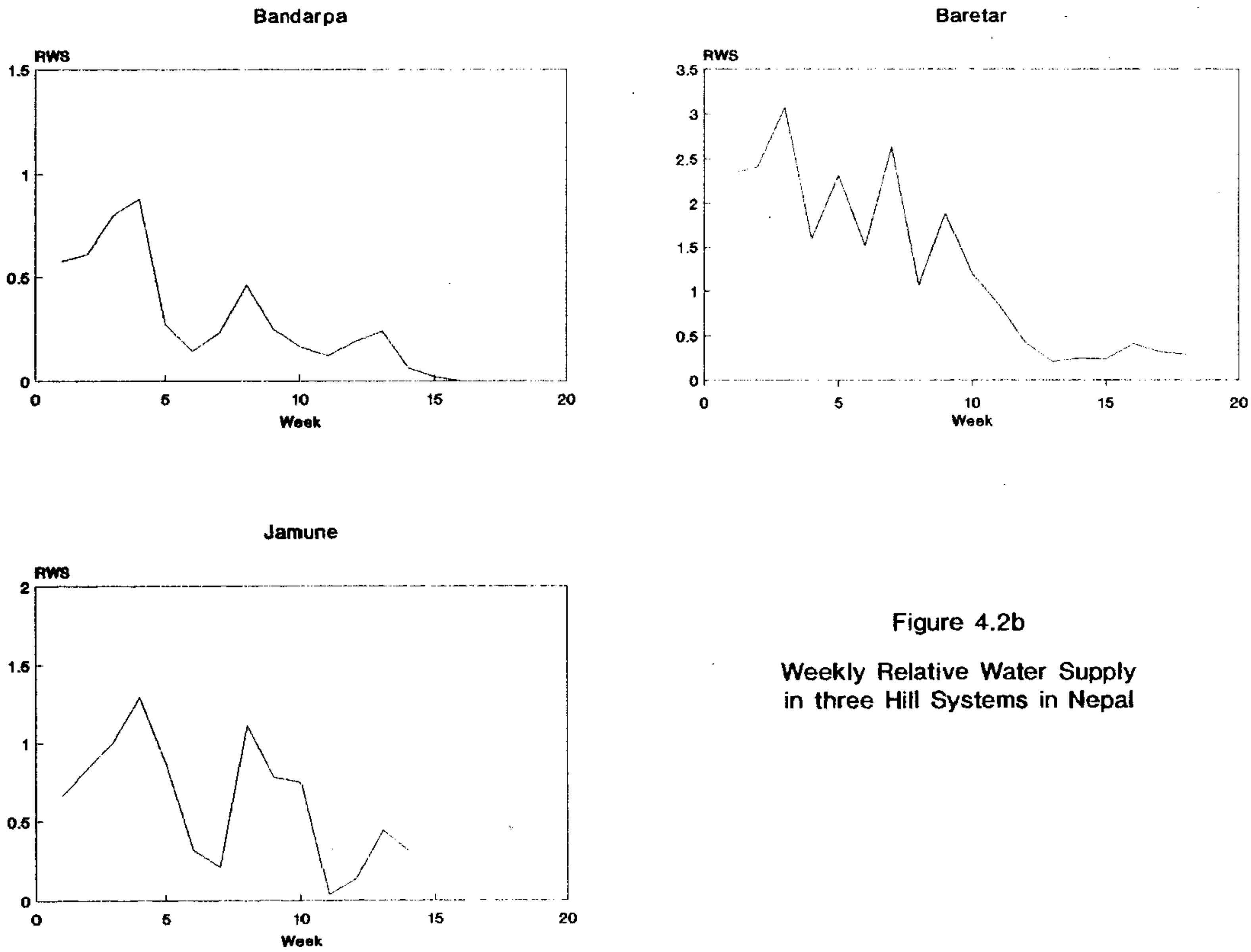
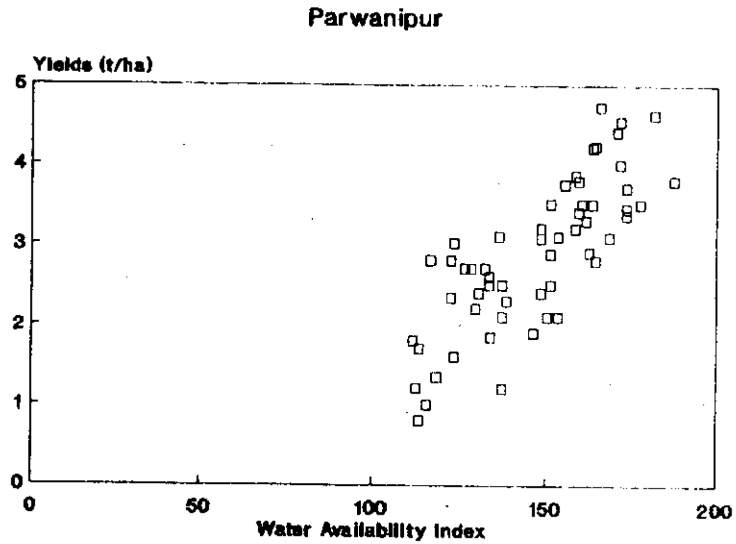
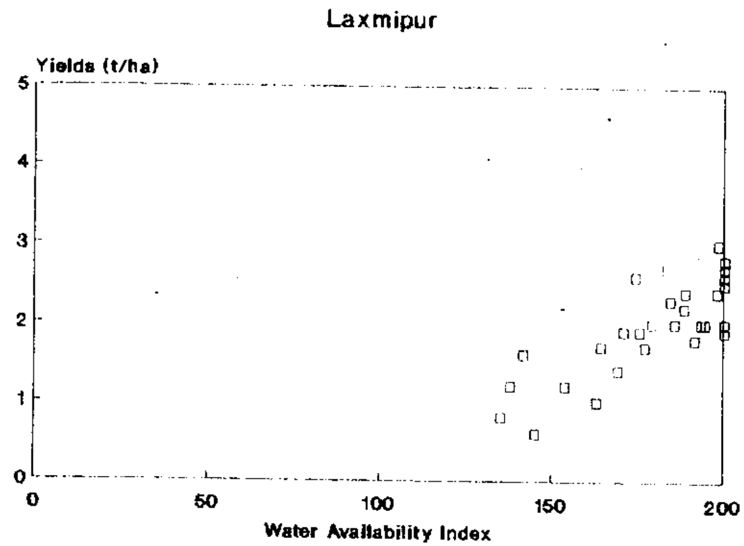


Figure 4.2b

Weekly Relative Water Supply
in three Hill Systems in Nepal





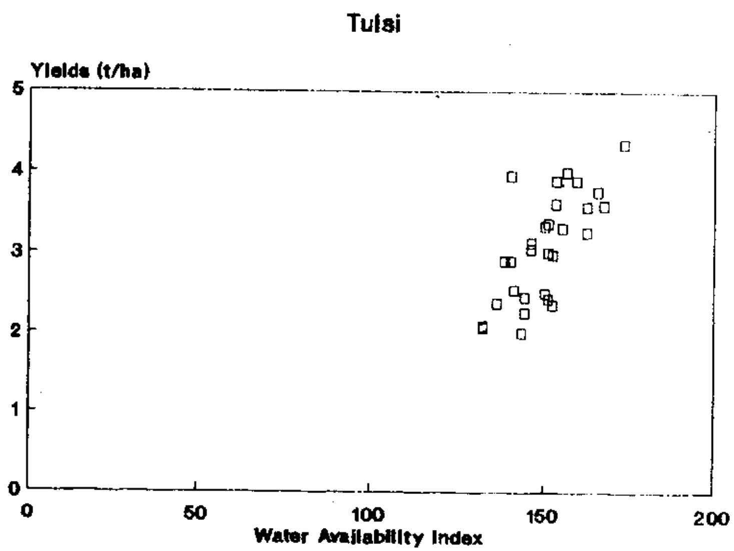
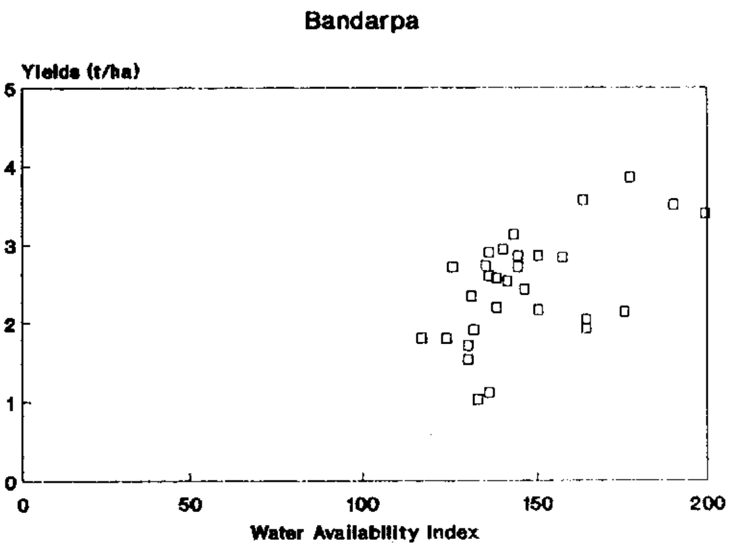
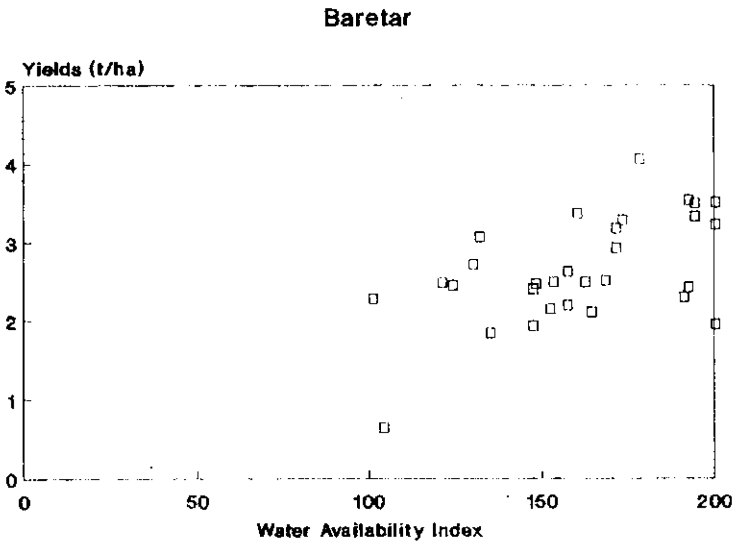


Figure 4.3a

Water Availability Index and Yield in three Tarai Systems in Nepal





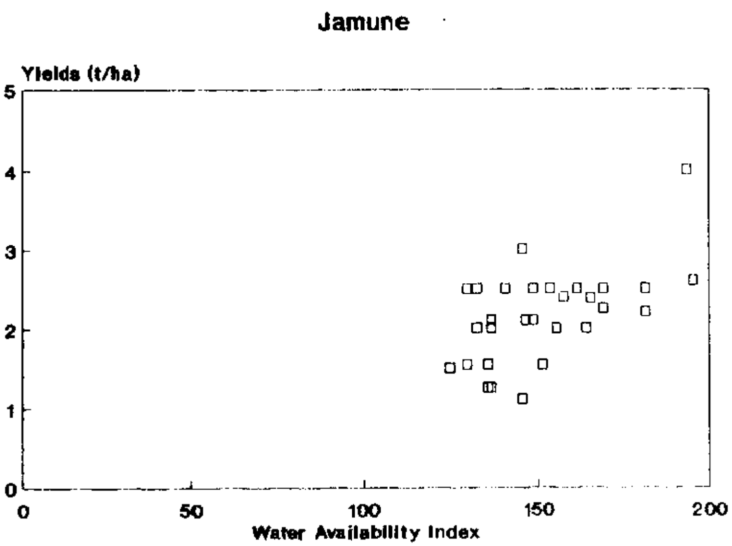


Figure 4.3b

Water Availability Index and Yield in three Hill Systems in Nepal

Table 4.1

Inter–quartile ratio (IQR) of water availability index (WAI) in six small schemes in Nepal

Location	Hills			Tarai		
System	Baretar	Bandarpa	Jamune	Tulsi	Parwanipur	Laxmipur
Average	161	146	144	146	144	179
	(a) By Distance from Head of System					
Head 25%	160	134	168	153	154	186
Tail 25%	151	154	141	149	135	162
IQR	1.06	1.15	1.19	1.15	1.10	1.15
	(b) Independent of Distance					
WAI Highest 25%	195	173	177	162	170	199
WAI Lowest 25%	124	127	130	138	120	158
IQR	1.57	1.36	1.36	1.17	1.40	1.26

Source: IIMI (1991)

Within the systems, however, adequacy show a distinctly different pattern. The variation of WAI between adjacent farmers is high, irrespective of whether the plots are near to or far from the head of the system. The Interquartile Ratio for the best 25% and worst 25% of sample plots (i.e. independent of distance) were much higher than head-tail differences (Table 4.1).

Yields in all of the Terai systems are closely correlated with the actual value of WAI (Figure 4.3a) and it appears that there is potential for improving overall output from the system, and of individual farmers, if water at tertiary level is shared more equally. In the Hills the same relationship is not found (Figure 4.3b). It is not clear from the data presented whether WAI variations are due to unequal access to water or because of differences in soil-water requirements. Increases in agricultural output will only come from improvements to management of agricultural inputs, not from improvements in water distribution at system level.

The result of the system of shares in Cipasir is that upper end land owners are able to cultivate rice three times a year. Farmers in the middle area have sufficient shares for two rice seasons and, if they wish, a third season of non-rice crops. Farmers in the newer expansion areas can normally only cultivate rice during the wet season, but may risk one non-rice crop in the dry season if they feel there is sufficient water available.

Reliability

The design provides little opportunity to manage reliability. The systems are highly dependent on the water conditions upstream of the head gate. In the Nepal cases it is clear that weekly RWS varies greatly (Figures 4.2 a&b), so that in any week it is difficult for farmers to predict how much water they will obtain. Because adjustments cannot be made to flows in the canal system, farmers have to either irrigate only a portion of their holding when water is in short supply or come to sharing arrangements with neighbors.

Table 4.2

Water supply along Wahby and Bahr Seila relative to total Fayoum water supply (May 1986)

Area	Discharge (m3/s)	Gross Command area (ha)	Supply (%)
Fayoum System Total	77.1	151,865	100
Bahr Yusuf at Lahun	50.0	102,181	96
Bahr Hasan Wasef	27.1	49,685	107
Bahr Wahby total area	13.6	30,660	107
Bahr Wahby d/s of Nasria	9.0	23,100	77
Bahr Wahby u/s Nasria total	4.6	7,560	120
Bahr Wahby u/s Nasria excluding Bahr Seila	3.0	3,405	173
Bahr Seila total area	1.6	4,155	75
Area B	0.35	685	101
Area C	0.37	1,094	66
Area D	0.33	943	68
Area E	0.26	705	71
Area F	0.29	730	79

Source: Wolters et al. (1987)

4.2.2 Performance Examples from Submerged Orifice Systems

Submerged orifice systems have the hydraulic capacity to deliver a reasonably uniform discharge over a range of different operating heads. The orifice serving each canal has to be sized and installed in such a way that the discharge passing through the orifice will meet the design objectives within the operating range.

Operational Inputs, concentrated at the few available control points at the head of secondary canals, are of critical importance because water level at any given point down the canal is dependent on the interaction between discharge, the channel cross-section, and any accompanying backwater effects of obstructions or bridges.

The exact range of allowable discharges that can be tolerated depends on what degree of inequity is acceptable: this can be readily calculated from the design of the system. Typically discharges less than 70-80% of full design discharge are considered unacceptable, and alternative operational strategies such as rotation between secondaries have to be adopted.

Maintenance Requirements: Maintenance is critical to these systems. Maintenance inputs must be made so that there is always a known relationship between discharge and water surface elevation at all offtakes. Erosion and sedimentation, change the water surface elevation for any given discharge and this affects the discharge through each orifice. Beyond a certain critical point water distribution may be completely different from that which was intended. Maintenance on the downstream side of each orifice is important to eliminate backwater effects.

The two case studies representing this design environment come from secondary canals in Pakistan and India, both of which form part of the Punjab irrigation systems that were designed to spread limited amounts of water over as wide an area as possible.

Water Distribution Equity

Both studies show that there are wide differences between target and actual discharges. In all of the secondaries included in the Lower Gugera System (Case Study #4) sedimentation is a perennial problem. In canals that have not undergone periodic desedimentation the changed cross-section results in a failure to meet target discharges. In the head ends of secondaries the increased bed level means that the head upstream of orifices is higher than designed, and discharge through the orifice is typically 150-200% of design. As long as discharge into the secondary is at design level, it is inevitable that tail end tertiaries will not have sufficient water. In extreme cases no water reaches the tail of the secondary even though discharge at the head of the secondary met the target (Figure 4.4)

The importance of maintenance can be seen from similar measurements taken following desilting. In one case (Khikhi) discharges into tail end tertiaries were above design following desilting of the top half of the canal (Figure 4.5a). In the second case (Lagar), where maintenance inputs were more modest but focussed on the most silted sections, tail end water conditions improved significantly, even though they did not achieve target discharges (Figure 4.5b). Before desilting in Lagar Distributary, the IQR was 5.03 when discharges were at or close to design, a highly inequitable situation. Following desilting the IQR was reduced to 1.24.

Much of the variation following desilting appears to be the result of differences between the intended size and elevation of the each orifice and the actual situation in the field. The differences can be attributed to deliberate tampering of orifice dimensions by farmers as well as to imprecision in the actual installation of the orifice. In a system of this nature very precise installation is required to ensure that the operating head above the sill of the orifice is as designed.

Data from two similar distributaries in India (Mudki and Golewala, Case Study #5), where sediment is not a problem and where operational factors do not seem to have significant influence, show much less variability between head and tail than was the case in Lagar (Figure 4.6), with IQR values of 1.98 at Mudki and 1.35 at Golewala. The distribution of the variability is not related to distance along the canal and again appears to reflect differences between designed and actual installation of the outlets.

The second management input that directly affects the performance of submerged orifice systems is the operation of the gate at the head of the secondary canal. Data from Lagar Distributary demonstrate the effect of operation of canals at lower than recommended discharges (Figure 4.7a). When operated at 100% of Full Supply Discharge (FSD) the IQR was 5.03. When incoming discharges were at 60% the IQR rose to 44.15 because the last 20% of the canal received no water at all, while the upper half of the outlets still received more than design. In the worst case, when discharges were only 25% of FSD no water passed the halfway point of the canal, and no outlets received their design discharge.

The impact of maintenance can be seen on the relative IQR at different discharges. Immediately after maintenance had been completed, the IQR at 100% of FSD was 1.24, and only increased to 2.97 at 60% of FSD (Figure 4.7b).

Adequacy

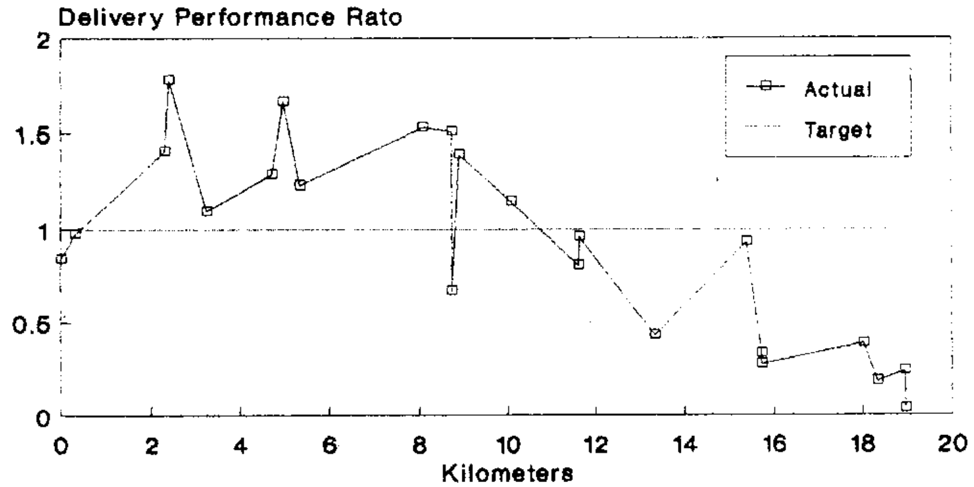
The Pakistan case study is an example of intensive conjunctive use of surface and groundwater. In upper parts of all the canals groundwater accounts for more than 60% of all irrigation water, increasing to as much as 90% in tail end areas.

This makes it difficult to directly relate adequacy, as indicated by cropping intensities, cropping patterns or yields to surface water management of the canal system alone. There is some evidence that yield per unit of water in Pakistan is highest for wheat cultivation when farmers have access to a

Figure 4.4

Water Distribution Equity, Lower Chenab Canal, Pakistan

(a) Lagar Distributary



(b) Pir Mahal Distributary

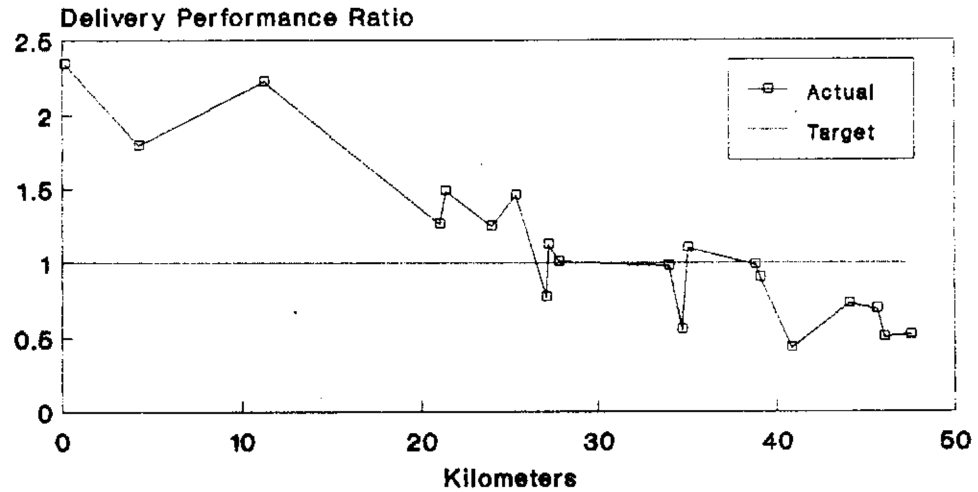
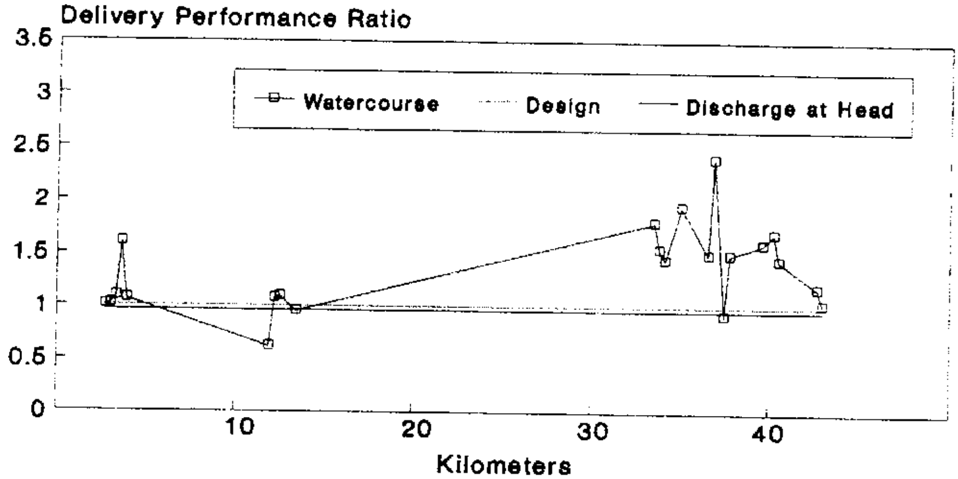


Figure 4.5

Water Distribution Equity After Desilting
Lower Chenab Canal, Pakistan

(a) Khikhi Distributary



(b) Lagar Distributary

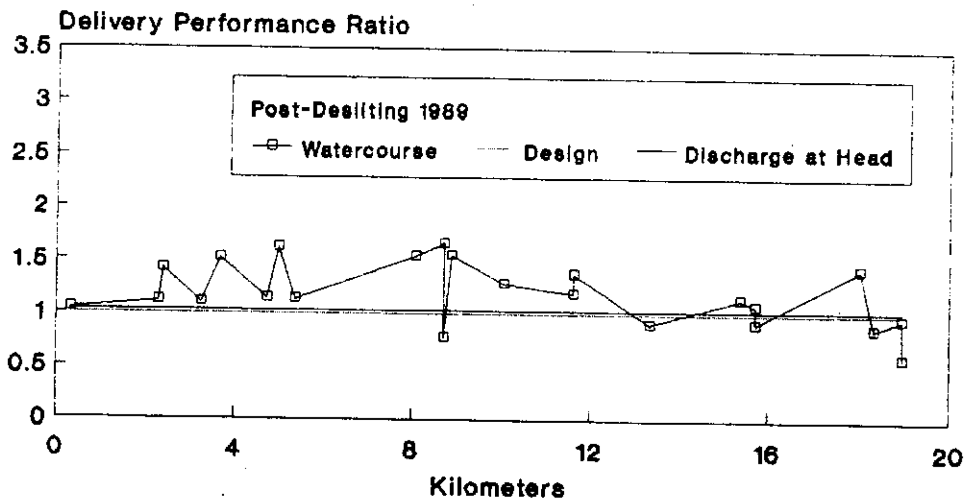
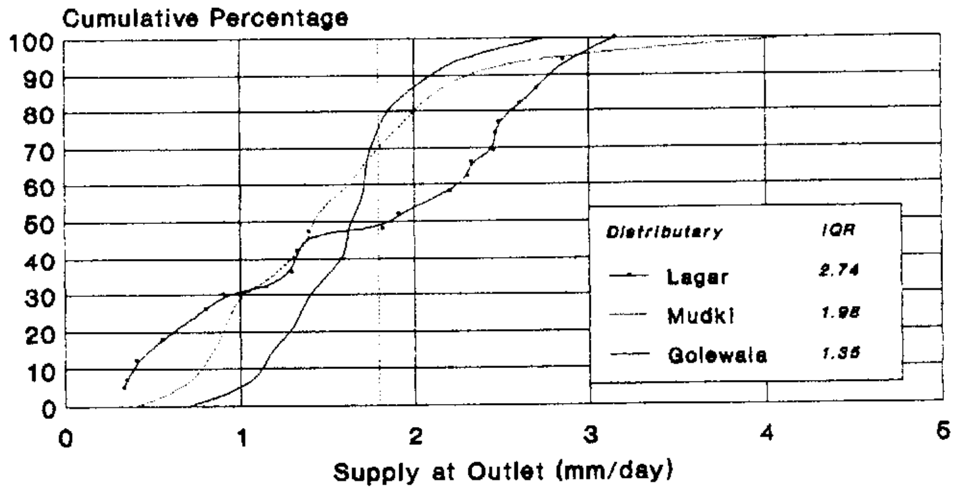


Figure 4.6

Mudki and Golewala, India, and Lagar, Pakistan

Water Distribution Equity



combination of surface water, shallow tubewells and deep tubewells (Bhatti et al., 1989). Nevertheless, access to surface water appears to determine certain cropping choices: more rice is grown by farmers with reliable access to surface water supplies because it is cheaper and of better quality, and cropping intensities are highest in areas where surface water supplies are most abundant (Vander Velde, 1990).

Most importantly, however, is the question of salinity resulting from underirrigation. Canal water in distributaries has low salinity (Ec of 0.2), and is used by farmers to compensate for high usage of lower quality tubewell water: in upper end areas shallow groundwater has EC values of 0.75-1.25, deteriorating to 2.0 or above in tail end areas. Evidence is mounting that the present intensity of groundwater use is leading to soil salinization in areas of relatively good quality groundwater and this is depressing both yields and cropping intensity (Kijne, 1990). The solution to this problem is to use surface water for leaching, but this is not an option available to many tail end farmers because of the inequitable distribution of canal water under current management inputs. Fixed orifice systems have severe limitations in any strategy to provide short duration additional supplies for leaching.

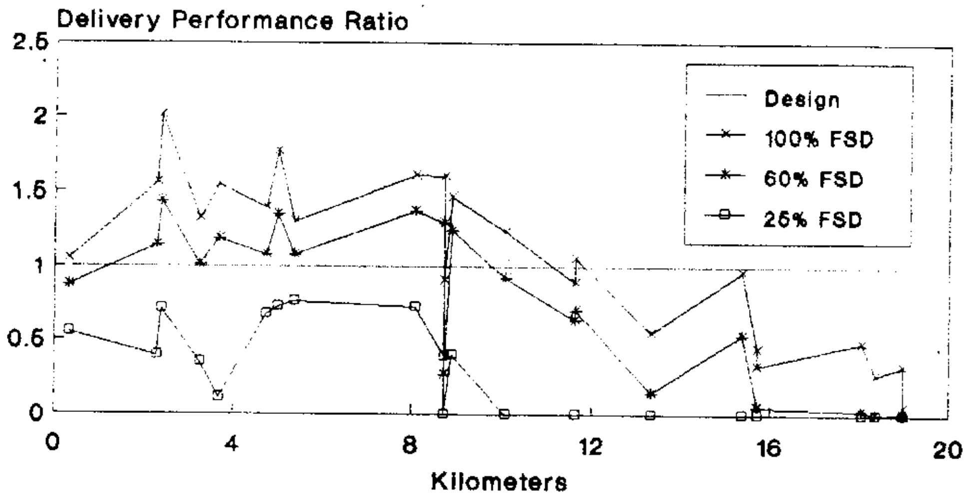
Reliability

The impact of these operational inputs on reliability at tertiary level can be seen through analysis of the coefficient of variation of monthly discharges into tertiary watercourses (Figure 4.8). In both Lagar and Pir Mahal Distributaries there is an almost exponential increase in monthly variability of discharge along the canal: tail end farmers cannot predict how much water they will receive in each irrigation turn. Even though the systems are designed to deliver water continuously to all watercourses they do not: the differential access to water along Pir Mahal, expressed in the percentage of time each watercourse fails to receive water, is shown in Figure 4.9. Even though these data come from a period when rotational irrigation was being practiced, the operational plan was intended to share water deficits equally between all watercourses.

