# Irrigation System Performance Assessment and Diagnosis

# Irrigation System Performance Assessment and Diagnosis

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***Cover:***

The graphs and the chart on the cover illustrate three of the elements essential for assessment and diagnosis of performance in irrigation systems. Access to accurate and reliable ***data*** is the first step. The data then require ***analysis*** to determine actual levels of performance. The third step involves ***decision making*** in response to actual conditions so that performance into the future will continue to improve.

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# PREFACE

THE IRRIGATION SYSTEM Performance Assessment and Diagnosis Project has been undertaken jointly by the International Irrigation Management Institute (IIMI) whose headquarters are based in Colombo, Sri Lanka. and the International Institute for Land Reclamation and Improvement (ILRI) in Wageningen, the Netherlands. Planning and advisory support, have 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.

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# EXECUTIVE SUMMARY

THIS REPORT DESCRIBES the work of a project funded by the Dutch Government to look at issues of performance assessment and diagnosis in irrigation systems in Asia, Africa and South America. It was undertaken jointly by the International Irrigation Management Institute (IIMI), the International Institute for Land Reclamation and Improvement (ILRI) and the Institute for Hydraulic and Environmental Engineering (IHE).

The issue of performance in irrigation is of increasing concern to investors, managers and water users alike. As population increases in a finite world, the need for more effective and efficient use of land and water resources cannot be stressed too strongly. Nevertheless, there is a remarkable lack of a good framework within which irrigation managers can assess performance and diagnose ways to lead to better performance in the future.

Performance is viewed as having two dimensions: the attainment of a specified set of relevant objectives, and doing so with efficient resource use. The framework used in this paper distinguishes between operational performance, primarily the concern with water delivery and agricultural output, and strategic performance that addresses issues of how well decisions are made, given the particular level of physical, financial and human resources available. For both of these aspects of performance, however, emphasis is placed on a cycle of objective setting, planning for implementation, operations, monitoring and control, and periodic evaluation of the management process and review of objectives. Wherever possible, parallels are drawn from the business world where there has traditionally been more concern with performance than is the case in the irrigation sector.

To facilitate comparative assessment of performance across different systems a categorization is made of different types of design of irrigation systems. These include fixed control systems with few or no locations where discharges can be adjusted, and systems with different densities of operable control structures that permit greater control over both discharge and water levels in canals. A categorization is also made of different ways in which water is allocated among potential users, and the rules by which allocations can be temporarily suspended in times of water shortage. These two categorizations are accompanied by a discussion of the institutional and organizational conditions that foster or hinder agencies in attaining higher performance.

This report uses information from 15 case studies where there was reasonably reliable information on water delivery performance. It was not possible to undertake a similar comprehensive analysis of agricultural and economic performance as data were not always available.

The evidence from the case studies is that little systematic measurement of performance is made by system managers. Much of the data referred to is the result of research or other special projects rather than the result of routine activities of irrigation agencies. This by itself is an indication of the lack of importance placed on good performance at system level.

Many of the studies report wide gaps between quantified operational targets and actual conditions, suggesting that there is little feedback from the field, or little capacity to respond to information if it is available.

A significant conclusion is that simplicity both in system design and in system objectives leads to higher levels of performance than does complexity. Although systems with a high density of control structures should achieve higher precision of water control, they rarely appear to do so. This suggests that much of the poor performance identified is the result of weak management by agency personnel rather than anything inherent in the system design. This conclusion is reinforced by a few successful case studies of managerial intervention where performance has dramatically improved.

Based on the case studies, the paper presents a series of propositions that can guide irrigation managers on how to improve performance. Most of these propositions focus on the development of a systematic approach to performance.-oriented management. A conclusion from the paper is that these management improvements can largely, but not always, be achieved without major physical investment. Once managerial capacity has been strengthened and stabilized then the likelihood increases that physical investments will be more worthwhile.

A common thread among almost all the case studies is that there is little evidence of concern for long-term sustainability of irrigatedagriculture. Little attention appears to be paid to threats to the internal resource base of irrigation systems by waterlogging, salinity, water quality, health or inequity. Similarly, existing planning processes show little concern for competition for water and financing with other sectors, changing water supplies through upstream environmental degradation, or tochanges in national policy that may lead to greater accountability for inefficient use of resources.

The report concludes with a brief examination of future activities that can build on the framework and propositions provided.

# CHAPTER 1

# Irrigation System Performance Assessment and Diagnosis

## THE GROWING CONCERN FOR IMPROVEMENT OF IRRIGATION PERFORMANCE

IN RECENT YEARS there has been a growing concern that performance in the context of irrigated agriculture is less than had been anticipated. The anticipated potential through irrigation of land earlier dependent on unpredictable and unreliable rainfall has not always been achieved, and in some respects. irrigation has lost much of its glamour as an investment strategy for developing countries.

The shortfalls in performance can be cited at almost every level of the imgation sector. Those concerned with major lending programs for irrigation, notably the banks and certain bilateral funding agencies, have begun to feel that the return on investment is not really justified. Greater emphasis has been placed on other sectors at the expense of new investment in irrigation, or in the rehabilitation or modernization of existing systems.

Similarly, at system level, there is disappointment in levels of cropping intensity, irrigation intensity and yields from many irrigated areas. The economics of irrigated agriculture are such that many farmers have not been able to achieve a more prosperous and healthy life.

At the level of water distribution there are innumerable references to inequity of water distribution leading to major disparities between head and tail areas, to deficit water supplies and loss of production in some locations, or to excess water delivery and development of waterlogging and salinity in others. Water supplies at any given location are often poorly matched to crop needs, highly variable in both timing and discharge, and are, sometimes, of increasingly poor quality.

These comments serve to highlight two aspects of irrigated agriculture. The first is easily forgotten: without the investments in irrigation over the past hundred years, and especially in the last thirty years in conjunction with agricultural technologies such as high yielding varieties, cheap pumps, and huge increases in fertilizer use, famine would still be the major threat in Asia as much as it is in parts of Africa at the present time. It may be true that the efficiency of water and land resource use for irrigated agriculture is low, but it is a technological package that feeds billions of people.

The second aspect is perhaps more topical. The great increase in awareness in environmental issues, particularly for the conservation of natural resources in the context of a still increasing population, means that the sense of living in a finite world has become increasingly dominant.

Good performance is not only a matter of high output, but also one of efficient use of available resources. This paper looks at ways in which, through the introduction of more performance-oriented management processes, it should be possible to increase both output and sustain these increases into the future.

The examples of perceptions of poor performance given above highlight the relative lack of a consistent framework for assessing performance: individuals and disciplines have their own individual subjective views of what is good and what is poor performance. They are rarely the same for different constituencies, let alone for different individuals. In the same vein, the methods for assessing performance are inconsistent and poorly defined.

This paper is based on a project conceived with the twin objectives of learning from existing case studies and developing a framework that provides for systematic assessment of the actual performance of imgation systems.

## DESCRIPTION OF THE PROJECT AND ITS OBJECTIVES

The primary objective of the Performance Assessment and Diagnosis Project when submitted for consideration by the Dutch Government was to see if it was possible to develop a set of hypotheses that would assist in determining the causes of g o d or bad performance.

Initially seen as a multiyear endeavor, the project was reduced in scope to a six-month effort to look at existing case studies of irrigation performance and to try to elucidate from the data and descriptions provided some of the underlying reasons for the level of performance achieved. To assist in this process, part of the project was designed to try to draw parallels between irrigated agriculture and business management on the basis that business is generally more responsive to performance, at least in financial terms.

If the combination of hypotheses development using case studies and the introduction of assessment processes drawn from business were to be successful, then the project should have the potential to be expanded into a wider and more comprehensive approach to the development of improved performance in irrigation.

The overall principle underlying this project is that while performance of an imgation 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 g o d manager will ensure that the appropriate management strategies adopted are. compatible with both the physical and the 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. A further set of difficulties arose from the case studies themselves: there was a wide variety of system design and operating conditions, a general lack of clearly stated objectives for the systems under study, and significant differences in the amount and type of data reported.

Given these conditions, it was necessary to devote initial efforts to examining 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. Rather than develop definitive hypotheses that can be confirmed or refuted through additional data collection, the emphasis shifted towards developing a set of propositions about the conditions and procedures by which managers should be able to improve system performance. Further, there was a shift in emphasis towards assessment only of water delivery performance because of the scarcity of good comparative data on agricultural, social, economic or environmental objectives and conditions.

A final objective is that the results reported from the study would contribute to the proceedings of the 15th Congress of the International Commission on Irrigation and Drainage to be held in the Hague in September 1993. An earlier draft of this report was presented at the Executive Committee Meeting of the ICID held in Beijing, China in April 1991.

## LAYOUT OF THIS PAPER

The remainder of this paper is divided into eight chapters that follow a logical sequence of establishing a framework for performance assessment, testing it with data from case studies, assessing the validity of the framework, drawing conclusions, and identifying some concerns that need to be addressed in future activities.

The issue of why performance needs to be evaluated is addressed in Chapter 2. By drawing parallels between the world of business management and irrigation management it is possible to adopt some types of assessment undertaken in commercial enterprises 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. The discussion looks at performance as a concept, examines performance indicators and the need to develop standards that provide acceptable ranges of values for those indicators, and describes an assessment framework that can be adopted by irrigation managers in moving towards the development of institutional capacity to respond to actual performance.

This is followed in Chapter 3 by a broad classification of the main types of design of irrigation systems, and how the design may affect management decisions. For each design a description is provided of the primary characteristics of the physical irrigation infrastructure and the typical water allocation principles that are appropriate to those designs. A separate description is given of some of the organizational and institutional conditions that may hinder or favor moves to more performance-responsive management. This part of the work concludes by looking at issues of setting objectives for a system and the need to address interrelationships between design and the management of operations and maintenance.

The first set of 5 case studies, presented in Chapter 4, provides details on performance in respect of adequacy, equity and reliability from systems that are designed to divide. water as far as possible without operational inputs. These can be seen as supply-driven systems insofar as they normally have no control capacity that managers can use to respond to relative small or short-term changes in demand for water. Two design variants are included in the analysis: systems designed to divide water in a fixed percentage using simple overflow weirs. and more complex systems that use submerged orifices to control the discharge into each offtake.

The second set of 10 case studies, presented in Chapter 5, addresses the same set of issues in systems designed for greater operational control and flexibility. All of the systems included in this discussion have gated offtake structures at the head of every secondary canal and at the head of each teniary block. This additional level of control means that, at least in theory, managers can respond more effectively to changes in both water supply and demand if they are successful then the potential for more efficient use of water should be realized but if they are not, then the opportunities for mismanagement are greater than in simpler systems. Three design variants are distinguished: those with no cross-regulation capacity, those with fixed weir cross-regulation, and those with adjustable gated cross-regulators.

Following the presentation of the case studies, Chapter 6 provides a discussion of the primary interpretation of the results. The overall conclusions drawn at this stage are that few of the case studies show much evidence of having adopted a systematic framework for performance: instead, systems seem either not to have clearly stated objectives or, at best, are only concerned with a single objective; operational targets do not appear to lead towards the stated objectives; and actual performance shows large differences between expected and actual conditions in most of the case studies.

Chapter 7 describes a set of propositions for an overall performance-oriented management framework that. if followed, provides the basis for achieving improved performance. 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 the management of the system.

Although few of the case studies deal explicitly with environmental or resource utilization issues, Chapter 8 briefly examines the importance of assessing performance in respect of nonagricultural conditions including sustainability of physical resources, health, and income distribution. It also raises some general issues of how well systems respond to external changes such as changing agricultural targets and increased competition for water, land and labor resources.

The overall conclusions are presented in Chapter 9. These include the recognition that in most systems there is no effective framework for performance assessment. no clearly stated objectives or no effective distinguishing between local and national concerns, and that institutional and organizational impacts on performance are rarely discussed. The systems that perform best under present institutional conditions are often those that are simple, either in design of physical infrastructure or in operational rules. The chapter concludes with a brief description of some future opportunities to develop a better framework for performance assessment that will include a wider set of objectives dealing not only with water but with other concerns including agricultural performance, improvements in economic and social well-being, and those having a concern for long-term impacts on the environment.

# CHAPTER 2

# Performance, Performance Indicators and Performance Frameworks

## RESOURCE USE AND PERFORMANCE

THE EXPLOITATION AND utilization of water for irrigation require that there are periodic evaluations of its utility and efficiency of use. This concern with performance within the irrigation sector is increasing as pressure grows on water resources in all parts of the world, and as concerns increase regarding the sustainability of irrigated agriculture systems. 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 rain-fed 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 it has a stake. To do this these groups 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.

## 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, and 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 rain-fed 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 a different assessment time frame. These ideas are discussed further by Small and Svendsen (1992) in their paper on ***A framework for assessing irrigation performance*** at different levels of a nested hierarchy that ranges from the irrigation system to the national social and political system.

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 ***operational performance*** and ***strategic performance.***

> ***Operational performance*** is the degree of fulfillment of either a ***specific quantified output target,*** typified by such things as yield, water use efficiency, and cropping intensity, or a ***specific input target*** such as discharge, water level or timing of irrigation deliveries. Foncomparative purposes between systems, output performance is frequently best expressed as a dimensionless ratio, or percentage. More commonly the output itself is treated as a measure of performance, but this does not favor comparison because of a host of site-specific influences: simple comparison of yields between different systems may not make much sense without knowing a great deal more about potential or possible performance levels that could be expected. Within the bounds of a single system, however, actual values are useful when treated as a time sequence, on the assumption that managers either try to increase certain factors such as yield or water use efficiency, or act to minimize others, such as poor water quality or other signs of potential environmental degradation.
>
> The same is true for inputs. At any given location a time series analysis of real values may be the most useful measure of performance, but dimensionless ratios are more effective in comparing performance at different locations during the same time period.
>
> ***Strategic performance*** 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 both available resources and the objective setting process. This means that it includes evaluation of performance of individuals in matching objectives and targets, in identifying and utilizing performance parameters that effectively reflect those objectives, and in responding to unexpected changes in resource availability. While assessment of managerial performance is less neutral and more individual than assessment of output performance. it may more clearly identify ways in which performance can be improved.

The third issue arising from Abernethy's definition is the change in performance expectations over time. An effective management system has to adjust to changes both in the external environment and within the system, and also 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 objectives.

These comments notwithstanding, 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 nonprofit, 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. To facilitate this process 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.

At this point, it is important to make a distinction between objectives and targets as they represent different aspects of the manager's task. The definitions used in this paper are as follows:

*An objective is a broad goal that reflects the overall purpose of the irrigation system or the sector within which the irrigation system falls. Typically, objectives are not precise, exemplified by such phrases as crop diversification, equity, adequacy, or sustainability.*

Defining objectives such as these is the starting point for system managers to develop shorter-term operational plans that can be monitored and controlled. For this reason it is important to have tangible or quantitative targets.

*A target is a specific value of something that can be measured: it provides operational staff with information on the desired conditions that should be met if the objective is to be fulfilled.*

For an objective such as equity of water distribution, for example, specific discharge targets at each control or measurement point need to be developed so that each gatekeeper can work in isolation to meet a specific numerical discharge target and yet simultaneously be fulfilling the overall equity objective for the system. Deviations from the target provide quick feedback to managers as to the extent to which the overall objective is being fulfilled, through the use of performance indicators.

*Performance indicators do more than measure the value of a particular item such as yield or canal discharge. They have to include a measure of quality as well as of quantity, and be accompanied by appropriate standards or permissible tolerances.*

***If the value of the indicator falls outside a particular range of values then performance is presumed to be unsatisfactory.***

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.

## 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. The development of performance indicators that can be applied to irrigation systems worldwide. The performances of a particular system can then be compared with performances of similar systems elsewhere. Bos and Nugteren (1974) followed this approach for irrigation efficiencies, using qualitative and quantitative data. Small and Svendsen (1992) 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. The comparison of actual results with what was planned. Figure **2.1.** from Wolters and 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.

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.

# PERFORMANCE INDICATORS IN BUSINESS

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 and Reece (1983) describe as

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

Within this overall concern for management accounting it is useful to distinguish between different types and levels of performance, each requiring different assessment procedures and indicators.

## 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:

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

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 year's overall performance of the business they have invested in with those in other years, or those 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 shares 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, purchase of goods and services for resale or manufacturing, payment of wages, interest expenses, research and 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.

## Operational Control

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

Business managers make plans for providing products or services that will contribute to the overall net profit of 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 dafa 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 those standards 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. In so doing, however, there is little or no expectation of changing the overall purpose or direction of the enterprise: in other words, the objectives do not get changed every time there is an operational shortfall.

This process is essentially the same as the one in Figure 2.1 which depicts the irrigation water management process. Operational management of irrigation systems is not significantly different from any other enterprise except that rather than dealing with profit, the emphasis is on achieving Specific targets. The process is identical for assessment of seasonal or annual performance and for assessment of water delivery performance on a short-term basis.

Drawing up operational performance standards that accompany the targets set by managers serves several purposes (Anthony and 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 acfivities.

5. As a basis for evaluating the performance of individual managers and employees, and

6. As a way to develop insights into the detailed workings of the various parts of the organization and their interrelationships.

A weakness in irrigation management compared to business enterprises is that there appears to be less concern with standards. In most irrigation systems discharge targets are given to gatekeepers but no parallel information is readily available to indicate the permissible level of deviation. Such a lack of standards immediately makes the process of operational control much more difficult because all deviations are treated as an equal error irrespective of the actual value of the deviation. and little effort is made to rectify management at those locations where deviations are first encountered.