Figure 4.7

Factors Influencing Water Distribution Equity
Lagar Distributary, Pakistan

(a) Inflow Discharge Variations



(b) Desedimentation

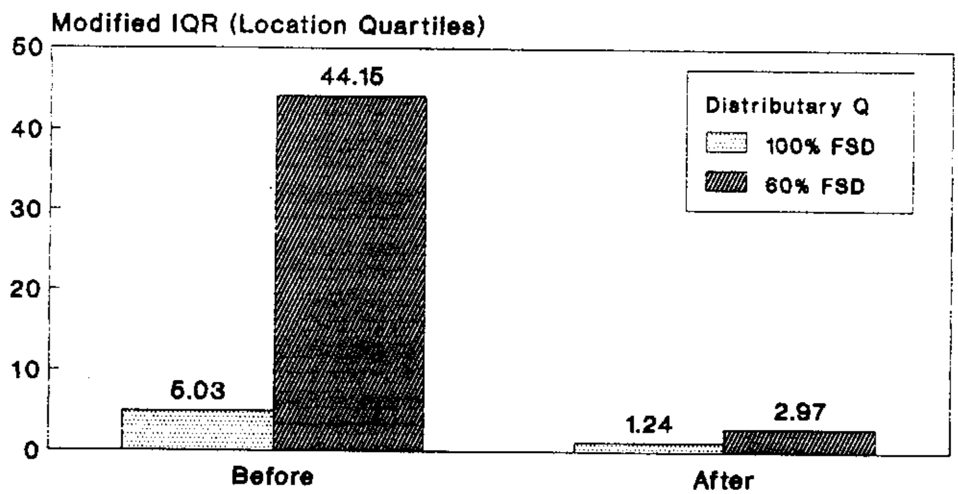
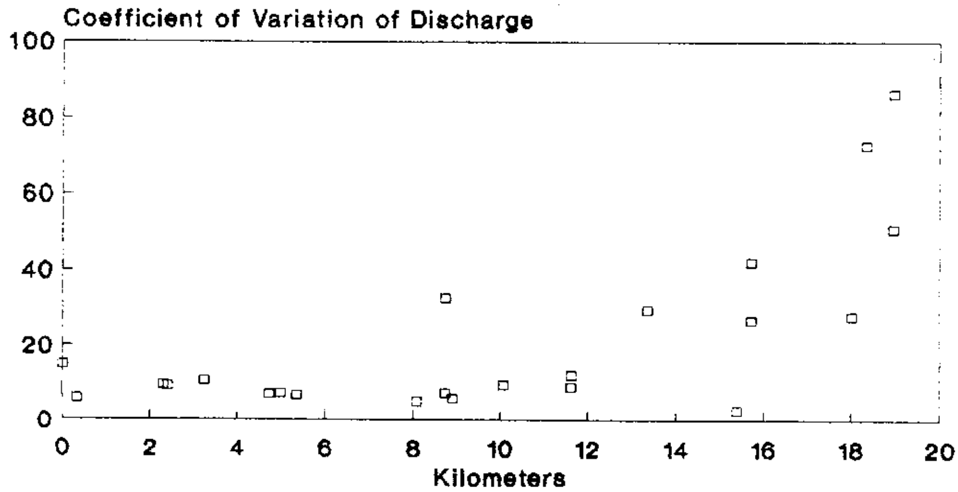


Figure 4.8

Monthly Variation of Watercourse Discharges
Lower Chenab Canal, Pakistan

(a) Lagar Distributary



(b) Pir Mahal Distributary

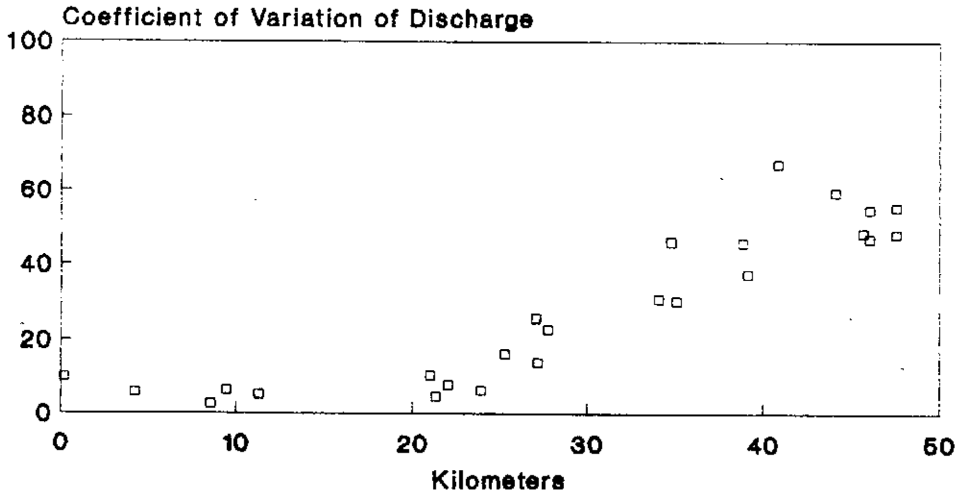
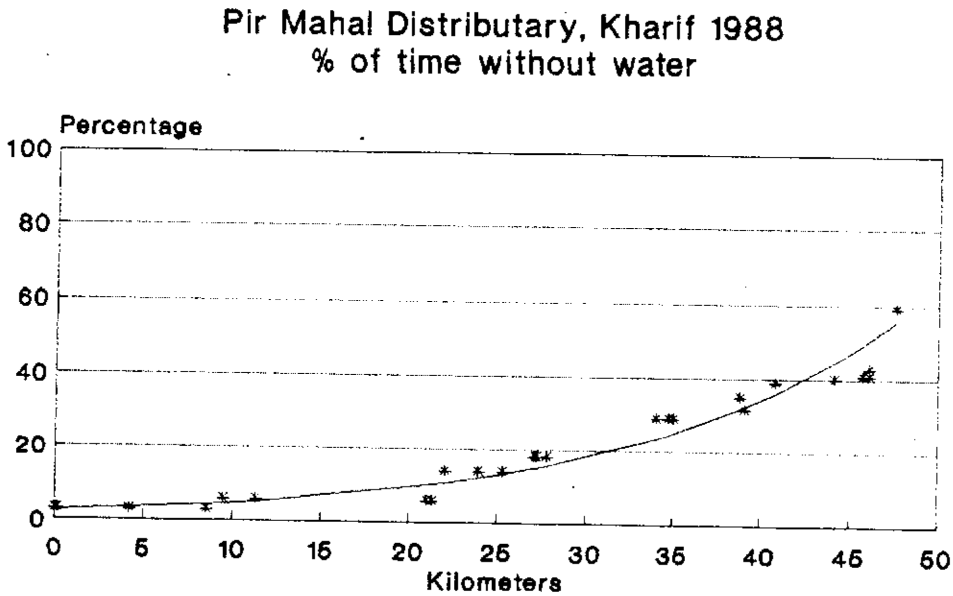


Figure 4.9



4.3 Gated Systems

Gated systems provide much greater flexibility in operations than ungated systems, and therefore tend to have lower maintenance requirements. This flexibility means that there are fewer limitations on the objectives, and it is possible to manage the system for a wide variety of combinations of adequacy, reliability and equity.

This flexibility is, however, a double-edged weapon. Sliding gates can be just as easily abused as used, and well planned water distribution patterns can be disrupted due to improper, illegal or merely malicious gate operations by field staff and farmers alike.

The nature of cross-regulation along the main canal system determines what degree of flexibility exists, the case studies treat each of the three main design variations separately.

4.3.1 Performance Examples in Systems with Little Cross-Regulation

This design type is characteristic of older irrigation systems in relatively flat areas where it is comparatively easy to design canal long sections to meet hydraulic requirements at each offtake. Five case studies of this type of system are presented in this report: Gal Oya Left Bank and Hakwatuna Oya in Sri Lanka, Tungabhadra in India, Lower Talavera in the Philippines and the Lower Chenab Canal in Pakistan.

Operational inputs at the head of the canal are essential to achieve reliable and dependable water supplies in systems with little or no canal cross-regulation capacity. Each fluctuation in discharge into the head of the canal will result in changes in water surface elevation on the upstream side of each offtake structure, and necessitate a change in the setting of the offtake gate if a stable discharge is to be maintained through the offtake.

Management requirements at offtake gates are highly sensitive to the quality of operational inputs at the head of each controlled canal reach. If discharges at the head of the reach are stable then offtake gates need not be adjusted very often unless there are changes in demand. Unstable main canal discharges require more frequent adjustment of offtake gates.

Opportunities for implementing rotation irrigation are limited. The lack of capacity to close off sections of the main canal means that all gates must be operated in order to implement rotations between tertiary blocks. Rotations between secondaries are simple to implement.

Table 4.3

Average water deliveries in mm/day to main canals and units of Gal Oya Left Bank

	Main Canals at Uhana Bifurcation			Units Below Uhana			Main Canals at Weeragoda Bifurcation			Units Below Weeragoda	
Year	U/S	LB	UB	LB	GG	Uhana	U/S	WG	MD	M1	M6
1974	18.5	17.5	19.3	20.1	16.1	27.8	16.0	9.3	20.0	21.0	19.4
1975	19.5	21.7	19.3	20.8	22.8	19.7	19.0	32.0	16.7	18.0	16.0
1976	19.1	19.5	18.9	30.9	13.6	23.3	14.4	13.3	22.7	19.4	22.7
1977	8.8	6.2	10.6	9.0	3.0	11.6	10.3	7.9	11.3	10.7	11.6
1978	16.9	15.1	18.1	21.3	11.8	24.2	15.4	16.3	14.9	15.1	14.8
1979	18.3	14.5	21.2	14.1	14.8	26.7	18.6	-	17.3	16.8	17.7
1980	15.8	16.0	15.6	17.9	14.8	24.2	12.1	11.4	14.3	11.8	15.7
1981	15.5	12.5	18.2	15.3	9.9	13.5	25.6	-	19.6	23.4	15.9

U/S	Upstream	Uhana	UB1A-17
LB	Left Bank Main	WG	Blocks 26 and J
UB	Uhana Branch	MD	Mandur Distributary
LB	LB 14-22	M1	Mandur 1-5
GG	Gonagolla Branch	M6	Mandur 6-32

Source: Murray-Rust (1983)

Maintenance input requirements in these systems are high. The hydraulic integrity of the system is determined by uncontrolled head-discharge relationships on the upstream side of each offtake, so that if canal maintenance is not undertaken properly and the canal cross-section deteriorates then eventually hydraulic conditions anticipated at the design stage cannot be attained. In this respect they have similar maintenance requirements to submerged orifice systems, but some degree of canal deterioration can be compensated for by modifying gate operations at each offtake.

Maintenance is also required to ensure that all offtake gates remain in working condition. If gates cannot be operated properly then upstream offtakes will receive more than their allotted share, a situation only made worse if canal cross-sections are also not maintained properly.

Assessment of Water Distribution at Main and Secondary Level

Data from the Gal Oya system in Sri Lanka (Case Study #6) show major differences in water deliveries to the different units of the system (Table 4.3). Head end units received significantly more than their share, while tail end areas received comparatively less. The actual water distribution pattern failed to meet the targets set down at the start of each season.

Analysis of water distribution between secondary canals within two of the blocks during the 1981 dry season showed even greater variation (Figure 4.10). Although there is a decrease in water deliveries from head to tail the primary cause of inequity of water distribution can be directly attributed to design conditions. Water delivery into each secondary is closely related to the ratio between the diameter of the offtake culvert and the area served by that culvert (Figure 4.11). In most cases, smaller command areas benefitted more, while larger ones only just managed to receive the minimum estimated requirement of 2.0 l/sec/ha.

Evaluation of the degree of approximation between culvert diameters and the design command area indicate the extent to which precise management of the gate is necessary to achieve the desired water distribution equity (Figure 4.12). 9-inch (22.9 cm) diameter culverts served command areas ranging from 10 to 40 ha, while some smaller command areas had 12-inch (30.5 cm) diameter culverts were installed that only served 20 ha.

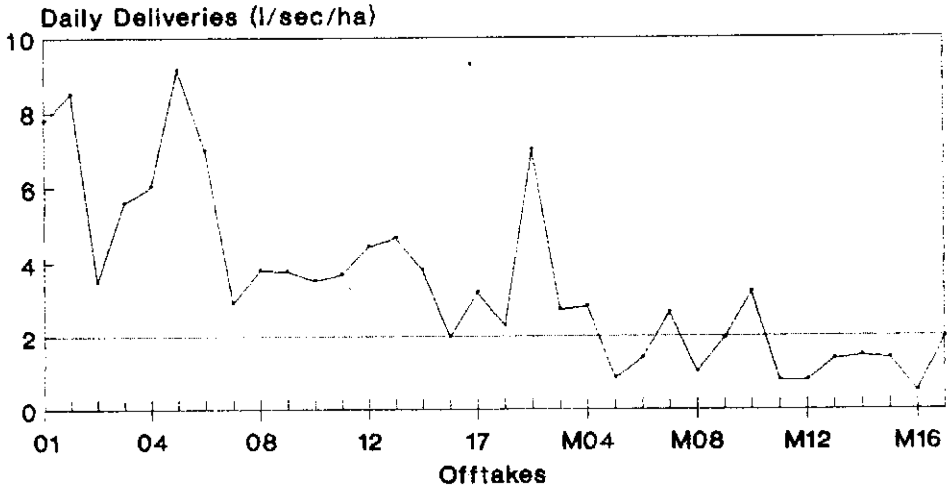
At the design stage, for legitimate financial reasons, culvert sizes were chosen on the basis of standard dimensions, and as long as the size matched or exceeded the maximum design requirement of the secondary, it was assumed that operation of the gate would permit any fine tuning. However, virtually none of the gates were functioning at the time of the study, and those that existed were rarely operated. This is a clear example of where a failure to operate and maintain gates results in an a highly inequitable division of water.

Tungabhadra Irrigation System, Karnataka, India (Case Study #7) shows similar problems with water distribution, both in terms of overall equity as well as between adjacent outlets. At subsystem level upper end outlets receive water more or less according to target discharge, while tail end outlets receive less than 50% of the target (Figure 4.13). The cumulative effect of this is that the tail end reach of D36 distributary, which is 35% of the total command area, received on average only 20-40% of target discharge, while the upper five reaches all received more than their target (Figure 4.14).

Figure 4.10

Water Distribution Equity
Uhana and Mandur Branches, Gal Oya Left Bank, Sri Lanka

(a) Daily Water Deliveries



(b) Misallocated Volume

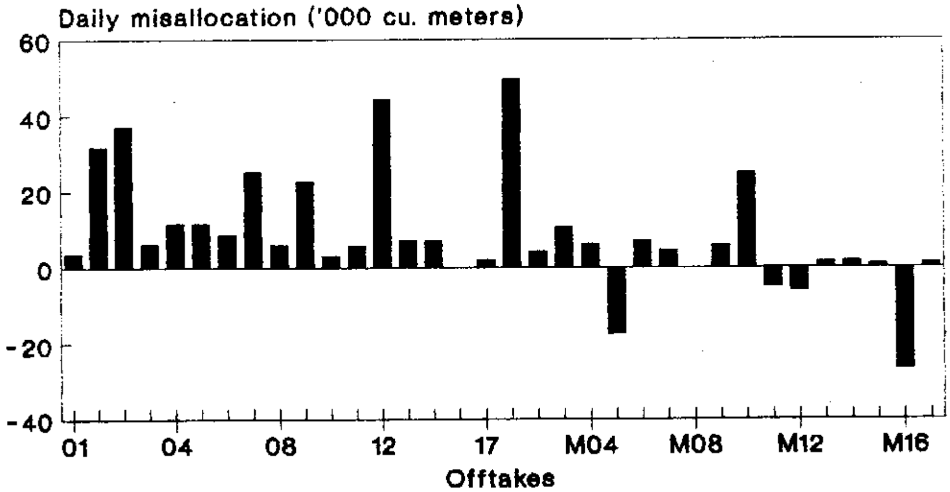
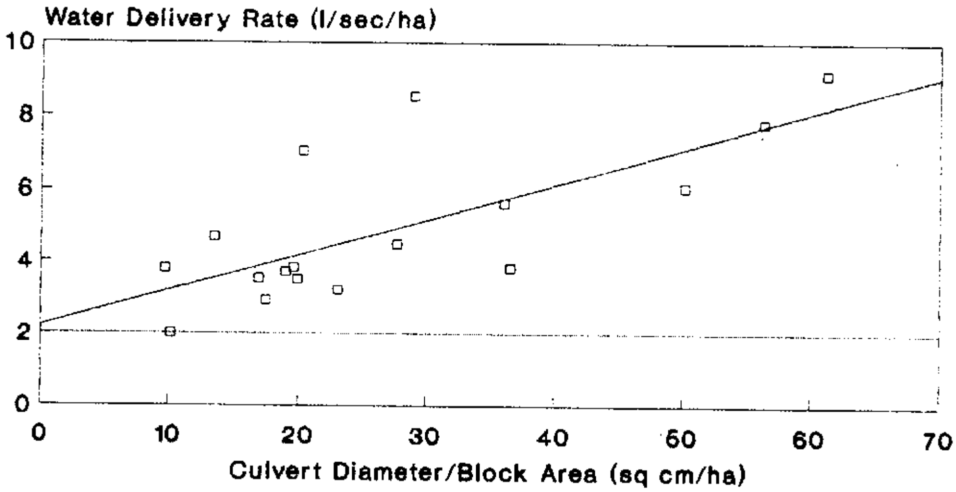


Figure 4.11

Design Impact on Water Delivery: Gal Oya, Sri Lanka

Effect of Culvert Size on
Water Delivery Performance



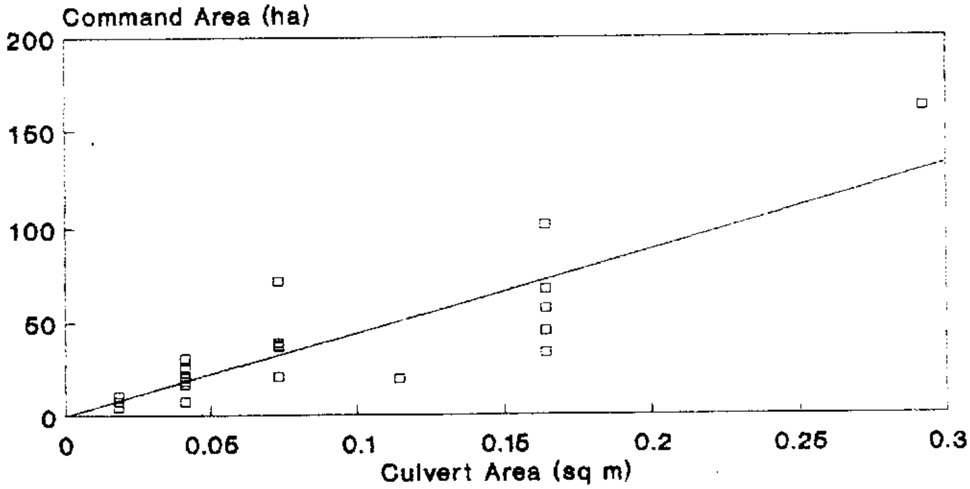
Associated with these overall inequities is a deterioration of reliability of discharge down the main canal. Discharges at the head are rarely close to the target, and show some daily fluctuation. Half way down the canal targets are not met and daily variability is very high (Figure 4.15). The lack of frequent cross-regulators along the canal means that if fluctuations are present at the canal head, they cannot be stabilized further down the canal.

One design issue arising from systems such as Gal Oya and Tungabhadra is that mixing small and large offtakes along the main canal makes operation more difficult. Distribution of designed discharges from Tungabhadra (Figure 4.16a) shows the extent of this problem. The dimensions of the management task can be clearly seen from Figure 16b: along the main canal of Tungabhadra 50% of all gates control only 9% of the total discharge, 80% of gates control only 31%, while 10% of gates control a full 52% of discharges. It takes the same management input to control small offtakes as large ones. Because there is a tendency to ignore the management of small outlets, they are allowed to take more water than their share. Although the error is relatively small in volumetric terms the cumulative effect is large and has a direct impact on tail end water deliveries.

Figure 4.12

Relationship between Culvert Dimensions and Command Area, Gal Oya Left Bank, Sri Lanka

(a) Structures with One Culvert



(b) Structures with Two Culverts or Box Culverts

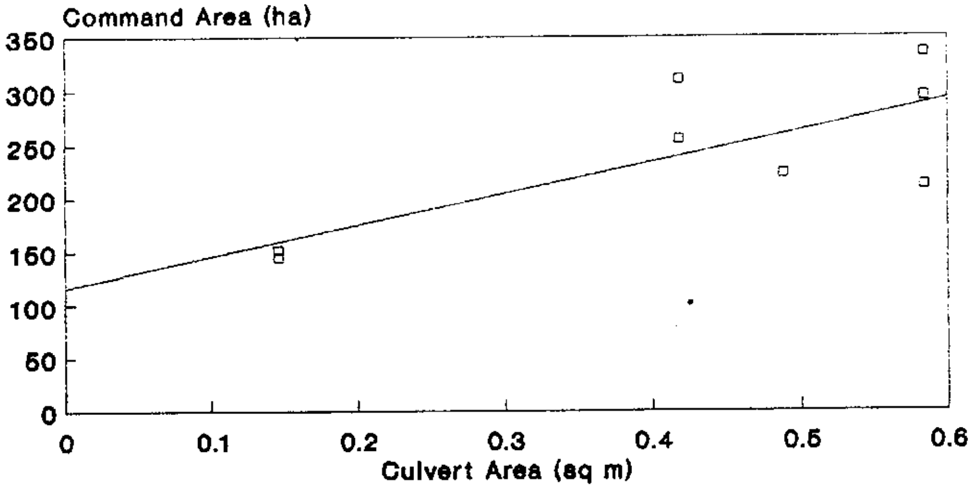
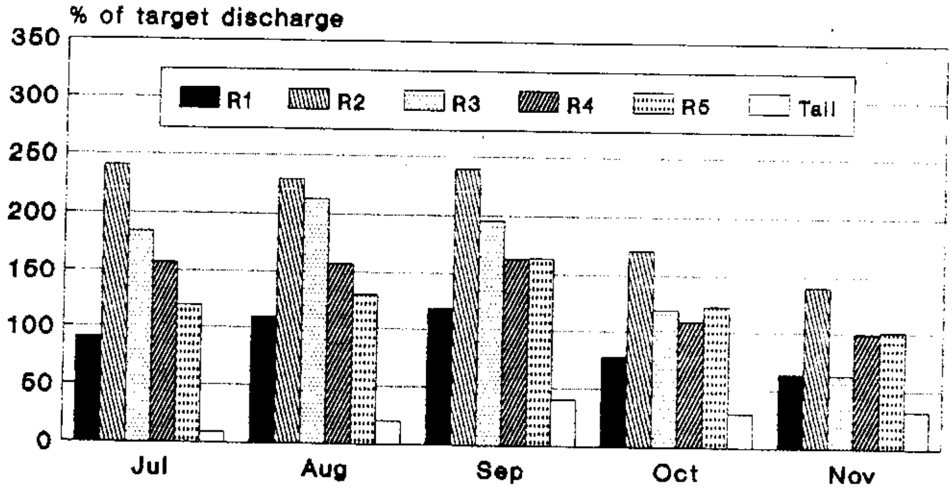


Figure 4.13

Water Distribution Equity along Distributary D36
Tungabhadra Irrigation System, India

(a) Kharif 1987



(b) Rabi 1987-88

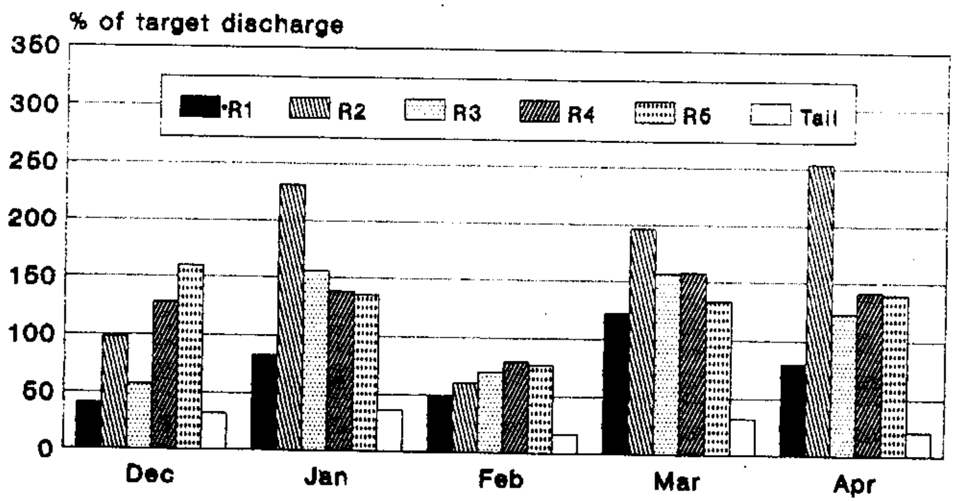
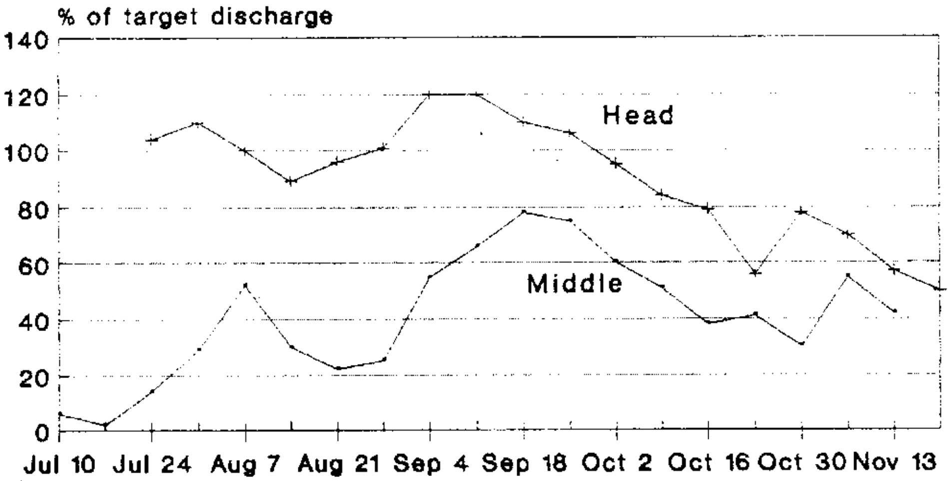


Figure 4.14

Water Delivery Performance along Distributary D36, Tungabhadra Irrigation System, India

(a) Kharif 1987



(a) Rabi 1987-88

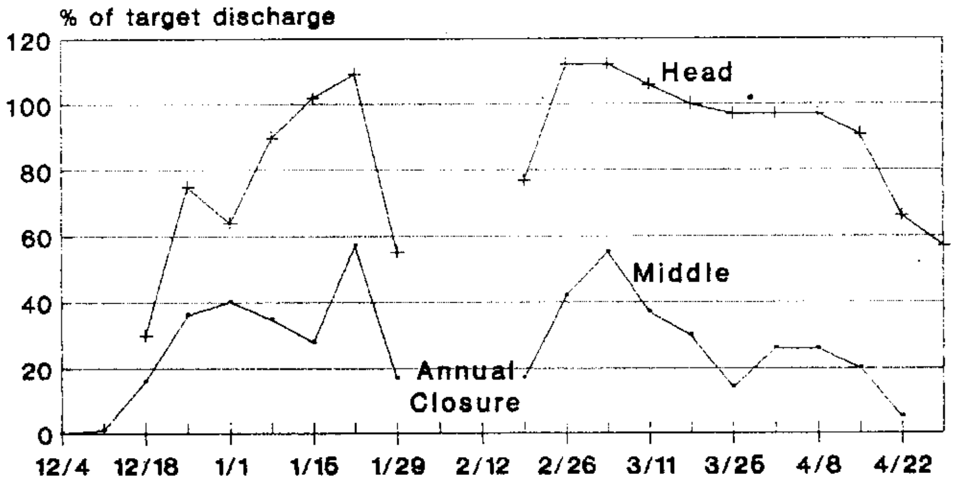
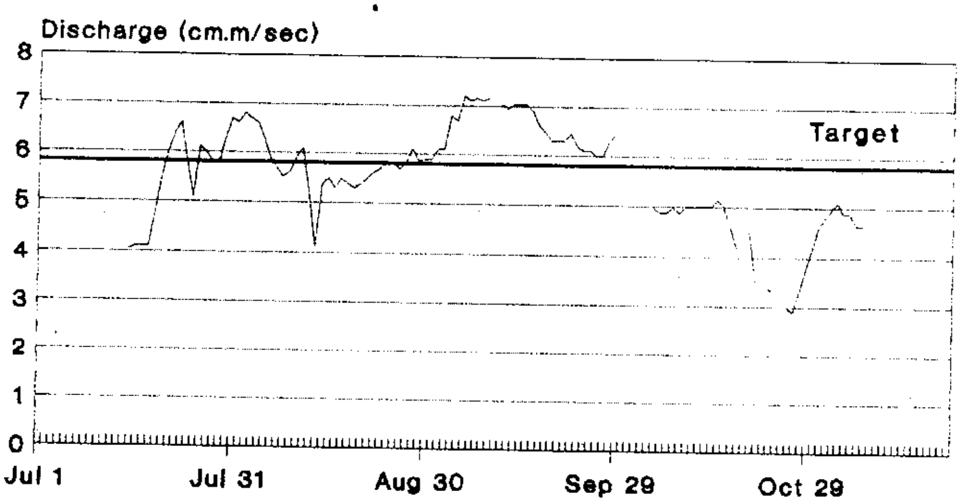


Figure 4.15

Variability of Flows along Distributary
Tungabhadra Irrigation System, India

(a) Flow at Head (MD1)



(b) Discharge at Middle (MD9)

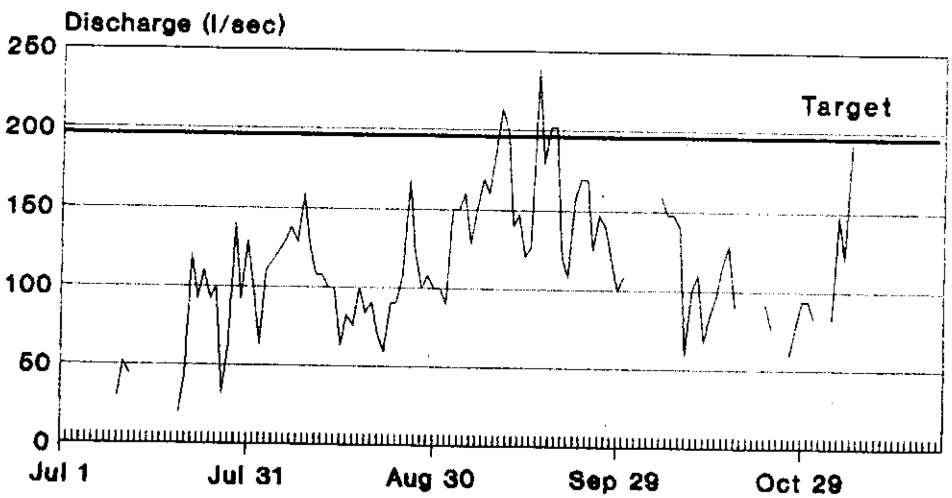
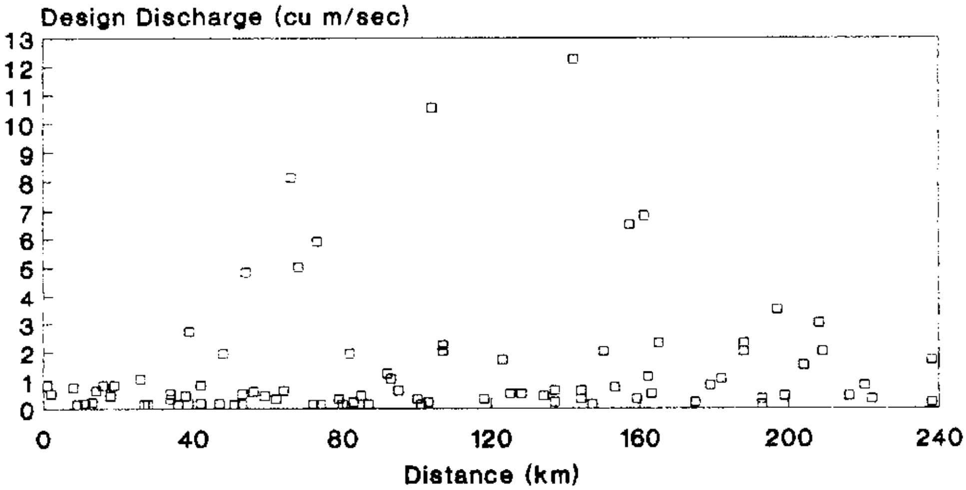


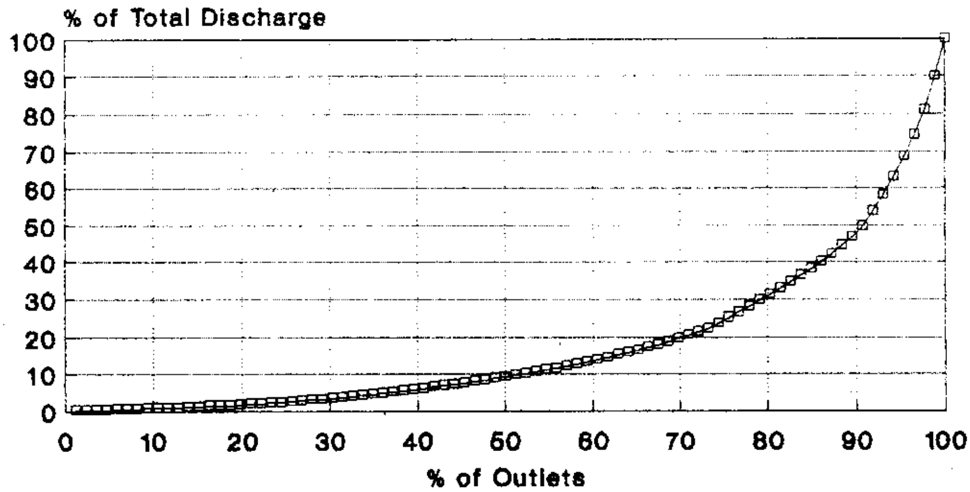
Figure 4.16

Design Discharges Along Main Canal
Tungabhadra Irrigation System, India

(a) Design Discharges



(b) Outlet Discharges



Tungabhadra also demonstrates clearly the effect of long-term changes in the system. Post-construction addition of outlets and expansion of command area has meant that the total sanctioned water supply and losses greatly exceed the design capacity of the main canal. At the head of D36 canal the sum of official discharges from all outlets plus official allowances for conveyance losses is about 40% higher than the designed canal capacity. Data on main canal operations in the Hakwatuna Oya system (Case Study #8) show the potential for improving equity with only minor increases in control infrastructure. Along the Right Bank Main Canal, where there are no cross-regulators, it is impossible to manage head other than by controlling discharges at the head gate. Although offtake gates can be managed, interquartile ratios of 1.63 and 1.76 were recorded for two successive dry seasons between head and tail areas.

The Left Bank Main Canal at Hakwatuna Oya has a bifurcating layout and there are three cross-regulation structures that can be used to control water distribution into the different branches of the system. This small amount of additional control resulted in interquartile ratios of 1.49 and 1.34 for the same period. This better performance over a 50% larger command area was achieved with an identical set of objectives as for the Right Bank because of effective operation of the cross-regulators.

Improved monitoring procedures adopted in Hakwatuna Oya enabled simple and rapid feedback of performance during each water issue. A typical water distribution report expressed both volumetrically and in total depth of water applied, is presented in Figure 4.17. This can be used by the system manager to evaluate water delivery performance immediately after each issue.

The importance of precise gate control where there is relatively little cross-regulation is demonstrated by results from Gugera Branch of the Lower Chenab Canal in Pakistan (Case Study #9). Water levels which directly affect the operating head at offtakes are largely a function of upstream discharge. If offtake gates are not managed to respond to these changes in main canal discharge, then the variability of discharge into the secondary may be significantly higher than those in the main canal (Figure 4.18).

This study also indicates the consequences of designing only for one set of operational conditions. The basic design assumption is that main canal discharges will be constant, thereby maintaining adequate head upstream of each offtake. However, if river discharges at the head of the system are low it is not possible to maintain discharge or head in main canals. Along the main canals, the sill levels of offtake gates are well above the bed elevation of canals. It is impossible to deliver water into secondary canals if discharge in the main canal falls below a critical value. Figure 4.19 shows the effect of the number of gate operations on the ratio of coefficient of variation in Mananwala Distributary (MNW) to that of Upper Gugera Branch (UG). When frequent gate operations are undertaken, Mananwala has a coefficient of variation of less than twice that of Upper Gugera, but if the gates are left unattended the coefficient of variation in Mananwala increases to as much as 6 to 12 times that of Upper Gugera.

The absence of sufficient cross-regulators in the main canal means that the secondary canals are dependent on control of discharge into the head of the main canal, several tens of kilometers upstream.

Water Distribution at Tertiary Level

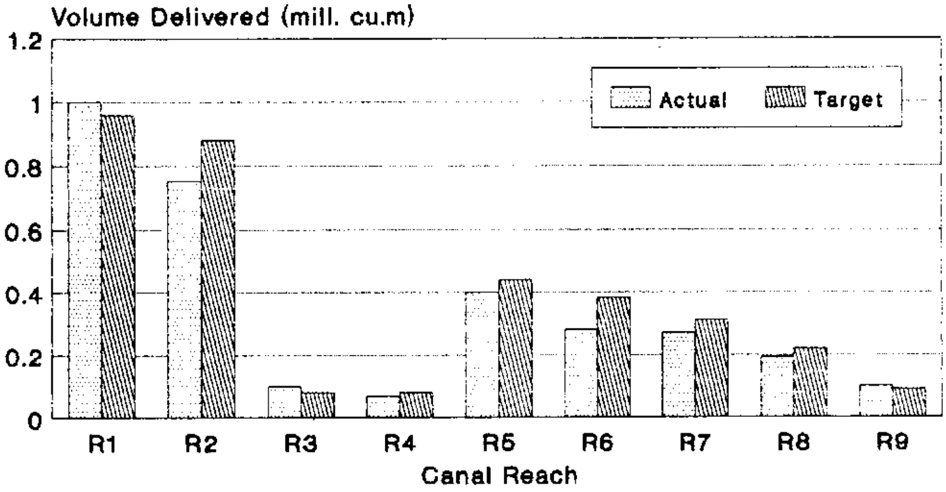
Despite the poor water distribution between secondary canals in Gal Oya, water distribution within secondary canal command areas was much more equitable (Table 4.4). Detailed studies in three of the larger secondary commands show few variations in either water availability or in yields from head to tail of tertiary blocks (Wijayaratne, 1986). Although farmer groups had no control or influence on main and secondary level water distribution, they were apparently able to manage water quite equitably among themselves at the tertiary level.

These data are a strong argument for ensuring that water distribution along the main and secondary canal should be made as reliable as possible, thereby enhancing the management capacity of farmers to utilize this water according to their own objectives at farm level.

Figure 4.17

Water Distribution Report for a Single Issue
Hakwatuna Oya, Sri Lanka

(a) Delivery by Volume



(b) Delivery by Dpeth

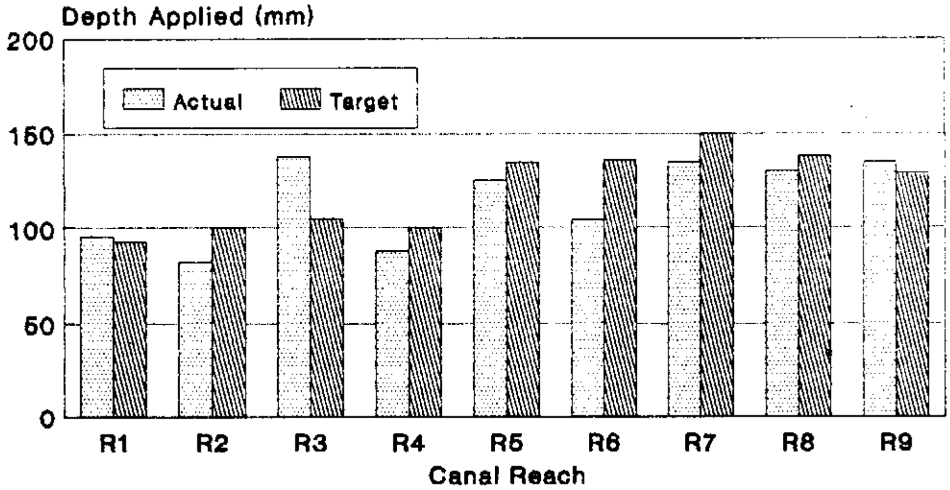


Figure 4.18

Coefficient of Variation of Discharges
Upper Gugera Branch, Pakistan

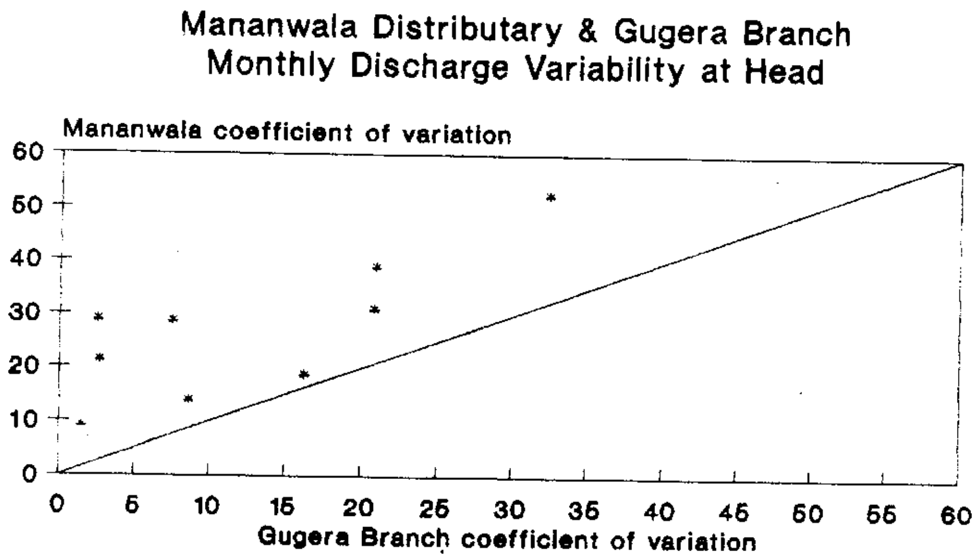


Figure 4.19

Relative Variability of Discharge
Head of Mananwala Distributary, Pakistan

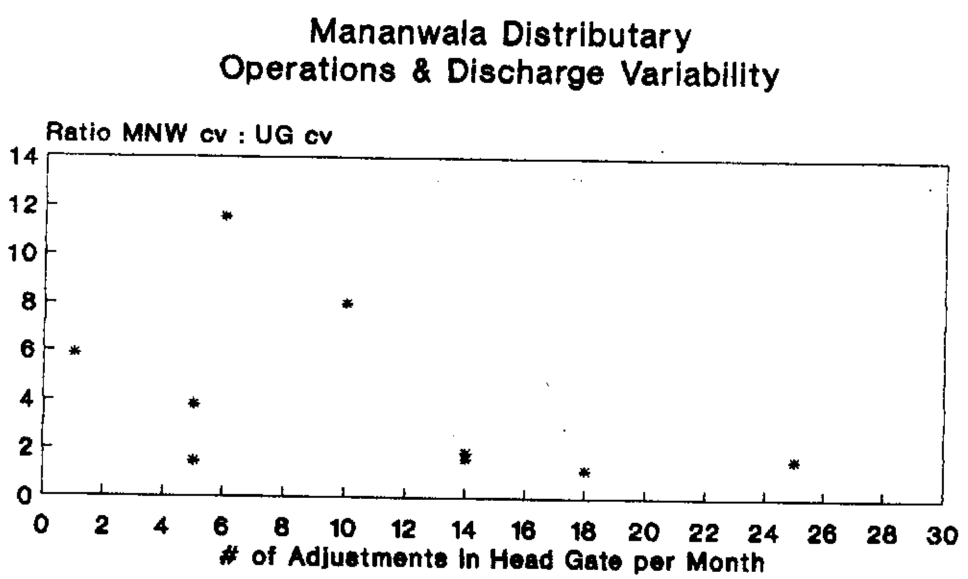


Table 4.4

Differences in Water Availability Index (WAI) by Field Channel and Farm Position Dry Season 1982, Gal Oya Left Bank

Secondary Canal Location	By Tertiary Canal			Average	Ratio Head–Tail
	Head	Middle	Tail		
Head	190	186	184	186	1.03
Middle	181	176	175	177	1.03
Tail	164	166	151	160	1.09
Average	178	176	170	174	1.05
	By Farm Location			Average	Ratio Head–Tail
	Head Farms	Middle Farms	Tail Farms		
Head	186	183	185	186	1.01
Middle	180	177	175	177	1.03
Tail	166	152	161	160	1.03
Average	177	171	174	174	1.02

Source: Wijayaratne (1986)

Adequacy

Gal Oya is an example of how information needs to be upgraded before performance-oriented management can be implemented. Seasonal plans were based on official estimates of the irrigable area of each block, underestimating actual areas by 15-20%. Yield data collected by the Agricultural Department used administrative areas different from hydrological divisions, making it impossible for managers to put the two sets of information together. Research data on yields show a high degree of association between water availability and yield (Figure 4.20).

Tungabhadra demonstrates clearly the impact of poor main canal water distribution on cropping patterns. Not only is total cropping intensity much lower at the tail (20% of target) than in head and middle sections (90-120% of target), but also the chance to grow rice is greatly reduced towards the tail (Figure 4.21). Equity of production and farm income almost certainly show a less favorable trend than for water distribution because the water that does reach the tail is less reliable and thus has lower income potential for farmers: they are obliged to grow more drought resistant, lower value crops.

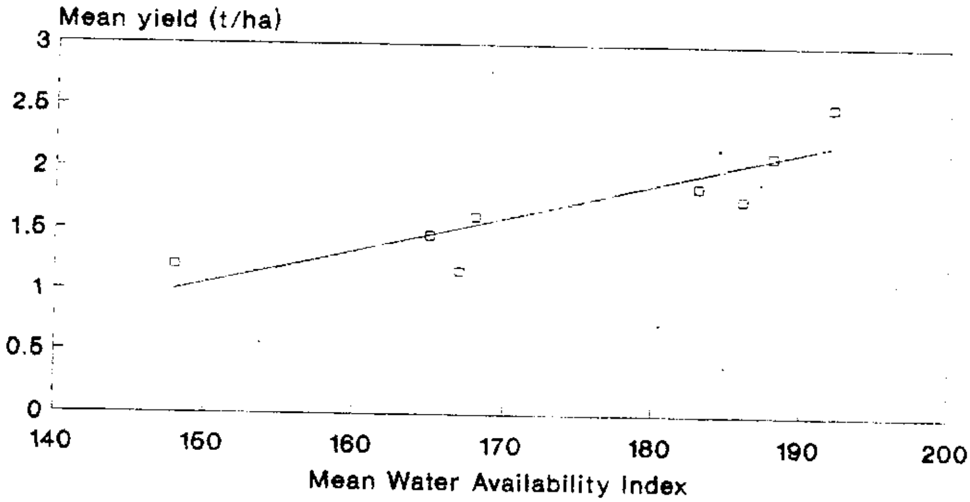
Reliability and the Implementation of Rotational Irrigation

Implementation of plans for rotational irrigation appears to be a major cause of unreliability of water deliveries. The Gal Oya study demonstrates the difficulties encountered in implementing rotations during periods of water shortage. The lack of cross-regulation in the main and secondary canal system meant it was difficult to implement rotations between small parts of the system. Since 1973 an operational plan had been established that called for rotations at main canal level throughout the dry season, with each half of the total system receiving water for five days at a time. Analysis of these rotations over an eight year period reveal several issues relating to implementation.

Figure 4.20

Distributary level Water Availability Index and Yields

Gal Oya, Sri Lanka, 1979-80 Wet Season



There was a reasonable degree of equity achieved at the main control structure used to divide water between the two halves of the system (Table 4.5). However, although there was a commitment to implement the rotational pattern on a 5-day on, 5-day off basis, the actual schedule was unpredictable (Table 4.6). During the 1981 dry season farmers never knew when water would be delivered, and this lead to considerable uncertainty and loss of confidence over water delivery scheduling by the irrigation agency. It is incumbent on an irrigation agency not only to advertise rotational schedules but also to implement them as advertised.

At the same time, the type of rotation adopted was probably the best given the deteriorated condition of the system. Analysis of water distribution equity at different discharges in the main canal demonstrate that greater equity is obtained by operating the canal as close as possible to full design discharge for 50% of the time rather than operating it at 50% of discharge on a continuous basis (Figure 4.22). The total saving in water is estimated at 72,000 cubic meters per day. This is, of course, only true when there is no control at the head of each secondary canal and no opportunity to implement rotations at a lower level in the system.

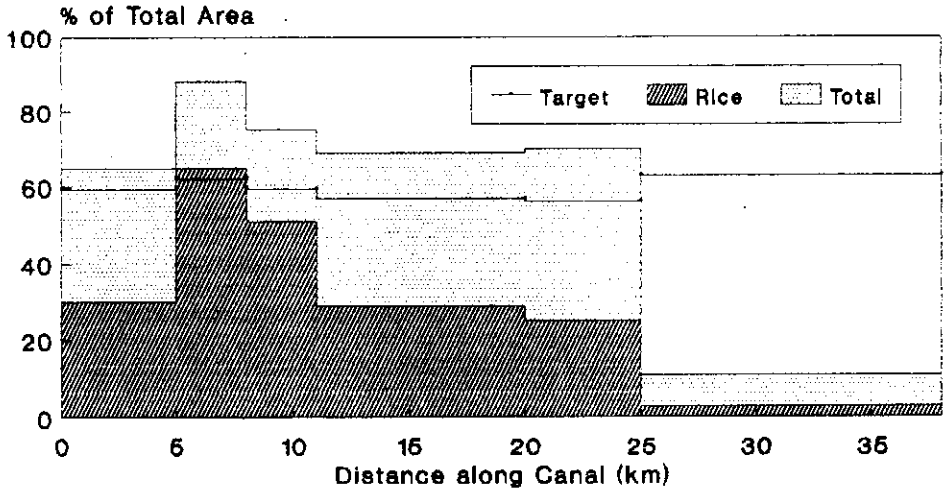
It was also apparent that the rotational schedule did not fit in with the normal working conditions of the irrigation agency. A 10-day irrigation cycle requires, over the course of a season, that gates will need to be adjusted the same number of times on each day of the week. In practice, gate operations showed a distribution related to day of the week: far fewer gate adjustments were made on Saturdays and Sundays than during the normal working week, with the most active days being Tuesday and Friday (Table 4.7). Development of operational schedules clearly need to fit in with the standard working practices of agency staff, or else agency staff have to adjust to the irrigation requirements of the system.

The communication infrastructure required to support effective irrigation management was lacking. Gate keepers and their supervisors had to come personally to the main irrigation office as there were only three telephones in the entire command area, there was only one vehicle for routine operational inspections, and fuel allowances

Figure 4.21

Planned and Actual Cropping Patterns
Tungabhadra Irrigation System, India

(a) Kharif, 1987



(b) Rabi, 1987-88

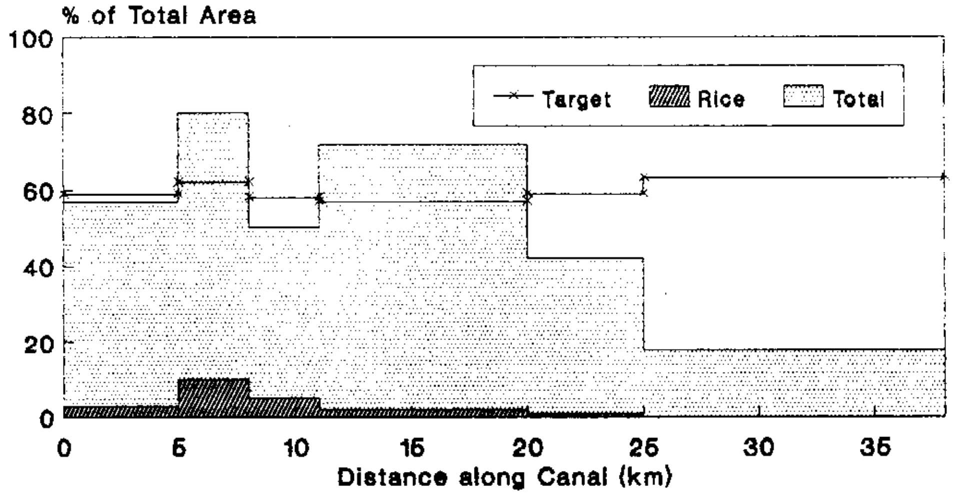
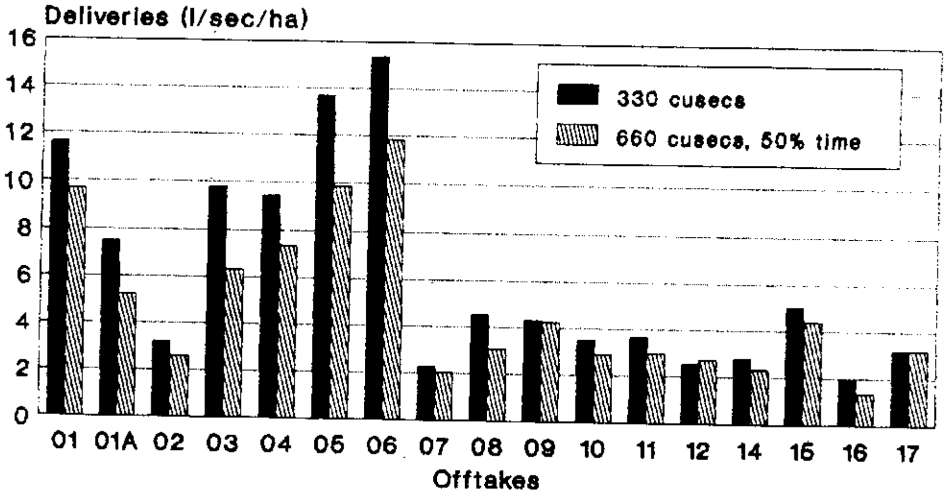


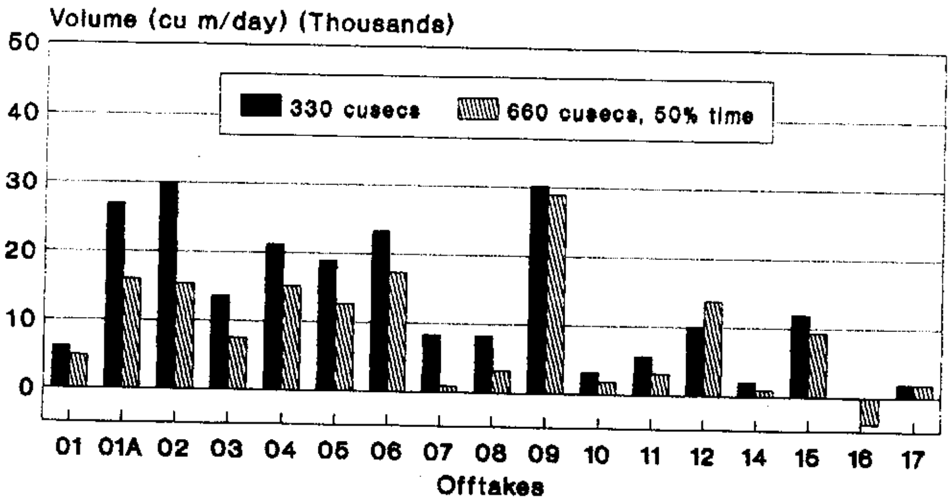
Figure 4.22

Effect of Rotations on Water Distribution Equity
Uhana Branch, Gal Oya Left Bank, Sri Lanka

(a) Daily Deliveries



(b) Misallocated Volume



Misallocation at 330 cusecs: 221,000 cu m/day
Misallocation at 660 cusecs, 50% time: 149,000 cu m/day

Table 4.5

Dry Season Land and Water Allocations At Gonagolla Bifurcation 1974–81

Year	Left Bank Units (LB14–32) Land %	Left Bank Units (LB14–32) Water %	Gonagolla Distributary Land %	Gonagolla Distributary Water %
1974	34.4	39.5	65.5	60.5
1975	54.3	52.1	45.7	47.1
1976	34.4	54.3	65.5	45.7
1977	54.3	78.3	45.7	21.7
1978	34.4	48.6	65.5	51.4
1979	40.9	39.6	59.1	60.4
1980	37.4	41.9	62.6	58.1
1981	47.2	58.0	52.8	42.0
Average	42.5	51.6	57.9	48.6

Source: Murray–Rust (1983)

Table 4.6

Variability of Issue and non–Issue Periods During Dry Season Rotations, Uhana Branch, Gal Oya

Year	Average Length of Issue Periods (days)			Average Length of Non–issue periods (days)		
	Plan	Actual	C.V.(%)	Plan	Actual	C.V.(%)
1969*	5	4.2	23.7	7	7.4	25.0
1970	5	4.3	17.3	5	5.0	14.2
1971	5	5.1	6.1	5	4.8	13.2
1972	5	5.1	9.0	5	5.1	4.5
1973*	5	5.0	17.6	5	5.3	30.0
1974	5	5.0	16.8	5	4.9	28.1
1975*	4	4.8	33.0	6	5.6	22.7
1976	5	4.7	16.6	5	5.1	23.5
1977*	4	3.5	32.0	10	11.3	9.1
1978	6	4.8	22.5	6	7.7	18.4
1979	6	4.6	23.5	7	8.2	18.9
1980	5	4.1	38.1	5	5.8	26.6
1981*	5	5.3	16.6	6	6.6	28.8

* Water Short Years

Source: Murray–Rust (1983)

Table 4.7

Dry Season Gate Operations by Day of the Week 1974–81

Gate Operation	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Daily Average
	(a) Years with no water shortage							
Open	13	17	16	11	13	15	6	
Close	10	18	10	15	13	9	9	
Total	23	35	26	26	26	24	15	25
	(b) Years with water shortage							
Open	7	14	9	9	8	6	3	
Close	9	10	10	3	10	8	9	
Total	16	24	19	12	18	14	12	16
	(c) Total							
Open	20	31	25	20	21	21	9	
Close	19	28	20	18	23	17	18	
Total	39	59	45	38	44	38	27	41

Source: Murray-Rust (1983)

permitted only about 200 km per month of official travel. On average it took between 1 and 2 days on to implement a change of gate settings at major control structures.

Similar time lags were observed when efforts were made to close gates in response to rainfall (Table 4.8). There is some evidence that during particularly dry years there was a more rapid response to rainfall in efforts to conserve scarce water in the reservoir.

Analysis of implementation of rotational schedules in the Lower Gugera Branch in Pakistan shows a similar deviation between planned and actual practices. During the dry season when discharges are often well below design capacity of canals, some rotation is required. The rotation is organized on a priority basis, with each canal accorded first, second or third priority on a strict roster. First priority canals will be operated at design capacity, the balance being allocated to second priority canals. If discharge is adequate to meet the design capacity of the second priority canals, third priority canals receive any remaining water. Figure 4.23 shows the degree to which rotational schedules were actually implemented between the four distributaries at Bhagat Head Regulator, the end of the Lower Gugera Branch canal. Pir Mahal and Khikhi Distributaries show reasonable adherence to the schedule, but Rajana and Dabanwala do not. The reasons for these differences between canals at the same regulator are not clear, but it is not impossible that the presence of detailed research studies along Pir Mahal and Khikhi Distributaries may have resulted in more favorable treatment.

Analysis of these data indicate that the priority system is not fully followed, and deliveries into each canal are not predictable. The result is that some canals receive very low discharges for extended periods and, given that downstream water allocation is through fixed orifices, there are inevitable and severe negative impacts on water availability and thus production at the tail end of the less favored secondaries (Figure 4.24).

Rotational irrigation in Tungabhadra shows similar problems. The rotation is relatively simple, with four reaches of the main canal scheduled to receive water either between Saturday evening and Wednesday morning, or Wednesday morning to Saturday evening. However, irregular operation of offtake gates along the canal means

Table 4.8

Time (in days) taken to respond to daily rainfall greater than 13 mm/day Gal Oya Left Bank 1974–81

	Gates at Reservoir		Gates at Himidurawa
Year	Right Bank	Left Bank	Left Bank
1974	1.00	1.50	2.17
1975*	1.40	1.25	1.50
1976	--	--	--
1977*	1.80	1.50	0.70
1978	2.00	--	0.67
1979	1.40	1.80	1.80
1980	0.80	1.00	1.67
1981*	1.20	0.57	1.00
Averages			
Wet Years	1.3	1.43	1.58
Dry Years	1.47	1.11	1.07

Source: Murray–Rust (1983)

Figure 4.23

Differential Water Allocations Between Canals
Bhagat Head Regulator, Lower Gugera Branch, Pakistan

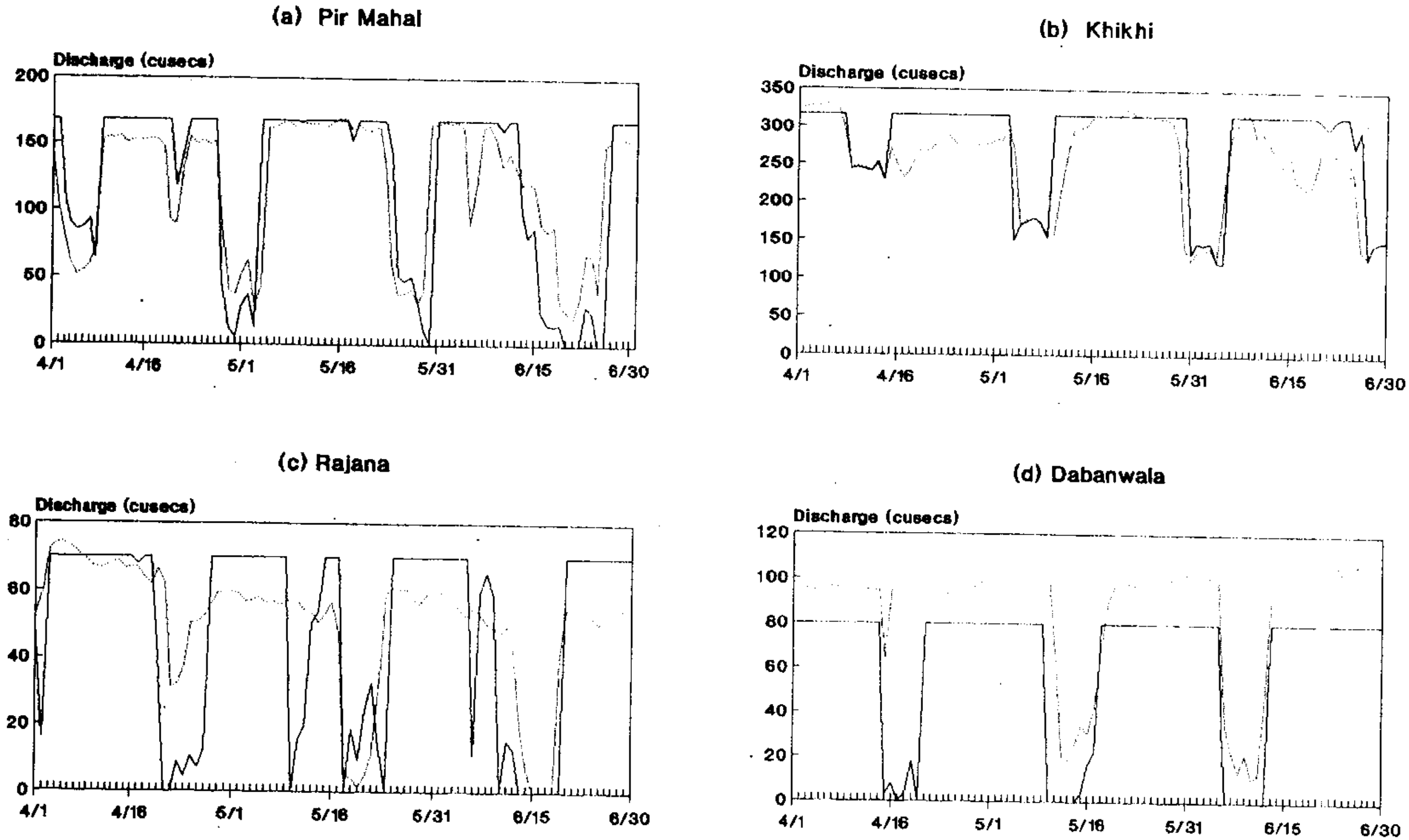
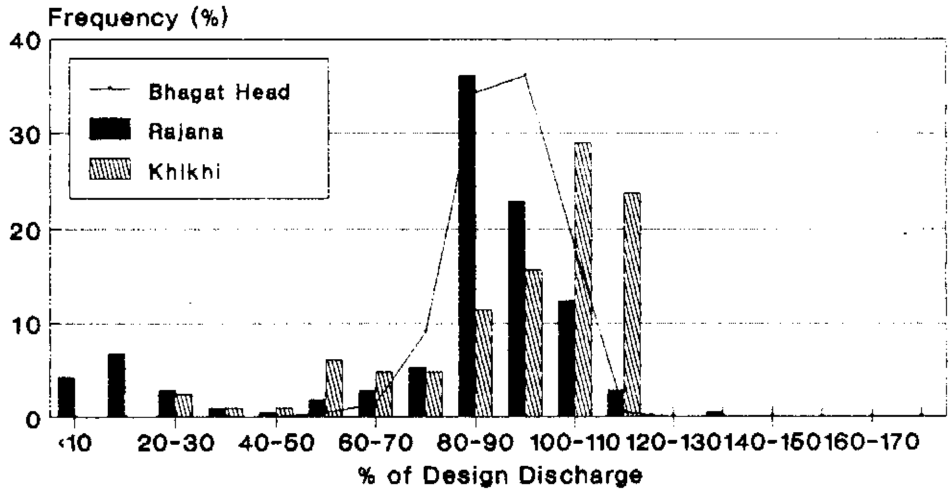


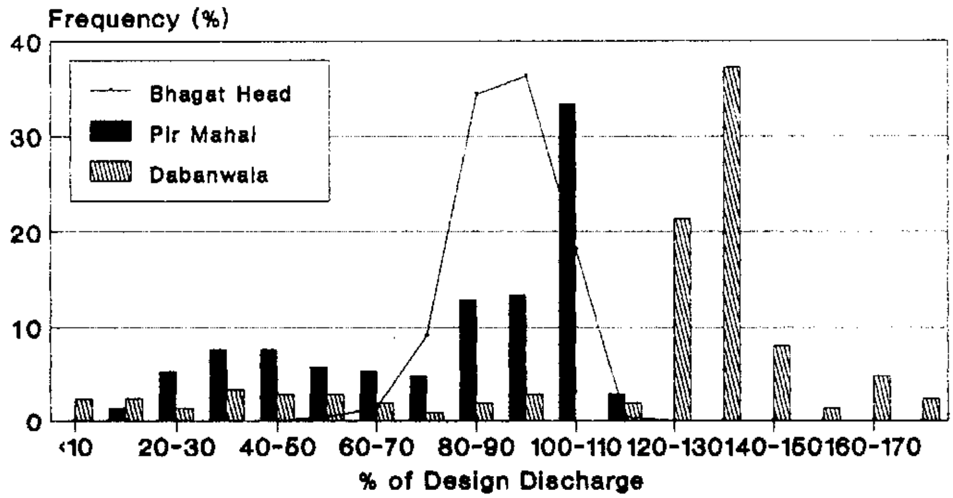
Figure 4.24

Water Distribution Equity Between Canals
Bhagat Head Regulator, Lower Gugera Branch, Pakistan

(a) Rajana and Khikhi



(b) Pir Mahal and Dabanwala



that discharges fluctuate during each rotation period, and may never reach the target, while closure is sometimes ignored entirely (Figure 4.25). The rotational pattern adopted appears to increase discharges into upper end outlets compared to non-rotational periods, and the entire purpose of getting more water to the tail is lost.

There is no evidence that the actual implementation of main and secondary level rotations relates to the tertiary level rotational schedules that assume a constant flow into the head of the tertiary canal. This means that the capacity of farmers to share available water on some form of agreed time sharing is lost. This may lead to greater uncertainty and conflict than under a more rigorous water distribution plan that focusses first on reliability and only secondarily on adequacy.

One aspect of implementation of rotational irrigation practices common to all the above examples is there was essentially no communication or cooperation between the irrigation agency and farmers. Results from the Philippines illustrate the benefits that can be obtained where agencies and farmers can work together for a common purpose even though the design may not be optimal.