## Strategic Control

In a well-managed business there is a parallel process of strategic review and decision making that examines whether the fulfillment of targets is actually fulfilling overall objectives. The senior management of a business enterprise periodically reviews the degree of performance of individual components of the enterprise, and makes strategic decisions that will help to address deficiencies. These strategic decisions might include dropping an unprofitable line or product from the overall range, reorganization to make interrelationships between different divisions more effective, dismissal of inefficient managers or operators, or investment in new technology. Failure to do so may lead to a business becoming out of touch with its customers, and inefficient in resource use. Ultimately it will go bankrupt.

Whatever the measure, the process by its very nature requires an evaluation not merely of operational performance but of the objectives of the company itself. Further, the environment within which a particular company operates is not static: consumer choices change over time, there may be new policies or legislation that force companies to modify existing operations, or there may be changes in the relative price of inputs that require rethinking of efficiency.

Put in another way, the process of strategic control simultaneously asks two questions:

***"Am I doing things righf?"*** (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 the overall performance of an enterprise in respect of both output or services provided and the internal management performance of the company.

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.

## Using 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. The closest parallel to this in irrigation is water rights or some similar process of allocating resources between users, with an annual accounting that clearly shows whether the right has been properly satisfied.

2. They require businesses to maintain a detailed and accurate record of day-to-day transactions, both for reporting and for evaluation purposes. Similarly, for irrigation, determination of whether a water right is satisfied annually or seasonally requires daily or weekly discharge deliveries to different locations in the system.

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:

   a. 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 the same type of business.

   b. During implementation, the model is tested and refined, through constant monitoring of operational performance and measurement of its contribution to the overall result.

   c. 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.

   This type of performance-responsive framework is not unique to business: it represents a cyclical precess of planning, implementing, monitoring and control, and review and evaluation (Murray-Rust 1992).

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 take 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, there is still a process of accountability built into the system to ensure that efficiency levels are acceptable.

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 aansfer at least some of the lessons from business to irrigation management in respect of provision of service rather than of making profits.

## PERFORMANCE IN IRRIGATED AGRICULTURE.

### An Overall Framework for Performance Assessment and 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 2.3 presents a summary of the paths by which a diagnosis could be undertaken. By asking a series of questions that help to identify 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 require priority attention if performance is to be improved.

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 are not available, then there is no possibility of making a careful analysis of the problem:

> ***If, and only if, the appropriate data are 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 database was inadequate. Personal experiences at field and system level suggest that many irrigation agencies do not keep good records of field-level conditions: indeed, most of the case studies are based on research activities specifically designed to measure real life performance.

## Target and Objective Achievement

A fundamental characteristic of the process summarized in Figure 2.3 is that information on outputs from the system is not used as the end result, but as the first step in assessing system management. 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 a 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.

As an example of the difficulties faced in undertaking performance assessment studies, it is salutary to recall that Yudelman (1985), 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.***

We have seen earlier that in a business environment nothing is obtained by setting standards higher than what can realistically be achieved within the concept of overall profitability. Setting unrealistic standards in the planning stage may lead to wrong investment decisions, which undermine 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 to 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.

To do so requires a clearer definition of what the organization really is, and who are the different customers whose interests *are,* presumably, taken into account by managers within the agencies or organizations responsible for irrigation.

## Organizations and Customers in Irrigation

As discussed earlier, Ansoff (1979) 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*** ?

Organizationally, the irrigated agriculture system is frequently divided hierarchically by basic functions required at each level. IIMI's current strategy document clearly indicates that overall performance requires attention to three different levels (IIMI 1992). These parallel the **nested** hierarchy of Small and Svendsen (1992).

At the highest level, frequently referred to as the ***irrigation sector.*** the primary constituents are policymakers who are concerned with the overall performance of the sector vis-a-vis other sectors. This may well affect decisions on 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 to industry or urban growth. These sector-level planners must also 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 are often 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 dismcts 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, managers are viewed as synonymous with the system-level engineers within the irrigation agency, although a significant percentage of the total irrigated area in many countries is operated and maintained by farmers. Management of larger systems is normally geared towards the 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.

There is also a similar range of customers. Just as a business has a range of different customers and stakeholders (consumers, shareholders, Board of Directors and bankers), irrigated agriculture has a similar range.

The ultimate customers of irrigated agriculture are the consumers of agricultural products. At the level of the irrigation system the customers are the farmers. Irrigation agencies are designed specifically to either deliver water as a service, or to sell it to make an operatingprofit, and must thus treat farmers as the primary customer.

A different set of stakeholders are individuals within agencies who are concerned with job security, promotion. pay, or professional recognition and who are dependent on the effective performance of the irrigation organization at different levels to meet these aspirations.

Many irrigation systems are evaluated in terms that satisfy donors or investors who provide the initial capital for system construction, renovation or modernization or, to a lesser extent, for operational costs. The evaluation may be narrowly focused, such as the cost-effectiveness of a particular system or may look at broader contributions to the national wealth.

Finally, and increasingly important, is a recognition that future generations are legitimate customers: they have a right to expect that the current generation will manage resources sufficiently carefully that there is no overall degradation or loss of potential of the natural resource base.

## FOCUSING ON IRRIGATION SYSTEM PERFORMANCE

This study is not a full evaluation of performance at all levels of the irrigation sector. It focuses on the issue of management of the main system and, in particular. on 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, whom we consider as ***their customers.*** The way we distinguish between main system managers and their customers differs from the role distinctions made by Small and Svendsen (1992):

> ***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 parallel with business 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 fanners from certain important decision-making processes: identification of seasonal or annual objectives, determination of concepts of equity, and concurrence with proposals forxhedulingofdeliveries, but does requireoperational division between the roles of irrigation agencies and farmers.

There **are,** of **course,** also farmer-managed irrigation systems. This does not present a major conceptual difficulty: in those cases fanners are the managers of the main system and at the **same** time they **arc** their own customers. Planning and decisions **on** how **to share** water at system level **are** undertaken **as** a collective activity while individuals manage 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 fanners' needs, within the limitations imposed by national policies and objectives and by overall resource availability; 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 viewed as a free good.

Thelackofadirecteconomic linkagebetween managers' performance and the needs and requirements of fanners means that a 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 irrigation system managers, the expected service must be clearly defined. The process by which service criteria are established is essentially one of negotiation. We shall not attempt to give general guidelines on how this negotiation needs to be conducted nor 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 to be used to measure the adequacy of the services provided by the irrigation system managers,

* the methods to 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, and
* the consequences of not meeting the agreed performance standards.

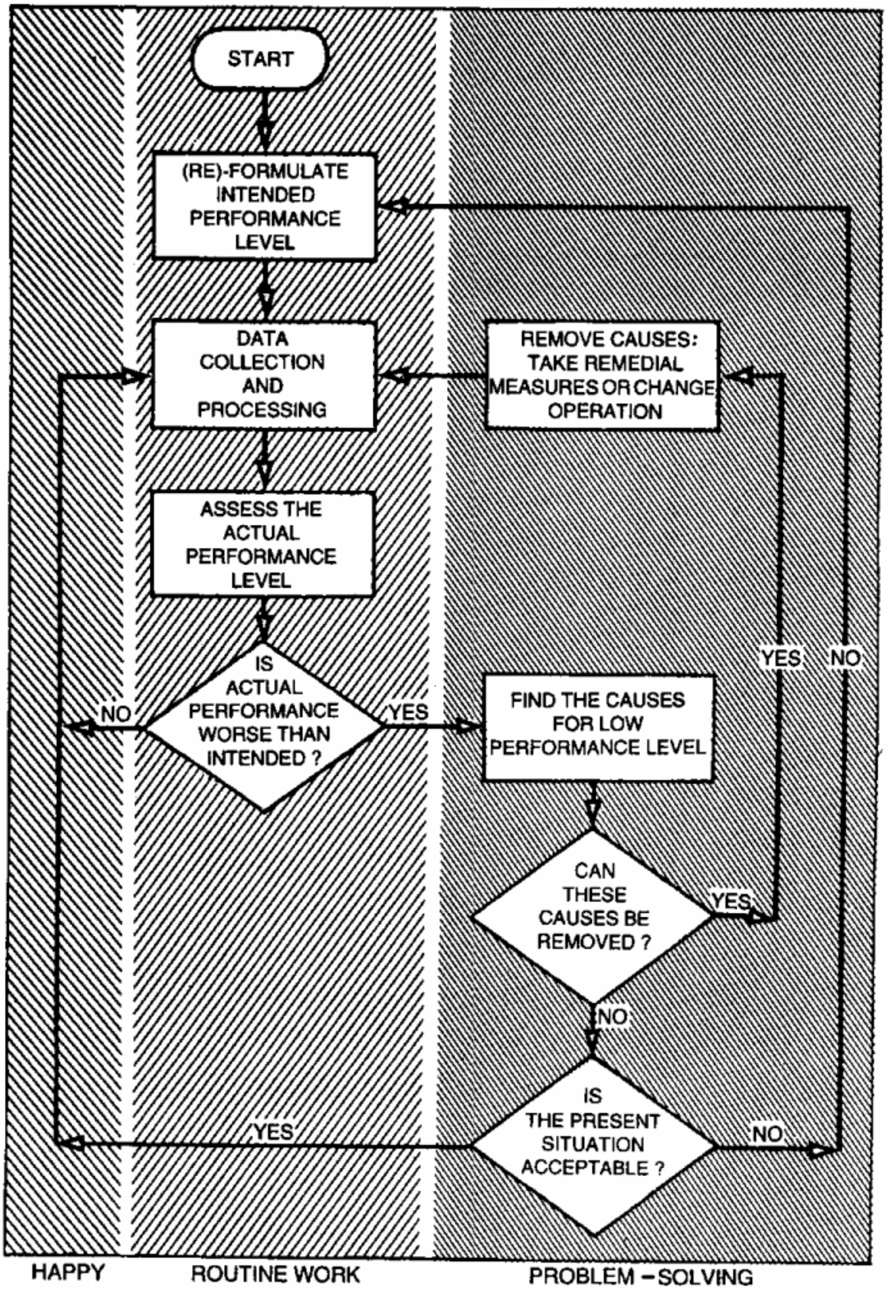
However, there is no infinite degree of flexibility for either managers or water users:

*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.

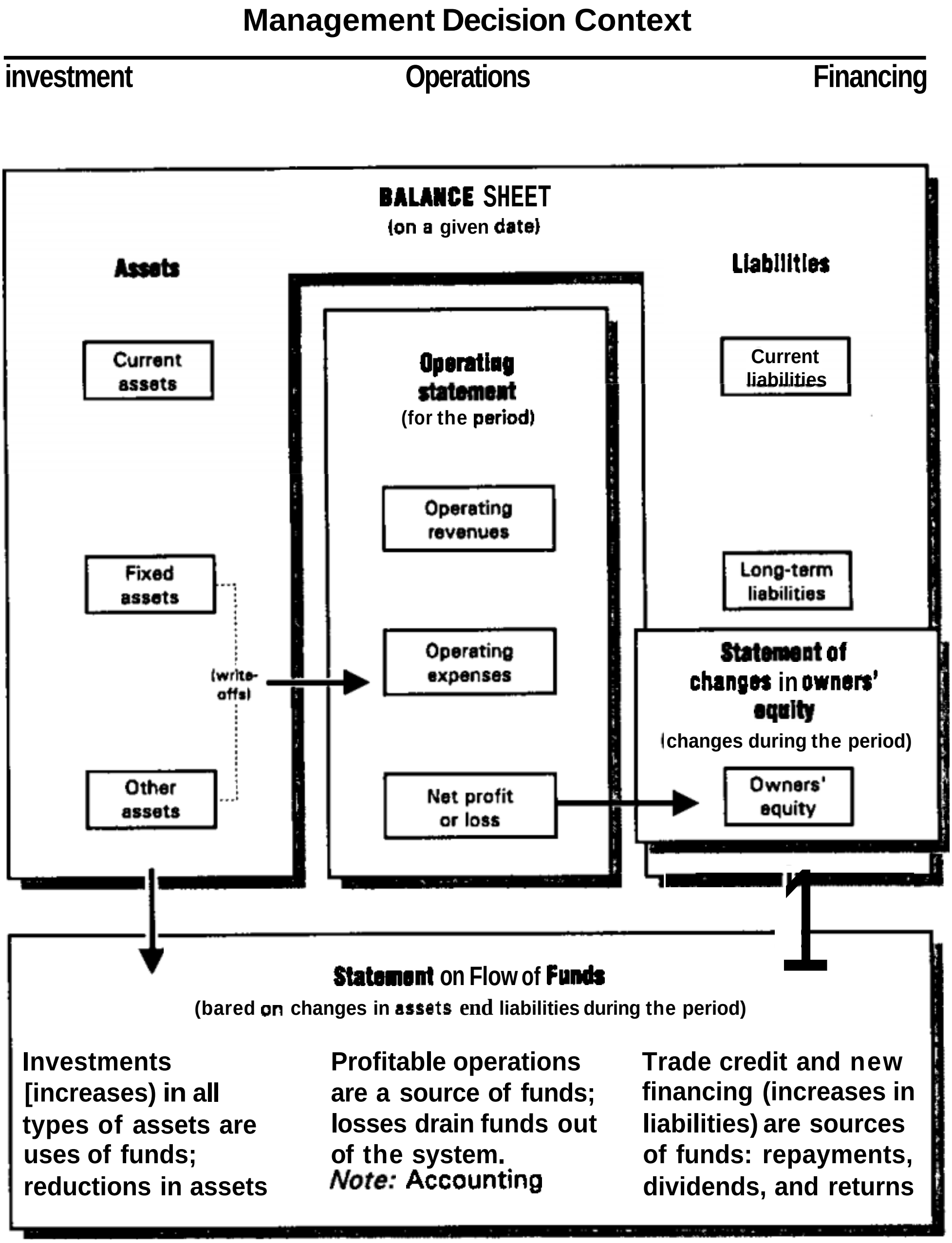
Before proceeding to performance from selected case studies, presented in Chapters 4 and 5, the next chapter looks at different design environments in terms of their potential for managers to provide different types of service, which in turn will affect the level of performance that can be achieved.

*Figure 2.1. A simple flow chart of irrigation water management.*



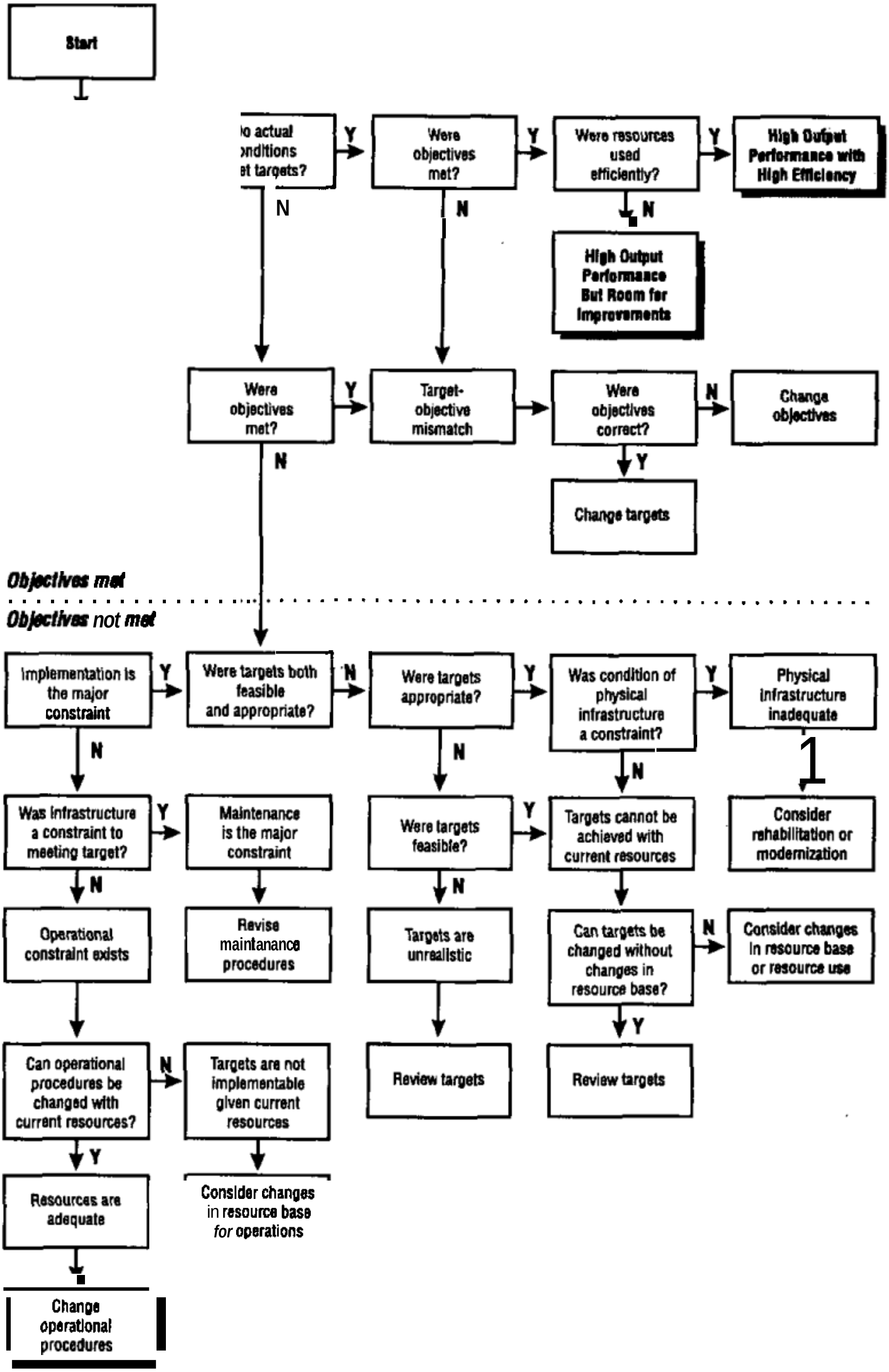

*Source:* Wolters and Bos, 1990.

*Figure 2.2. Generalized overview of financial statements.*




Source: *Arthur* Helfert, 1987.

*Figure 2.3. Flowchart to show process of performance assessment and diagnosis.*



# CHAPTER 3

# Design-Management Environments and Irrigation System Management Objectives

## DESIGN-MANAGEMENT ENVIRONMENTS

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 two primary conditions which cannot be changed in the short run:

* 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; and
* 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 degree to which the manager can or cannot make short-term adjustments is affected by 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.

The 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 chapter 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.

## PHYSICAL DESIGN OF CANAL IRRIGATION SYSTEMS

Variations in each of the components of the design-management environment have significant impacts on 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.

### Upstream Control Systems

Upstream control systems comprise the vast majority of irrigation systems in the world. Upstream control means that discharge or water level is controlled by operating a gate at the upper end of a canal or a canal reach. Operation of gates further downstream does not affect the upstream inflow condition. 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.

***Fixed division*** systems are those where water can only be managed at the head of the canal; discharges into subsidiary canals or offtakes along the canal are achieved through fixed division structures that do not have gates.

Two design variations exist within this class of systems that cater for different water allocation principles. Water division is done either by:

* 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; or by
* submerged orifices that are designed to deliver a relatively constant discharge into the offtake over a range of different water levels on the upstream side of the offtake.

***Gated division systems*** have gates at each offtake along the canal, allowing water to be manually controlled 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 the 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 tornanage water levels irrespective of the actual discharge.

## Downstream Control Systems

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 changes in water level and send signals to electrically operated gates. The choice of technology adopted does not affect the purpose of the system.

This report does not include assessment of performance in downstream control systems. At the time of writing there were insufficient data to permit a proper comparison with upstream control systems. It is strongly hoped that such a study can be initiated in the near future.

# WATER ALLOCATION PRINCIPLES

An essential component of the design phase is knowledge of the principle by which water will be allocated between individuals or groups of water users. Simple and static water allocation rules may be supported by simple designs, while complex rules may require complex systems for water control. Water allocation is normally defined by two sets of rules. The first set of rules determines the principles by which water will be shared between individuals, and forms 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 determines the overall right to water in each system, at any given moment in time: the rules have to be clearly known before any assessment can be made of performance related to water distribution.

## 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. Different bases for defining water rights include:

* ***Share per unil 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 unil area,*** where water is delivered volumetrically in proportion to the potential irrigable area;

* ***Fired 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 any 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 the local power structures: in some cases it may be anarchic, in others it may rely on a process of frequent negotiations that reestablishes or reaffirms traditional rights.

## 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; and

* *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.

# INSTITUTIONAL AND ORGANIZATIONAL CONDITIONS

As discussed under Design Management Environments (at the beginning of Chapter 3) 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 case studies used in this report rarely describe institutional or organizational conditions. It is therefaredifficult to make a specific categorization of these aspects. Obviously 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. Conditions that affect management capacity include:

## 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, particularly where more sophisticated infrastructure is involved. Maintenance skill levels are higher for automated or hydraulically controlled gates than for simpler control facilities.

## Financial Resources

The annual allocation of financial resources for operation 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.

## 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 operation 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; this may 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 further reducing 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.

## 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.

## 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.

## Incentives and Accountability

Perhaps the most important aspect of all of the institutional conditions 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.

# 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 subsection addresses some of the more important ways in which the design of the system interacts with management requirements.

## 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 fanners 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 fanners 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.

## Reliability

Reliability 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.

## 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 division 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 canals rather than between tertiary offtakes.

**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.

## 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.

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.*** 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 smaller variations in discharges as upstream water conditions fluctuate 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 and 100% of design), and discharge fluctuations kept to a minimum.

***Gated division systems.*** 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 among agency staff and between agency staff and fanners. 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.

It is possible at the design stage 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 staffmg 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.

## 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.

Maintenance is required for three different purposes: minimizing conveyance losses, prevention of failure of 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 relate to 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 control structures.*** Maintenance intensities for prevention of failure of control structures are also easy to quantify, and are constant for each system. The intensities increase as the number of control structures increases. Maintenance is critical: for automatic systems and instantaneous demand systems 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 rhe 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 syslems with little or no cross-regulation means that head-discharge relationships at offtakes will be different from 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.

## ASSESSING PERFORMANCE IN DIFFERENT DESIGN ENVIRONMENTS

The discussion in this chapter 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:

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

2. 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?

3. 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 two chapters. Chapter 4 focuses on fixed control systems where the opportunity for operational inputs is limited but the potential for changing performance through management of maintenance is high. Chapter 5 looks at gated control systems where both operational and maintenance inputs affect performance. For obvious reasons not all questions could be satisfactorily answered because there was not always sufficient information provided.

*Table 3.1. Potential system management objectives for different designs.*

| | Reliability | Adequacy | Equity |
|---|---|---|---|
| Ungated overflow | † | — | ‡ |
| Submerged orifice | † | — | ‡ |
| Gated little cross-regulation | † | t | † |
| Gated, fixed weir cross-regulation | † | t | † |
| Gated, adjustable cross-regulation | ‡ | ‡ | ‡ |
| Downstream control | ‡ | ‡ | — |

Key to symbols: ‡ very important † important — no concern

*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 | t | · | — | (†) | — |
| Submerged orifice | t | — | — | ‡ | — |
| Gates, little cross-regulation | t | t | — | † | † |
| Gated, fixed weir cross-regulation | t | t | — | (†) | † |
| Gated, adjustable cross-regulation | t | t | † | (†) | † |
| Downstream control | — | — | — | (†) | ‡ |

Key to symbols: ‡ critical † important (†) lo avoid losses — no input

# CHAPTER 4

# Performance in Fixed Division Systems

## DESIGN DIFFERENCES IN FIXED DMSION SYSTEMS

As DESCRIBED IN Chapter 3, fixed division systems incorporate the water allocation principle into the design so as to eliminate as far as possible the need for operational inputs below the head gate controlling discharge into the canal.

There are two basic subdivisions of fixed division systems: overflow systems where all water division is at weir structures, and submerged orifice systems where control is determined by the relationship between water level upstream of the orifice, the dimensions of the orifice, and in some cases the downstream water level on the downstream side of the orifice as well.

These two design variants cater for different water allocation principles. Overflow systems always divide water in exact proportion to the width of the weir, and the percentage delivered to each canal below the weir remains unchanged. In submerged orifice systems, however, the percent of total flow diverted through an offtake will vary iftheupstream water level varies. This means that unless the water level is constant, there will be some inequity in water deliveries.

## FIXED OVERFLOW SYSTEMS

This type of design meets the two main setsofcriteriaviewed as important in farmer-managed irrigation 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. 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; agricultural benefits have to be assessed in the context of utilization of water by farmer groups and individuals, not by system managers. There are few detailed studies of this type of system 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. All casestudiesreferred to in this chapter and Chapter 5 aredescribed in moredetail 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 Figures 4.1 a and b, which show 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 the 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 percent 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 subcommand 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 percent 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 80percent of the area. water distribution is conuolled 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 as the result of modifications to division structures to allow more water to pass along the canal than was originally intended.

## Adequacy

Adequacy in run-of-the-river systems (the Nepal and Indonesian cases) is dependent on river discharge. There is little farmers can do if the river discharge falls below total demand for water, although excess water can readily be passed down the river rather than being diverted into the system where it is not needed. 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 (Figures 4.2 a and 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 and do not divert excess water into the canal. Smaller systems in the hills tend to have lower RWS values, 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.

Within the systems, however, adequacy shows a distinctly different pattern. The variation of WAI between adjacent farms is high, irrespective of whether the plots are near to or far from the head of the system. The Interquartile Ratios for the best 25 percent and worst 25 percent 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 landowners 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.

In the Fayoum there is no intention *to* meet the total potential crop water demand. Water rights represent an allocation of a share of total water available, and is intended to be less than farmers might require to cultivate all their lands under the most water-demanding cropping pattern. With water effectively rationed by the system demand, adequacy is controlled by the farmers' cropping pattern choices and is not included in the system manager's set of operational objectives.

## Reliability

Fixed overflow designs provide little opportunity to manage reliability below the head gate controlling flow into the canal. The systems are highly dependent on the water conditions upstream of the head gale. In the Nepal cases it is clear that weekly RWS at the head of the system varies greatly (Figures 4.2 a and b), so that in any week it is difficult for farmers to predict how much water they will obtain. In Cipasir there are no flow data available. In the Fayoum, discharges into each subsystem will be reliable as long as discharges into the main canal are uniform.

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. None of the case studies provided information on tertiary-level management arrangements in this regard.

## SUBMERGED ORIFICE SYSTEMS

Submerged orifice systems have the hydraulic capacity to deliver a reasonably uniform discharge into a tertiary offtake over a range of different operating heads on the upstream side of the offtake. 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.*** 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 percent 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 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 the secondaries included in the Lower Chenab System (Case Study #4) sedimentation is a major problem. In canals that have not undergone periodic desilting the changed cross section results in a failure to meet target discharges into offtakes. In headends, the increased bed level means that the head upstream of orifices is higher than designed, even when the target discharge into the secondary is achieved: discharges through head-end orifices are typically 150-2200 percent of design. As long as the 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 the 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 focused 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 in Lagar Distributary following desilting appears to be the result of differences between the intended size and elevation of 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 installations 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 percent of Full Supply Discharge (FSD) the IQR was 5.03. When incoming discharges were at 60 percent the IQR rose to 44.15 because the last 20 percent of the canal received no water at all, while the upper half of the outlets still received more than the designed discharge. In the worst case, when discharges were only 25 percent of FSD, no water passed the halfway point of the canal and no outlets received their design discharges.

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

## Adequacy

The designers of the Punjab irrigation systems never intended to include adequacy in their calculations in determining discharges at each orifice. The design principle merely attempted to deliver a little water to as many farmers as possible, with planned annual cropping intensities of 50–75 percent.

To complicate matters further, throughout the Punjab, farmers and irrigation agencies have taken advantage of new technology to pump both shallow and deep groundwater. It is common to find that over 60 percent of all water used is pumped, making it impossible to assess adequacy of canal water delivery in isolation.

## Reliability

The impact of these operational inputs on reliability at tertiary level can be seen through an 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 is intended to share water deficits equally between all watercourses.

There is an enormous spatial variation in access to reliable canal supplies. Tail-end farmers get not only less water, but less reliable water deliveries as well. The causes of this lack of reliability are the same as those for equity: canals are poorly maintained so that tail-end areas are deprived of water, and there is weak management that permits discharges to be delivered far below the minimum stated in operational guidelines.

*Table 4.1. Interquartile ratio (IQR) of water availability index (WAI) in six small schemes in Nepal.*

| Location of system | Hills | | | Terai | | |
|---|---|---|---|---|---|---|
| | 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 | I54 | 186 |
| Tail 25% | 151 | 154 | 141 | I49 | 135 | 162 |
| IQR | 1.06 | 1.15 | 1.19 | 1.15 | 1.10 | 1.15 |
| | (b) Independent of distance | | | | | |
| WAI highest 25% | 195 | 173 | I77 | 162 | I70 | 199 |
| WAI lowest 25% | I24 | 127 | 130 | 138 | I20 | 158 |

*Table 4.2. Water supply along Wahby and Bahr Seila relative to total Fayoum water supply (May 1986)*

| Area | Discharge ($m^3/s$) | 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.I | 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 Wahr Wahhy 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 |

*otes:* d/s = downstream; u/s = upstr 1.
*urce:* Wolters et al. (1987).

*Figure 4.1a. Relationship between distance and water availability index (WAI) in three Terai systems in Nepal.*

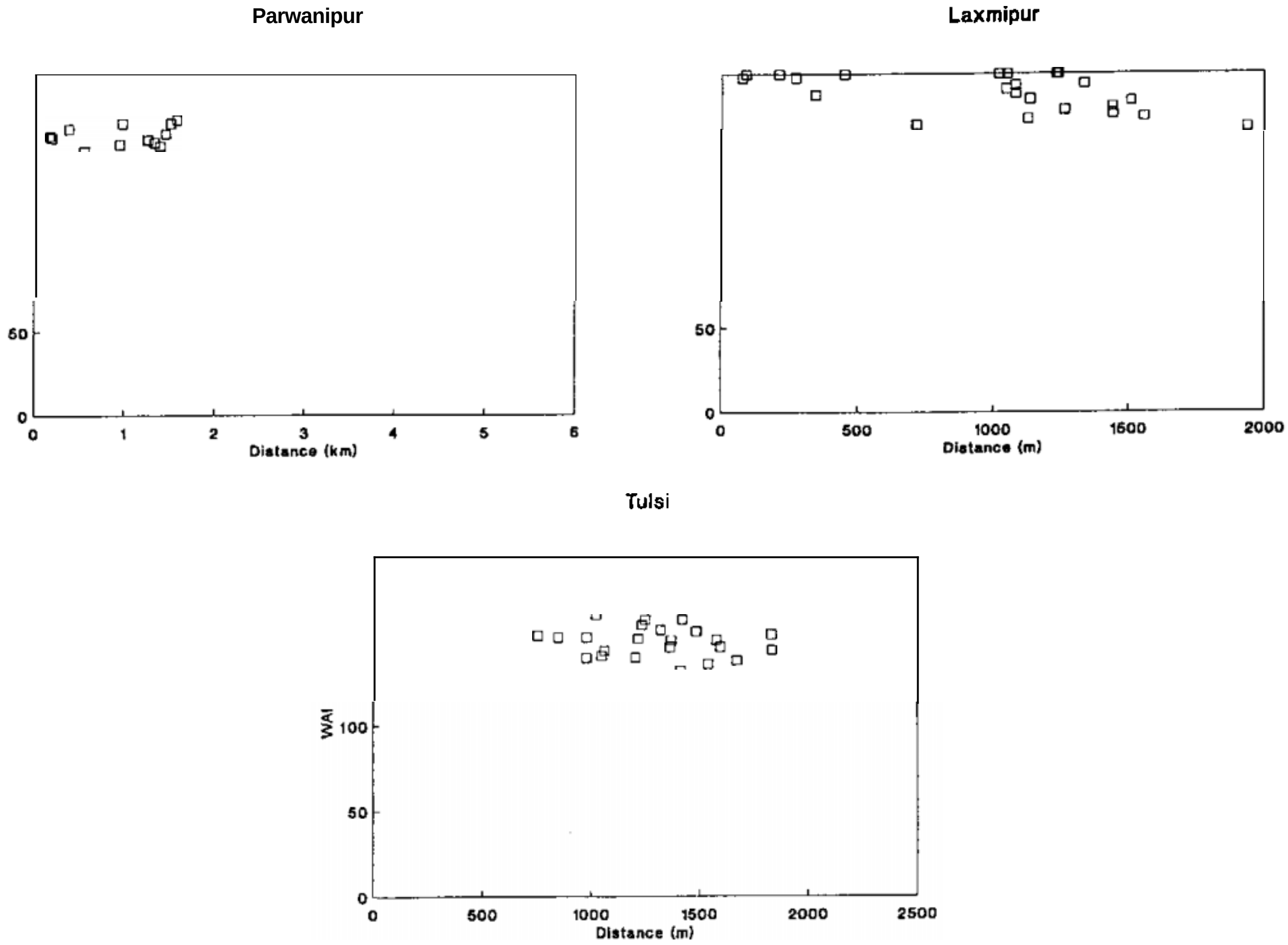


*Figure 4.1b. Relationship between distance and water availability index (WAI) in three hill systems in Nepal.*