The Lower Talavera River Irrigation System (LTRIS) in Central Luzon (Case Study #10) contains a set of lateral canals with little or no cross-regulation capacity. To provide adequate head it has to be operated close to design discharge: at lower discharges the head and middle areas can capture more than their fair share and tail end areas suffer as a consequence.

Prior to action research interventions, inequity was high: both head end and tail end areas obtained poor yields compared to the middle section of the system, and in all areas water use efficiencies were low. Over half the total production came from 35% of the system, with the largest area uncultivated being in tail end areas (Table 4.9).

Although there were nominal efforts to try to distribute water more equitably, there was no effective rotation schedule between different tertiary areas, and there was evidence of significant conflict between head and tail end farmers.

In efforts to redress this situation a joint effort was arranged between the National Irrigation Administration and farmers throughout the system. A rotational schedule was drawn up which divided the system into three zones, with each zone being scheduled for either two or three days of water each week. During the scheduled period for water deliveries all tertiary gates along that stretch would be opened, and the canal blocked at the downstream boundary. This pattern would then be repeated in sequence, with all offtakes upstream of the scheduled area remaining closed.

The results of this relatively simple set of activities were dramatic. Water use efficiency improved throughout the system and yields increased in all parts of the system. Total production doubled as a result of this management intervention (Table 4.9).

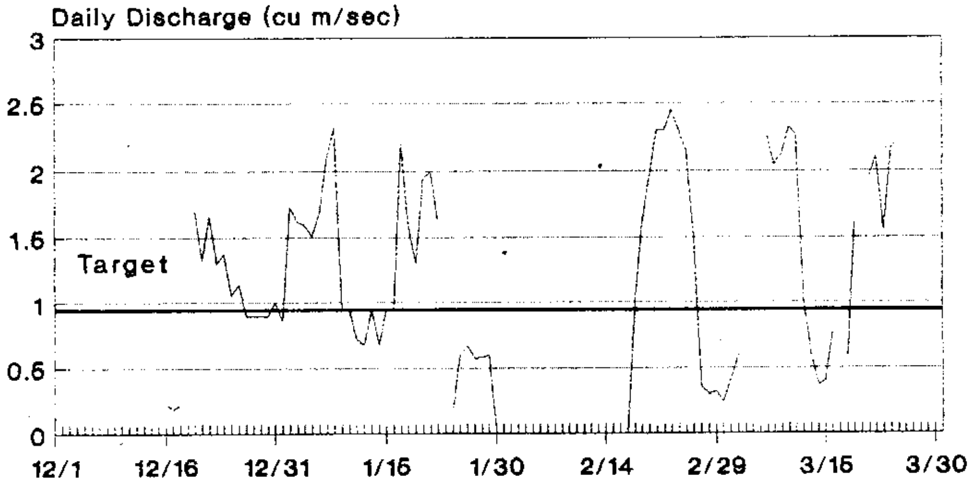
This example demonstrates two important principles. First, even where designed infrastructure is not ideal for implementation of rotational irrigation because of the low density of control infrastructure, it is possible to develop alternative operational plans that adjust to the existing design. It is therefore not necessary to consider a complete redesign of system infrastructure prior to operational innovation.

Second, it is essential that water users are fully involved in both planning and implementing alternative operational practices. Not only must the basic principle behind the operational plan be acceptable to users, but they must be fully prepared to play their role in implementation and checking of the operations.

Figure 4.25

Effects of Canal Section Rotations, Rabi 1987-88
Tungabhadra Irrigation System, India

(a) Direct Pipe Outlets, Reach 4



(b) Direct Pipe Outlets, Reach 5

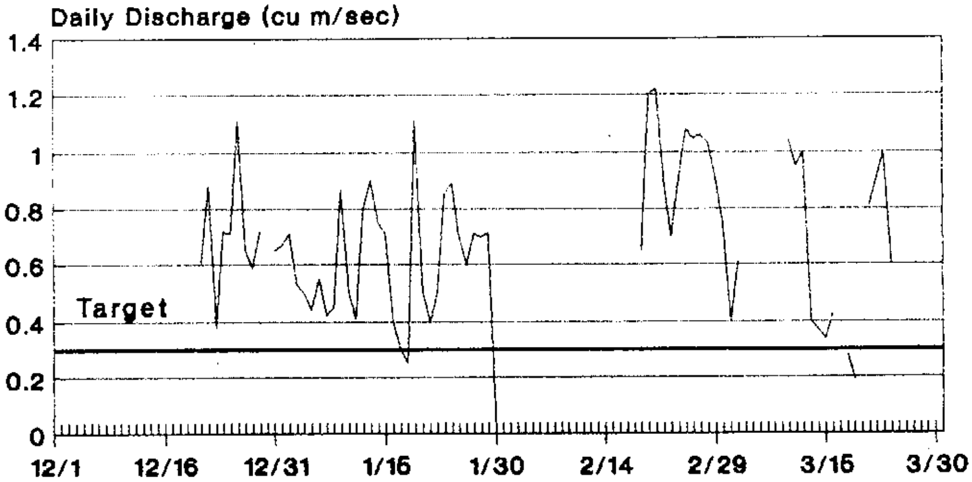


Table 4.9

Increases in yields, production and water use efficiency
Lower Talavera River Irrigation System, Philippines

Lateral canal (section)	Area (ha)	Yield (t/ha)	Total production (tons)	Water-use efficiency (%)
	Before Intervention (1976)			
Lateral A (head)	442	1.6	707	73
Lateral E (middle)	442	3.3	1459	66
Laterals G,H & I (tail)	297	2.4	713	70
Total	1181	2.4	2879	69.7
	After Intervention (1980)			
Lateral A (head)	475	4.3	2043	98
Lateral E (middle)	436	5.3	2311	75
Laterals G,H & I (tail)	262	5.3	1389	86
Total	1173	5.0	5743	86.3

Source: Greenland and Murray-Rust (1986)

4.3.2 Performance Examples in Systems with Fixed Cross-Regulation

One way of overcoming the problems associated with maintaining proper hydraulic conditions along sections of canals that have no cross-regulation capacity is to install fixed overflow weirs in the main or secondary canal immediately downstream of each offtake.

This variation in design does not materially affect the offtake structure itself; it eliminates any backwater effects and stabilizes head-discharge relationships on the upstream side of the offtake gate. The only design requirement is that there is sufficient slope to provide the required drop in water surface downstream of the weir.

Operational inputs do not change significantly compared with those systems with little or no cross-regulation. Water distribution depends on the proper operation of all offtake gates in a coordinated fashion.

Maintenance requirements, however, are reduced. The presence of weirs along the canal mean that it is no longer necessary to maintain canal cross-sections to original design specifications throughout their length. As long as sedimentation immediately upstream of the weir is avoided, stable head-discharge relationships can be maintained irrespective of canal conditions upstream and downstream of the weir. Canal maintenance has to focus only on minimization of losses, not on the canal cross-section.

Only one case study is referred to in this report, that of the Kalankuttiya Branch of Mahaweli H System (Case Study #11).

Water Distribution Equity

The case study reports that, during the wet season, when discharges were at or close to the design capacity of the canal, water distribution equity was relatively uniform and tail end areas received a reasonably high percentage of their planned share.

However, when water deliveries were reduced in the dry season and rotations adopted within each secondary canal command, the equity pattern changed because secondary gate offtake operations did not match with the water allocation plan. This plan expected that water deliveries into each secondary canal would be reduced in proportion to the total reduction of water delivery at the head of the main canal, requiring partial closing of each offtake gate along the canal to reduce discharge.

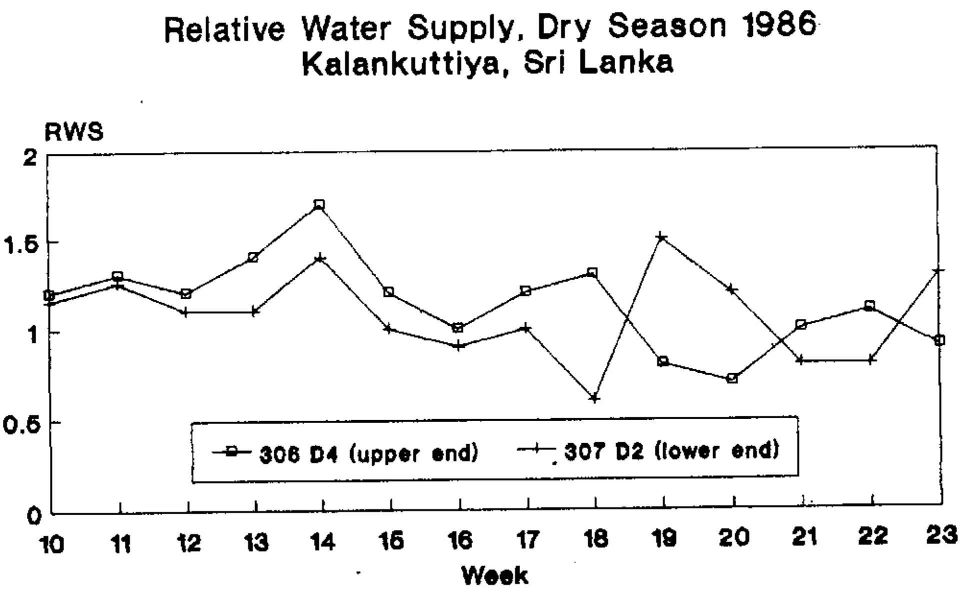
In reality head end offtakes were able to obtain proportionally more water than their offtakes further down the canal (Figure 4.26). The duck-billed weirs maintained heads at or close to design elevations even when discharges were below design capacity. This provides a situation where, without careful operation of the offtake gates, the offtake will deliver full design discharge even though the allocation is much lower.

4.3.3 Performance Examples from Gated Cross-Regulation Systems

The previous sections have demonstrated that if there is limited cross-regulation along the main or secondary canals it is difficult to implement water distribution plans when the discharge in those canals is below design, and water levels are inadequate on the upstream side of offtake structures.

Although it clearly increases the cost of construction, provision of gated cross-regulators along the main or secondary canal at or close to offtake structures provides the potential benefit of regulating both discharge and head in efforts to provide proper control over water along the entire length of main and secondary canals. The increased density of control locations provides a greater potential for response to changes in demand and supply.

Figure 4.26



From the performance perspective the objective set is similar to that for all other variations of gated systems. However, because there is much greater potential for precise management of head, discharge and timing of deliveries performance expectations will also be higher.

Operational inputs are clearly greater for these systems because there is a greater density of gates than in unregulated or fixed regulation systems. Gate operators have to be able to manage a combination of gates at a single structure and thereby maintain target discharges both into the offtakes and along the main canal. This means that the operational rules for each structure are more complex. The number of field staff does not have to be increased, but their training and knowledge may have to be better.

Maintenance tasks are not different in substance between systems with fixed cross-regulation and gated cross-regulation. However, the greater number of moveable gates requires that overall budgets be higher to reflect the increased concern with deterioration of gates and their operating mechanisms.
Four case studies are presented here that illustrate the extent to which management requirements associated with the installation of adjustable cross-regulators.

Water Distribution Equity

The Viejo Retamo secondary canal in the Rio Tunuyan irrigation scheme of Argentina (Case Study #12) provides an excellent insight into how gated cross-regulation can be used effectively to implement an unambiguous water allocation schedule.

In this system rotational irrigation is the standard operational practice. Each tertiary unit receives a fixed volume of water for a specified period of time twice a month, the time being proportional to the irrigated area. At any given moment only two clusters of two or three tertiary units, one in the upper half and one in the lower half, receive water. All users know the time schedule, which is published in advance.

Water distribution equity under this system is extremely high (Figure 4.27a). Almost all units show similar values for the ratio of intended to actual water deliveries, and there is no noticeable tail end effect. Two of the deviations are explained by the relatively small command area involved, where actual deliveries were slightly higher than intended. However, from a volumetric perspective (Figure 4.27b) these deviations were small and had no effect on overall volumetric distribution along the canal. Of the 33 units along the canal, one head end unit received substantially less than its fair share, while excess deliveries were concentrated in two larger tail end units.

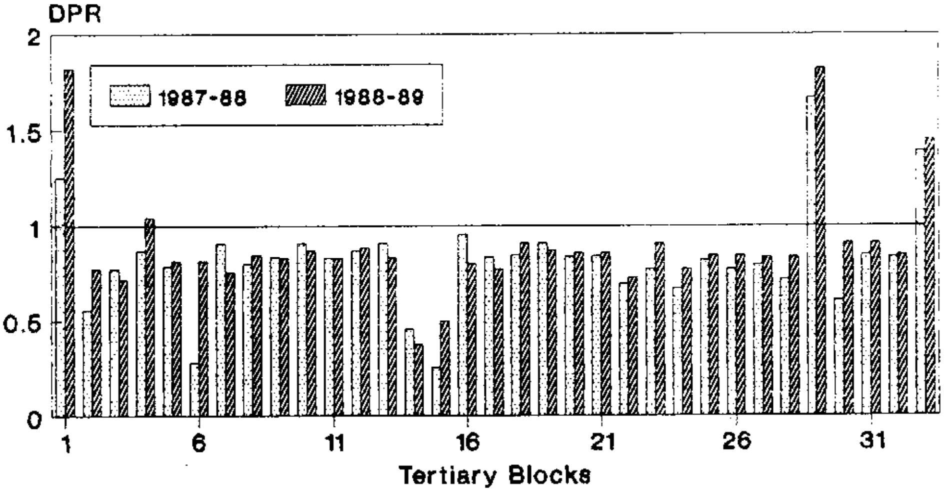
The simplicity of this operational system leads to few complaints: farmers know the schedule for the entire canal, see it as fair and do not interfere with water distribution. Where deviations were identified, remedial measures appear to have been easy to implement so that a situation of near-perfect implementation of water allocation plans was achieved.

One interesting design feature of the main canal system serving each of the secondary command areas is the presence of adjustable proportional division structures. The division is by proportional overflow, but there is an adjustable vane that can modify the percentage of discharge delivered to each secondary. Operation of this vane allows staggering of cultivation between secondary canals throughout the system, starting with a higher allocation at the commencement of cropping, and reducing the allocation as demand tails off. Although the vane is adjustable, the principle of overflow division is not violated, and provides a simple and incontrovertible measure of how much is being delivered into each canal without the need for complex gated division structures and measuring devices.

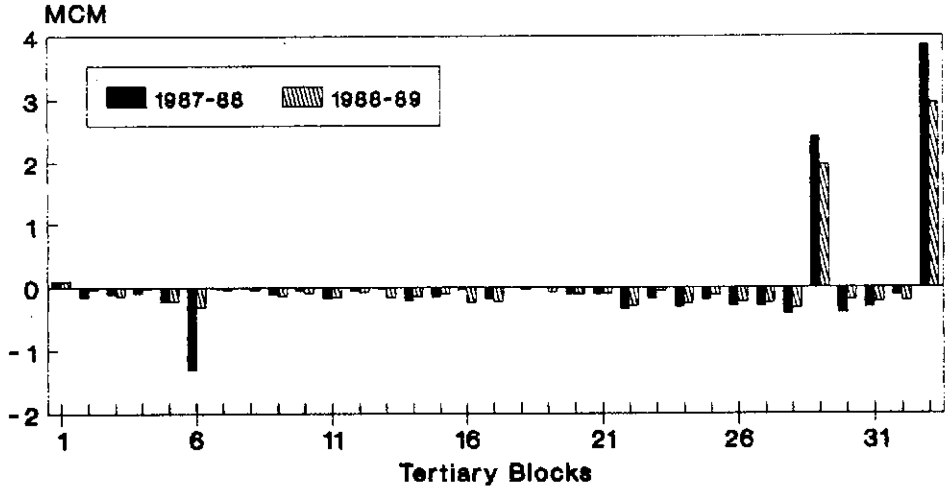
Figure 4.27

Water Distribution Equity, 1988-89
Viejo Retamo, Argentina

(a) Delivery Performance Ratio



(b) Misallocated Volumes



The high level of fulfillment of water delivery targets in Viejo Retamo system is probably an exception. Data from other gated division systems show a less equitable pattern because of incongruities between design and management inputs.

The overall water distribution pattern in the main system of the Fayoum, show a lower degree of distribution equity (Table 4.10). However, complete equality of water distribution is not planned: efforts to manage salt and minimize waterlogging account for much of the difference in allocations because areas that drain directly into Lake Qarun are normally given less water than those that drain into other parts of the system.

The Fayoum data also show that overirrigation is not a major problem, partly because overall water allocations are low, less than 5.0 mm/day. Overall system efficiencies are around 60%, but the similarity of the overall conditions with the Pakistan environment suggest that the potential for undesirable soil salinization does exist.

Kirindi Oya irrigation system in southern Sri Lanka (Case Study #13) shows a case where design intentions were not backed with proper operational inputs. The Right Bank Main Canal has 15 cross-regulators, roughly one a kilometer, intended to stabilize head upstream of every offtake gate. However, no operational plan was developed that provided rules for opening and closing of the gates under different discharge conditions.

Field studies indicated that actual operation of these cross-regulators resulted in different conditions than had been planned. Gate keepers were acting unilaterally, opening and closing regulator gates in response to changes in water levels at each regulator. It took several weeks at the beginning of each season before discharges in the system stabilized. Using a computer program that modelled the advance of a wave front created by opening the main sluice, it proved possible to determine the correct sequential operations of cross-regulators that stabilize water levels to at target levels within a few hours of opening the head gate (Figure 4.28).

Table 4.10

Division of the gross water supply over The Fayoum

			Percentage of equal share of water at Lahun								
Month	Total Supply m3/s	Total Supply mm/day	Bahr Yusuf at Lahun	Bahr Hasan Wasef	Bahr Wahby total area	Bahr Wahby u/s Nasria	Bahr Wahby d/s Nasria	Bahr Yusuf d/s Hawara	Bahr El Gharaq	Bahr El Nezle d/s Tagen	Bahr El Nezle u/s Tagen
Apr	70.9	4.0	95	110	86	94	84	102	145	91	77
May	69.0	3.9	95	110	86	86	86	102	149	89	74
June	77.6	4.4	94	111	81	68	85	103	157	86	72
July	88.4	5.0	91*	119*	74*	112*	82*	101*	181*	80*	69*
Aug	88.8	5.1	91*	119*	68*	99*	73*	104*	181*	80*	68*
Sept	80.2	4.6	94	112	82	85	80	102	168	79	66
Oct	78.5	4.5	94	112	79	78	80	103	156	88	74
Nov	76.4	4.4	96	108	81	82	80	106	151	85	71
Dec	61.4	3.5	92	116	77	57	84	102	155	95	78
Gross command area (ha)			102181	49685	30660	7560	23100	69421	20557	26880	2100

Values marked with an * in the months of July and August were calculated with the rating for Bahr Wahby intake that was valid before August 1985. This rating is subject to frequent change.

Source: Wolters et al. (1987)

Figure 4.28

Timing of cross-Regulator Gate Operations to stabilize discharge in main canal, Kirindi Oya, Sri Lanka

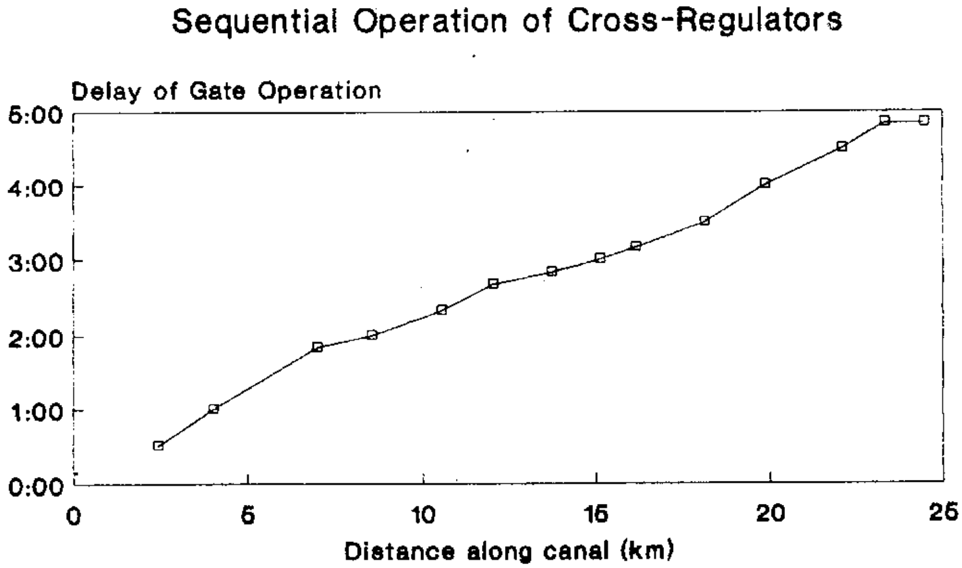
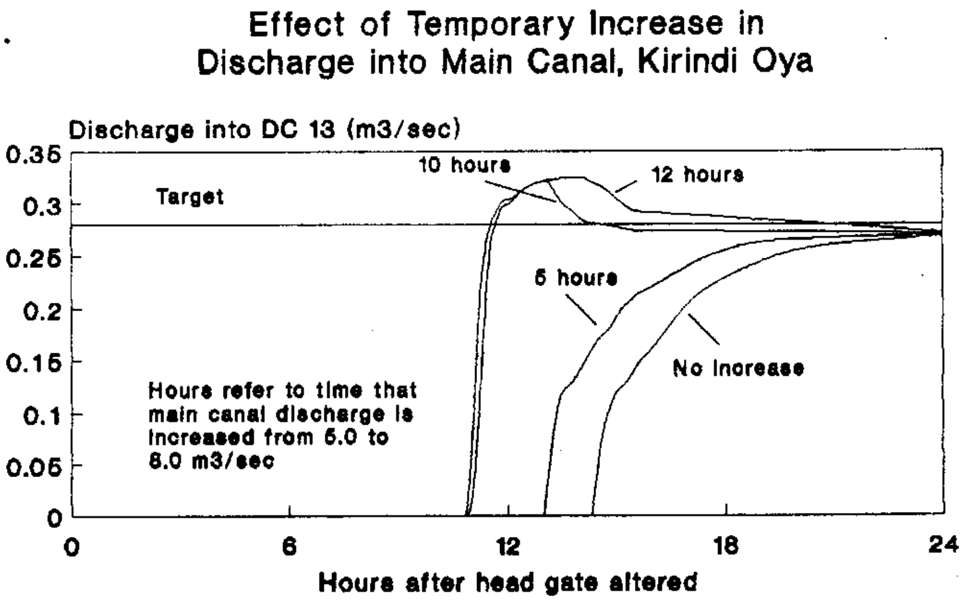


Figure 4.29

Efficient Operations through Computer Simulation Kirindi Oya, Sri Lanka



Computer analysis of operation of the main canal also showed it was possible to stabilize discharges into distributary canals without changing offtake gate settings. This can be achieved by issuing excess water for a few hours at the beginning of an issue, leading to a more rapid water advance rate. For a target issue of 5 m^3/sec discharges at offtakes near the tail can be stabilized very rapidly if the first 10 hours of the issue are actually made at 8 m^3/sec (Figure 4.29). Prior to this analysis there was no set of operational manuals or instructions as to how to operate the cross-regulators effectively, and variability of discharges was probably higher than if there had been no gated cross-regulators.

A second phase of analysis was undertaken to determine how the system could be operated to maximize the contribution of rainfall to crop production. Ever since its completion, Kirindi Oya has suffered water shortages in the reservoir, so that the actual irrigated area has been much smaller than designed. Operational guidelines were developed that permit design water levels to be re-established rapidly after rainfall events so that there will not be undue delays in resuming irrigation deliveries following rainfall. Before this analysis, the system manager rarely responded to rainfall because of the complexity of operations required to restore stable flow conditions.

The primary lesson of this case study is that it is essential that operational manuals and strategies be developed at the design stage so that system managers will know how to make the best use of the infrastructure under a range of different operational scenarios. In the Kirindi Oya case no manager had ever had experience with operation of this type of design, and the result was that in most cases the cross-regulators were used ineffectively or not at all. This negated both the cost of installation and the potential it provided for control over water distribution.

Wet season water distribution in Way Jepara, southern Sumatra, Indonesia (Case Study #14) also shows the design consequences of failure to operate gates as planned. While there was no difference in access to water between head and tail of the system (Figure 4.30a) because water and rainfall were abundant, actual distribution was controlled by the ratio of gate width to command area of each tertiary block (Figure 4.30b). Analysis of the relationship between gate width and design command area indicates a similar pattern to that found in Gal Oya: while there is a broad relationship between command area and gate width it is only approximate, and there are several instances where designers appear to have chosen a wider gate than is necessary (Figure 4.31a).

Water distribution in two dry seasons shows a different trend. There is no longer a significant relationship between the gate width-command area ratio and water deliveries (Figure 4.32a). Nor is there a significant head-tail difference (Figure 4.32b). More frequent gate operations during the dry season resulted in a more random pattern of water deliveries. There was a marked decline in reliability of discharge along the main canal in both wet and dry seasons, even though discharges from the reservoir into the head of the main canal were very stable. While water supplies remained adequate in both seasons, the data show little effort to use cross-regulators to stabilize water levels.

Maneungteung Irrigation System in West Java, Indonesia (Case Study #15) shows contrasting results even though the results are different. In the wet season there is evidence of head-tail differences in access to water along the main canal. (Figure 4.33a). Along secondaries, however, the pattern of water distribution between tertiary blocks is not so clear, although there is a net decline in access to water toward the tail end. (Figure 4.33b).

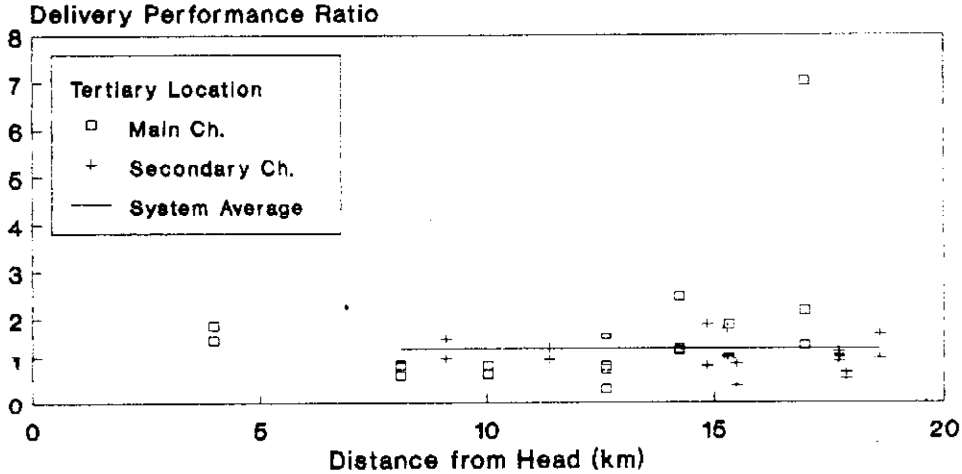
In the dry season, however, the trend is different. There appears to be closer attention to operation of the offtakes along the main canal, eliminating the head-tail effect (Figure 4.34a), while along secondaries the head-tail effect is still present but less marked than in the wet season (Figure 4.34b)

Analysis of the physical facilities at the boundaries between different administrative sections of Maneungteung demonstrates another mismatch between design and management requirements. Operational plans require control and measurement of discharge at each handover point between water masters, but only 11 out of 15 locations had a gate that permitted control of discharge and only 8 locations had measurement devices (Table 4.11). This made it almost impossible to fulfill the discharge-based operational targets in the main system.

Figure 4.30

Water Distribution Equity
Way Jepara, Indonesia, Wet Season 1988-89

(a) Water Distribution Equity



(b) Design Impact on Equity

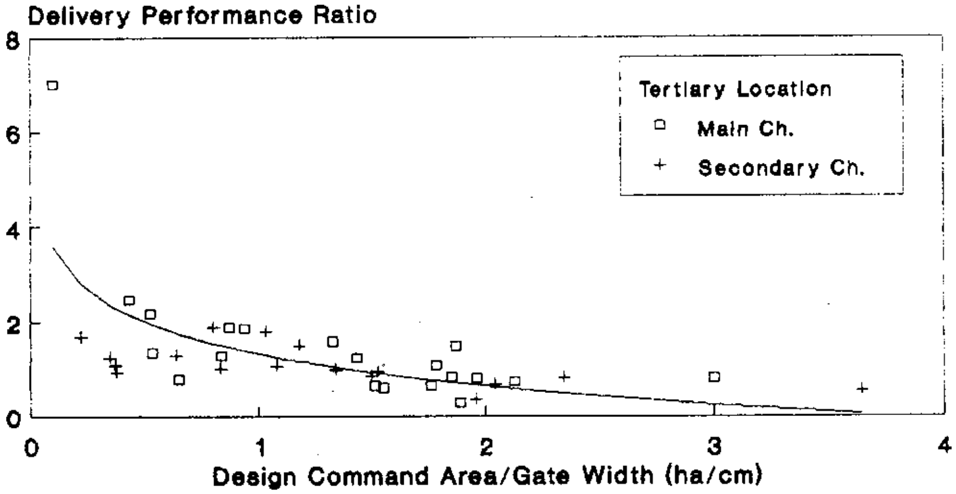
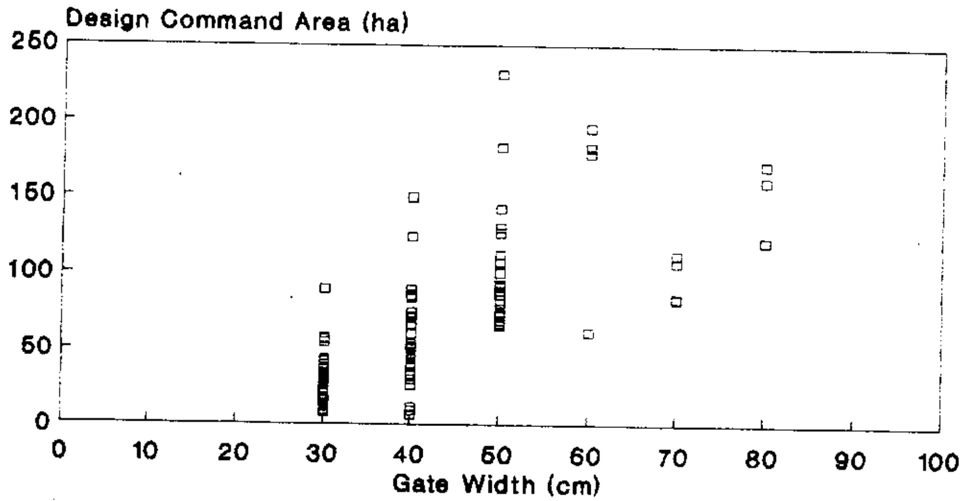


Figure 4.31

Gate Widths and Design Command Area
Two Examples from Indonesia

(a) Way Jepara



(b) Maneungteung

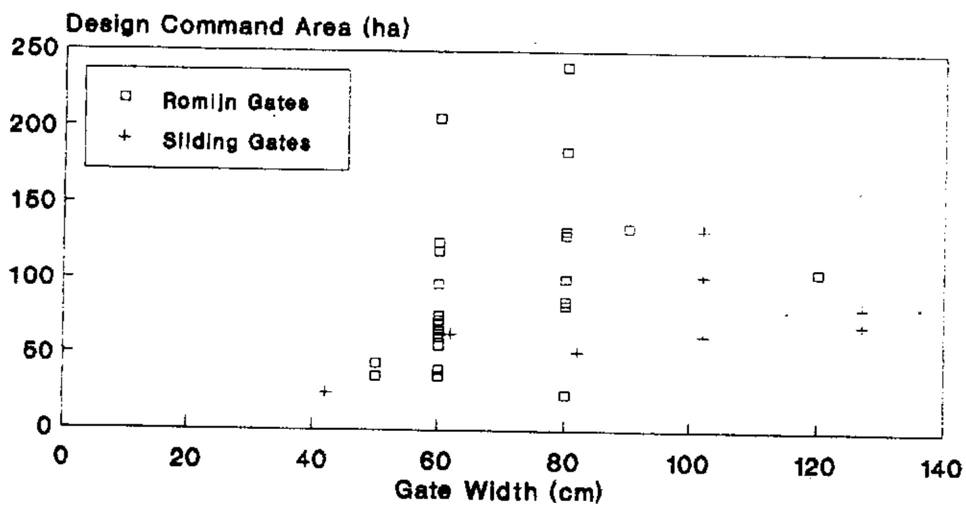
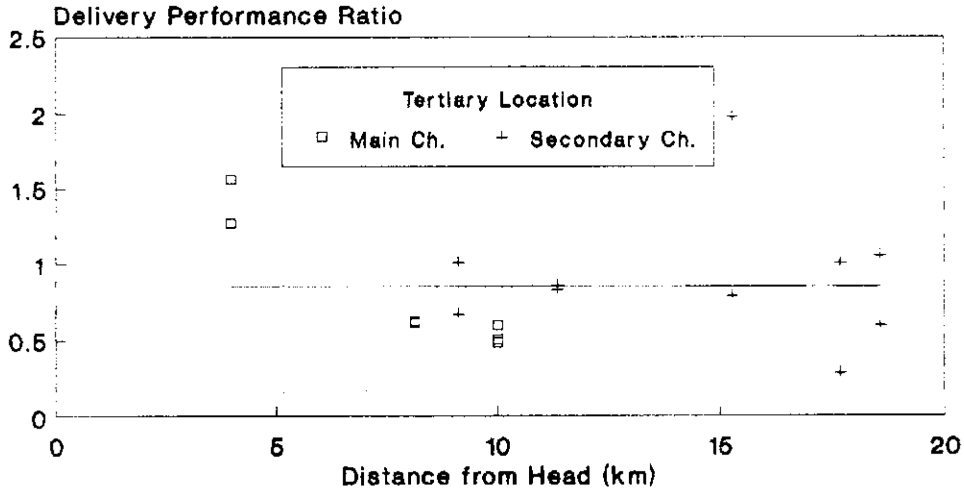