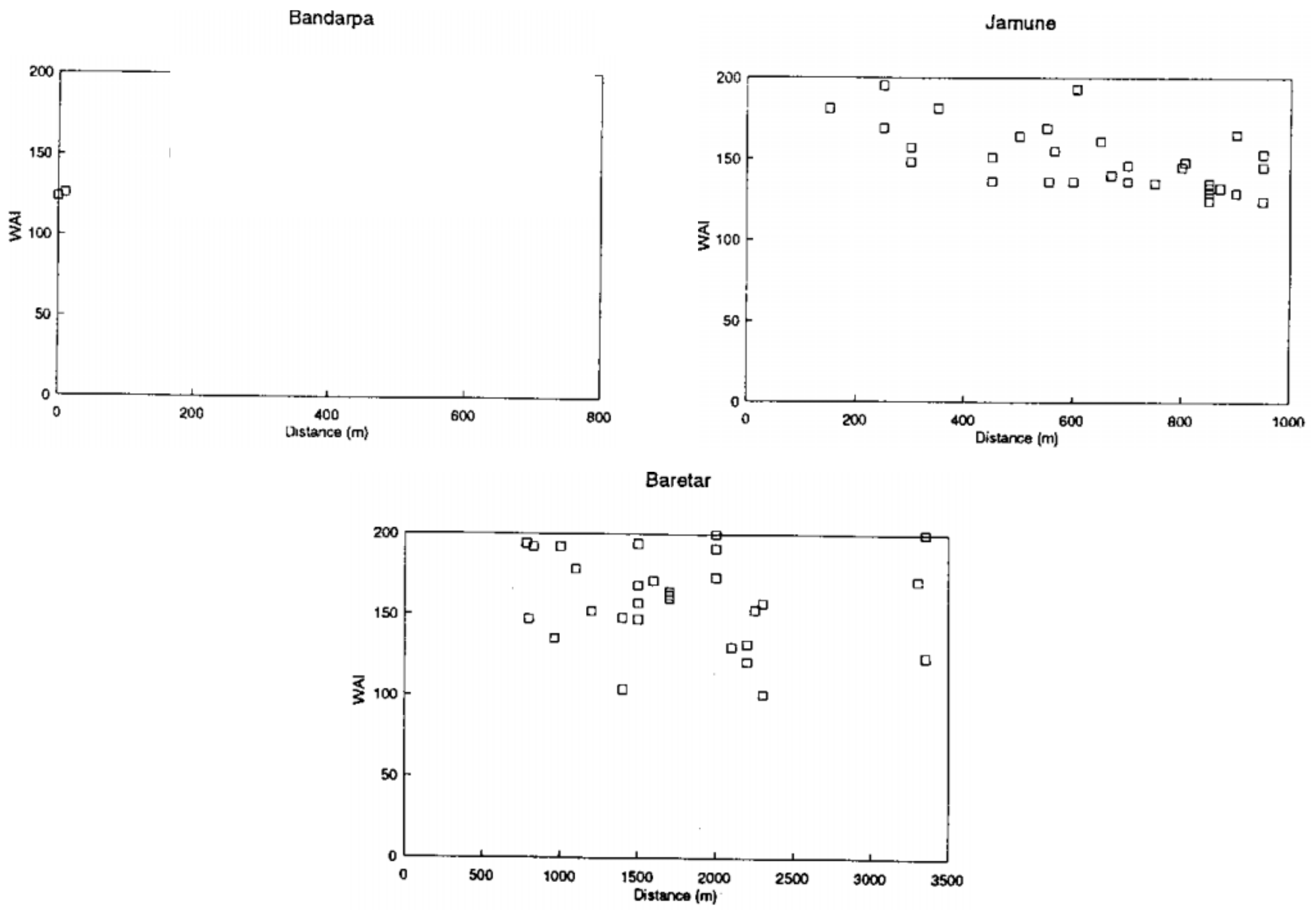


*Figure 4.2a. Weekly relative water supply (RWS) in three Terai systems in Nepal.*

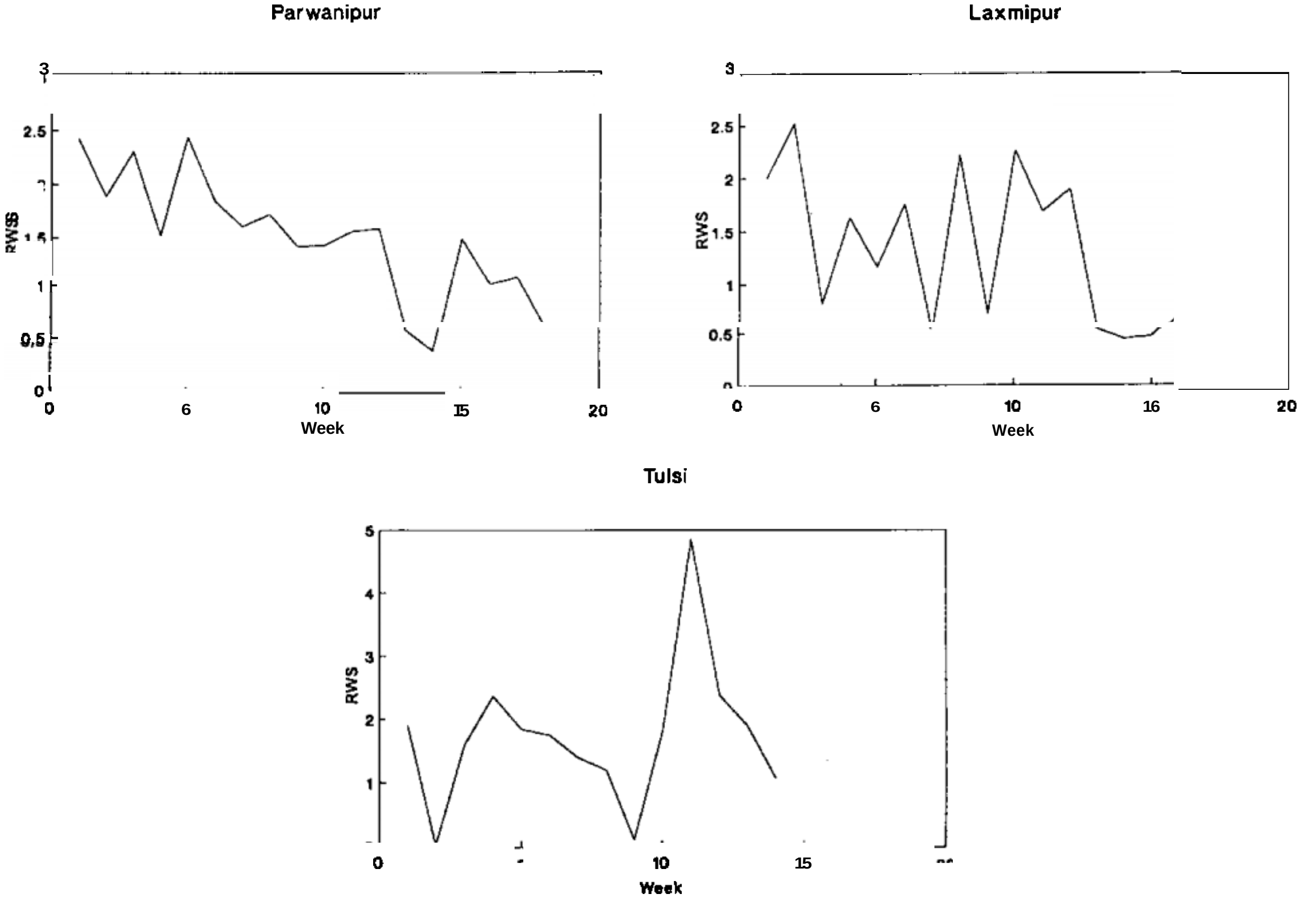


*Figure 4.2b. Weekly relative water supply (RWS) in three hill systems in Nepal.*

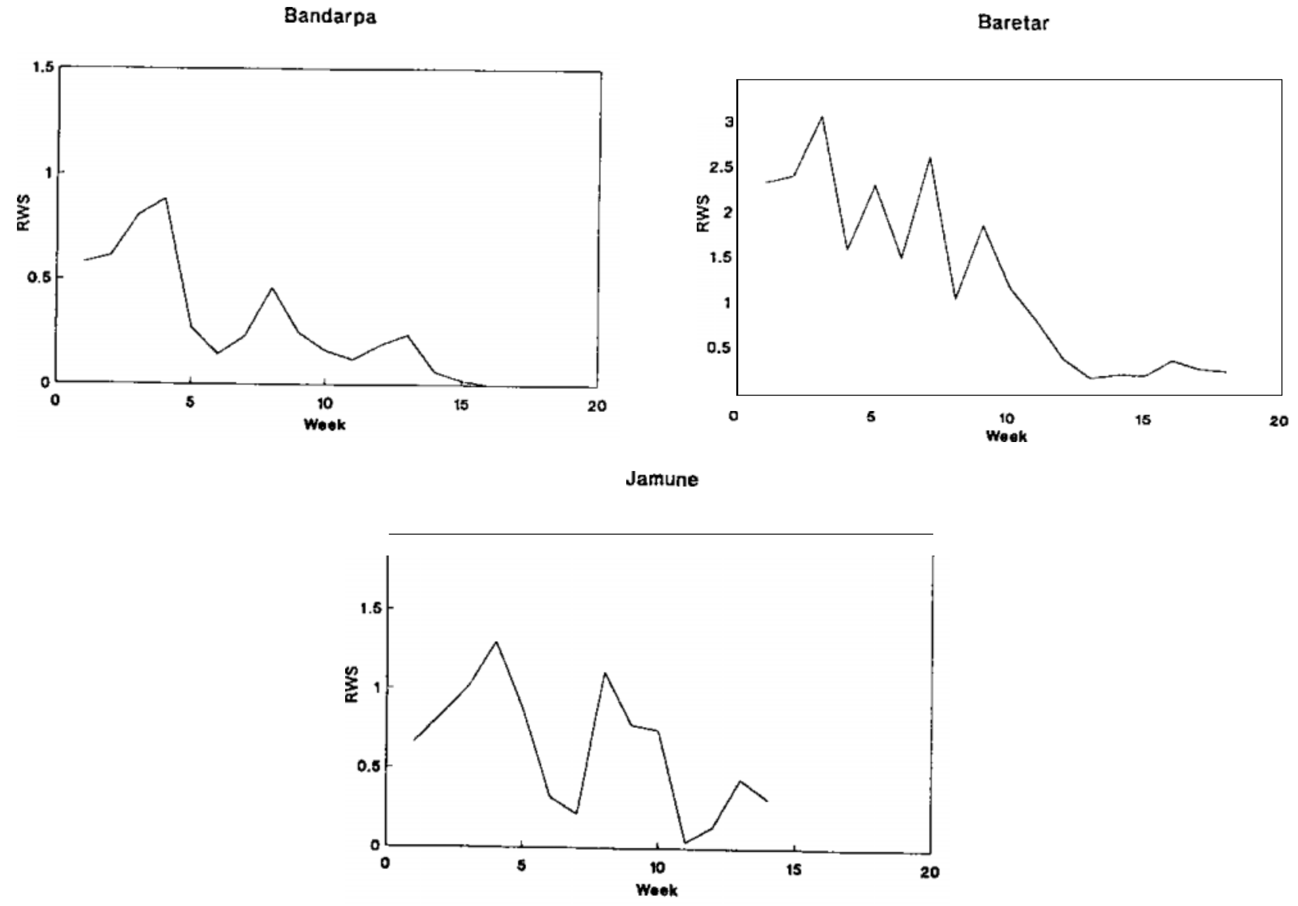


Figure 4.3a. Water availability index and yield in three Terai systems in Nepal.

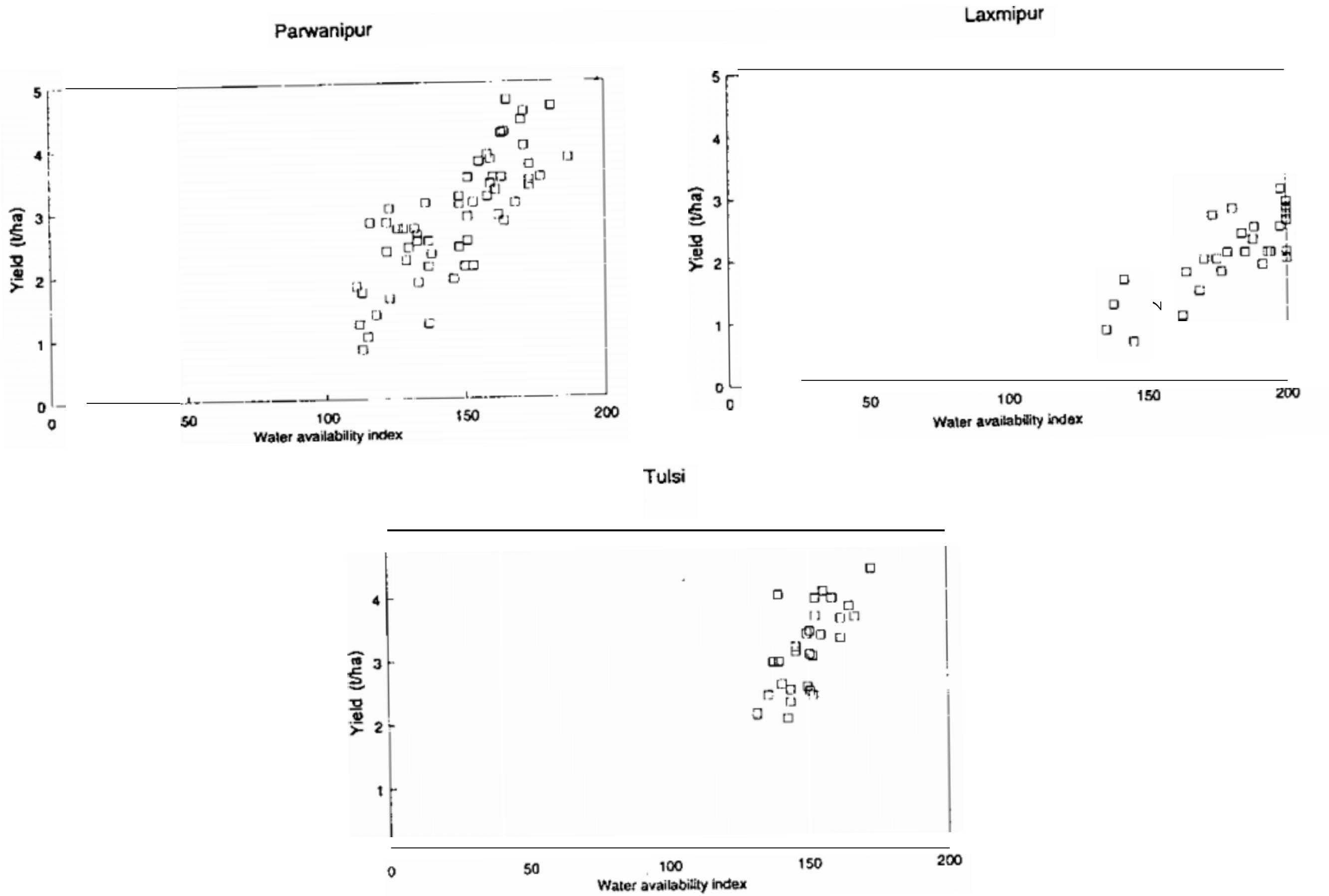


*Figure 4.3b. Water availability index and yield in three hill systems in Nepal.*