Figure 4.32

Design Impacts on Water Distribution Equity
Way Jepara, Indonesia, Dry Season 1988

(a) Water Distribution Equity



(b) Impact of Design on Equity

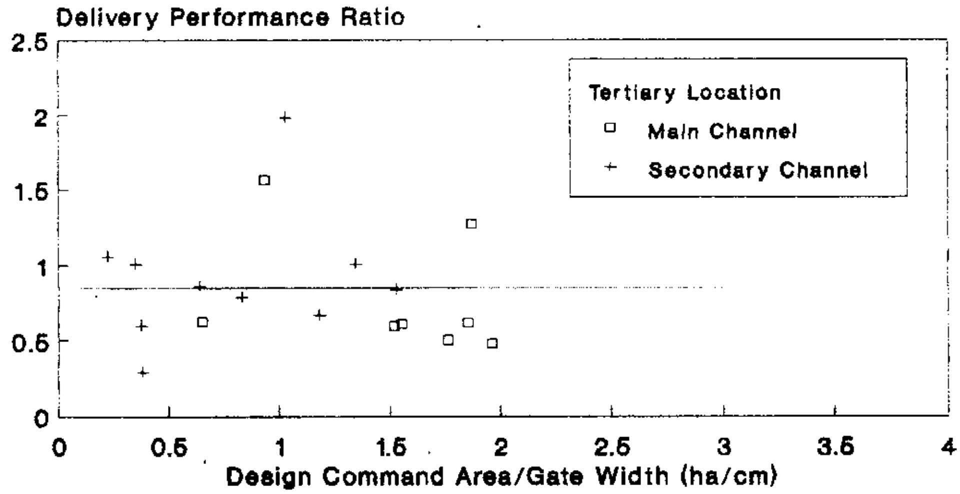
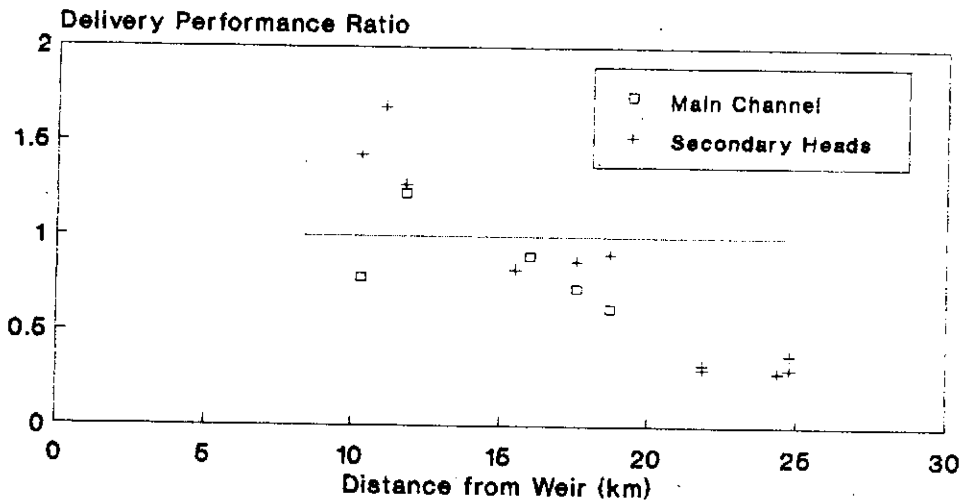


Figure 4.33

Water Distribution Equity
Maneungteung, Indonesia, Wet Season 1988

(a) DPR along Main Canal



(b) DPR of Sample Tertiary Blocks

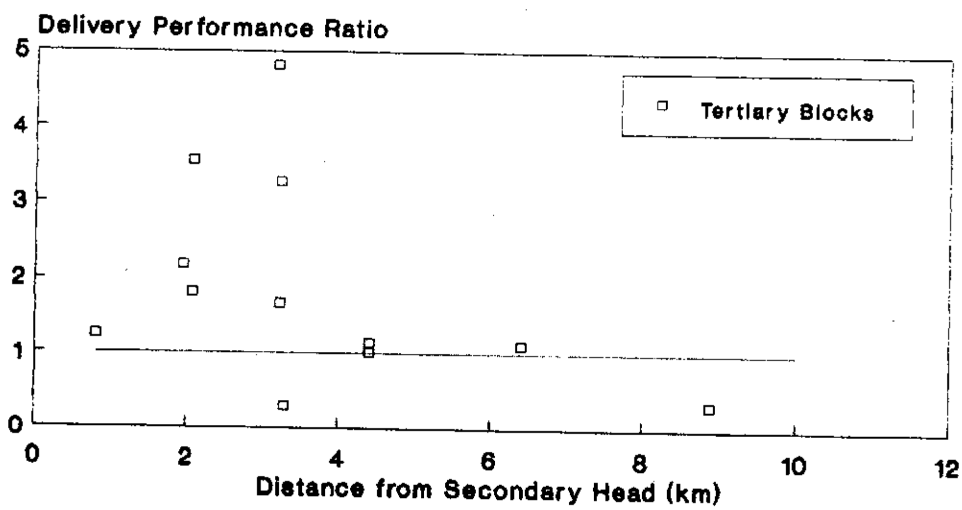
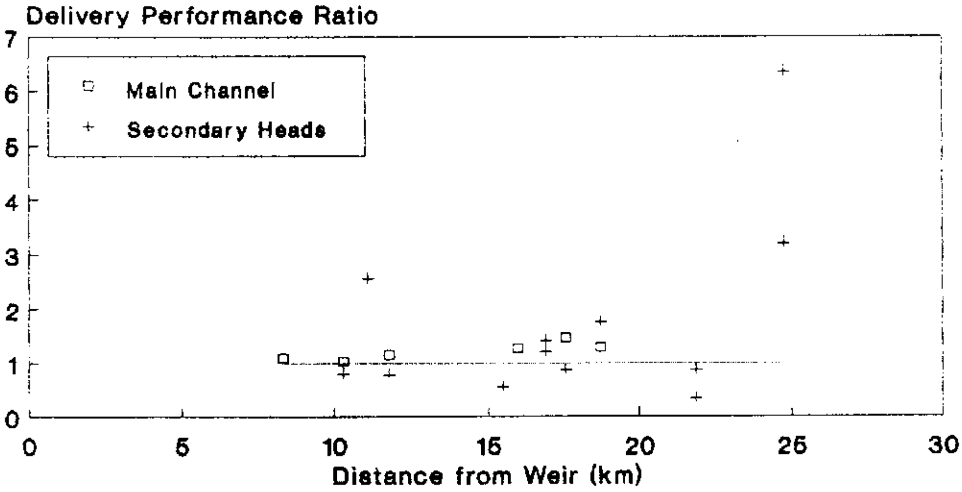


Figure 4.34

Water Distribution Equity
Maneungteung, Indonesia, Dry Season 1988

(a) DPR along Main Canal



(b) DPR for Sample Tertiary Blocks

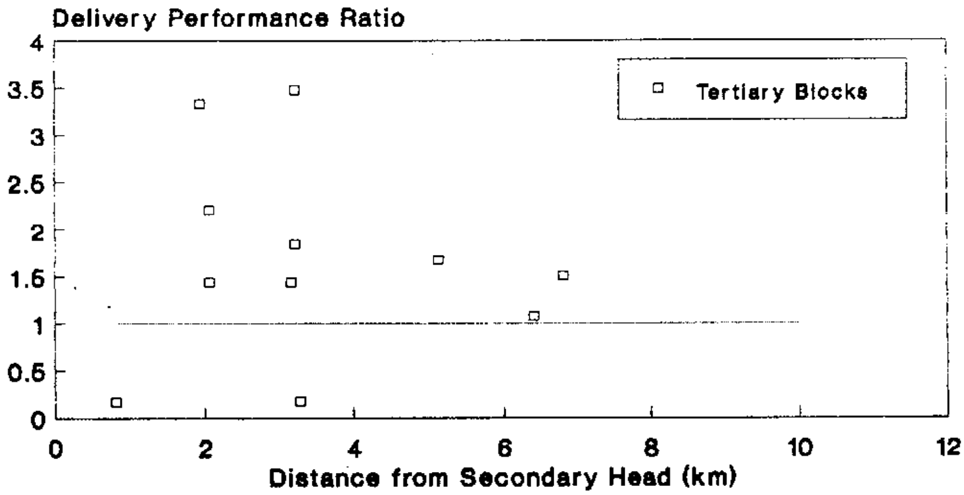


Table 4.11

Handover Conditions between Irrigation Inspectors
Maneungteung Irrigation System, Indonesia

From	To	Location	Gate Type	Measurement
	Maneungteung Barat (Ciledug)			
Area 1	Area 2	MTR 4 Main	Stop logs	Cipoletti
Area 1	Area 2	MRT 4 Sec. JTS	Sliding (new)	Cipoletti
Area 2	Area 3	MTR 5 Main	Sliding (new)	None
Area 3	Area 4	PB 1 Main	Sliding (new)	Cipoletti
Area 4	Area 5	PB 4 Main	Sliding (new)	None
Area 3	Area 6	BLS 3 Main	Stop logs	None
Area 6	Area 7	BLS 9 Main	Stop logs	None
Area 6	Area 7	BLS 11 Main	Sliding (new)	Cipoletti
Area 7	Area 6	BLS 10 Main	Sliding (new)	None
	Maneungteung Timur (Waled)			
Area 8	Area 9	Weir	Sliding	Parshall Flume
Area 9	Area 10	M 5 Barat	Sliding	Parshall Flume
Area 9	Area 1	M 5 Timur	Sliding	Cipoletti
	Maneungteung Timur (Babakan)			
Area 10	Area 11	MB 5 Main	Sliding	None
Area 11	Area 12	MB 8 Sec. GG	Sliding	Cipoletti
Area 11	Area 12	MB 10a Main	Stop logs	None

Control Facility	Sliding	11	(73%)
	Stop logs	4	(27%)
Measurement Capability	Parshall Flume	2	(13%)
	Cipoletti	6	(40%)
	None	7	(47%)

Source: IIMI (1989)

Tertiary Level Water Distribution

More detailed studies of operations at individual structures show a number of other concerns relating to the management requirements of complex structures. At each structure the gate operator is required to deliver a specified discharge into every offtake and along the continuation of the main canal. However, analysis of discharge patterns at several different structures in both Way Jepara and Maneungteung reveals significant deviations between planned and actual practices. deviations from planned activities.

The first is that under normal conditions it is common for water deliveries to offtakes to be more than planned, and the downstream continuation of the main canal to receive less. This is demonstrated in Way Jepara (Figure 4.35), although the discrepancies are less in the dry season when water is in scarcer supply. The relatively stable pattern is attributed to the high reliability of main canal discharges due to controlled reservoir releases.

In Maneungteung the pattern is similar, although there is a greater variation due to more frequent gate operations which may result from higher variability of main canal discharges (Figure 4.36). Because it is possible to operate cross-regulators to maintain adequate head on the upstream offtakes, it is easy to maintain discharges into offtakes at or above target levels even though the total discharge arriving at the structure is less than the target for that structure.

There is also a persistent trend of delivering relatively more water to smaller canals and relatively less to larger canals at the same structure (Figure 4.37). It is not clear whether this is because the design resulted in a larger width of gate per unit area for smaller canals, or because gate keepers favor nearby farmers in contravention of water allocation plans.

Additional analyses indicate that there are several problems of coordination between successive structures along sections of both main and secondary canals. Figure 4.38 gives a good example from Way Jepara where the upper structure on a short secondary canal extracted as much water as it needed to supplement rainfall during the wet season. When harvesting started in early April both tertiary gates were partially closed and a higher percentage of water allowed to pass down to the tail end structure. There appeared to be no effective mechanism to reduce discharge at the head of secondary canal when demand along the canal decreased.

A similar set of events is seen in Maneungteung where structures near the middle of a secondary extract water more or less at will, closing gates when harvesting occurs; the tail end structure on the same secondary canal has no control over how much water is received (Figure 4.39).

One factor in this is the degree to which water masters and gatekeepers are given the facilities and conditions in which to undertake their tasks. Analysis of several systems in West, Central and East Java demonstrate the mismatch between expected workloads and available resources (Table 4.12). It is almost impossible to see how field staff of the agency can undertake their tasks more than once a day at the best. Since setting of all offtakes to their target discharge would require several adjustments at both offtakes and cross-regulators, this means that achieving such target discharges is beyond the capacity of the field staff.

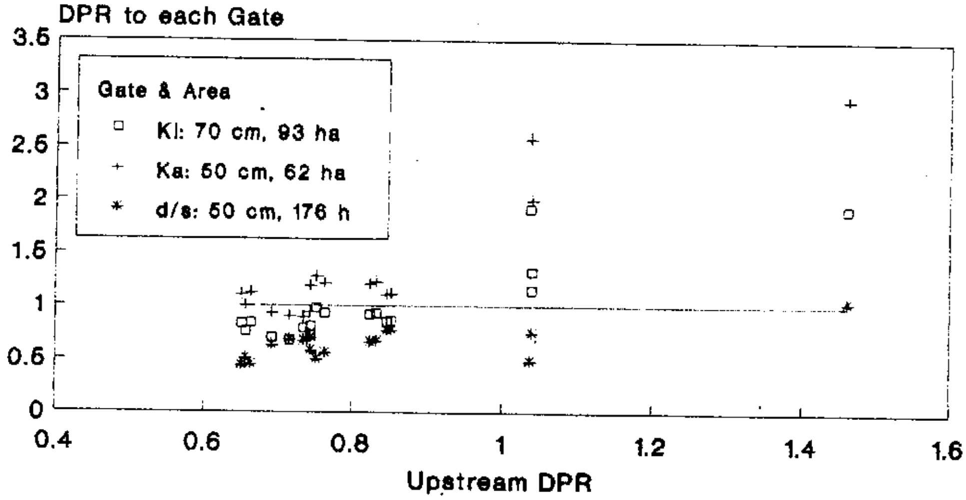
The operational plan also assumes water can actually be measured. In Maneungteung only 48% of installed measurement devices were functional. As a result water distribution was actually achieved through the individual judgement of gate keepers, not through a systematic response to actual water conditions.

Two examples of different responses to rainfall are provided from Maneungteung. There is no evidence of any response to rainfall at the head gate of Maneungteung East Main Canal (Figure 4.40a), either in to local rainfall (the bar graph) or average rainfall over the system (incorporated into the broken line). For tertiary gates, there is no evidence of immediate response to rainfall even though discharges are above target levels (Figure 4.40b). Any response that occurs appears to be delayed by several days.

Figure 4.35

Gate Operations favoring Smaller Offtakes
Way Jepara, Indonesia

(a) Structure BB III, Wet Season 1988-89



(b) Structure BB III, Dry Season 1989

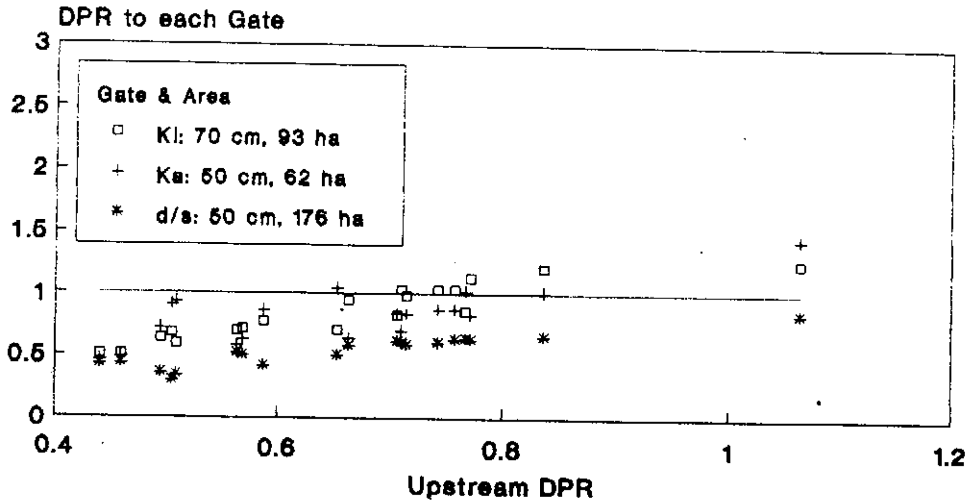
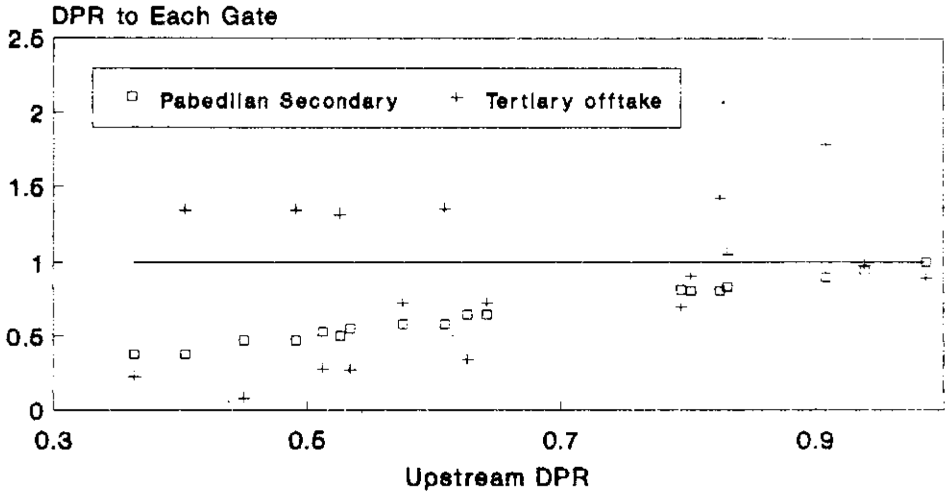


Figure 4-36

Gate Operation Effects on Water Distribution Equity
Maneungteung Irrigation System, Indonesia

(a) Structure PB1, Wet Season 1989



(b) Structure PB3, Wet Season 1989

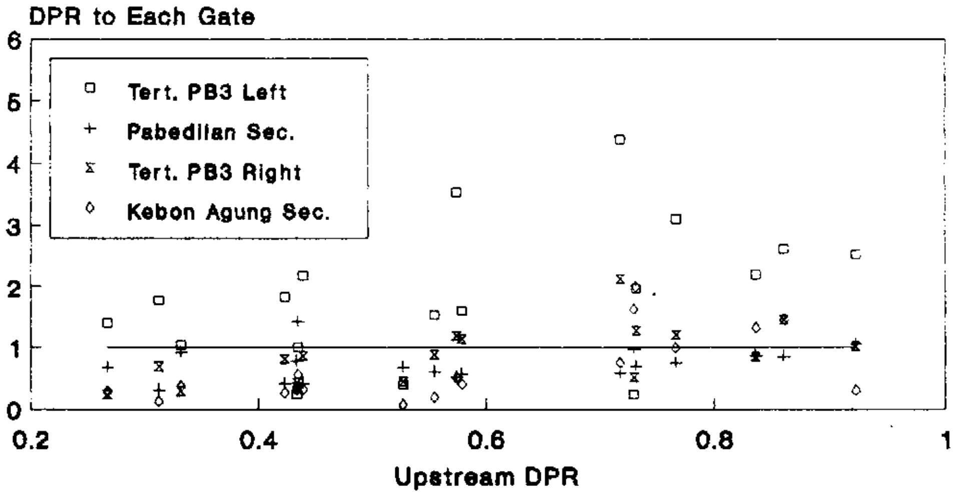
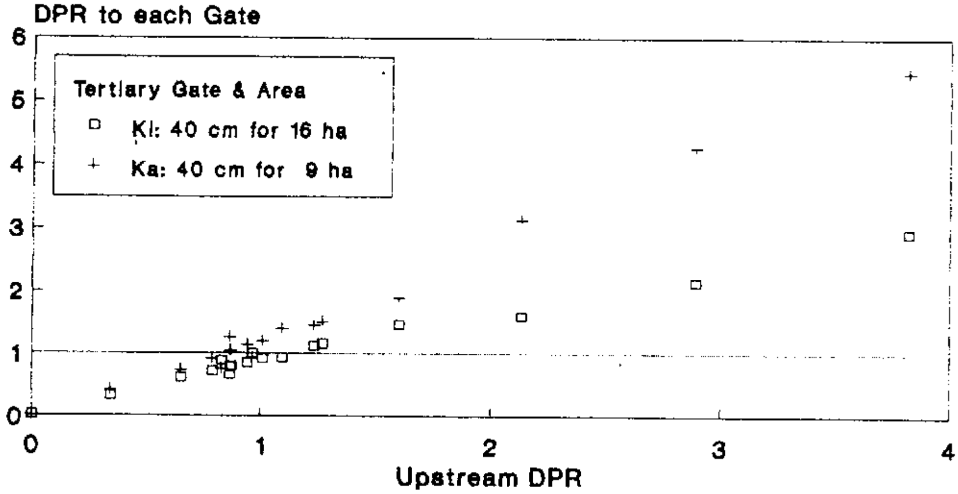


Figure 4.37

Impact of Gate Dimensions on Equity
Way Jepara, Indonesia, Wet Season 1988-89

(a) Structure BJT VII



(b) Structure BJKi 15

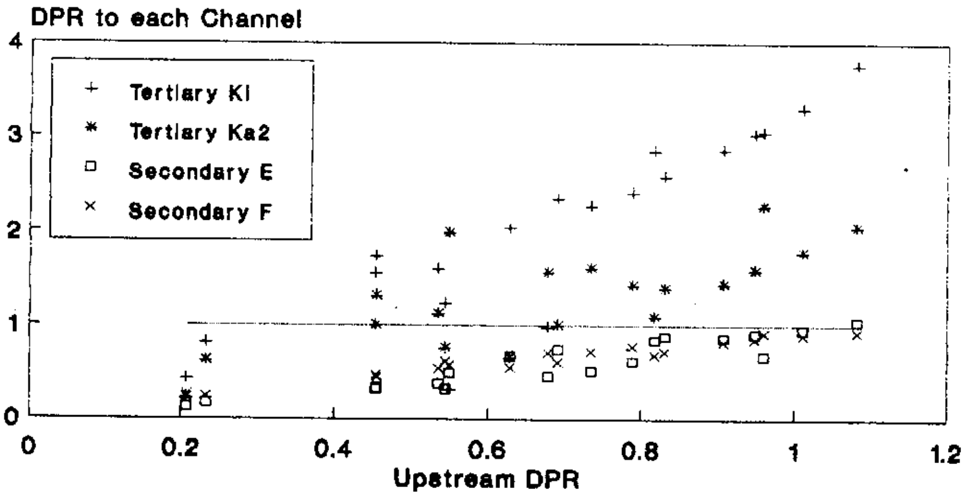
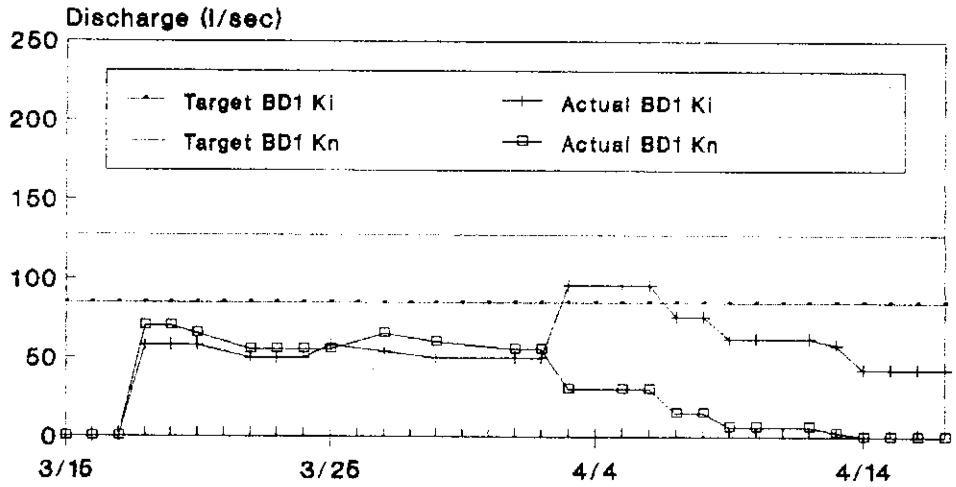


Figure 4-38

Uncoordinated Gate Operations
Secondary D, Way Jepara, Indonesia

(a) Structure BD1, Wet Season 1988-89



(a) Structure BD2, Wet Season 1988-89

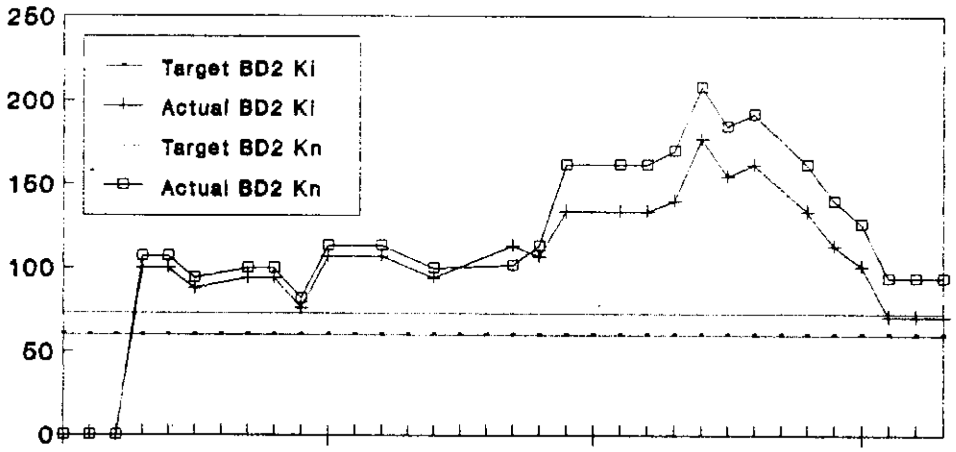
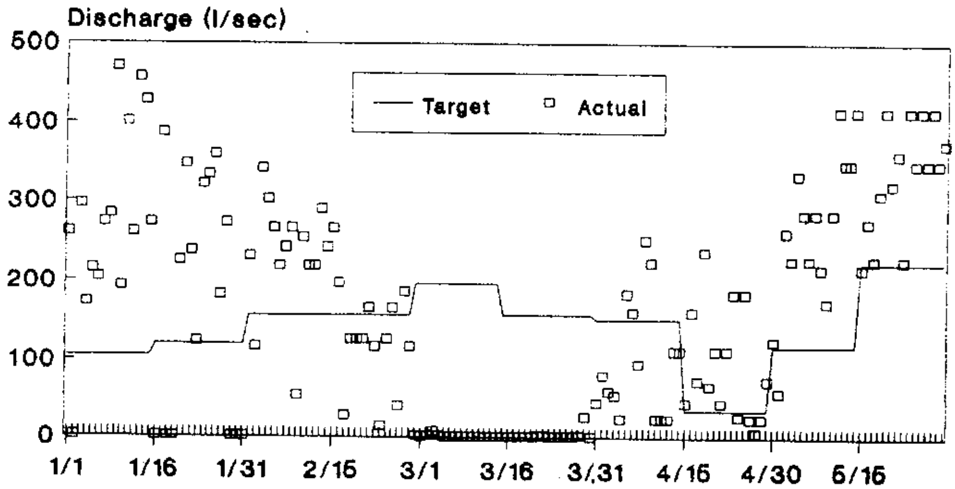


Figure 4.39

Changes in Water Distribution along JTS Secondary Maneungteung Irrigation System, Indonesia

(a) Structure JTS 3, Wet Season 1989



(b) Structure JTS 6, Wet Season 1989

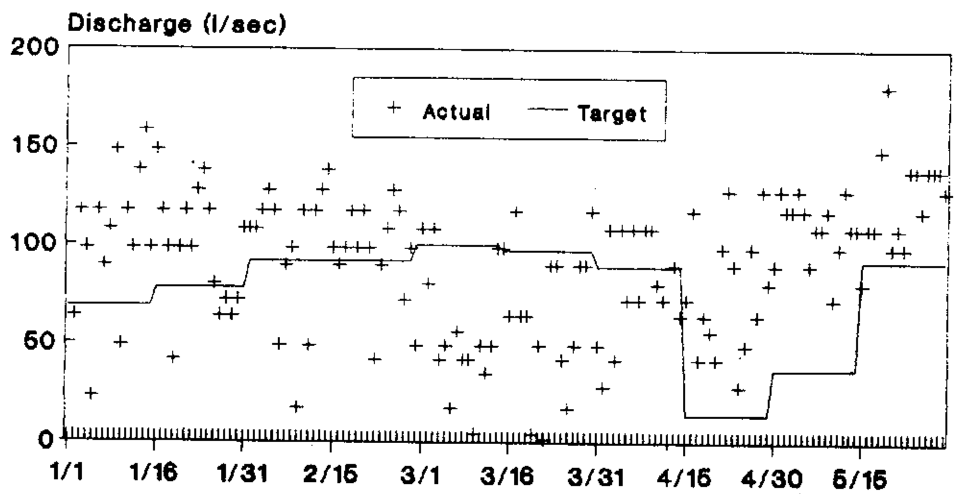
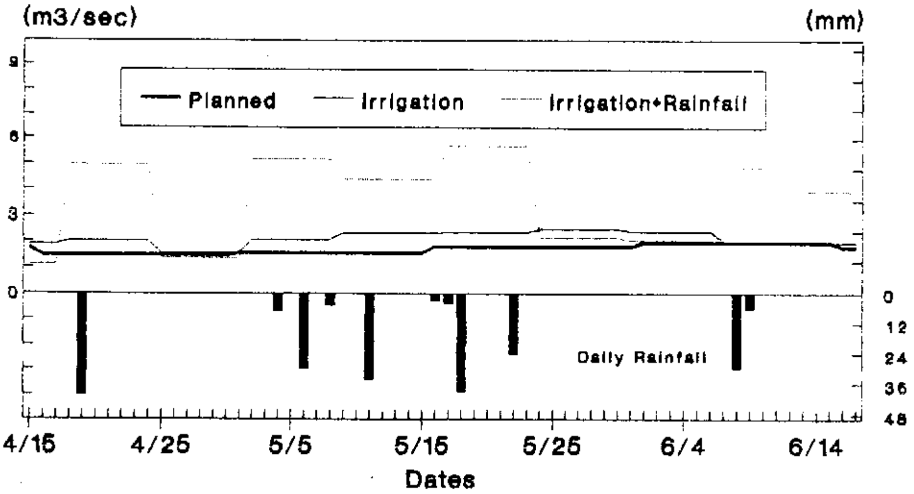


Figure 4.40

Lack of Response to Rainfall
Maneungteung Irrigation System, Indonesia

(a) Maneungteung East Main Canal



(b) PB5 Tertiary

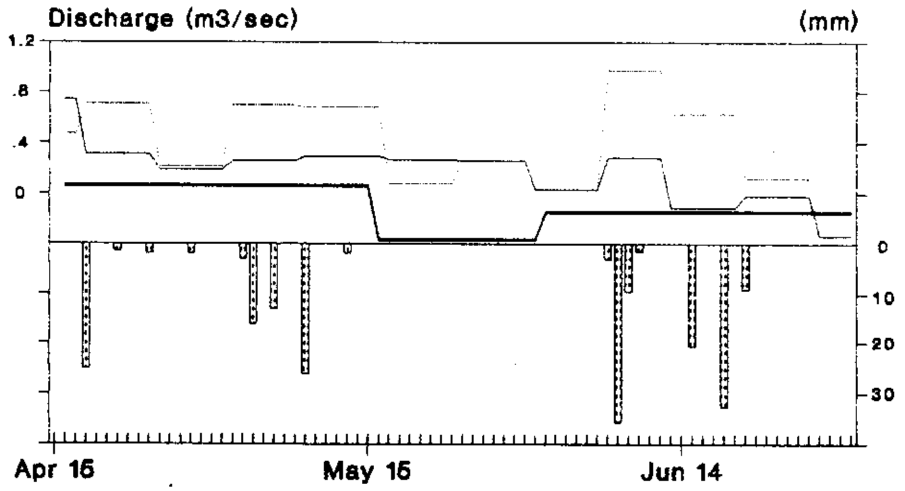


Table 4.12

Workloads of irrigation agency field staff
West, Central and East Java, Indonesia, 1987

	West Java	Central Java	East Java
(a) Workloads of Irrigation Inspectors			
Number interviewed	20	9	15
Average size of work area (ha)	849	799	626
Average number of gates controlled	18	20	19
Daily round trip distance (km)	13.9	25.1	22
Percent owning motorcycle	30%	44%	87%
Number of gate keepers to supervise	2.5	6.5	2.0
(b) Workloads of Gate Keepers			
Number interviewed	50	57	28
Average size of work area (ha)	340	126	335
Average number of gates controlled	7.0	3.1	10.0
Daily round trip distance (km)	5.5	4.1	11.3
Percent owning pedal cycle	96%	98%	100%

Source: IIMI (1987)

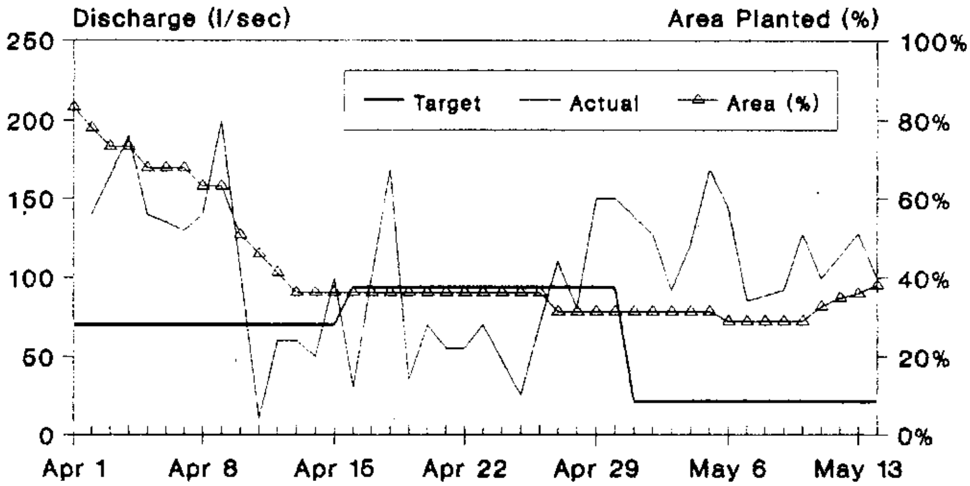
The relative ineffectiveness of system management to respond to changes in demand resulting from changing crop patterns within this complex system suggests strongly that the operational targets are not matched to actual conditions. Figure 4.41a shows an example where demand is estimated to increase when the cropped area is actually declining towards the end of the wet season, and then drop dramatically even though the area planted is stable. Actual water delivery shows a closer match to actual demand, indicating the gate operators do have better knowledge of what to do than contained in their instructions. However, at the end of the first dry season, during implementation of rotational irrigation, the volume delivered in each successive rotation increased although demand decreased due to harvesting Figure 4.41b).