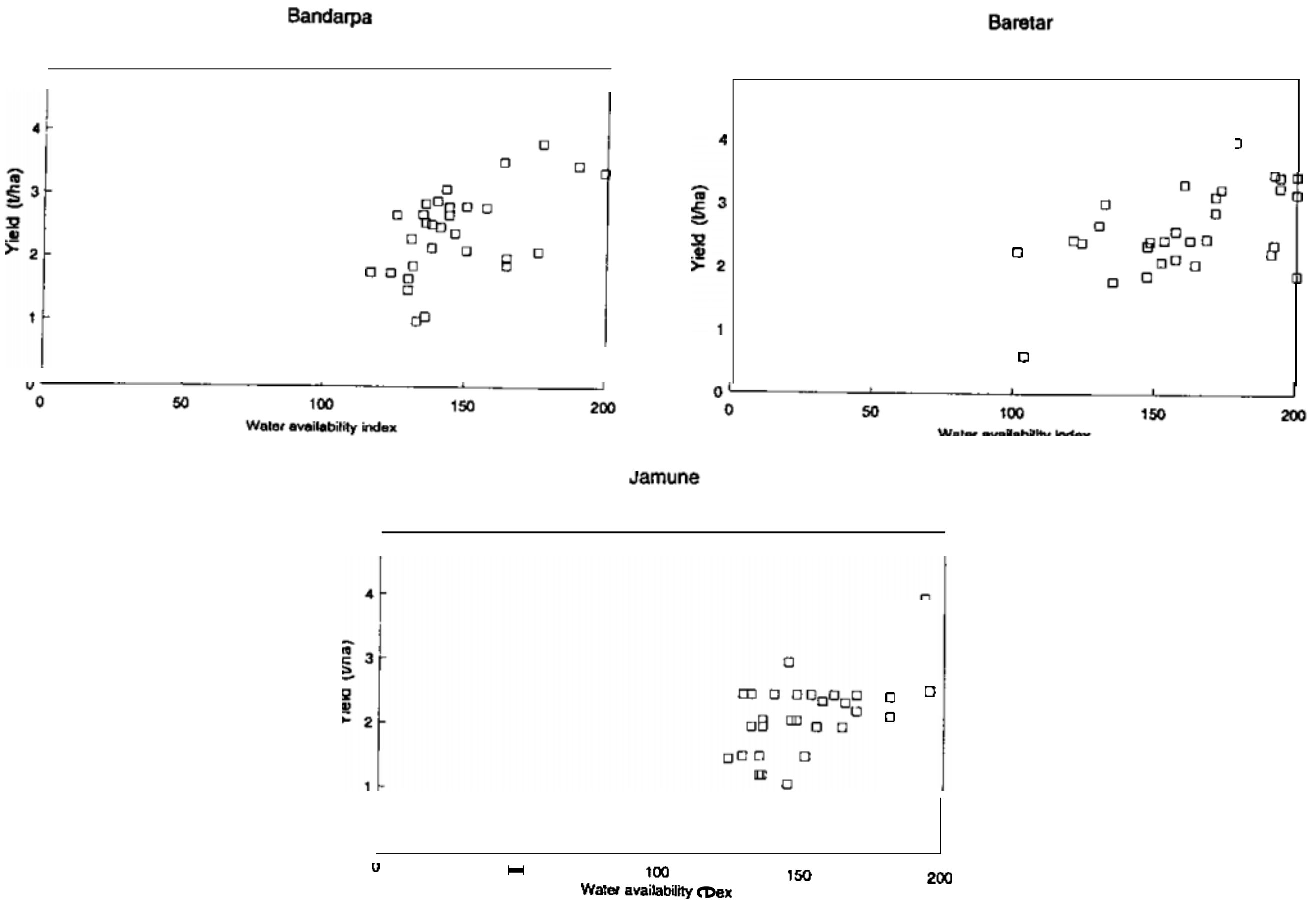


*Figure 4.4. Water distribution* equity, *Lower Chenab Canal, Pakistan.*

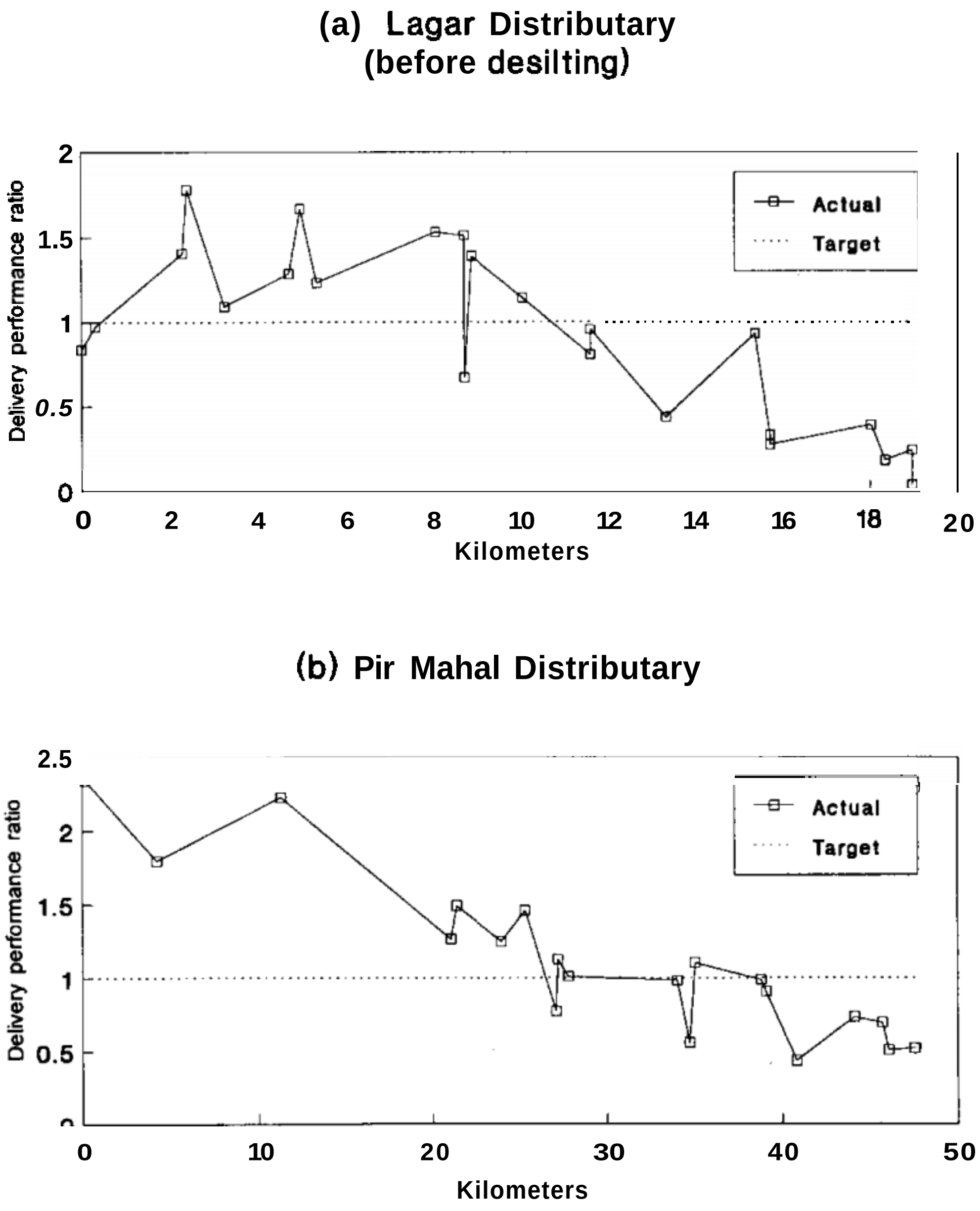
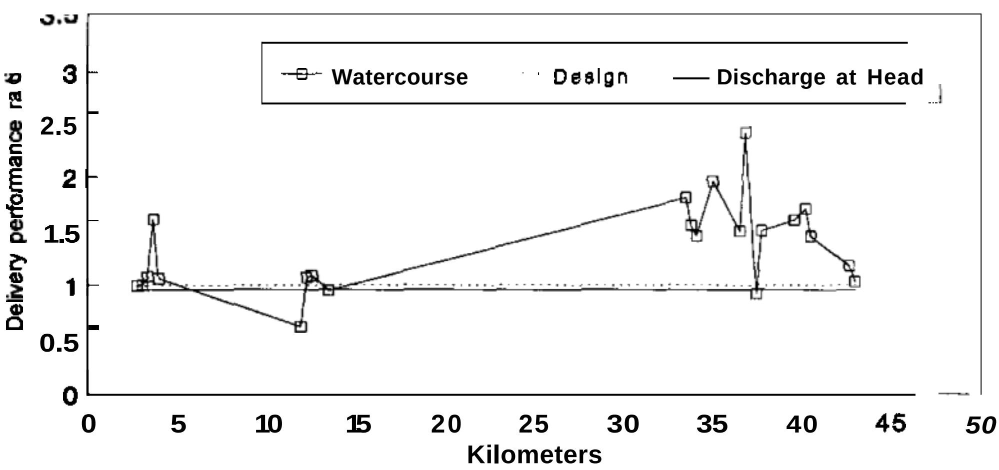


*Figure 4.5. Water distribution equity after desilting Lower Chenab Canal, Pakistan.*

## (a) Khikhi Distributatary




## (b) Lagar Distributary

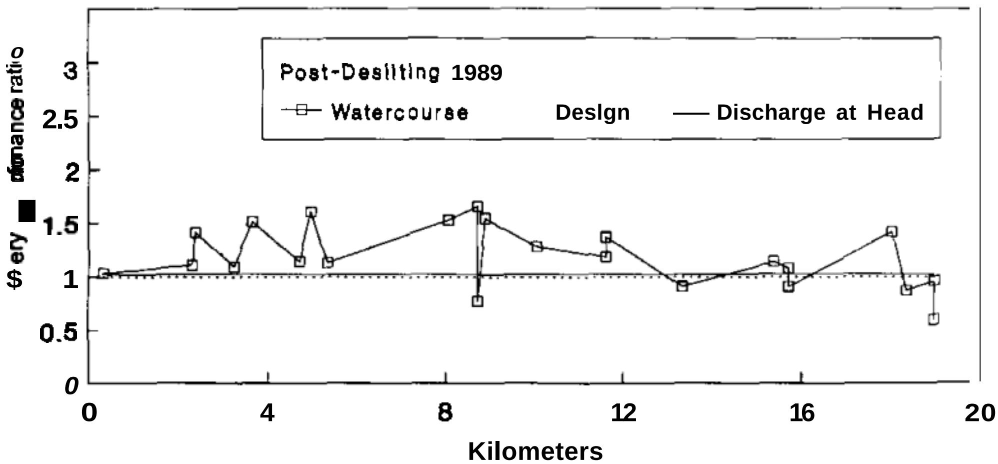


*Figure 4.6. Water distribution equity, Mudki and Golewala, India and Lagar, Pakistan.*

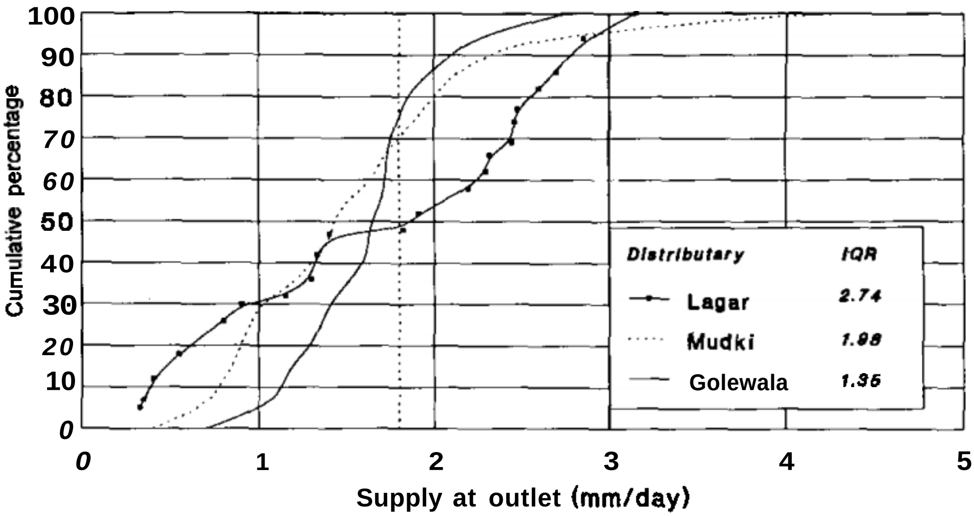
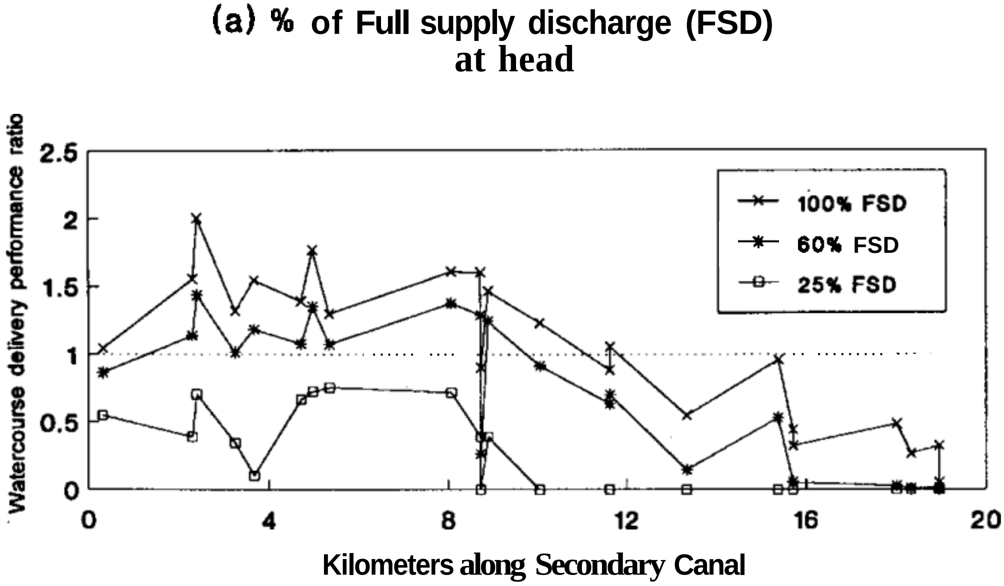


*Figure 4.7. Factors influencing water distribution equity, Lagar Distributary, Pakistan.*



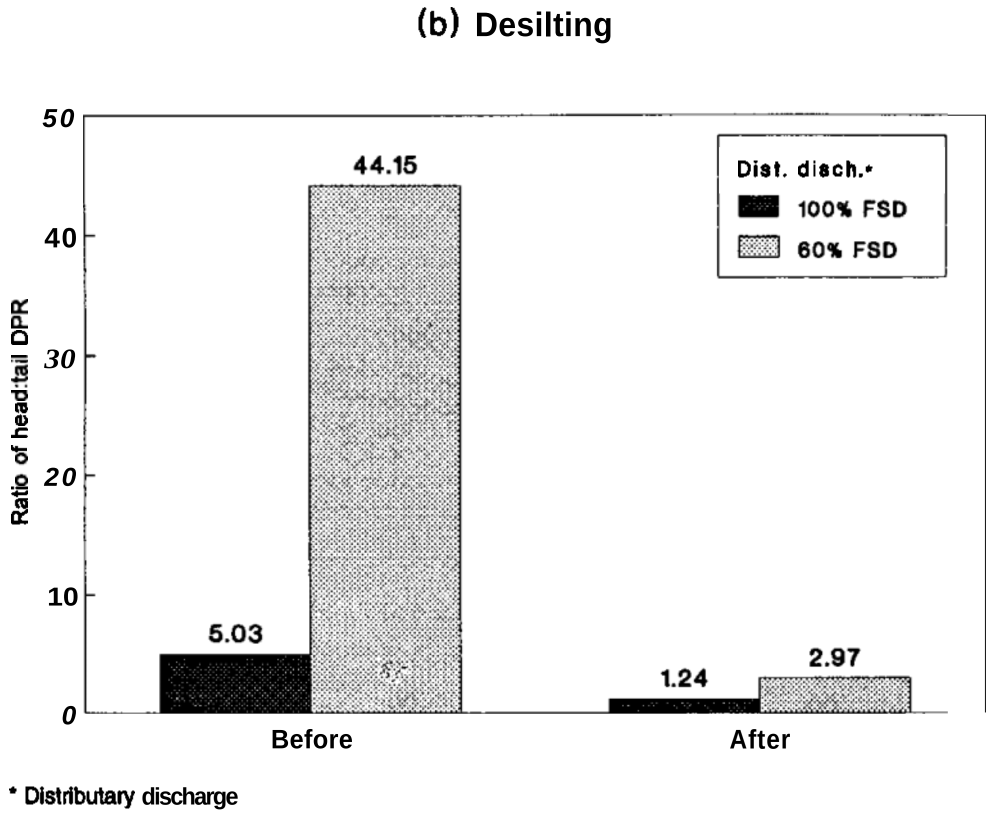
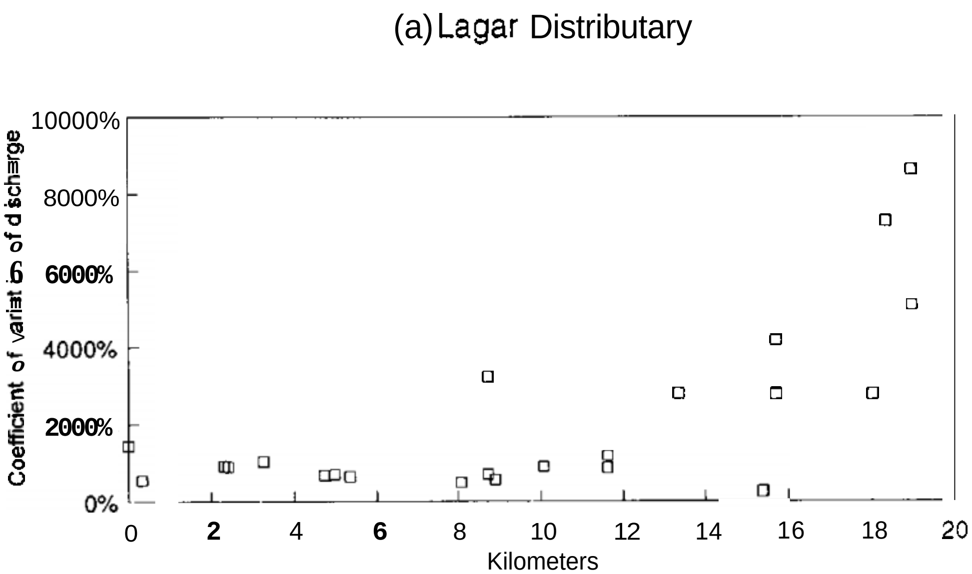



*Figure 4.8. Monthly variation of watercourse discharges, Lower Chenab Canal, Pakistan.*



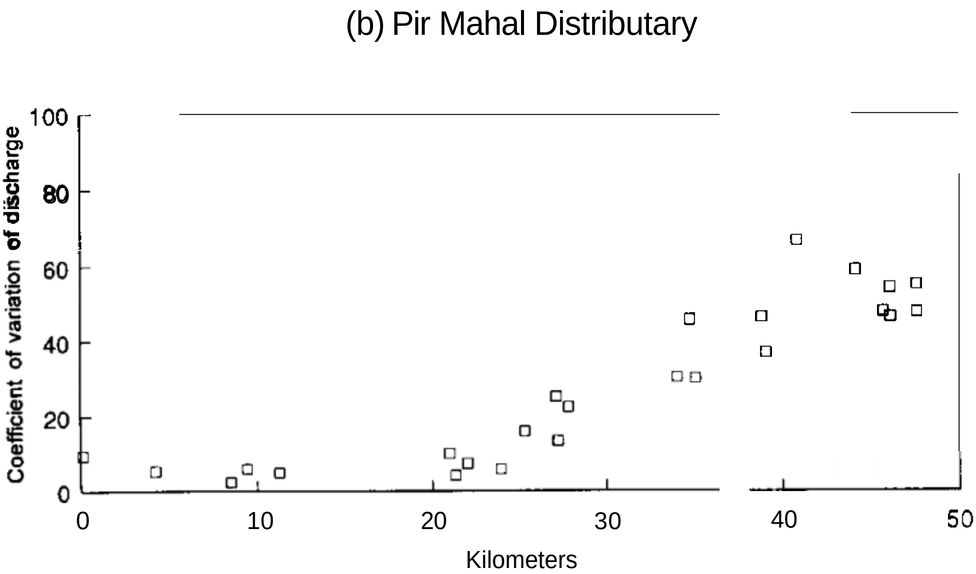
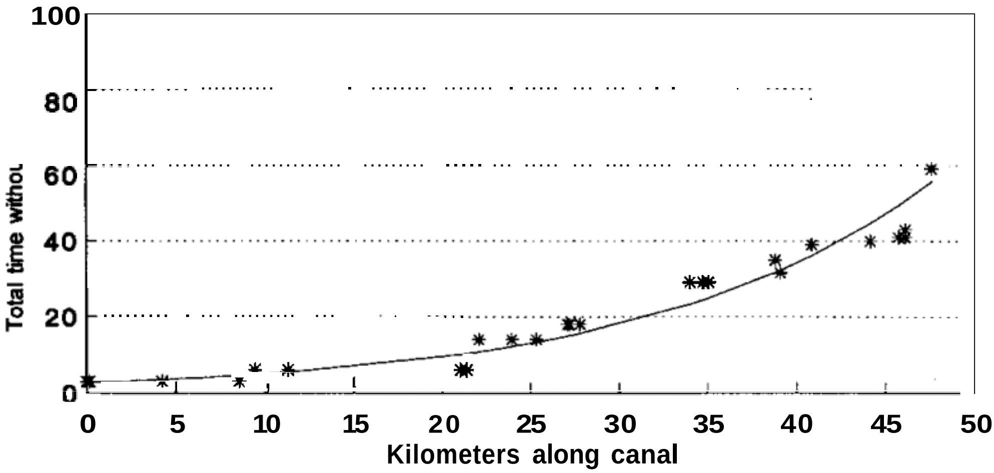



*Figure 4.9. Pir Mahal Distributary, Kharif 1988, % of time without water.*



# CHAPTER 5

# Performance in Gated Division Systems

## OPERATIONAL FLEXIBILITY OF GATED DIVISION SYSTEMS

GATED SYSTEMS PROVIDE much greater flexibility in operations than ungated ones, 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.

This chapter looks at three different variations of this type of design. The common thread is that each offtake along the main canal, and each offtake along secondary canals is provided with a gate that provides a great deal of operational flexibility. The distinction between the three systems comes in the opportunities to control water level in the main and secondary canals on the upstream side of the offtake gate.

Because these systems have considerable control capacity it is common to split performance assessment into two parts: assessment of main and secondary canals, and assessment of tertiary-level operations.

## 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 long canal sections and still achieve appropriate water levels upstream of each offtake. Five case studies of this type of system are presented: 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; these changes, in turn, necessitate a change in the setting of the offtake gate if uniform 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. Unstable main canal discharges require more frequent adjustment of offtake gates.

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 pmperly and the canal cross section deteriorates then eventually hydraulic conditions anticipated at the design stage cannot be attained.

Preventive maintenance is also required to ensure that all offtake gates remain in working condition. If gates cannot be operated properly then effective control over water is lost.

## Equity 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 different subsystems (Table 5.1). 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 5.1). Although there is a decrease in water deliveries from head to tail the 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 5.2). In most cases, smaller command areas benefited 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 indicates the extent to which precise management of the gate is necessary to achieve the desired water distribution equity (Figure 5.3). Nine-inch (22.9 cm) diameter culverts served command areas ranging from 10 to 40 ha, while some smaller command areas had 12-inch (30.5cm) diameter culverts which served just 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 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 a highly inequitable division of water.

Tungabhadra Irrigation System, Karnataka, India (Case Study #7) shows similar problems with water distribution, 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 percent of the target (Figure 5.4). The cumulative effect of this is that the tail-end reach of Distributary D36. received on average only 20–40 percent of the target discharge, while the upper five reaches all received more than their targets (Figure 5.5).

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. Halfway down the canal, targets are not met and daily variability is very high (Figure 5.6). 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 5.7a) shows the extent of this problem. The dimensions of the management task can be clearly seen from Figure 5.7b: along the main canal of Tungabhadra 50 percent of all gates control only 9 percent of the total discharge, 80 percent of gates control only 31 percent, while 10 percent of gates control a full 52 percent of discharges. 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.

Tungabhadra also demonstrates clearly the effect of long-term changes in the system. Post-construction addition of outlets and expansion of command area mean 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 designed discharges from all outlets plus official allowances for conveyance losses is about 40 percent higher than the designed canal capacity.

Data on main canal operations in the Hakwatuna Oya System (Case Study #8) show how equity can be improved 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 two seasons. This better performance over a 50 percent 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 5.8. This can be used by the system manager to evaluate water delivery performance immediately after each issue. Such performance reports are not described for any of the other case studies.

The importance of precise gate control where there is relatively little cross-regulation is demonstrated by results from the 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 the main canal discharge, then the variability of discharge into the secondary may be significantly higher than that in the main canal (Figure 5.9).

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. Figure 5.10 shows the effect of the number of gate operations on the ratio of coefficient of variation in Mananwala

Distributary to that of Upper Gugera Branch. 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 let? unattended the coefficient of variation in Mananwala increases to as much as 6 to 12 times that of Upper Gugera. Given that this is the only control structure for the entire 20,000 ha command of Mananwala, it is critical for water delivery performance that the head gate is operated effectively.

## Water Distribution at Tertiary Level

Despite the poor water distribution between secondary canals in Gal Oya, water distribution between tertiary offtakes within secondary canal command areas was much more equitable (Table 5.2). 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 fanner 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 make a strong argument for ensuring that water distribution along the main and secondary canals 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.

## 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 percent. Yield data collected by the Department of Agriculture used administrative areas different from hydrological divisions, makiig it impossible for managers to put the two sets .of information together. Research data on yields show a higb degree of association between water availability and yield (Figure 5.11), and yet no data are available to managers on a regular basis.

Tungabhadra demonstrates the impact of poor main canal water distribution on cropping patterns. Not only is total cropping intensity much lower at the tail (20 percent of target) than in head and middle sections (90–120 percent of target), but also the chance to grow rice is greatly reduced towards the tail (Figure 5.12). 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

Irrigation systems included in all of the case studies have similar problems with reliability. In the wet season, canals flow continuously (except in periods of heavy rain) but require rotations in the dry season to accommodate limited water supplies in relation to demand. The analysis of how well rotations are implemented helps understand the overall concept of reliability.

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 mtations between small parts of the system. Since 1973 an operational plan bad 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. Analyses of these rotations over an eight-year period reveal several issues relating to implementation.

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 5.3). 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 5.4). During the 1981 dry season farmers never knew when water would be delivered, and this led to considerable uncertainty and loss of confidence in the water delivery scheduling capacity of the irrigation agency.

At the same time. the type of rotation adopted was probably the best, given the deteriorated condition of the system. An analysis of water distribution equity at different discharges in the main canal demonstrates that greater equity is obtained by operating the canal as close as possible to full design discharge for 50 percent of the time rather than operating it at 50 percent of discharge on a continuous basis (Figure 5.13). The total saving in water is estimated at 72,000 cubic meters per day.

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 the 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 Tuesdays and Fridays (Table 5.5). 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.

Similar institutional concerns were observed when efforts were made to close gates in response to rainfall (Table 5.6). 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, but at the cost of increased uncertainty for farmers.

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 5.14 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.

If the priority system is not fully followed, some canals receive very low discharges for extended periods and this has inevitable and several negative impacts on water availability at the tail end of the less favored secondaries (Figure 5.15).

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 between Wednesday morning and Saturday evening. However, irregular operation of offtake gates along the canal means that discharges fluctuate during each rotation period, and may never reach the target, while closure is sometimes ignored entirely (Figure 5.16). The rotational pattern adopted appears to increase discharges into upper-end outlets compared to nonrotational periods, and the entire purpose of getting more water to the tail is lost.

One aspect of implementation of rotational irrigation practices common to all the above examples is that there was essentially no communication or cooperation between the irrigation agency and fanners. Results from the Philippines illustrate the benefits that can be obtained where agencies and fanners 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 water levels 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 percent of the system, with the largest area uncultivated being in the tail-end areas (Table 5.7).

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 5.7).

## 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 means that it is no longer necessary to maintain canal cross sections to exact 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 System H (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 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 5.17). 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.

# SYSTEMS WITH GATED CROSS-REGULATION

The previous subsections 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 when 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 the main and secondary canals. The increased density of control locations provides a greater potential for response to changes in demand and supply.

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 are 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 cluster in the upper half and one cluster 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 5.18a). 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 5.18b) 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 overtlow, but there is an adjustable vane that can modify the percentage of discharge delivered to each secondary. Operation of this vane facilitates staggering of cultivation between secondary canals throughout the system, starting with a higher allocation at the commencement of cropping in upper-end canal commands, 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.

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 (Egypt) shows a lower degree of distribution equity (Table 5.8). 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.

Kirindi Oya Irrigation System in southern Sri Lanka (Case Study #13) shows a case where design intentions were not backed with proper operational planning. The Right Bank Main Canal has 15 cross-regulators, roughly one per 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. Gatekeepers were acting independently, opening and closing regulator gates in response to changes in water levels at each regulator. It took six weeks at the beginning of the 1987 dry season before discharges in the system stabilized. Using a computer program that modeled 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 at target levels within a few hours of opening the head gate (Figure 5.19). This was successfully implemented in 1988.

Computer analysis of operation of the main canal also showed it was possible to stabilize discharges into distributary channels without changing offtake gate settings. This can be achieved by issuing an excess of 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 5.20). Prior to this analysis there was no set of operational manuals or instructions on how to operate the cross-regulators effectively, and variability of discharges was probably higher than if there had been no gated cross-regulators.

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.

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 5.21a) because water and rainfall were abundant, actual distribution was controlled by the ratio of gate width to command area of each tertiary block (Figure 5.21b). 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 5.22a).

Water distribution in the dry season shows a different trend. There is no longer a significant relationship between the gate width-command area ratio and water deliveries (Figure 5.23a). Nor is there a significant head-tail difference (Figure 5.23b). More frequent gate operations during the dry season resulted in a more uniform pattern of water deliveries.

Maneungteung Irrigation System in West Java, Indonesia (Case Study #15) shows contrasting results even though the system design is the same as that at Way Jepara. The same pattemof alackofdirectrelationshipbetween gatewidthandcommandareaispresent(Figure 5.22b). In the wet season there is evidence of head-tail differences in access to water along the main canal (Figure 5.24a). Along secondaries, however, the pattern of water distribution between tertiary blocks is less clear, although there is a net decline in access to water towards the tail end (Figure 5.24b).

In the dry season, however, the trend is different. There appears to be closer attention to operationof the offtakes along themaincanal, eliminating the head-tail effect (Figure 5.25a), while along secondaries the head-tail effect is still present but less marked than in the wet season (Figure 5.25b).

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 5.9). This made it almost impossible to fulfill the discharge-based operational targets in the main system.

## Reliability

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 this clearly: water was plentiful throughout the season (the reservoir spilled almost continuously) but only half the command area was irrigated.

The 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 and reliability take a higher priority. It also requires a high level of management: gates have to be opened, closed and monitored frequently.

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. Further, some blocks were scheduled to receive water on several days each week, while others were scheduled only for one delivery a week. 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 5.10).

A pilot testing of a more equitable and reliable rotation plan in 1989 showed dramatic improvements in performance. In a planning meeting arranged between irrigation officials and fanner leaders held before water conditions deteriorated, a revised set of rotational units was 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 implementing actions agreed to at this meeting (Figure 5.26). 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.

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 percent even though equity increased dramatically (Table 5.11 and Figure 5.27).

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 Ratio or DPR) at the bead 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 the scheduled rotational blocks was frequently below target (Figure 5.28a).

Following intervention this pattern changed significantly. Whenever the 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, with any excess water delivered to blocks not scheduled to receive a turn (Figure 5.28b).

*Table 5.1. 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 | LBM | UB | LB | GB | Uhana | U/S | WG | MD | MI | 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 |

*Notes:*
U/S Upstream
LBM Left Bank Main
UB Uhana Branch
LB LB 14–22
GB Gonagolla Branch
Uhana UB1A–17
WG Blocks 26 and J
MD Mandur Distributary
MI Mandur 1–5
M6 Mandur 6–32

*Source:* Murray-Rust (1983).

*Table 5.2. Differences in water availability index (WAI) by field channel and farm position, dry season 1982, Gal Oya Left Bank.*

| Seconday canal location | By tertiary canal | | | Ratio | |
|---|---|---|---|---|---|
| | Head | Middle | Tail | Average | Head-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 | | | Ratio | |
| | Head farm | Middle farms | Tail farms | Average | Had-Tail |
| Head | 186 | 183 | 185 | 186 | 1.01 |
| Middle | 180 | 171 | 175 | 177 | 1.03 |
| Tail | 166 | 152 | 161 | 160 | 1.03 |
| Average | 177 | 171 | 174 | 174 | 1.02 |

*Source:* Wijayaratna (1986)

*Table 5.3. Dry-season land and water allocations at Gonagolla Bifurcation, 1974–81.*

| Year | Left Bank Units (LB14-32) | | Gonagolla Distributary | |
|---|---|---|---|---|
| | Land % | Water % | Land % | 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 5.4. Variability of issue and nonissue periods during dry-season rotations, Uhana Branch, Gal Oya.*

| Year | Average length of issue periods (days) | | | Average length of nonissue 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.I | 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 5.5.* 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).

*Table 5.6. Time (in days) taken to respond to daily rainfall greater than 13 mm/day, Gal Oya Left Bank, 1974–81.*

| Year | Gates at reservoir | | Gates at Himidurawa |
|---|---|---|---|
| | 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 | 1.30 | 1.43 | 1.58 |
| Dry Years | 1.47 | 1.11 | 1.07 |

*Water-short years.
*Source:* Murray-Rust (1983)

*Table 5.7. Increase 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 and 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 and I (tail) | 262 | 5.3 | 1389 | 86 |
| **Total** | 1173 | 5.0 | 5743 | 86.3 |

*Table 5.8. Division of the gross water supply over the Fayoum.*

| | | | Percentage of equal share of water at Lahun | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Total supply $m^3/s$ | 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 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' | [illegible] |
| 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 |

*Note:* Values marked with an asterisk (*) in the months of July and August were calculated with the rating for Bahr Wahby intake. This rating is subject to frequent change.

*Source:* Wolters et al. (1987).

*Table 5.9. 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 I | Area 2 | MRT 4 Sec. JTS | Sliding (new) | Cipoletti |
| Area 2 | AM3 | MTR 5 Main | Sliding (new) | None |
| Area 3 | Area 4 | PB 1 Main | Sliding (new) | Cipoleni |
| 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 |
| | | Mancungtcung Timur (Babakan) | | |
| Area 10 | Area 11 | MB 5 Main | Sliding | None |
| Area 11 | Ares 12 | MB 8 Sec. GG | Sliding | Cipoletti |
| Area 11 | AM 12 | MB 10a Main | stop logs | None |

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

*Source:* IIMI (1989)

*Table 5.10. 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/days | 3 | 2 | 3 | 2 | 2 | 3 | 4 | 2.7 |
| **1989** | | | | | | | | |
| Tertiary blocks/day | 15 | 7 | 9 | 12 | 12 | 13 | 7 | 10.7 |
| Irrigation inspectors/days | 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 the use of stop logs to block canals) | | | | | | | |
| **1989** | 1 | 2 | 2 | 0 | 1 | 1 | 0 | 7 |
| | (all 1989 operations involved the 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 | 152 | 734 | 576 | 655 | 748 | 4871 |
| Length of canal used | 9375 | 10306 | 15540 | 14795 | 15282 | 19789 | 20351 | 105438 |

*Source:* Vermillion and Murray-Rust (1991).

*Table 5.11. 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 and 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.**

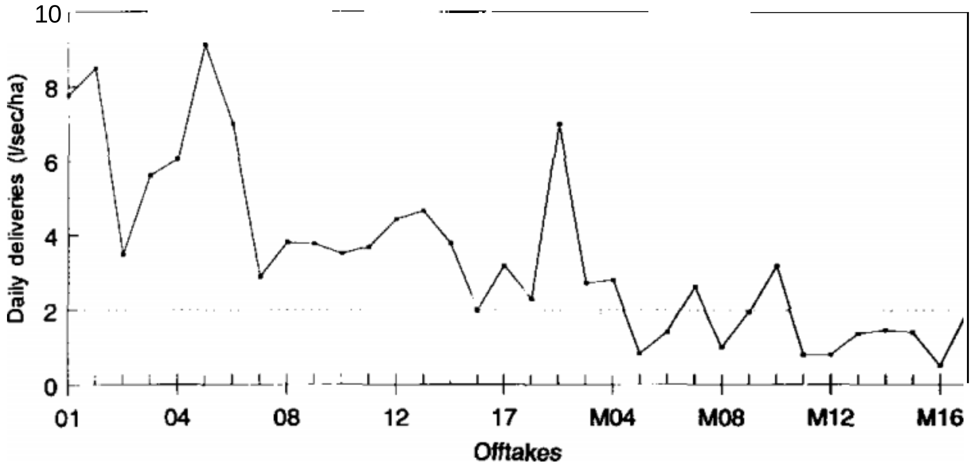
**"Downstream** flow must be stopped" means that the main or secondary *canal* needs to be controlled to prevent downstream **areas** getting water out of turn.