At system level, the effects of inequitable distribution of water on agricultural output can be seen by examining cropping in patterns in four tertiary blocks stretching from head to tail of the system (Figure 4.42). In the first case, a head end tertiary, planting commenced on December 1, and the entire tertiary planted rice. The rapid planting enabled a quick start to the first dry season, and approximately 80% of the tertiary planted a non-rice crop by early June. An alternative strategy was adopted in the second tertiary block, in the middle of the system: early planting at the start of the wet season was followed by rapid planting of both rice and non-rice over a smaller portion of the entire command area. In the third case, further down the system, planting was delayed until the end of January, but the entire block planted rice for the wet season. Little planting of non-rice had occurred by early June because most farmers had decided to go for one crop only. The final case, towards the tail of the system, however, wet season planting was delayed until February, and then only 60% of farmers had enough confidence in water conditions to plant a crop.

Figure 4.41

Response to Harvesting Conditions
Tertiary PB3Kn2, Maneungteung, Indonesia

(a) April 1 - May 15, 1988



(b) July 1 - July 31, 1988

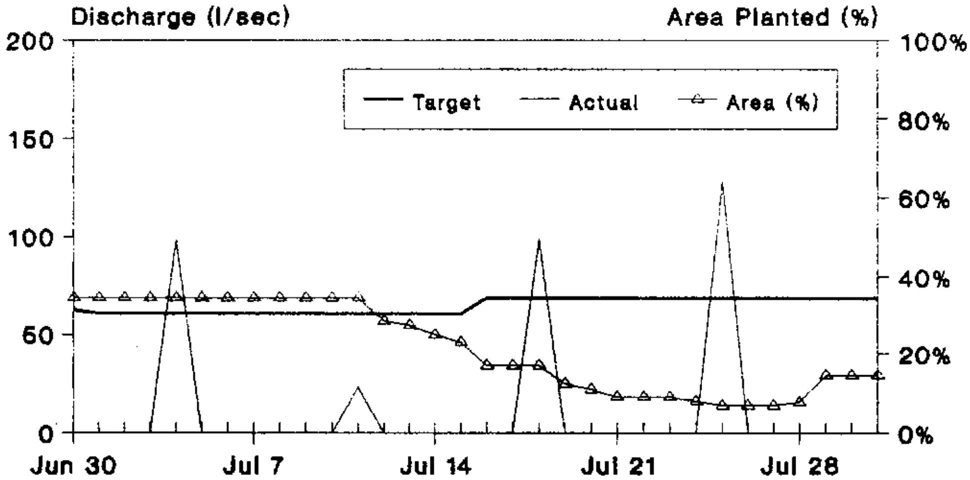
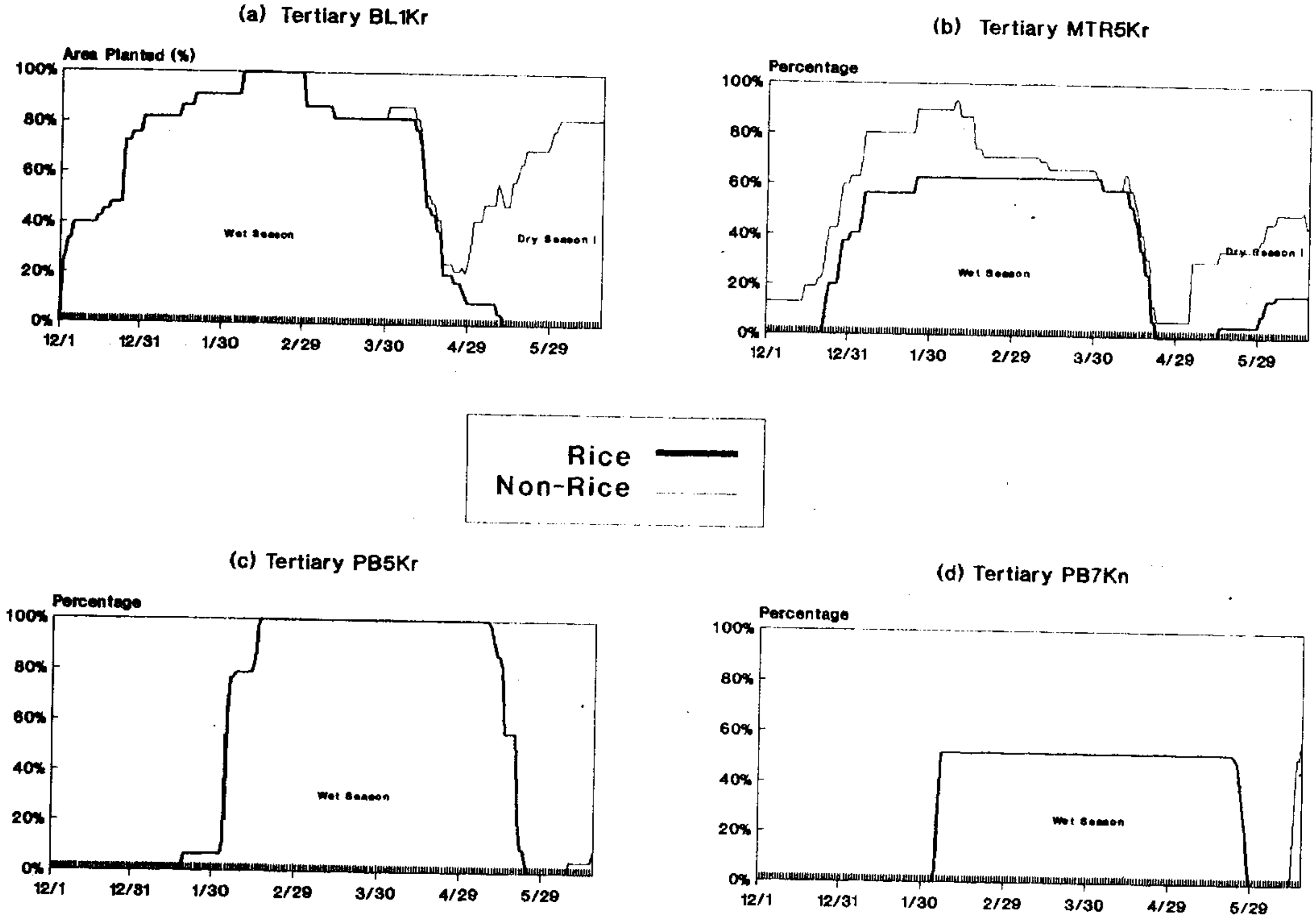


Figure 4.42

Cropping Pattern Changes from Head to Tail
Maneungteung Irrigation System, Indonesia



Rotational Irrigation

The two Indonesian case studies provide contrasting management strategies when water is inadequate to meet all demand.

In Way Jepara water shortages are avoided by restricting the area sanctioned for irrigation. This is based on a two year cycle: in one dry season the upper half of the system receives all available water, while in the subsequent dry season only the lower half is entitled to water. This strategy has several advantages: it is simple to implement, it is predictable, it maintains adequacy as an objective, and over the two year cycle it is highly equitable. The plan also requires good discipline by agency staff and head end farmers. However, it has one important drawback: it does not permit much flexibility, so that if water is abundant there is little opportunity to expand the irrigated area. The 1989 dry season demonstrated that clearly: water was in plentiful throughout the season (the reservoir spilled almost continuously) but only half the command area was irrigated.

This type of operational plan does not require much physical infrastructure, and thus does not utilize the full management potential provided by having cross-regulation gates at every offtake structure.

Maneungteung system, in contrast, has a complex rotational plan. Although the annual plan attempts to restrict cropping patterns on the basis of experience of likely water supplies at the weir, it is expected that rotational irrigation will be required during the latter half of the first dry season, and throughout the second dry season.

The purpose of the rotational pattern is to share water between groups of tertiary blocks on a predetermined schedule. This type of arrangement means that adequacy objectives are no longer important: equity takes a higher priority. It also requires a high level of management: gates have to be opened, closed and monitored on essentially a daily basis.

Evaluation of rotations in 1988 showed that the actual rotation was highly inequitable, highly unpredictable, and poorly monitored. Although the apparent objective of the rotational plan was based on a fair share of water between all tertiary blocks, actual plans favored upper end areas where farmers had already planted large areas. The rotation plan therefore increased water distribution inequity. Further, some blocks were scheduled to receive water on several days each week, while others only had one delivery a week scheduled. Canals were filled and drained more than once in each cycle, and the boundaries of rotational blocks did not always coincide with control structures (Table 4.13).

Implementation problems included slow response to changes in water availability at the weir, failure to implement rotational schedules as planned, and poor regard for discharges into tertiary blocks during rotational deliveries.

A pilot testing of a more equitable rotation plan in 1989 showed that if physical facilities for control over water were used to determine rotational boundaries, if a more strict implementation schedule was followed, and if all areas were scheduled to receive a fair share of water, the result was a more efficient, less contentious management system.

In a planning meeting arranged between irrigation officials and farmer leaders held before water conditions deteriorated, a revised set of rotational units were drawn up that aimed at treating all areas of the system equally irrespective of how much land was planted at the time rotational irrigation would commence. In 1988 the ratio of the area due to receive water on the most favored and least favored days was 3.30, and this was reduced to 1.49 as a result of this meeting (Figure 4.43). Complete equality could not be achieved because of the concern to keep each rotational unit contiguous and controlled by an operating structure at its upper boundary.

Table 4.13

Changes in conditions between 1988 and 1989 rotations
Maneungteung East Irrigation System, Indonesia

(a) Number of tertiary blocks scheduled to receive water each day

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Average
1988								
Tertiary blocks/day	19	16	16	11	8	14	15	14.1
Irrigation inspectors/day	3	2	3	2	2	3	4	2.7
1989								
Tertiary blocks/day	15	7	9	12	12	13	7	10.7
Irrigation inspectors/day	2	2	2	1	2	2	2	1.9

(b) Number of locations at which main and secondary canals must be blocked

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Total
1988	3	0	2	1	2	2	0	10
	(all 1988 operations involved use of stop logs to block canals)							
1989	1	2	2	0	1	1	0	7
	(all 1989 operations involved use of adjustable gates to block canals)							

(c) Area irrigated (ha) and lengths of main and secondary canals (m) used each day

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Total
1988								
Area irrigated	1331	902	995	433	403	1017	870	5951
Length of canal used	13539	21947	12458	12925	16380	19962	21295	118506
1989								
Area irrigated	842	564	752	734	576	655	748	4871
Length of canal used	9375	10306	15540	14795	15282	19789	20351	105438

Source: Vermillion and Murray-Rust (1991)

Figure 4.43

Changes in Equity during Rotational Irrigation
Maneungteung Irrigation System, Indonesia

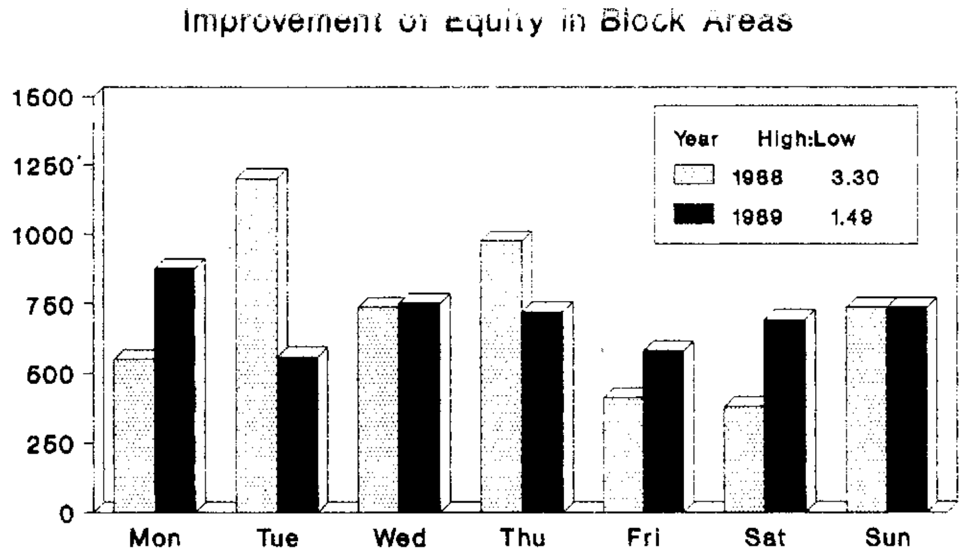


Figure 4.44

Changes in Management Inputs during Rotational Irrigation
Maneungteung Irrigation System, Indonesia

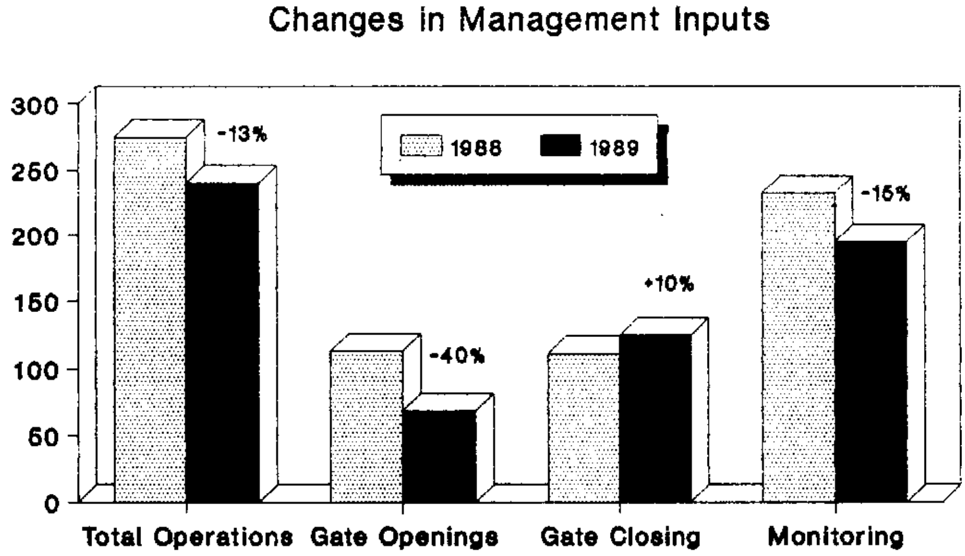


Table 4.14

Improvements in Rotations, Maneungteung East

Irrigable Area (ha):	4871
Number of Gates:	114
Number of Tertiary Blocks:	70

1. Management Inputs	1988	1989	% Change
Total Management Inputs	279	241	-13.6
Total Gate Openings & Closings	104	94	-9.6
Gate Supervision (hrs/week)	32.4	27.4	-15.4
a) Gates to be adjusted	16.4	9.7	-40.9
b) Gates to be kept closed	16.0	17.7	10.7
Downstream Flow Must Be Stopped:	10	6	-40.0
a) Using Stop Logs	10	0	-
b) Using Sliding Gates	0	6	-
2. Equity of Rotations			
Tertiary Blocks with >1 Day/Week of water	6	0	-
Weekly Inequity Index	3.30	1.49	-54.8

Notes:

"Gate Supervision" means that either a gate must be kept closed because water is flowing on the upstream side, or that water is passing through the gate and discharge must be controlled to distribute water fairly. Keeping a gate closed is an easier management input than having to control discharges throughout the rotation period.

"Downstream Flow Must be Stopped" means that the main or secondary canal needs to be controlled to prevent downstream areas getting water out of turn.

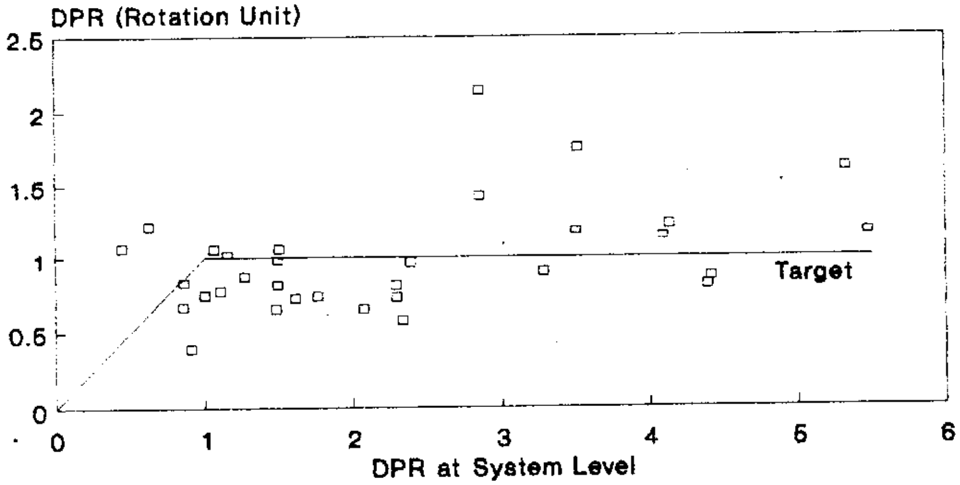
"Weekly Inequity Index" is the ratio of the maximum to minimum area planned for irrigation on different days of the same week.

These benefits were acheived at no additional cost to normal operational budgets

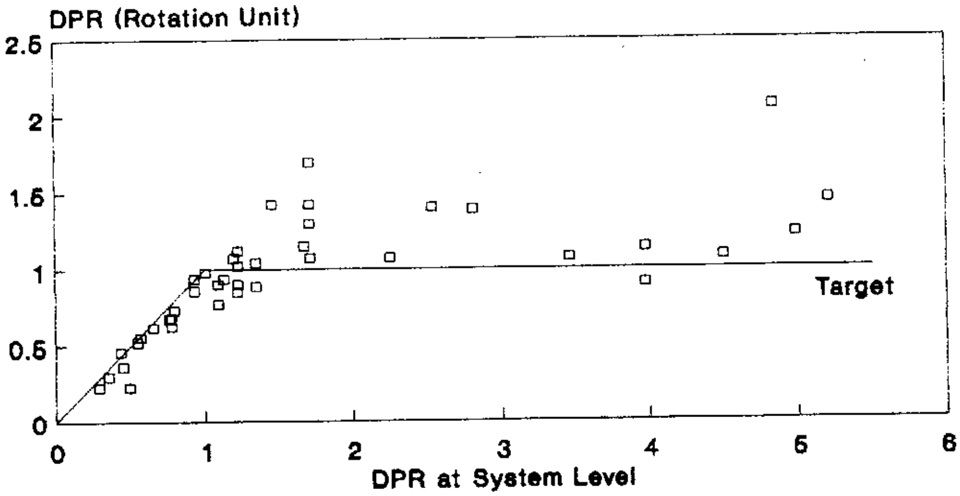
Figure 4.45

Improvement in Water Delivery Performance
Maneungteung Irrigation System, Indonesia

(a) June - September, 1988



(b) August - October, 1989



The revised rotational boundaries reduced the total number of management inputs required, expressed in terms of the total number of times gates had to be opened or closed, and the total length of time during the week each gate had to be monitored to ensure the rotation was being implemented according to plan. The total management input actually decreased by 10% even though equity increased dramatically (Table 4.14 and Figure 4.44)

At the end of the trial period it was possible to assess the degree of effectiveness of the revised plan. In 1988, prior to intervention, there was little relationship between the ratio between actual and planned discharges (Delivery Performance Ration or DPR) at the head of the system and the DPR for each rotational unit. Even when water at the system head greatly exceeded the target discharge for the area scheduled for irrigation, stealing and other interventions meant that water delivered to rotational blocks was frequently below target (Figure 4.45a).

Following intervention this pattern changed significantly. Whenever DPR at system level was at or below 1.2 the scheduled rotation unit received virtually all available water. At higher levels of system level DPR, the DPR into each rotational unit rarely rose above 1.5, showing that only excess water was delivered to blocks not scheduled to receive a turn (Figure 4.45b).

Limiting excess deliveries

Maneungteung demonstrates some of the difficulties in managing a complicated water distribution pattern for multiple objectives. Concern for adequate delivery of water to the upper parts of the system in an environment where there is limited capacity to respond to field level conditions means that in periods of high rainfall or reduced demand tail end areas receive too much water. Water tables build up quickly during the wet season, effectively preventing an early start to the main rice season. Tail end farmers are obliged to delay planting for some months, and then may not be able to grow a second crop due to water shortages. The consequence is greatly reduced cropping intensities in tail end areas, and even land abandonment. With improved response to drainage conditions these tail end areas could be more productive; however, this requires coordinated operational actions throughout the entire system and this cannot be achieved with current information management capacity.

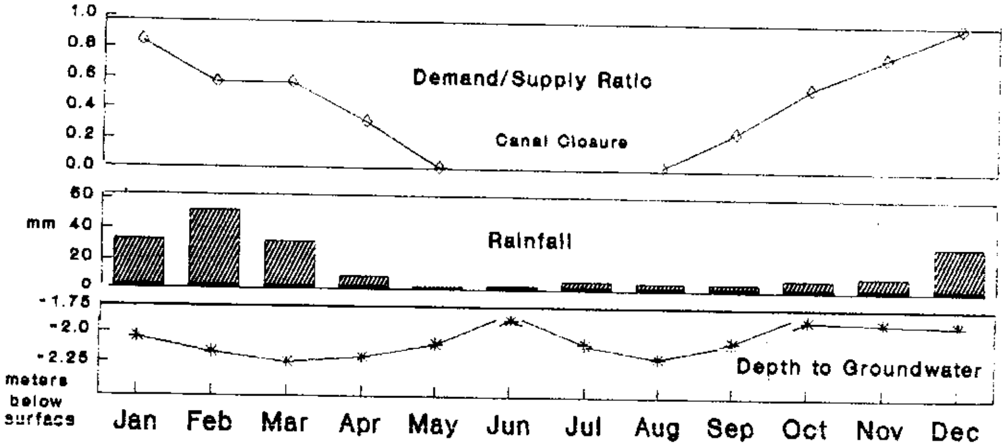
The Viejo Retamo case study provides an example of how groundwater levels could be managed through an effective monitoring program. Research indicates that groundwater fluctuations are directly linked to the ratio of water requirement to delivered water, not to rainfall (Figure 4.46). If deliveries are reduced during periods of low evapotranspiration the water table level can be kept below damper levels.

The simplicity of objectives of this system means that it is possible to simultaneously achieve equity and reliability while maintaining a concern for long term productivity of the agricultural system. Adequacy is not an operational objective; it is left to individuals and water user groups to adjust their cropping patterns to meet the planned water delivery schedule.

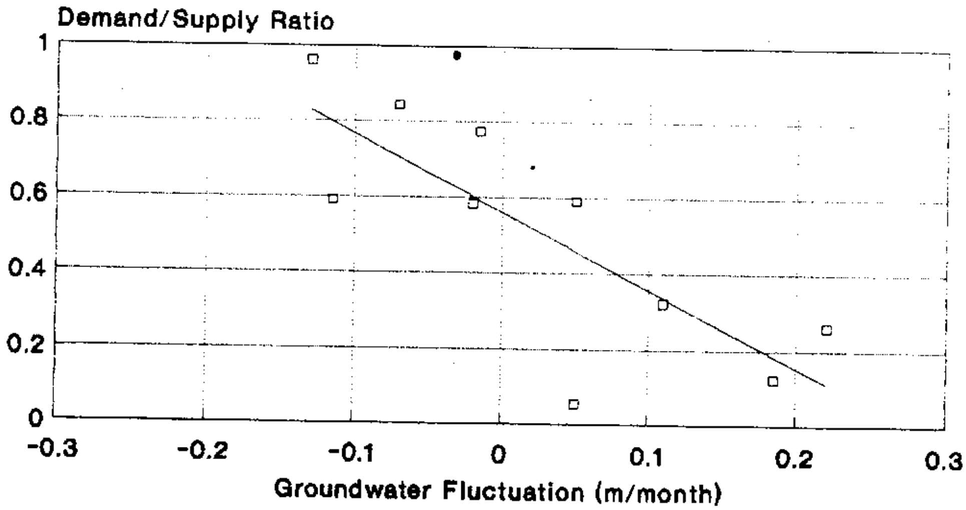
Figure 4.46

Effect of Irrigation Management on Groundwater
Viejo Retamo, Argentina

(a) Demand/Supply, Rainfall & Watertable



(b) Irrigation Impact on Groundwater



Section 5

Sustaining and Improving Performance

5.1 Long Term Aspects of Performance

Section 4 has largely focussed on short-term aspects of performance as a consequence of the physical design of the system: indicators utilized included water distribution, its utility for irrigated agriculture, and some assessment of outputs such as yield, cropping intensity, and irrigated area. These indicators are most likely to be those used by system managers because they are directly related to the seasonal and intraseasonal goals that they helped to establish.

Of increasing concern, however, is the issue of longer term impacts of irrigation, and the consequences of continuing current management practices on the sustainability of irrigation systems. Irrigation which is poorly managed has the capacity to be self-destructive.

One set of concerns addresses issues of **sustainability** of performance with current levels of management inputs. A major failing, reflected in many of the case studies, is that current data output indicators do not show trends. Monitoring and information management requirements to determine trends are completely different to those required for determining short term performance.

A second type of concern is whether the management system is capable of responding to **changes in existing objectives** caused by changes in conditions external to the system itself. Agencies that are more administrative than managerial in nature are less likely to respond to such changes because reassessment of objectives and resources is not built into the monitoring-evaluation-response cycle.

The extent to which the irrigation system managers are receptive to these concerns is a reflection both of the effectiveness of any evaluation process that exists to assess performance over time, and the effectiveness of any process that assesses the links between target setting and fulfillment of objectives.

In the vast majority of cases there is a clear gap between management at system level and the objective setting/evaluation process conducted at higher levels. Short term evaluations incorporated into the process of setting annual, seasonal or daily targets rarely consider longer term issues: more commonly management is concerned with fulfilling short-term informal objectives developed jointly between system operators and water users.

5.2 Sustainability of Performance without External Change

All of the case studies included in Section 4 describe short-term performance levels, but they do not address the wider issue of whether these levels are sustainable into the future given the current management system. This makes it difficult to discuss sustainability and the consequences of continuing to perform at current levels at system level.

5.2.1 Waterlogging, Salinity and Soil Degradation

The case studies suggest that system managers are not very concerned with whether the physical resource base of the irrigable area is being sustained. Active management in response to lake levels within the Fayoum in Egypt is the notable exception, where discharges into areas that drain directly in Lake Qarun are reduced to avoid water level rise above a specified limit. Other case studies are less encouraging.

The Viejo Retamo system from Argentina provides a simple management guide that provides opportunities for managers to limit gross inflow into the system when evapotranspiration is low. Yet, at least as far as the case study is concerned, there is no evidence that the management guide was adopted.

In Pakistan, which has been known to be a fragile irrigation environment for decades, the situation is more complex. It is true that both waterlogging and salinity are recognized once they have built up to a level where production is being lost, but there is comparatively less success in establishing an early warning system that would facilitate management responses to alleviation of the problem.

This is partly due to institutional factors, where watertable monitoring, salinity monitoring, surface water management, and deep tubewell management are undertaken by different government organizations. Farmers completely independently are responsible for private shallow tubewell development and management.

There has been a technological fix to the problem through installation of drainage systems once the problem has arisen, but because installation and operational costs for drainage systems are rapidly rising, there is now an increasing concern with finding alternative ways to alleviate the problem. Changed system management practices could help, but they require major changes in the timing and volume of water deliveries to tertiary blocks, a situation not feasible with the existing design. Further, production objectives must be modified if water allocations are modified to minimize salinity build-up.

Some authorities have expressed concern that soil fertility may be declining as a consequence of continuous irrigation, particularly in humid tropical rice-based irrigation systems that result in anaerobic soil conditions for months or even years on end.

These physical changes are the direct consequence of system operations, and yet there is no simple set of methodologies for system managers to adopt that allow a sustainable balance between short term output targets and long term sustainability to be pursued.

5.2.2 Health

There are increasing concerns with the impact of irrigation on prevalence of water-borne diseases, vectors such as mosquitoes or snails, and contamination of drinking water from agricultural inputs such as fertilizer and pesticides. All of these lead to a decline in the quality of life and the physical capacity of farmers and their families to maintain production.

For vector-borne and water-borne diseases there is already a good understanding of the hydrologic conditions that favor or reduce the incidence of diseases, but little progress appears to have been made in transforming these into operational rules or guidelines for system managers. Health hazards from irrigation are still viewed merely as a cost that has to be paid for maintaining production rather than an integral part of the objective set to be considered when drawing up shorter term plans for water allocation and distribution.

5.2.3 Inequitable Access to Benefits of Irrigation

Effective and efficient irrigation performance depends heavily on the mutual cooperation of all involved. There can be little doubt that water allocation and distribution play a significant role in determining whether such cooperation exists.

When water is insufficient to meet demands of all, there may be benefits in terms of gross production in concentrating water delivery within a limited portion of the system. However, this strategy has to be weighed against the long term social cost of depriving the same group of farmers each time. If a long term objective of the system is to provide equal access to water to all beneficiaries then allocation plans and distribution practices must reflect this objective.

At the system level there is plenty of evidence from the case studies that current water allocation and distribution practices result in highly unequal access to benefits. Tail enders almost always suffer a disproportionate burden when water is in short supply; this often results in conflict and disruption of management of the system.

The case studies show a wide variety of approaches to this issue. In the more arid areas such as Egypt and Pakistan, water allocation principles share deficits equally among farmers, even though in practice this may not actually be achieved.

In humid areas, however, the picture is more confused. Way Jepara in Indonesia shows an effort to spread deficits equally to all users over a two-year period, albeit with a potential loss of production in wetter years as a consequence. Other case studies, such as Maneungteung, Gal Oya and Tungabhadra, are examples of how operational practices can continuously favor head end farmers at the expense of those at the tail. In systems of this type it is not surprising in such cases to find land abandonment at the ends of many canals, and a high level of friction between farmers and agency staff and conflicts within the farming community.

The LTRIS case study indicated positive benefits from an intervention aimed at a more equitable sharing of access to water. Similarly, the establishment of farmer organizations in Gal Oya in association with rehabilitation, enabled farmers to participate in water allocation decisions at secondary, sub-system and system level. Engineers operating the system both before and after the establishment of farmer organizations report that conflicts were reduced dramatically, and that water distribution was far more equitable by the end of the project. Despite these relative successes, there is depressingly little evidence that these gains are sustained long beyond the period of intervention.

A second dimension of inequitable access is the problem of reduced benefits of irrigation for landless families, women and other disadvantaged groups. None of the case studies show any evidence of specific management strategies to accommodate these interests. Unfortunately, this is not unexpected. Whenever unequal access to resources is not directly related to spatial distribution of water at the main system level, system managers have little or no opportunity to modify allocation and distribution procedures to favor a particular group within the farming community as a whole. In larger systems it remains largely beyond the scope of irrigation system managers to find ways of targeting the disadvantaged, and requires action at the community level.

In small systems, particularly those where a new water source is created through installation of tubewells, there are opportunities to establish water rights for targeted disadvantaged groups. In Bangladesh and India there have been pump groups created that are operated by landless people and women, enabling them to earn an income through selling of water and charging for a water distribution service. A long term indicator of success of this approach is, of course, the extent to which additional income is reserved for maintenance and replacement of pumping equipment.