**"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 achieved at no additional cost to normal operational budgets

*Figure 5.1. Water distribution equity, Uhana and Mandur branches, Gal Oya Left Bank, Sri Lanka.*

## (a) Daily water deliveries




## (b) Misallocated volume

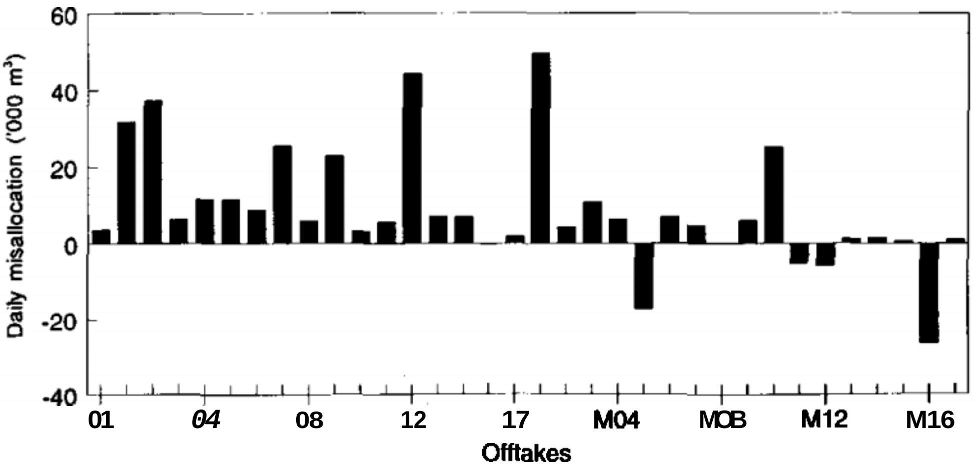
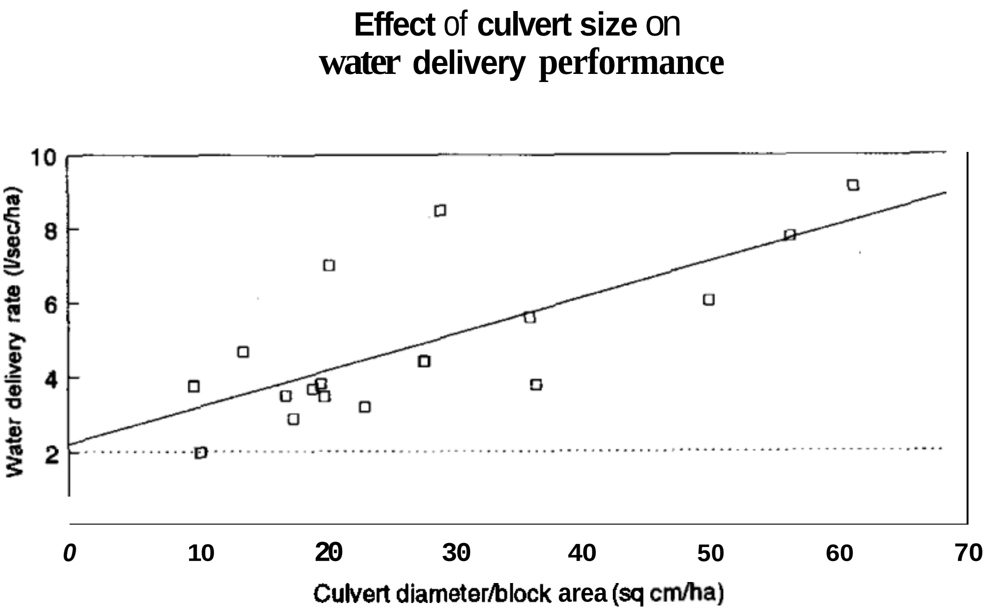
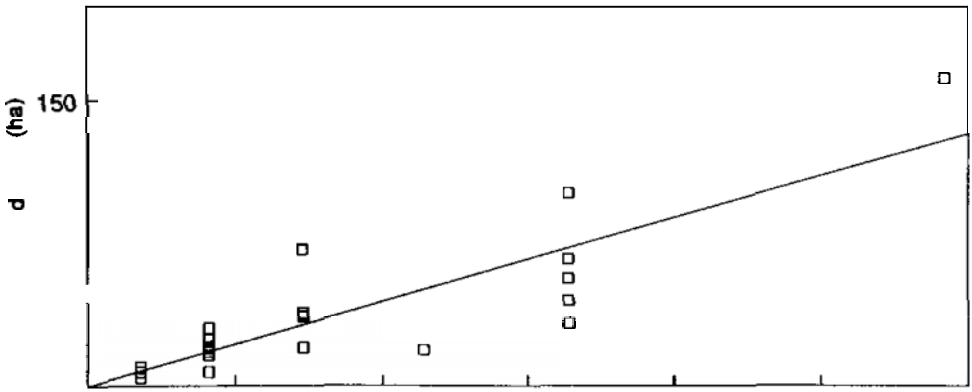


*Figure 5.2 Design impact on water delivery, Gal Oya, Sri Lanka.*



*FigureS.3. 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**

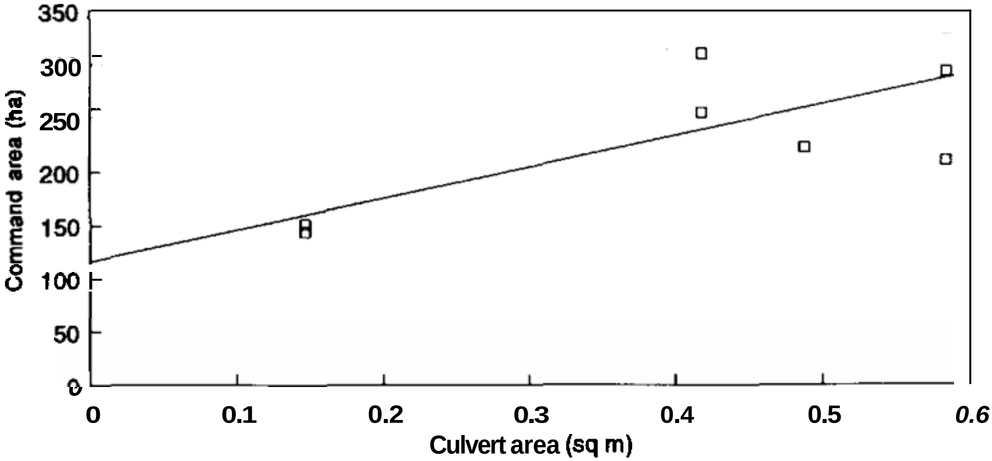
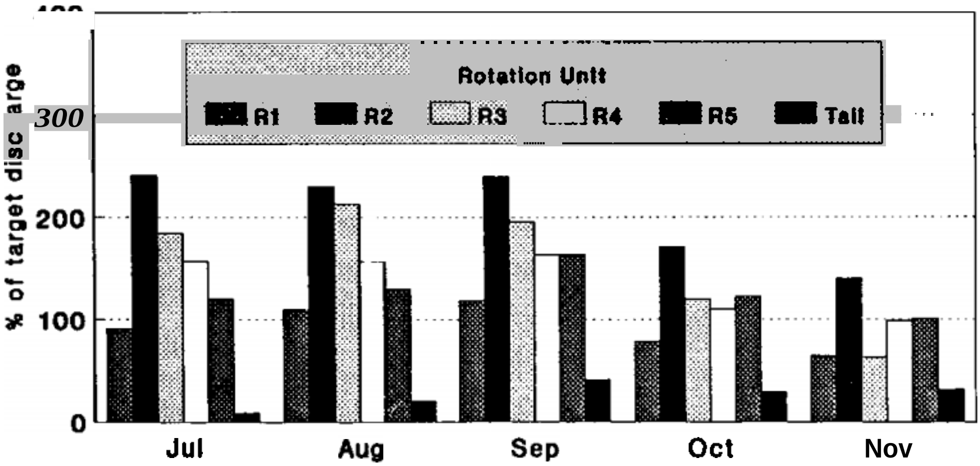


*Figure 5.4. Water distribution equity along Distributary D36, Tungabhadra Irrigation System, India*

**(a) Kharif 1987**




**(b) Rabi 1987-88**

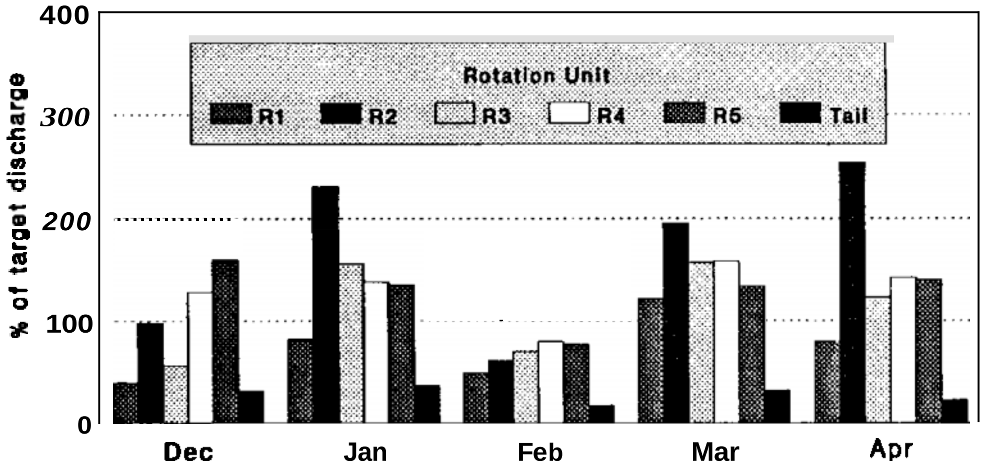
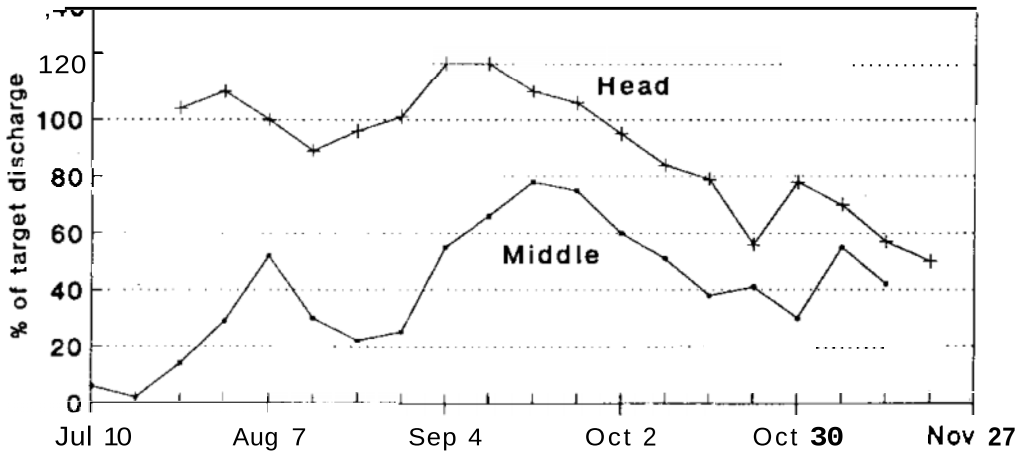


*Figure 5.5. Water delivery performance along Distributary D36, Tungabhadra Irrigation System, India.*

(a) Kharif 1987




(a) Rabi 1987-88

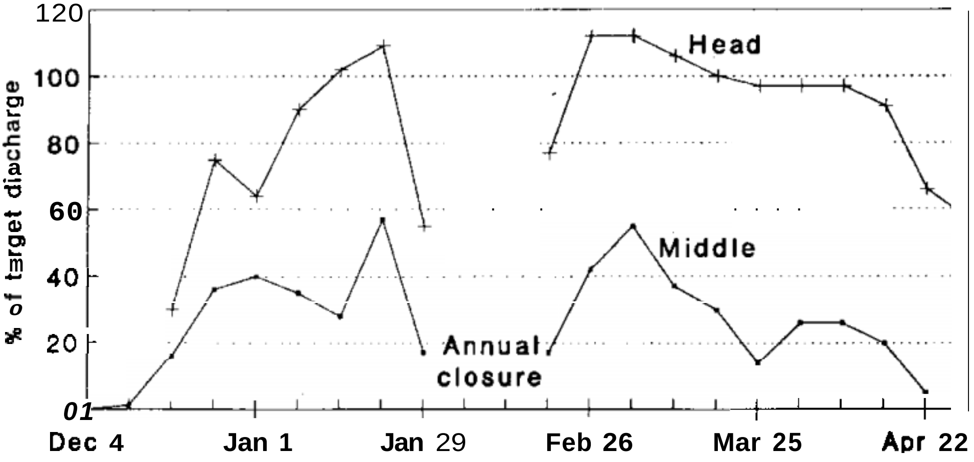


*Figure 5.6. Daily variability of discharge along distributary, Tungabhadra Irrigation System, India.*

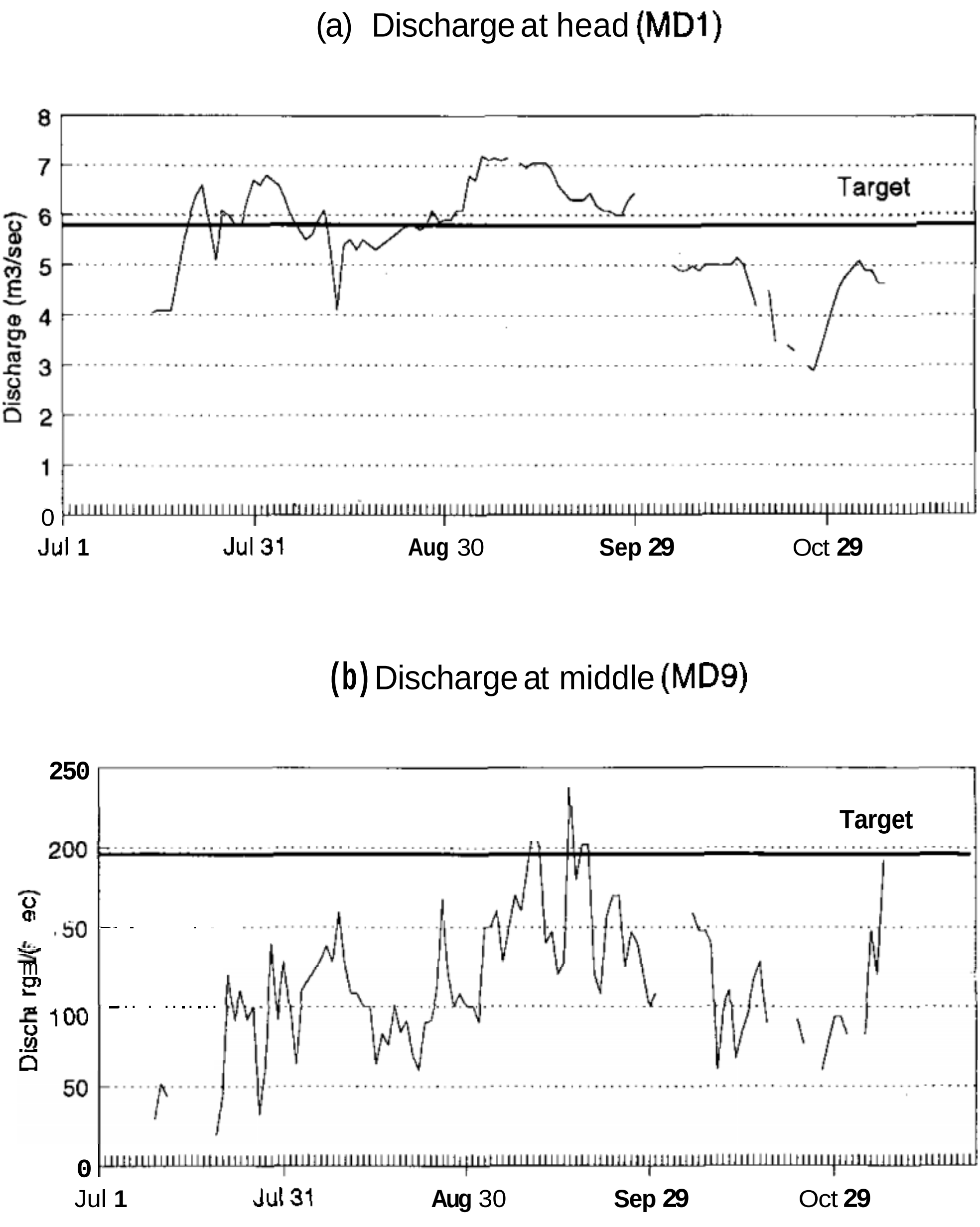
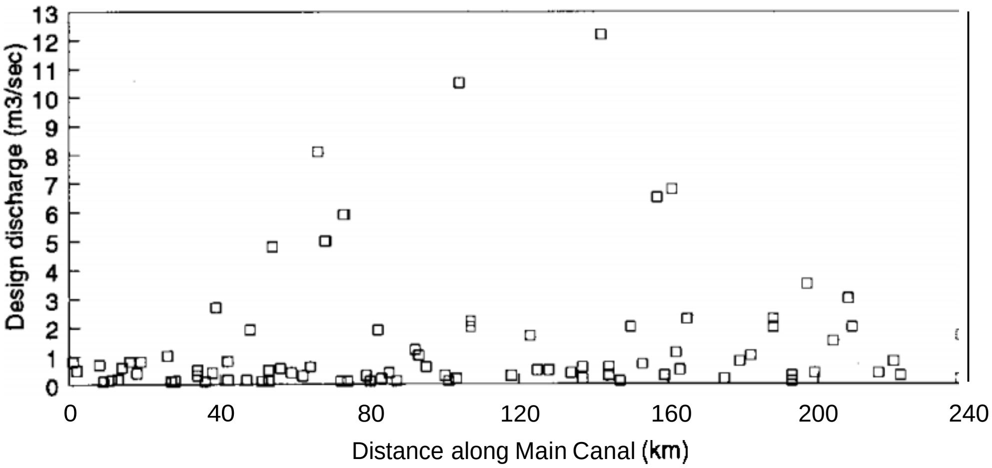


*Figure 5.7. Design discharges for secondary canals, Tungabhadra Irrigation System, India.*