5.3 Management Response to External Changes

None of the case studies reveal any significant concern with long term changes in the external resources and conditions that affect the potential of the system to maintain performance into the future. To some extent this may be because case studies by their very nature tend to be short-term views of performance, concentrated into one or two seasons. They may also be based in some way on a diagnostic approach within the context of some form of special study so that longitudinal aspects are missing, and trends cannot be observed.

There are, however, institutional factors affecting the capacity or interest of agencies responsible for irrigation management to respond to external changes. Because they do not have a direct role in managing these external changes, it is easier to ignore them than respond to them. The interest of most irrigation management agencies is likely to remain short term, particularly in organizations where transfer is frequent and there is little or no response to actual levels of performance.

External factors that create changes in the resource base available to the system, or which change demand for outputs from the system. A few typical examples are briefly discussed below.

5.3.1 Competition of Water Resources

In none of the case studies covered was there any evidence of effective monitoring and analysis of water resource availability at the head of the system. Some of the studies reported clear rules as to how to respond to short-term, within-season changes in water availability, but what appears to be lacking is any systematic process whereby water resource availability is seen as a long term concern that feeds directly into the annual planning process.

At the same time it is clear that water resources allocation for irrigation are under threat in many of the countries included in the case studies. Typical causes of this threat are increasing demands for water from non-agricultural sectors such as water supply, industry, aquaculture or hydropower generation. A recently emerging trend in a number of countries is a concern for water quality, resulting in the establishment of minimum discharges in rivers to sustain acceptable quality standards. This may lead to changes in the total volume of water available for irrigation, as is already occurring in East Java.

Given that many of the systems included in the case studies are able to abstract water from rivers with relatively little control or concern for downstream discharge conditions, it is not surprising that these concerns are not included in the management strategies of irrigation agencies. It is inevitable that appropriate responses will have to be developed in the not too distant future as water gets increasingly scarce.

In the Small Scale Irrigation Turnover Project in Indonesia, for example, it has become apparent that watercourse management, which involves sharing of water between existing systems and decision-making over creation of new systems, is an essential component of the objective of turning over all systems less than 500 ha to farmers. It is interesting to note that this function is already undertaken for all of Eastern Bali by the high priest of the water temple system, who must authorize every change in water abstraction from rivers.

5.3.2 Declining Water Resources Availability

A related issue is that of decreasing water resource availability, irrespective of whether demand is increasing or not. Watershed changes, such as deforestation and soil erosion, can change the hydrology, flood pattern and sediment load downstream. The implications for reservoir life lengths, and the increased load on maintenance staff in run-of-the-river systems are obvious.

These long-term changes in water availability require commensurate changes to water allocations made during the annual plan process. However, the case studies provide no evidence that such long-term changes are being recognized by irrigation system managers.
Groundwater extraction faces related problems. Water tables in some locations are dropping sufficiently rapidly that shallow wells, and in a few cases even deep tubewells, can no longer pump water.

5.3.3 Changes in Agricultural Demand

Changes in government policies towards the agricultural sector may have profound impact on the way irrigation systems are managed.

In the case studies where water is divided by fixed structures, such as Egypt, Pakistan, Argentina, and the small systems of Nepal and Indonesia, most management change will have to occur within the boundaries of the tertiary block: water allocations cannot change without major redesign of all division structures. It is the responsibility of farmers to decide, either independently or in small groups, how to respond to incentives to move from one cropping pattern to another.

In systems where there is flexible control over water delivery there should, in theory, be plenty of scope for response to changes in agricultural demand such as diversification away from rice to other crops following the achievement of rice self-sufficiency. However, there is little evidence from the case studies from either Sri Lanka or Indonesia that any systematic revision of operational rules and guidelines for the system has taken place to enable managers to serve the needs of farmers who have changed or who wish to change from rice to another crop. Results from the Philippines also indicate that experimentation with water management at system level in diversifying systems is still continuing.

Pakistan shows an anomalous situation: diversification is to some extent from non-rice to rice, because of the high export price for Basmati rice. This has placed pressure on the system because extensive rice cultivation is not possible under existing water allocation rules. There is evidence of significant conflict over water at the start of the wet season as more influential farmers attempt to establish large areas of rice.

Despite this exception, the most productive and diverse systems in the case studies appear to be those with simple allocation and operational rules. As long as water supply is reliable farmers appear quite flexible in their cropping choices to respond to agricultural changes. Surprisingly, where there is greater potential flexibility in water deliveries, notably in the humid tropics, there tends to be less diversification.

5.3.4 Financial Sustainability

Many irrigation agencies are facing financial crises at the present time. This is in part because they were able to grow rapidly in parallel with the massive investments in new construction but, as the levels of construction levelled off and then declined, income into the agencies was reduced commensurately. The traditional levels of financing of operation and maintenance costs provided through annual recurrent budgets are too small to meet the increased establishment but many governments cannot readily dismiss surplus staff.
Most irrigation agencies feel that if only the O&M appropriation were increased, they could do a better job managing the systems. Many policy makers remain unconvinced, feeling that past performance does not justify increased expenditure. The standoff continues, but there are other changes to consider.

Many governments, either unilaterally or under pressure from lending agencies are attempting to reduce annual appropriations, not just for irrigation but across the board. Irrigation agencies that are not self-financing face great difficulties in maintaining their O&M budget, and a huge proportion of what is made available has to go to staff costs rather than to improving operations or maintenance.

The performance consequences of charging farmers for part or all of O&M costs are also not clear: roles and responsibilities of agencies undoubtedly have to change because they will have to be more responsive to the needs of users who foot the bill will.

The recent trends of turnover of O&M responsibilities to farmers at tertiary and even secondary level, and the handover of full O&M responsibilities for smaller systems, may well have an impact on performance of systems. However, it is too early to find good data following these changes.

5.3.5 Competition for Land or Labor

One final example of external change is competition for non-water resources, notably for land and for labor.

In the Maneungteung case, actual irrigated land was about 10% less than officially reported. This is symptomatic of tremendous demand on land for housing and other non-agricultural land. Similar trends can be seen in all areas of dense population, and these inevitably lead to decreases in irrigation potential.

In Malaysia and other Asian countries experiencing rapid industrialization, agricultural land is being abandoned because other sectors offer better and perhaps more congenial employment opportunities. Malaysia has abandoned its policy of rice self-sufficiency, promoting higher value agro-industrial crops instead. Significant areas of former rice lands are now left idle.

Finally, and not insignificantly, in many countries younger engineers have found it more attractive to work in West Asia than to join government service. There is also increasing competition from private sector engineering concerns.

Section 6

A Framework for Performance Assessment

6.1 The Need for a Framework

The case studies presented in Section 4 focussed primarily on the extent to which the design of the system limits the objectives open for managers to select, and the relative success in achieving those given the management environment in which systems were being operated. Given such a small sample from several different types of irrigation system design it is impossible to draw definitive conclusions concerning the interactions between design and management that lead to different levels of performance. This task is made more difficult because virtually all the case studies describe outputs without an accompanying description or evaluation of the management conditions and processes that resulted in those outputs.

The temptation under these conditions is to substitute a comparison of outputs for a comparison of performance. There are three compelling reasons not to fall into this trap.

Firstly, the objectives of this project are to see if there are commonalities in both the process by which performance can be assessed and in the development of hypotheses that can usefully form the basis for more detailed analytical assessment of performance and its underlying causes. Too much implied criticism of existing managers based on secondary data is somewhat unfair, and is not what was intended of the project.

A second reason for avoiding focus only on short term outputs is implicit in the discussions presented in Section 5. None of the case studies show any serious efforts to manage things differently in the short run even when there is clear evidence that these efforts have a long term detrimental impact on the sustainability of irrigation systems. This is, at least in part, a consequence that irrigation system managers themselves focus on short term outputs without a utilizing an appropriate management system that reviews performance and outputs on a systematic basis.

Finally, a focussing on outputs and how to raise their levels provides little or no assistance in determining the appropriate strategies for intervention: it leads to a site specific focus on the symptoms of poor management rather than on an understanding of more fundamental weakness in the management process. That is not to say that output improvements cannot be obtained, but that the improvements will either not be sustainable or that it will be impossible to attain the full potential of the system and available resources. In the long run, therefore, it is desirable to address performance assessment in a more process-oriented way.

At this stage it is therefore appropriate to look in more detail at how a process of diagnosis may proceed and from this draw some conclusions and hypotheses for further studies along these lines.

6.2 A Framework for Performance Assessment Diagnosis

A generic process of performance assessment cannot be solely output oriented. To be sure, outputs are integral to the assessment, but they are used to determine opportunities for improvement within the entire management cycle, not merely in raising the level of outputs as a single goal.

Figure 6.1 presents a summary of the paths by which a diagnosis could be undertaken. By asking a series of questions that help to diagnose some of the causes of poor performance, possible ways in which management performance could be improved are identified. The diagnosis falls into two parts: an evaluation of the degree to which initial objectives and targets were met, and a diagnosis of activities that appear to require the greatest attention if performance is to be improved.

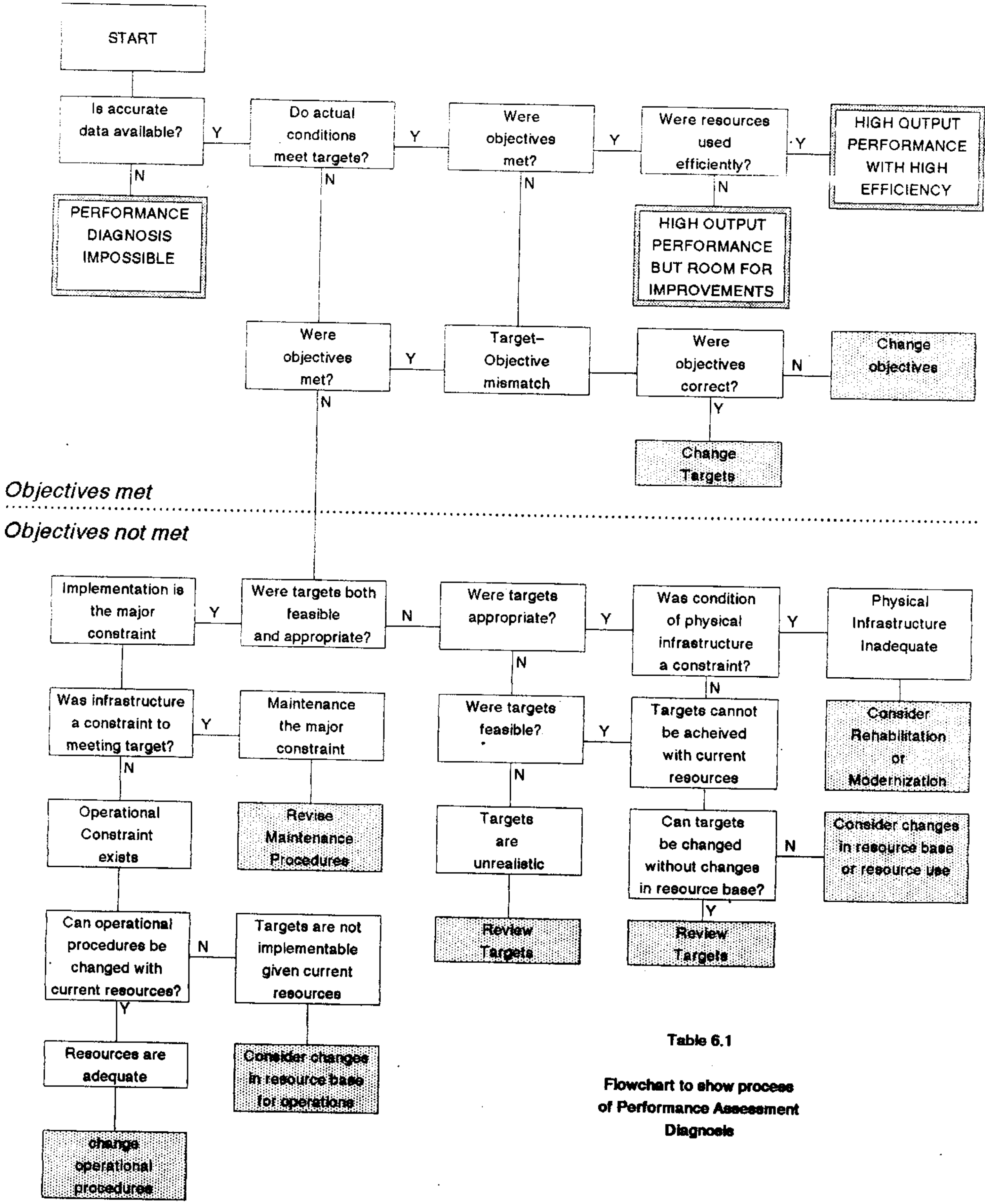


Table 6.1

Flowchart to show process of Performance Assessment Diagnosis

At the outset, it is obvious that the element of management control, the process by which the effectiveness of the various management functions of planning, organizing, and implementing is reviewed and adjusted, relies on having good information. If good data is unavailable, then there is no possibility of making a careful analysis of the problem:

> **If, and only if, the appropriate data is available is it possible to undertake a logical and analytical process of performance assessment.**

A number of possible case studies could not be included in this study because the data base was inadequate. Personal experiences at field and system level do little to create a more positive view about the overall availability and quality of data available for performance assessment.

6.2.1 Target and Objective Achievement

A fundamental characteristic of the process summarized in Figure 6.1 is that information on output is not used as the end result, but as the first step in assessing the full management cycle. There is no value judgement made of the level of output, but a clear analytical assessment made of whether the outputs are the same as those intended during the planning process. Put as simply as possible, if the desired targets and objectives were achieved, then the analysis of performance is concerned with whether the targets and objectives were ambitious enough, or whether they could have been accomplished with greater efficiency. The ideal performance, "things were being done right" and "the right things were being done", can be described as follows:

> **The ideal level of performance can only be achieved when targets were achieved, objectives were fulfilled, and there was an efficient use of available resources.**

An output oriented evaluation may lead to complacency if targets are met because the assessment does not look at the efficiency with which the target was met:

> **If targets and objectives are met but resource use is not efficient, then performance can be improved by institutional modifications that lead to better resource use: this can lead either to a reduction in resource utilization or definition of a more ambitious set of objectives to make use of the spare resource capacity.**

This second diagnosis is more likely than achieving the ideal because it is improbable that efficiencies are maximized. However, the end result is a success for management and the diagnosis merely reinforces the desire of a good and motivated manager to do even better in the future.

6.2.2 Target and Objective Mismatches

In the majority of case studies it appears that some shortfall occurred either in diagnosis achieving targets, in fulfilling objectives, or in both. The first step is to check whether the objectives and the subsidiary targets were correctly matched.

It is possible to find cases where objectives have been fulfilled even though component targets may not be fulfilled. One good example of this can be seen in several countries: the overall objective of rice self-sufficiency was achieved at national level even though individual systems failed to meet their operational targets: e.g. water distribution efficiency was low or cropping intensities were less than expected. This suggests that there is some form of mismatch between the objective and the targets because the objective was fulfilled inefficiently: "the right things were being done" but "they were not being done right".

If targets are not met but objectives are, then there is a target-objective mismatch: because the targets are short term efforts to fulfill wider objectives, the targets are more likely to require modification in the first stage of managerial intervention.

An alternative scenario is that targets were fulfilled but objectives were not achieved: "things were being done right" but "they were not the right thing". The diagnosis here is not clear:

If targets are met but objectives are not, then there is a target-objective mismatch. A review of both objectives and targets is required to determine whether it is the objectives or the targets that must be modified before performance can be improved.

The most common scenario, as exemplified by almost all the case studies, is that neither objectives or the component targets were met: "things were not being done right" and "the right thing was not being done".

Before discussing this set of conditions, however, a word of caution is necessary. All too frequently the assessment of performance is based on objectives that were different from those in place at the time of design or even of short term planning. A manager charged with operating a system for production goals cannot be judged on the basis of, say, equity if this was not a stated objective at that time. Instead, a mechanism is required to evaluate the impact of a management strategy on other conditions as well as performance is respect of achieving the stated objectives.

6.2.3 Assessment of Implementation.

The second part of Figure 6.1 addresses possible courses of action when neither objectives or targets are satisfactorily fulfilled. A basic assumption here is that when neither objectives are fulfilled or target achieved, then any remedial action is going to take a lot longer. It will require a much more detailed assessment of the management process in regard to the organization for management, the mobilization of resources, the utilization of those resources for operations and maintenance, and the management control process itself:

Where neither targets nor objectives are fully satisfied, then the most likely way to obtain long term improvements of performance is to focus on setting and achieving shorter term targets; once this basic management condition has been achieved it may be possible to broaden the scope of management improvements.

Behind this statement is an implicit recognition that current management performance is sufficiently poor that the actual capacity of the organization to meet a given set of targets is unknown. The diagnosis directs the remedial measures towards establishing a set of intermediate goals on the assumption that only when these have been achieved, and there is positive feedback for those involved, will there be overall improvements in management capacity to fulfil more ambitious sets of targets.

Only when shorter term targets have been fulfilled is it possible to make an evaluation of the utility of these targets in achieving the overall objectives laid down, and determine if the objectives are realistic.

This may seem rather conservative, but it aims at establishing a capacity to do things right first, and then see if they are really the right things. The focus then switches to an increasingly detailed assessment of relative priorities for management attention.

The lower part of Figure 6.1 gives the basic process by which a manager can determine which is likely to be the critical set of concerns. In many cases the critical issues will be in the field of operational implementation, while in others management of maintenance may be of greater significance. The rationale of each decision in this part of the diagram is not spelled out in detail here, but a few underlying assumptions should be stressed.

A management-oriented approach does not rule out the need under some circumstances either to make physical changes in the system design or to increase the level of financial and human resources. What it does do, however, is to view these measures as necessary only when existing resources have been used to their full capacity.

Rehabilitation and modernization, for example, is a legitimate strategy to improve output from a system, but it should only be advocated under a specific set of conditions: the operational targets were appropriate to fulfill objectives, but were not feasible because of a deficiency in the physical condition of the system. Assuming that rehabilitation will automatically
improve output is not appropriate if current management is deficient and is not addressed as a component part of rehabilitation.

Similarly, seeking greater financial resources is not necessarily a viable solution. It is true that a vicious circle may be operating here: increased appropriations cannot be justified based on current levels of output, but output cannot be improved with current levels of appropriations. It is incumbent on a good manager to demonstrate that full use has been made of existing resources, and develop a set of clear plans for the utilization of any increases in both financial and human resources.

Normally managers are forced to find some combination of modified targets, modified operational procedures, and modified maintenance inputs that can lead to improved performance. However, this must not be changed for the sake of change, or change in the hope that things will turn out better, but change based on assessment of current capacities and weaknesses.

If these basic assumptions are kept in mind, then it is possible to identify a few of the more obvious diagnoses.

> **If targets are both feasible and appropriate then the primary cause of poor water delivery performance is through poor implementation in respect of either operations, maintenance or both:**
>
> > **if the condition of physical infrastructure is not a primary constraint, then operational procedures merit greater attention; however,**
> >
> > **if the condition of physical infrastructure is the primary constraint, then maintenance procedures should be assessed first before addressing operational change.**

This requires a lot of data as well as an understanding of the effects of design and construction on subsequent operations and maintenance.

> **Where targets are appropriate but not feasible due to design or construction constraints, then improvements will have to be made to physical infrastructure if targets are to be met: any redesign of existing systems must be undertaken not only on technical criteria but also in relation to the probable management capacity and interest in operating and maintaining the physical infrastructure following reconstruction.**

The final phrase is important: rehabilitation projects and all of the associated benefits, are sometimes the reward for poor management. If physical infrastructure has been allowed to deteriorate because of a lack of interest or concern for operations and maintenance, then there has to be some guarantee that similar deterioration will not occur following the completion of the physical work.

All too often essential management inputs are assumed to be readily available. In practice they are frequently below expectation. This means that even if the system is potentially manageable, in practice it is unmanageable.

> **A major cause of poor performance is a mismatch between targets and the availability of financial and human resources: targets must be set that are realistic given resource availability even though this may result in more modest expectations of output from the system.**

Good management consists of making contingency plans. If desired resources are not available, then it may be essential that targets are scaled down. There is no managerial kudos in trying to do more than actual resources permit.

Section 7

Hypotheses for Improving Performance

This concluding section offers a set of hypotheses that, if followed by irrigation managers, should provide the basis for moving towards performance-oriented management. They are based in part on the management principles outlined in this report, in part on evidence from the various case studies of aspects of design-management interactions that appear to foster or inhibit high levels of performance. The hypotheses are divided into four sets: the first dealing with objective setting, the second with operationalization, the third with information management, the fourth with management conditions.

These four activities are not sequential. A properly managed organization relies on a never-ending cycle of planning, implementation, and review. This review has to be both of the management of the tangible resources available and the way in which the organization is structured and functions. It is accepted that there may be improvements in efficiency and in outputs from the system if individual components of this overall package are addressed, but it is not likely that long-term sustained performance will materialize without a more comprehensive approach to management of irrigation systems.

7.1 Objective Setting

A fundamental component of a managed organization is that there is a process that sets objectives, determines who is responsible for achieving them, and makes sure that all members of the management team are fully aware of, and committed to, achieving these objectives.

> **Objectives must be simple and clearly expressed, and the responsibilities for achieving them clearly defined.**

The case studies show that high performance is only obtained in systems where there are clearly stated, simple objectives for water allocation and delivery. In the case studies from Egypt and Argentina, for example, water delivery objectives are clearly defined, the operating rules understood, and short term targets are largely achieved. In most other case studies the objectives are unclear, let alone the operational targets, or they change frequently. Thus there is little or no opportunity for stabilization of management inputs.

> **Objectives must be based either on past experience from that system, or from systems facing similar design and management conditions, rather than on assumptions about what ought to be achieved.**

It is common to find in the preparation of projects, whether system or sector oriented, that objectives are developed that do not conform with the design of the system. Systems based on proportional division, for example, do not have much flexibility to respond to short term changes in agricultural demand. It is thus inappropriate to judge the performance of managers using indicators of agricultural output: the focus of performance assessment must be based on whether water delivery targets were achieved.

Assessment of the impact of difference levels of performance is, however, quite legitimate. The case studies indicate that there is a lack of clear distinction made between performance assessment relating to specific objectives of managers, and assessment of the impact of current management strategies on other aspects. A good manager, given the necessary control over resources, would normally be expected to concentrate on meeting a specific set of objectives. However, the same manager must also be aware of the impacts of these actions, and take action if the effect of those impacts is perceived as detrimental.

Performance of irrigation managers must initially be based on their fulfillment of a specified set of objectives. At the same time, there must be a parallel process of evaluation and reviews the impacts of current management actions.

There are many reasons why objectives do not match system design. In some cases the need to justify initial investments are on a set of financial or economic criteria even though the motivation for the investment is political or strategic in nature. Systems designed to achieve objectives of resettlement or regional development, for example, are still assessed solely on the basis of the value of agricultural output because the intangible objectives cannot be so readily quantified.

The case studies present contradictions of this nature: many of the countries have been highly successful in achieving the overall objective of rice self-sufficiency, notably Indonesia, the Philippines and Sri Lanka, because of major investments in new systems or upgrading of older ones. In such cases, at least in the drive towards achieving that objective, efficiency of resource use is not a major objective. Indeed, if all systems in those countries performed as initially anticipated at the feasibility stage, there would be a glut of production and prices would inevitably collapse. Yet it is easy to criticize managers of systems in these countries for low water use efficiencies or low cropping intensities when these may well reflect low prices and lack of demand.

Performance assessment under these conditions is difficult because the manager may face a complex set of objectives, some of which may be in direct conflict. It appears that although there is widespread recognition that there may be a direct trade-off between equity of water distribution and overall production, both objectives are included in the assessment of performance, a real no-win situation because a manager can never fulfill both conditions.

Higher levels of performance appear easier to obtain when the objective set is simple. Management for complex objective sets, particularly where different objectives require different actions over different time frames, is extremely difficult unless there is an explicit recognition of their relative priorities.

A manager faced with complex objective sets needs to know the relative importance of the different objectives. It is insufficient to draw up a list of objectives for managers such as high production, equity of access to benefits, land settlement, efficient water use and sustainability without also giving guidance as to which are more important at any given moment. Prioritized objectives existed in few of the case studies. There is some evidence that in the Fayoum study the first priority is with avoiding rises in lake and water table elevations, followed by equity of water distribution. In Viejo Retamo, the priorities appear reversed: equity of water distribution comes first, although there are opportunities for simultaneously minimizing rises in groundwater elevation.

Objectives must reflect the needs of all participants: policy-makers, planners, managers and users, rather than only one or two groups.

There is little evidence that objectives for each of these groups are ever systematically matched together. A major cause of low performance may well be that the objectives of each group are significantly different: water users may wish more water, agency staff may wish to conserve it, planners may want equity. The result is that many systems are characterized by a combination of formal or official objectives imposed from above, and informal objectives that develop within the system. If the assessment is based on the formal objectives alone, performance is likely to look quite poor.

Strengthening farmer participation in the annual or seasonal planning process and the development of operational plans and targets is one way of improving performance.

There is evidence from several of the case studies that performance is better where users are involved in setting objectives, both at the design stage and in the subsequent development of operational plans, rather than just being given additional responsibility for operations and maintenance is accordance with objectives set by the agency alone. This is obvious for the smaller systems, such as those of Nepal and Java, but appears equally true for Viejo Retamo. In this study the high degree of adherence to the schedule requires full and active participation from users and agency staff, a large contrast to systems characterized by high levels of conflict between users and agency staff.

This participation does not have to be full-time. The Viejo Retamo case is one where the participation is concentrated only in the planning of operations: implementation is undertaken by a particular cadre of staff of the agency with no farmer participation in operations, only in monitoring.

Performance assessment requires an evaluation not just of output but of the setting of objectives and of the management of available resources in attempting to fulfill those objectives.

Output in many systems covered in the case studies appears to fall well short of that required to fulfill the objectives: a common assumption in such cases is that performance was not adequate and needs to be improved. Far more frequently it appears that the objectives themselves were unrealistic: they represent a desire to achieve a level of perfection that is not possible.

This assumption has to be questioned. The case studies show instances where human resources are insufficient to meet the objectives, such as in Indonesia. In most cases individual managers cannot mobilize additional manpower or financial resources by themselves, and thus cannot be help fully responsible for lower than desired outputs if these output targets are imposed on them. A good manager should make sure that the objectives accurately reflect the probable availability of physical, manpower and financial resources: development of objective sets that merely assume that resources will be available is not good management.

7.2 Operationalization

Once objectives have been clearly defined the next task is to transform these into subsidiary targets that are required of each individual within the hierarchy. Operationalization clearly includes both the structure of the decision-taking process and the decisions themselves. It is therefore the dual task of managing the physical resources and the individuals within the system.

Each objective has to be transformed into a set of operational targets that match the responsibilities of each participant in the management process.

A major weakness in most of the systems included in the case studies is the presence of a gap between objectives and targets. It is one thing to define a set of objectives, but a completely different one to express these objectives in a set of practical and implementable targets.

This is especially true in cases where the objectives refer to social objectives rather than outputs in terms of water distribution or agriculture, or where the objective is on feasible when several different agencies manage their resources in a coordinated fashion.

The case studies show little or no evidence of responsiveness to the consequences of a particular level of performance on the secondary impacts of irrigation on sustainability or income distribution. In some respects this is because the responsibilities of any particular group do not cover these objectives, but it is also that there are few guidelines on alternative operational strategies that would fulfill these objectives without undermining the achievements towards other objectives.

It is unrealistic to expect managers at system level to develop or modify operational targets unilaterally that will meet objectives developed in the external environment.

In many of the case studies objectives laid down at national level are not achieved. In some cases this can be attributed to the addition of new objectives that were not included at the time the systems were established. When objectives are added to an established set, then it is important that system level managers are given guidance as how to achieve them.

Equally common, however, is the situation where operational targets do not change even though there are significant changes in national objectives: operational rules in many systems have stagnated for years.

Many system level managers believe they are evaluated on criteria over which they not only have little or no responsibility; they also feel that they are given no guidance on how to attain a specified level of output. This is partly true but it is also expected that good management would lead to establishment of system specific targets and achieve them using available resources.

Targets must be quantified to facilitate monitoring, and a set of standards developed to enable evaluation to be undertaken.

Many targets remain abstractions: if they cannot be quantified it is difficult to see how performance can be monitored.

A clear example of this arises in the case of equity objectives for water distribution. Equity is an expression of the relative share of resources that each person is entitled to. Each system has its own definition of equity, and until this is quantified into percentage share or discharge targets, effective management of available water is not possible. This process of quantification carries with it the implicit assumption that there are indicators available that can measure the extent to which targets were met.

From the perspective of evaluation the process has to go one step further. Evaluation carries with it a set of judgments as to whether a set of outputs is considered acceptable given the resources available, and thus enable an assessment of whether management performance was good or bad.

In the case of equity, for example, the Interquartile Ratio provides a measure of distribution of access to water. However, without knowing whether the water right is an equal share or some other proportion, it is not possible to compare IQR data from different systems.

7.3 Information Feedback and Management Control

Management systems include control mechanisms: these assess whether targets are being met, ensure that individuals are doing what they are supposed to, and provide feedback into the next phase of planning and objective setting. Although control is an essential condition for management, it is often weak or missing.

Without good and accurate information there can be no progress towards performance-oriented management.

The basic condition of comparison of actual and target conditions requires that there be sufficient information not just to make that comparison but to contribute to an understanding of why the desired level of output was or was not achieved.

The case studies suggest that in a number of cases agricultural output was acceptable even though the water delivery targets were not being met. This is possible if managerial inputs from water users are adjusted to compensate for uncertainties in water deliveries. It may also be that excess water deliveries were made. If there is an effective system of control ,it will in the long run lead to both target achievement and efficiency of resource use. The more common symptoms of complacency because objectives were met is no guarantee of sustained performance into the future.

Management cannot operate as a black box when either the internal or external environmental conditions are changing: it is essential that managers understand how to achieve particular targets under one set of conditions so that they can make appropriate operational changes when other conditions change.

If operations are based only on the assessment of outputs, then a long term managerial strategy does not result. Similarly, there may be a lot of experience built up with individuals but when they depart there is little or no residual understanding of how systems work. Indeed, rapid transfer in an environment where there are few clear objectives strongly favors administrative types of control over managerial ones: the tasks and rules remain unchanged as staff come and go.

The common tendency to report that targets have been achieved when in reality they were not is completely alien to the concept of performance-oriented management.

One depressing characteristic of almost all of the case studies is that very little of the data presented came directly from those involved in management of the irrigation systems. Instead, the data came from additional or external studies and may not reflect the internal information base on which managers can make informed judgments on how to better manage available resources.

Pressures to conform and not embarrass colleagues means that it is convenient to report what people want to hear rather than report what actually happened. At this point data collection becomes a pointless exercise.

Information on the levels of target achievement and the consequences for agricultural output must be directly integrated into the management structure.

There are many cases where monitoring programs have been established only to wither and die in a short period of time. While this has often led to a search for alternative parameters or monitoring techniques, the fundamental problem is that unless a manager desires to use information in a constructive manner there is no incentive or utility in collecting that information.

This is why there is little evidence from the case studies that modern technology for information management is being widely adopted. There are few instances of use of existing computer models to assess alternative operational and maintenance strategies. Such models enabling testing of different scenarios without jeopardizing agricultural output, and facilitate speedy processing of data collected through routine monitoring activities. In many cases the technology exists, but the institutional conditions do not.

7.4 Institutional and other Management Conditions

The final set of hypotheses relate to the institutional conditions within which systems are being managed. All the best management advice in the world will have little or no impact if the organization is not willing to adopt performance-oriented management techniques.

Performance-oriented management requires a set of incentives and commensurate accountability throughout the management structure.

Management, by its very nature, is not a static activity. There is constant change within irrigation systems and in the external environment. If the same management decisions are made year after year, they rapidly become inappropriate to the changing needs of systems and the sector as a whole.

The case studies suggest, however, that the decision-making process is largely static at system level because there are few rewards for improved performance, and little accountability for failing to achieve a predetermined set of targets. Under these conditions the process of setting targets and evaluating performance based on assessment of the degree of achievement of those targets is an abstraction.

Large irrigation agencies, particularly those where salaries, promotion, and other incentives are not linked to performance, are highly resistant to change and there are few examples of such changes occurring as a consequence of internal debate and planning. Where change has occurred, it has tended to come from outside the agency.

> **Evaluation of performance in respect of each objective requires an explicit statement of who is, and who is not, responsible for attaining that objective.**

Systems that have simple water allocation objectives, such as those relying on proportional division of available water, enable clear distinctions to be made between performance in terms of water deliveries and agricultural output performance. In such systems, as long as water is delivered as promised, the system manager cannot, in the short term, be held accountable for failure to meet production targets: these are the direct responsibility of farmers in conjunction with any agencies providing agricultural support services. This seems to be the case in the Fayoum and Viejo Retamo systems. When water delivery targets are not met, such as in the Pakistan case studies, the impact of water delivery performance of system managers is directly visible in terms of agricultural output performance.

> **Failure to clearly define responsibilities for achieving objectives appears to lead almost inevitably to lower levels of performance.**

In systems where there is more than one group of participants, then the definition of specific responsibilities is essential: the term "joint management" might be better expressed as "coordinated management". Planning can be undertaken jointly, with different groups expressing their desires and their constraints, but a necessary outcome of this process is that each group knows where they have full responsibility: joint responsibility for implementation to achieve certain objectives is not a satisfactory condition if there is no parallel system of joint accountability or joint benefit.

> **Accountability requires that there be specified targets or contracts at points of transfer of management responsibility which enable all parties to determine whether the agreed level of service has actually been achieved and to assess causes of failures to meet the terms of this contract.**

Without such a contract it is highly unlikely that either strategy will be successful because the basic condition of performance assessment, the comparison of actual and target conditions, will be absent.

> **The transition from current practices to performance-oriented management will be difficult: it requires changes in planning, in operations, in control and in the institutional setting. The transition also requires that patience and understanding are present to tolerate false starts and mistakes during this process.**

Irrigation management has to be undertaken in an uncertain environment. The best laid plans will inevitably fail at times despite every effort to avoid this happening. Administered systems are generally not tolerant of deviations from rules, even though there may be quite legitimate reasons for those deviations; a management-oriented approach is likely to be use these deviations as a learning experience rather than pretending they did not happen.

A management approach should not, of course, be used as an excuse to tolerate repeated failures indefinitely: it has to incorporate a learning as a process which will improve performance. The case studies suggest that the same errors are made repeatedly because the organizations involved cover up internally and blame other participants in the management process.

7.5 Concluding Comments

The evidence from the majority of the case studies is that they are not managed in response to performance. There are few examples where the objectives are clearly identified; targets frequently do not match the objectives they purport to fulfill; data availability on whether targets are actually achieved are patchy; where available, the data suggest that targets are rarely met. Informal objectives dominate but because these are unspecified they remain uncoordinated and short term in nature.

In none of the case studies was there much information on the organizational conditions and management conditions: the focus was almost exclusively on output. Consequently, it is clear that the conditions that favor performance-oriented management such as clear demarcations of bounds of responsibility and authority, adequate systems for sanction and reward for different levels of performance, and the development of a managerial cadre are largely absent.

Because of the lack of in-depth information on objectives, targets, and the management conditions, it is difficult to focus clearly on the extent to which the design of the system affects performance.

There are, of course, clear instances from the case studies where performance and design are closely linked: simple systems with most water being divided passively by structures perform well but are inflexible in their response to change, while the operation and maintenance of the more complex systems appear to stretch what limited management capacity there is to a point where performance again declines.

These observations require verification. The use of secondary case studies that contain insufficient information has to be replaced by a set of more in-depth studies that address the management process, and identify more precisely the complex relationships between system design, planning, implementation and control.

The need for more data through a set of carefully implemented case studies is obvious. It is always difficult to use secondary data, particularly where the objectives of those studies may be quite diverse. A systematic approach to measurement of output and management performance, taking into consideration institutional and resource conditions, is likely to result in a much clearer understanding of the factors that affect performance.

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Appendix 1

Glossary

The glossary provides definitions of a the ojectives and performance-related indicators used frequently throughout the text, to avoid any misunderstandings on terminology.

1. Objectives

Within this report three primary objectives for an irrigation system are referred to. Although these are described separately below, it is obvious that they are interrelated: unless it is clearly specified that the system does not intend to meet one or more of these objectives, assessment of only one or two of them will be unlikely to fully describe performance in respect of water delivery.

Adequacy

This is a measure of the degree to which water deliveries meet soil-plant-water requirements. A system that has adequacy objectives anticipates delivering water in sufficient volume at appropriate times to avoid potential yield reductions caused by periods of water shortages that create stress in plants.

Many systems that do not have adequacy as a water delivery objective because there is insufficient water in relation to land resources to permit all farmers to cultivate their land to its full extent. Under such conditions adequacy can only be managed by individuals, who have to make choices as to area irrigated or type of crop grown, thereby regulating their own demand to meet the expected water delivery schedule.

Equity

This is an expression of the share for each individual or group that is considered fair by all system members. It must not be confused with equality, which is only one specific equity condition. In designing irrigation systems there is a tendency to equate equity with equality by assuming that satisfying adequacy is the overriding water delivery objective, and that water demand can be directly related to unit irrigable area (or a modification thereof if enough is known of different soil or other physical conditions that alter adequacy values).

The experience from many small systems is that shares for individuals are highly variable, based on a reflection of other social values within the community. The same is true in societies that rely on water rights, be they first come-first served, inherited, allocated or purchased.

Most indicators referring to equity actually measure equality. This is not merely a matter of statistical convenience: because the concept of equity is different in each community, it requires prior investigation before it can be quantified.

Reliability

Reliability is an expression of confidence in the irrigation system to deliver water as promised. In continuous flow systems it is refers primarily to the expectation that a particular water level or discharge will be met or exceeded. Under such conditions, variability is the main concern, although only when water levels drop below a minimum value: if adequacy objectives are met, then variability is of relatively minor concern.

Where flow is intermittent, due to rotational irrigation or other water sharing arrangements, it also has to describe the predictability of the timing when flow will start and stop. The effectiveness of each irrigation turn in meeting either adequacy or equity objectives depends on the time of the turn, the volume delivered, and the predictability of the length of the turn and the length of the interval between turns.

If farmers can be certain when irrigation water is going to arrive, then they can make their own cropping choices to provide the level of adequacy they are willing to accept. When supplies are unreliable, they are likely to prove a major and insurmountable constraint to high agricultural output.

2. Performance-related Indicators

A number of performance-related indicators have been used in the report. While most will be familiar to readers, a brief description of a few of them is provided for clarification.

Delivery Performance Ratio (DPR)

The Delivery Performance Ratio is an expression of the actual discharge divided by target discharge at any location in an irrigation system.

In the text references have been made to "upstream DPR": this is the actual discharge reaching a structure divided by the total of target discharges for all canals at that structure. Comparison of DPR in each downstream canal with upstream DPR helps determine how water surplus or deficit is shared.

Interquartile Ratio (IQR)

In this report the term "Interquartile Ratio" refers to Abernethy's modified interquartile ratio that compares the average of the top 25% of values in a range with the average of the lowest 25% of values (Abernethy, 1989). It can be applied to many different output measures, such as discharge or yield, as well as to such indicators as DPR.

Relative Water Supply (RWS)

This indicator, developed by Levine (1982), compares water availability with actual demand. It is normally expressed as:

$$RWS = \frac{\text{Irrigation Supply} + \text{Rainfall}}{\text{Seepage} + \text{Percolation} + \text{Evapotranspiration}}$$

The value of RWS is an indication of the relative abundance of water with respect to adequacy, although it is sensitive to the scale of the area irrigated because of the influence of conveyance losses. At tertiary level an RWS value greater than 1.5 suggests water is sufficiently abundant that management inputs need not be very intensive, but with values at or close to 1.0 management inputs themselves will not necessarily compensate for the relative scarcity of water.

Water Availability Index

This indicator, developed by Wijayaratne (1986) is a simple method of quantifying water adequacy at field level. It is based on a qualitative scale of observations of water conditions in rice fields:

4.0	Water flowing from paddy to paddy
3.0	Standing water in the paddy field
2.0	Soil is moist, with water in depressions
1.0	Soil is dry and surface cracks are appearing

Field studies have indicated that WAI is most effective in describing the water conditions for rice plants during the critical 50 day period that starts 70 days before harvest. This provides a range of values from 200 (continuous water supply throughout the period) down to 50 (no standing water at any time).

Appendix 2.

Description of Systems used as Case Studies

This appendix describes the main characteristics of the systems used in the case studies. The descriptions are grouped according to the design environment in which the system has been classified. The following systems are described:

Ungated Overflow Systems

1. Six Farmer Managed Systems in Nepal
2. Cipasir, West Java, Indonesia
3. The Fayoum, Egypt

Submerged Orifice Systems

4. Upper and Lower Gugera Divisions, Pakistan
5. Mudki and Golewala Distributaries, India

Gated Division, Little Cross-Regulation

6. Gal Oya Left Bank, Sri Lanka
7. Tungabhadra, India
8. Hakwatuna Oya, Sri Lanka
9. Lower Chenab Canal, Pakistan
10. Lower Talavera River Irrigation System, The Philippines

Gated Division, Fixed Cross-Regulation

11. Kalankuttiya Branch, Sri Lanka

Gated Division, Gated Cross-Regulation

12. Viejo Retamo, Argentina
13. Kirindi Oya, Sri Lanka
14. Way Jepara, Indonesia
15. Maneungteung, Indonesia

As part of a wider evaluation of the benefits of the Agricultural Development Bank of Nepal program to improve small irrigation systems, IIMI staff undertook a detailed study of irrigation conditions in six sample systems (IIMI, 1991). Three systems are located in the Tarai lowlands south of the Himalayas, three in the Hill region of the Himalayan foothills.

The three Tarai systems are all established run-of-the-river systems that were scheduled for rehabilitation and possible expansion. Two of them, Laxmipur (134 ha) and Tulsi (70 ha) irrigated their full potential command area, while the largest, Parwanipur, irrigates 218 ha out of an irrigable area of 266 ha. However, in the initial design it was estimated to be capable of irrigating 400 ha.

All three rely on weirs diverting water out of wide rivers that have highly seasonal discharges, ranging from unpredictable flash floods throughout the rainy season to low base flow during the dry season. Parwanipur has a permanent weir, while the other two have smaller temporary diversion structures that require significant annual maintenance. In terms of physical conditions of structures in the conveyance system, all can be described as average: most structures and canals function but are not always in good condition.

Water supply in the wet season is ample, which allows the entire area to be irrigated, but is scarce in the dry season and only a limited area can be cultivated.

The three Hill systems are much smaller, Bandarpa irrigates 14 ha, Baretar 13 ha, and Jamune 10 ha. However, all have long canals leading from the water source to the head of the irrigated area: Baretar is the shortest, at 1.5 km, while the other two are approximately 4.0 km long, winding along steep hillsides. In the described cases, the intakes are not permanent and require a lot of annual maintenance in addition to repairs to the canals after landslides. In all these systems water is considered only adequate during the wet season, and is very scarce in the dry season.

All six systems rely on proportional division between each of the main sections of the system. Within each section, however, water distribution is negotiated between farmers either on the basis of time or perceived need for water.

Reference:

IIMI (1991). Evaluation Report of Agricultural Development Bank of Nepal program for assistance to small irrigation systems. (in preparation)

The authors grateful acknowledge the assistance of the IIMI Nepal Office in providing access to this data prior to submission of the final evaluation report, and to assistance provided by the Department of Irrigation of His Majesty's Government of Nepal. The study was funded by a grant from the Ford Foundation office in New Delhi, India.

Case Study #2: Cipasir, West Java, Indonesia

Cipasir represents a typical farmer system in West Java. Built in more or less its present form by farmers some 100 years ago, the system relies on a simple offtake in the Cipasir River and irrigates 39 ha.

Most water control is by overflow weirs placed in the main canal that divert water into a series of blocks a few hectares in size. The weirs were originally carved from tree trunks, but a number have now been replaced by concrete sections that still maintain the same proportions of crest length for main and offtake canals. In the steeper upper parts of the system, however, water deliveries are provided by a series of bamboo pipes leading directly out of the canal to avoid erosion.

Water rights within the system are complex, and do not divide water equally by irrigable area. Instead, each farmer has a certain right that reflects the length of time the family has been a member of the system: families involved in the initial development of the system, primarily those near the head, are entitled to a greater share of water and are thus able to cultivate two or three crops a year, depending on their location in the system. Farmers in more recent extensions to the system have smaller rights.

Typically rice is grown two or three times a year near the head of the system, with an increasing amount of non-rice grown towards the tail end, where it may be possible to grow only one or two crops a year.

In the 1970's the system was included in the official list of government systems and a weir keeper employed to operate the gate at the head of the main canal. All other operations and maintenance are undertaken by farmers.

The study was included as one of the 10 sample systems in the first phase of the Small Scale Irrigation Turnover Project to assess the needs for physical and organizational upgrading prior to handover of full operations and maintenance responsibilities to farmers.

Reference:

IIMI (1989) Efficient Irrigation Management and System Turnover TA 937-INO Indonesia: Final Report, Volume 3: Small Scale Irrigation Turnover Program. Colombo, Sri Lanka.

The authors gratefully acknowledge assistance from Dr. Douglas Vermillion of IIMI in providing additional material. The study was funded as part of a larger grant from the Asian Development Bank and the Ford Foundation, Jakarta.

Case Study #3: the Fayoum, Egypt

The Fayoum Depression, southwest of Cairo, has a gross irrigated command area of 150,000 ha, or which about 132,000 ha are currently irrigated. The main canal diverts water from the Nile 284 km upstream of the head of the system.

Each rotational unit, ranging in size from 8 to 200 ha is scheduled to receive continuous irrigation deliveries, with a maximum designed supply of 7.1 mm/day.

Water distribution in the main canal system is through a set of gated regulators with undershot gates at each of the main bifurcations in the system. However, below these regulator gates, water distribution is achieved through overflow weirs (known as a nasbah) where all crest levels are the same, and the width of each weir is proportional to the area served.

The cropping patterns, chosen annually by the Ministry of Agriculture in recognition of the limited operational flexibility, determines weekly demand for the entire year in advance, and adjustments made to each of the regulators on a weekly basis. Summer demand, for rice, cotton, and vegetables is much higher than for winter wheat, bersim and vegetables.

However, water allocations have had to be adjusted in efforts to prevent excess increases in the level of Lake Qarun, an internal depression from which there is no drainage. Rising lake levels cover productive land, a loss that cannot be tolerated in an environment where 96% of total land is desert and annual rainfall is about 10 mm.

The results reported here are from the Fayoum Water and Salt Balance Model Project, a cooperative activity between the Fayoum Irrigation Department, the Drainage Research Institute of the Water Research Center of the Ministry of Irrigation, and ILRI.

References:

Wolters, W., Nadi Selim Ghobrial and M.G. Bos (1987) Division of Irrigation Water in The Fayoum, Egypt. Irrigation and Drainage Systems 1, 159-172

Wolters, W., Nadi Selim Ghobrial, H.M. van Leeuwen, and M.G. Bos (1989) Managing the water balance of the Fayoum Depression, Egypt. Irrigation and Drainage Systems 3, 103-123.

Case Study #4: Upper and Lower Gugera Divisions, Pakistan

Since mid-1986 IIMI, in cooperation with the Punjab Irrigation Department, the Punjab Agriculture Department and the Water and Power Development Authority, has undertaken a series of studies on irrigation and agricultural conditions in various Distributaries in the Lower Chenab Canal command in Punjab Province.

The distributaries in Upper Gugera Division selected for special study were Lagar, 20 km long and irrigating about 8,000 ha through 23 submerged orifices, and Manawala, 45 km in length irrigating 27,000 ha with 125 submerged orifice outlets. In the Lower Gugera Division, more than 200 km further down the canal system, the distributaries studied were Pir Mahal, 47.5 km long and irrigating nearly 15,000 ha through 90 outlets, and Khikhi, 50 km long and irrigating 33119 ha through 158 outlets.

All distributaries have similar designs. Below the head regulator there are no adjustable gates, and all water distribution is through outlets dependent on the operating head. Although the vast majority of outlets are submerged orifices of the Adjustable Proportional Module type, a few open flumes also exist. In a few locations where minors (small distributaries) branch from the distributary some degree of water control is achieved through use of wooden stop logs, normally placed vertically in the canal. All regulation at Bhagat Head Regulator, which controls Khikhi, Pir Mahal and two other smaller distributaries, is through use of such stop logs.

Planned annual cropping intensities are either 50%, a design water allocation of 0.13 l/sec/ha, or 75%, equivalent to 0.2 l/sec/ha, depending on any existing water rights prior to construction in the 1900's. However, actual annual cropping intensities are frequently in excess of 100% due to intense groundwater use from a combination of public deep tubewells and private shallow tubewells.

When there is sufficient water, particularly in Upper Gugera Division, basmati rice is the preferred crop in the wet season. Other common crops include wheat, maize, millet, fodder, sugarcane, cotton and vegetables.

Below the outlet into each watercourse water distribution between farmers is through the warabandi system, each farmer taking the full discharge into the watercourse for a specified period of time.

References:

Kijne, Jacob W. and Edward J. Vander Velde (1990) Salinity in Punjab watercourse commands and irrigation system operations: a prolegomenon for improved irrigation management in Pakistan. Paper presented to the 6th. Internal Program Review. Colombo: IIMI. 34 pp.

Kijne, J.W. (1989) Irrigation management in relation to waterlogging and salinity: precis for a research agenda in Pakistan. Pakistan Country Paper No. 2, IIMI, Colombo, Sri Lanka.

Vander Velde, E.J. (1990) Performance Assessment in a large irrigation system in Pakistan: opportunities for improvement at the distributary level. FAO Regional Workshop on Improved Irrigation System Performance for sustainable Agriculture, Bangkok, October 1990.

Case Study #5: Mudki and Golewala Distributaries, India

The design of the systems of the Indian Punjab are almost identical to those described for the previous case study, based on the same type of submerged orifice. The description of the design is therefore not repeated. Design water allocations are 1.8 mm/day, about 0.2 l/sec/ha.

The only siginificant physical difference is that both distributaries are in a reservoir-backed irrigation system. This means that there is a lesser amount of sedimentation than in the Pakistan case. Maintenance requirements are significantly lower as a consequence, and discharges are almost always above the minimum of 80% of Full Supply Discharge that is permitted under current operational rules.

References:

Bird, J.D., M.R.H. Francis, I.W. Makin and J.A. Weller (1990) Monitoring and evaluation of water distribution: an integral part of irrigation management. FAO Regional Workshop on Improved Irrigation System Performance for sustainable Agriculture, Bangkok, October 1990.

Makin, I.W. (1987) Warabandi in Punjab, India. Hydraulics Research, Wallingford, Report No. OD96.

Case Study #6: Gal Oya Left Bank, Sri Lanka

Gal Oya Left Bank is located in the eastern coastal plains of Sri Lanka. The system was built between 1952 and 1960 following the construction of Senanayake Samudra reservoir. The designed irrigated area for the whole Gal Oya system was 43,000 ha, of which 13,000 ha existed before the project commenced. The Left Bank canal system is designed to irrigated approximately 13,000 ha, but some tail end areas have never been irrigated and rely on wet season rainfall for crop production.

The current irrigation system was superimposed on a series of smaller reservoirs dating back several hundred years. The main canal passes through several of these reservoirs, making it possible to control releases at several different locations. The main and secondary canal system is controlled through a series of undershot regulator gates, some vertical, others radial, at the major bifurcations. However, there were only three cross-regulators in the main canal system other than at bifurcations.

All offtakes from main and branch canals into distributary canals are gated culverts. There is a wide range of command areas of distributary canals, from 4 to 500 ha, with each distributary canal irrigating one or more tertiary units. There were no measuring devices installed in the system other than at the main reservoir, although some daily water level readings were taken.

The system grows almost nothing other than rice. In tail end areas there was a little tobacco and vegetables, but if water is insufficient for rice cultivation then land was normally left fallow. Annual cropping intensities were about 150%. Water allocations were on the basis of 1300 mm of water for wet season rice, and 1800 mm in the dry season.

The studies reported in this volume are based on research activities undertaken during the Gal Oya Water Management Project between 1979 and 1984. The research was conducted by the Agrarian Research and Training Institute, Colombo and Cornell University, together with the Sri Lanka Irrigation Department. Following this project conditions are very different than those described above.

References:

Murray-Rust, D.H. (1983) Irrigation water management in Sri Lanka: an evaluation of technical and policy factors affecting operation of the main canal system. Unpublished Ph.D. thesis, Cornell University.

Wijayaratne, C.M. (1986) Assessing irrigation system performance: a methodological study with application to the Gal Oya system, Sri Lanka. Unpublished Ph.D. thesis, Cornell University.

Case Study #7: Tungabhadra Pilot Irrigation Project, India

Tungabhadra Irrigation Project straddles the borders of Karnataka and Andhra Pradesh States in India, with a total command area of 510,000 ha. The Left Bank Command Area, studied in a collaborative project between the Command Area Development Authority and ILRI supported by Dutch Government funding, covers 244,000 ha.

The main Left Bank canal has a total length of 227 km, with 106 secondary offtakes. The command areas of these offtakes range from 50 to 35,000 ha. The main canal is lined throughout its length, while all other canals are essentially unlined. Each secondary is controlled by a gated culvert. There are four cross-regulators in the main canal. In secondaries there are no gated cross-regulators, but some drop structures exist that help stabilize water levels.

Water deliveries into each watercourse is also through a gated culvert, typically commanding 40-60 ha but sometimes as large as 200 ha. There are no structures within the watercourse distribution system.

Water allocations are protective in that water is insufficient to meet all demand. Typically they average 0.40 to 1.08 l/sec/ha, depending on the season and the crop to be grown. There is also a policy of localization that determines cropping patterns: 45% cropping intensity in the wet season (of which only 20% is to be rice), 37% in the dry season (none of which is supposed to be rice), plus 18% of perennial crops, notably sugar and cotton. Although this should result in an annual cropping intensity of 100% over two seasons, actual cropping intensity is about 67%, of which one third is rice.

References:

Jurriens, M., V. Ramaiah and J.G. van Alphen (1987) Irrigation water management in the Tungabhadra Scheme, India. ILRI Annual Report 22-32

Jurriens, M. and V. Ramaiah (1988) Water distribution in a secondary irrigation canal: results of a measurement program. ILRI Annual Report 35-36

Jurriens, M. and W. Landstra (1990) Tungabhadra Irrigation Pilot Project: Final Report Conclusions and Recommendations. ILRI, Wageningen.

Case Study #8: Hakwatuna Oya, Sri Lanka

Hakwatuna Oya is a 2,100 ha reservoir-backed system in north central Sri Lanka. The system is divided into two parts each with a main canal running along the contour. A series of secondary and tertiary canals offtake directly from the main canal, also of varying command areas controlled by a gated culvert. The Right Bank Main, approximately 13 km long, has no cross-regulation capacity and the head upstream of each offtake is dependent on the discharge released directly from the reservoir. The Left Bank main canal system is somewhat longer, approximately 20 km in total, but is subdivided into three branches with a bifurcation structure at the head of each sub-branch. Between these bifurcations, however, there is no cross-regulation.

A dual stage rotational pattern is adopted in the system in the dry season as storage in the reservoir is normally insufficient for continuous irrigation. The entire system is closed for about 5 days followed by water issues for about 6 days. Within this six day period water is issued to smaller areas in rotation, averaging approximately 80 ha, the rotation attempting to deliver water more or less in proportion to the area served, and rotating water between canals within each rotation period.

References:

Bird, J.D. and M.Y. Zainudeen (1989) Hakwatuna Oya Water Management Study, Sri Lanka: assessment of historical data and performance in Maha 1988/89 season. Hydraulics Research, Wallingford, Report No. OD112.

Bird, J.D., M.R.H. Francis, I.W. Makin and J.A. Weller (1990) Monitoring and evaluation of water distribution: an integral part of irrigation management. FAO Regional Workshop on Improved Irrigation System Performance for sustainable Agriculture, Bangkok, October 1990.

Case Study #9: Lower Chenab Canal, Pakistan

The Gugera Branch canal is a major part of the Lower Chenab Canal irrigation system constructed from 1900-1910. The head of the canal, at Sagar Headworks, where the Upper Gugera Branch starts, serves a total command of at least 1.2 million ha, has 176 distributary canals totalling at least 2800 km, and a Full Design Discharge of 310 m3/sec.

The total length of the canal is over 250 km, terminating at Bhagat Head Regulator in Lower Gugera Division. Along this length there is one major regulator, at Buchiana, where Burala Branch takes off. Otherwise there are virtually no gated cross-regulators but there are several drop structures that serve to stabilize water levels. Most drop structures are associated with scouring on the downstream side.

The high sediment load of the canal means that design velocities are normally more than 1.0 m/sec. This makes it difficult to regulate flows through using stop logs, although it is undertaken on the upstream side of some bridges. The bed level of the canal is in many areas much higher than designed, and freeboard has had to be sacrificed to get full discharge along the canal. Breaches are not uncommon, particularly in Lower Gugera Branch and require major and rapid attention when they do occur.

Most offtakes from Gugera Branch are undershot gated structures. There are some that are proportional dividers, but with a crest level well above that of the canal bed, and some are controlled only by vertical stop logs.

For most of the year the canal is operated at or near Full Supply Discharge, but is closed down for two or more weeks in the winter season for essential maintenance and repairs. The time involved in refilling the canal means that irrigation is effectively stopped for several weeks at the tail, although crop water requirements are very low at this time of year.

Reference:

Vander Velde, E.J. (1990) Performance Assessment in a large irrigation system in Pakistan: opportunities for improvement at the distributary level. FAO Regional Workshop on Improved Irrigation System Performance for sustainable Agriculture, Bangkok, October 1990.

Case Study #10: Lower Talavera River Irrigation System, the Philippines

The basic design of the Lower Talavera River Irrigation System in Central Luzon is very similar to that of Gal Oya in that along the main and secondary ("lateral") canals there is very little cross-regulation capacity. In the wet season this does not provide particular problems because river discharge almost always exceeds the design capacity of the main canal, and canals can be operated at, or close to, design capacity. In the dry season, however, the situation is more difficult because river discharges are low and less reliable, and certain areas cannot be scheduled for irrigation.

In an action research study conducted between 1974 and 1976 by the National Irrigation Administration and the International Rice Research Institute, efforts were made to find alternative ways of operating the system that would result in higher degree of water distribution equity and thus higher production and income for water users.

References:

Greenland, D.J. and D.H. Murray-Rust (1986) Irrigation demand in humid areas. Phil. Trans. R. Soc. Lond. A316, 275-295

Wickham, T.W. and A. Valera (1978) Practices and accountability for better water management. in Irrigation Policy and Management in Southeast Asia, pp 61-75. IRRI, Los Banos.

Case Study #11: Kalankuttiya, Mahaweli 'H' Block, Sri Lanka

Kalankuttiya Branch canal of the Mahaweli H Block was completed during the 1970's. The main canal is 11 km long, serving 20 secondary offtakes. The total command area is 2040 ha.

Discharges in the canal are controlled from a small reservoir supplemented by issues from the upstream portions of the integrated Mahaweli network. This enables plans to be drawn up on a seasonal basis with an indenting system for bulk issues of water into the reservoir.

There are duck-billed weirs immediately downstream of each offtake along the main canal, thereby ensuring stable head conditions on the upstream side of the offtakes. The offtakes themselves are gated culverts, with a broad-crested weir immediately downstream to facilitate discharge measurements.

Tertiary blocks served by a secondary canal are simple gated culverts with no measuring devices. They are designed to deliver approximately 30 l/sec, and an effort was made at the design stage to make tertiary blocks more or less uniform in size at 16 ha.

In the wet season, when water is abundant, the entire area is under rice. There have been major efforts since the system was completed to encourage cultivation of non-rice crops in the dry season, particularly on lighter textured soils, in an effort to avoid water shortages. This strategy has been partially successful, particularly for chili cultivation.

Reference:

IIMI (1989) Study on irrigation systems rehabilitation and improved operations and management. Final Report for ADB Regional Technical Assistance 5273, Volume 1: Rehabilitation and improvement for management.

We are grateful to Dr. R. Sakthivadivel of IIMI for his assistance in providing information included in this case study.

Case Study #12: The Viejo Retamo System, Argentina

Viejo Retamo is a secondary canal within the 74,270 ha Rio Tunuyan irrigation system of central western Argentina. It irrigates 4890 ha divided into 33 tertiary units. Average tertiary unit size is 150 ha, ranging from 30 to over 700 ha.

The head of the secondary canal is controlled by an overflow division structure. However, unlike most overflow structures that have fixed crest lengths, the proportion of flow between the main canal and secondaries is controlled by an adjustable vane. This allows for staggering of irrigation deliveries through the system to reduce peak demand.

Below this head structure, each tertiary block is controlled by a vertical sliding gate and a cross-regulator in the secondary.

There is a strict irrigation schedule based on time. Each tertiary receives two turns a month, with two clusters of two or three tertiaries receiving water at any given moment in time. The rotations turns move sequentially down the canal, and are controlled by a gate keeper employed by the federated water user association.

The simplicity of this system means that all farmers know precisely when water will be delivered, and how much will come in each turn.

The relatively shallow groundwater table, normally within 2.0 m of the surface, means that irrigation only provides a limited proportion of total crop requirements, especially for deep rooted crops.

References:

Bos, M.G. (1990) Developments in Irrigation Performance. FAO Regional Workshop on Improved Irrigation System Performance for sustainable Agriculture, Bangkok, October 1990.

Chambouleyron, J. (1989) The reorganization of water users' associations in Mendoza, Argentina. Irrigation and Drainage Systems 3: 81-94

Case Study #13: Kirindi Oya, Sri Lanka

The Kirindi Oya system in southern Sri Lanka has a command area of 12,900 ha, including 4500 ha of existing irrigated land prior to the project which started in 1986.

The Right Bank Main Canal included for the first time in Sri Lanka a significant increase in gated cross-regulation capacity in the main canal: along the 24.5 km length of this canal, 15 gated cross-regulators were installed making it possible to regulate water levels upstream of virtually all of the offtakes along the lower two thirds of the canal. The canal gradient is low (0.3 m/km) so that cross-regulators can have a significant backwater effect over 2.0 km.

Standard operations generally include rotational deliveries between tertiary canals, because of perennial and chronic shortages of water in the reservoir that have severely restricted the irrigable area in several seasons.

References:

Berthery, D., H. Sally, and J. Arumugam (1989) Mathematical modelling of irrigation canal systems. IIMI Working Paper No. 9

IIMI (1989) Study on irrigation systems rehabilitation and improved operations and management. Final Report for ADB Regional Technical Assistance 5273, Volume 1: Rehabilitation and improvement for management.

We are grateful to Dr. Hilmy Sally of IIMI for his assistance in providing information included in this case study.

Case Study #14: Way Jepara, Indonesia

Way Jepara is a reservoir-backed system in southern Sumatra started in 1981 and designed to irrigate 6,700 ha. By 1989 only about 5,500 ha of the command area had been developed, and some 500 ha was not irrigable due to the collapse of a siphon on the smaller Right Bank Canal.

The system conforms with current design guidelines of the Department of Public Works in Indonesia. Along the main canal their are a series of control structures at which combinations of secondary and tertiary blocks offtake from the main canal. At each structure there is a cross-regulator in the main canal. In some locations the cross-regulator consists of one or more undershot sliding gates, while in other locations cross-regulation is achieved through the use of stop logs that act as overflow weirs. Gates for every secondary and most tertiary canals are Romijn gates, vertically adjustable broad-crested weirs although there are a few tertiaries controlled with undershot sliding gates.

The current operational plan is simple. The entire system is irrigated in the wet season, and all farmers cultivate rice. In the dry season approximately 50% of the area is scheduled for irrigation, again only for rice. However, there is a well-implemented program that the dry season area rotates between the upper and lower half of the system in alternate years. It is a measure of the cooperativeness of farmers in the upper half of the system that when they are not scheduled to receive dry season irrigation they do not interfere with irrigation supplies passing down the main canal to the lower half of the system. Farmers not scheduled for irrigation grow rain fed crops, normally cassava or maize, with good results as rainfall is persistent well into the main dry season.

The system was included within the Asian Development Bank - Ford Foundation grant to IIMI for collaborative studies within Directorate of Irrigation 1, Department of Public Works, and the Lampung Provincial Irrigation Service.

Reference:

IIMI (1989) Efficient Irrigation Management and System Turnover: ADB Technical Assistance TA 937-INO Indonesia. Final Report, Volume 2: Efficient Irrigation Management.

Case Study #15: Maneungteung Irrigation System, Indonesia

Maneungteung Irrigation System is east of Cirebon, West Java. Served by a weir in the Cisanggarung River at Cikeusik and an 8 km long main canal to the head of the system, the total irrigated area is 7611 ha.

The design is essentially the same as that of Way Jepara, although there are rather more sliding gates serving tertiary blocks due to flatter topography in the tail end, and a few secondaries do not have a proper headgate or measuring device.

The tail end portion of the system borders on the Java Sea. It is subject to flooding in the wet season, so that much of the lowest 500 ha has either been abandoned or converted to shrimp farms.

The western third of the system, irrigating 2400 ha, is dominated by sugarcane cultivation, up to 50% of the total area at any one time. The eastern two-thirds, however, have only about 20% of sugar cultivation, much more wet season rice, and extensive onion cultivation that relies on hand irrigation from trenches dug into paddy fields and filled using canal water. There are many shallow wells in the lower third of the system, either relying on hand irrigation or using portable diesel pump sets, to supplement scarce dry season canal supplies.

The system was included within the Asian Development Bank - Ford Foundation grant to IIMI for collaborative studies within Directorate of Irrigation 1, Department of Public Works, and the West Java Provincial Irrigation Service.

References:

IIMI (1989) Efficient Irrigation Management and System Turnover: ADB Technical Assistance TA 937-INO Indonesia. Final Report, Volume 2: Efficient Irrigation Management

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