(a) Distribution along main canal




(b) Cumulative distribution

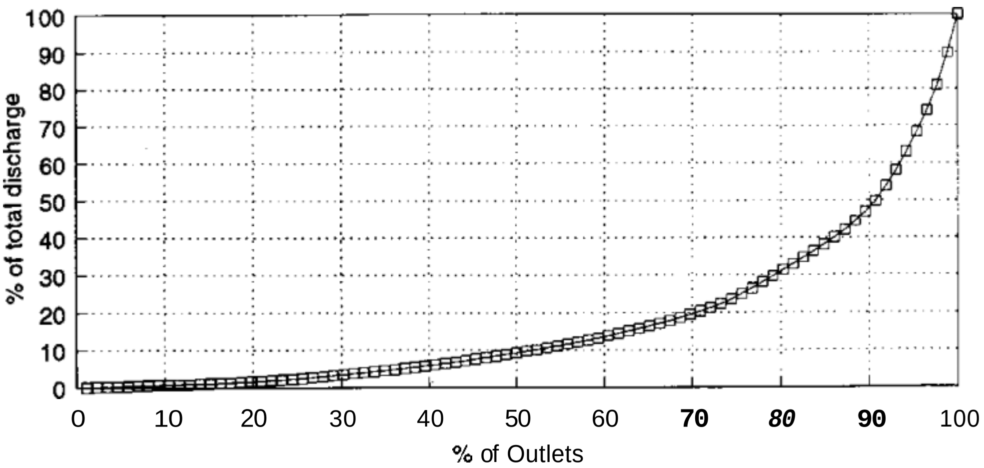
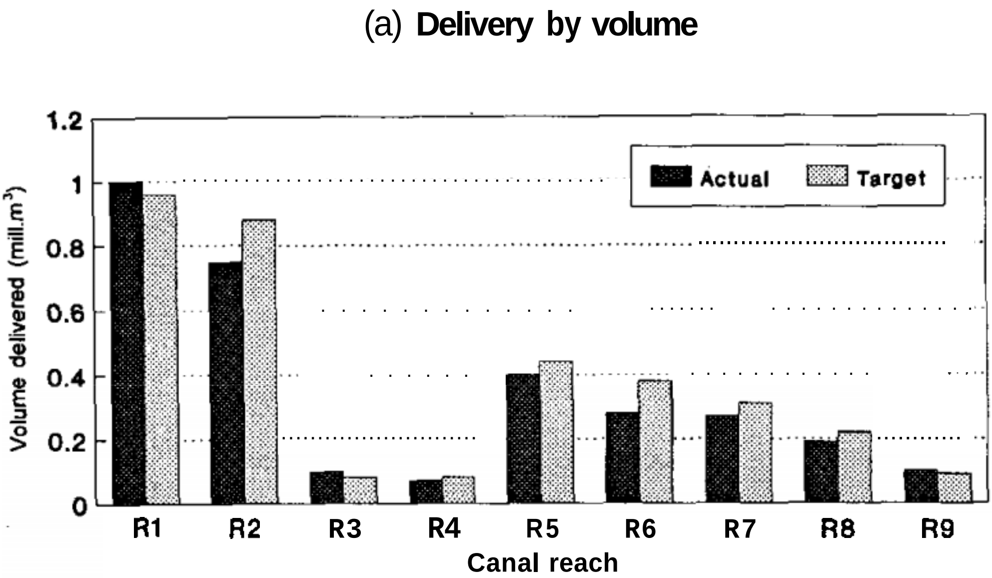


*Figure 5.8. Weekly water distribution report, Hakwatuna Oya, Sri Lanka.*



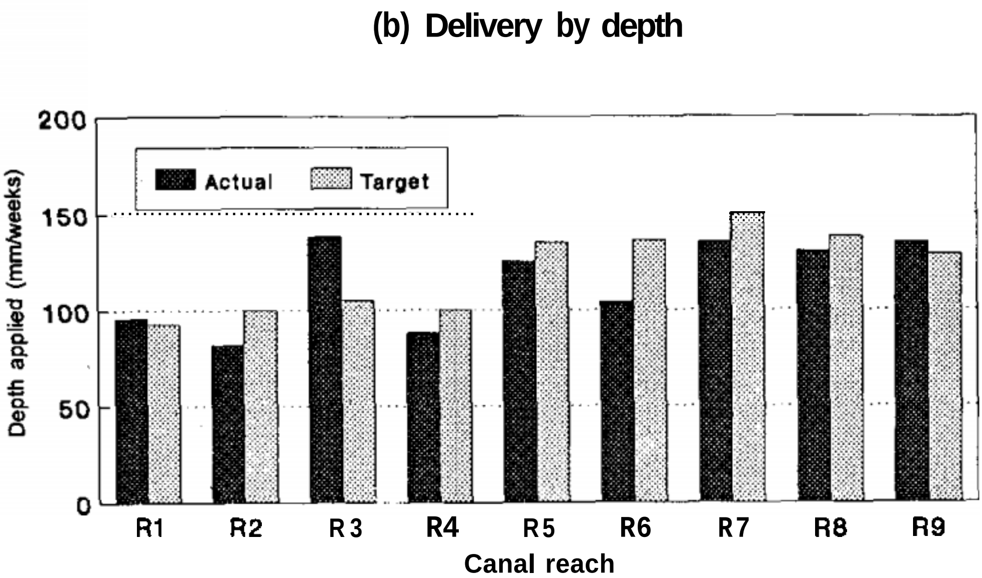



*Figure 5.9. Coefficient of variation of discharges, Upper Gugera Branch, Pakistan*

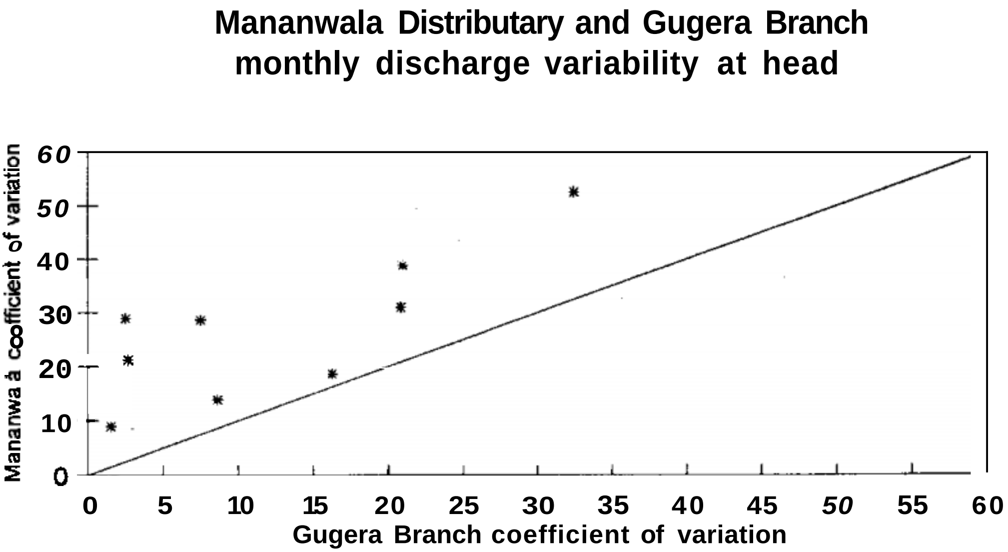



*Figure 5.10. Effect of number of head gate operations on variability of discharge into secondary.*

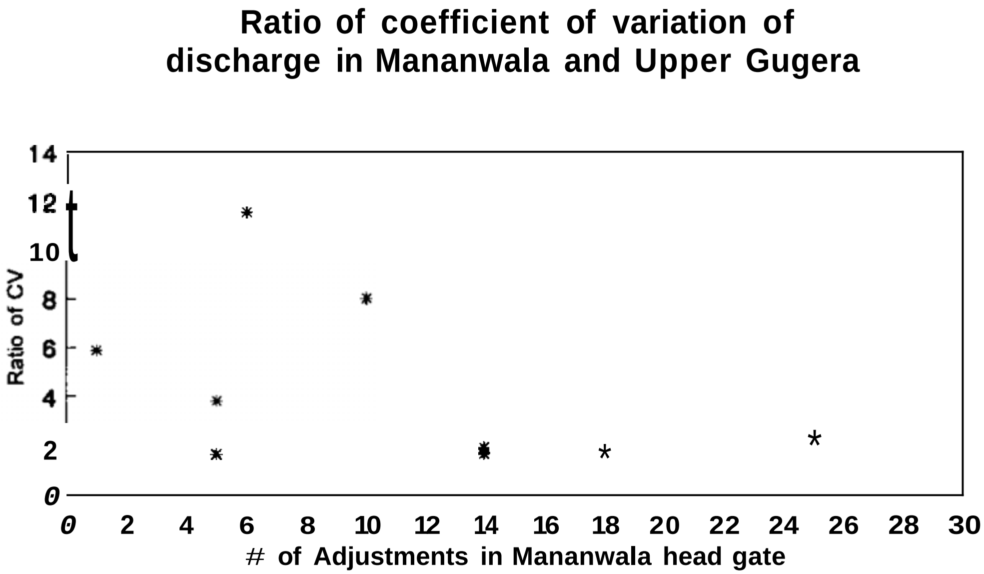


*Figure 5.11. Distributary level. wateravailability index andyields.*

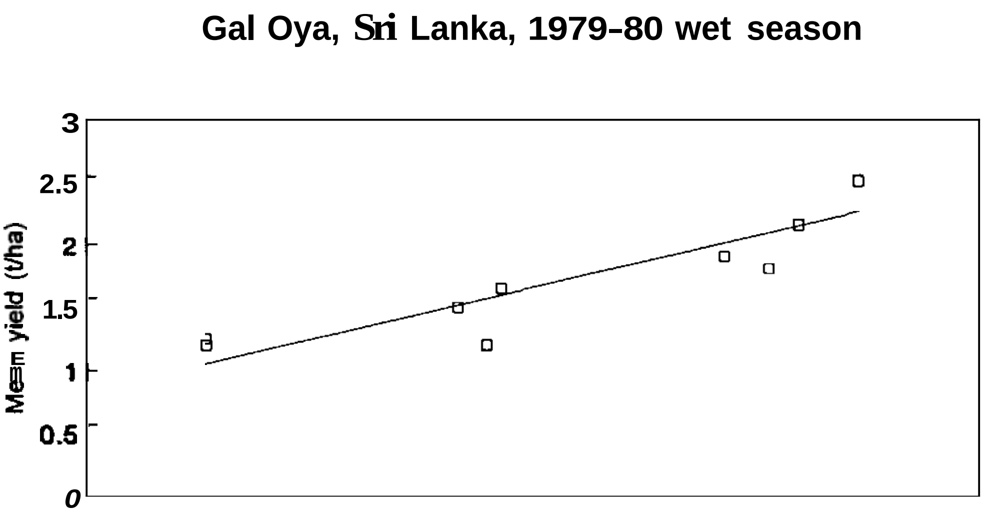
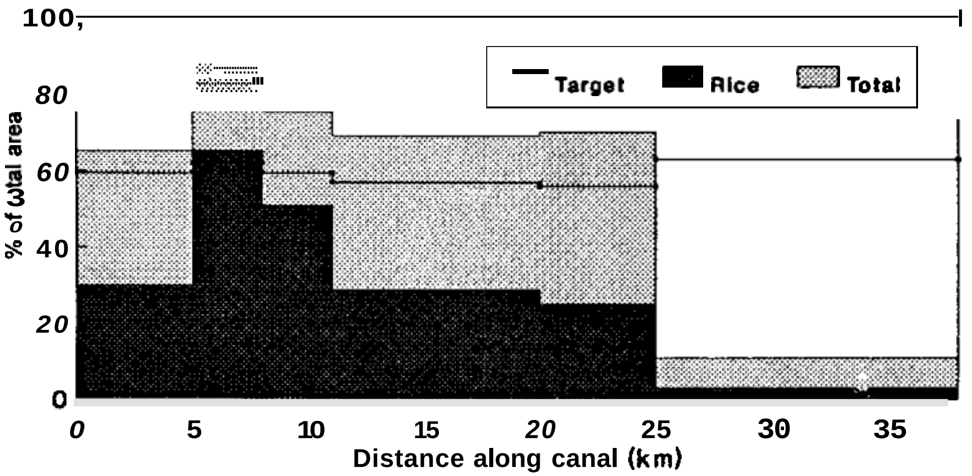


*Figure 5.12. Planned and actual cropping patterns, Tungabhadra Irrigation System, India.*

(a) Kharif. 1987




(b) Rabi. 1987-88

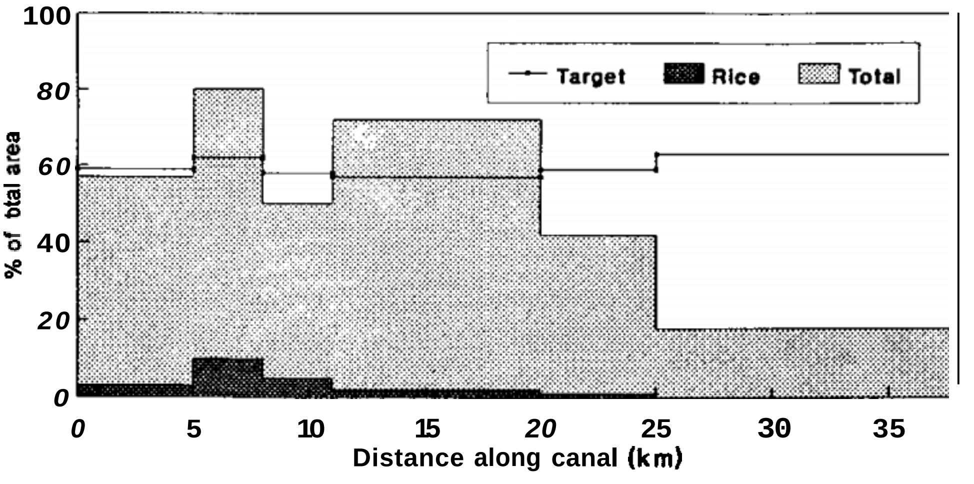
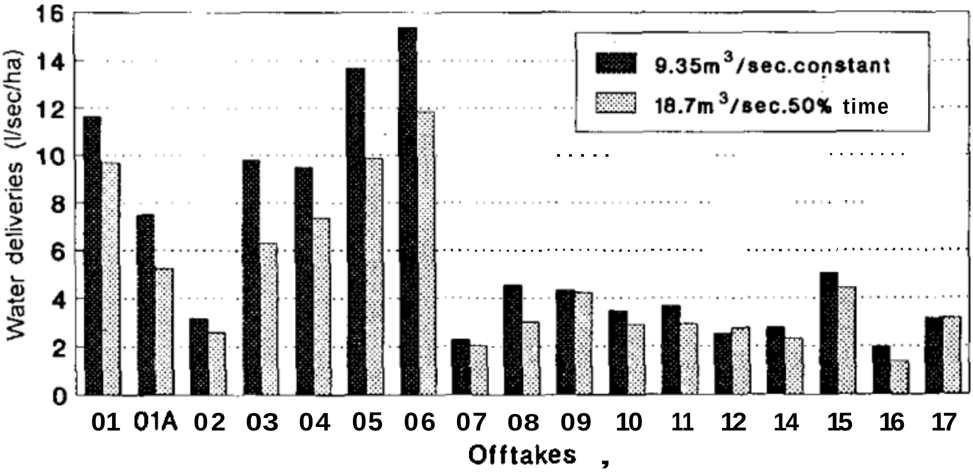
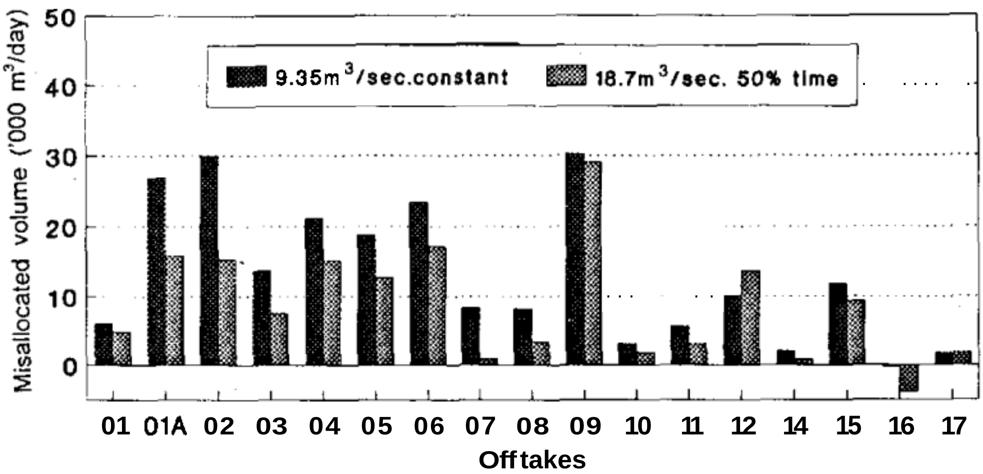


*Figure 5.13. Effecr of rotations on water distribution equity, Uhana Branch. Gal Oya Left Bank. Sri Lanka.*

## (a) Daily deliveries




## (b) Misallocated volume




**Misallocation at $9.35 m^3/sec.$, constant flow: 221,000 cu m/day**
**Misallocation at $18.7 m^3/sec.$, 50% time: 149,000 cu m/day**

*Figure 5.14. Differential water allocations between canals, Bhagat Head Regulator, Lower Gugera Branch, Pakistan.*

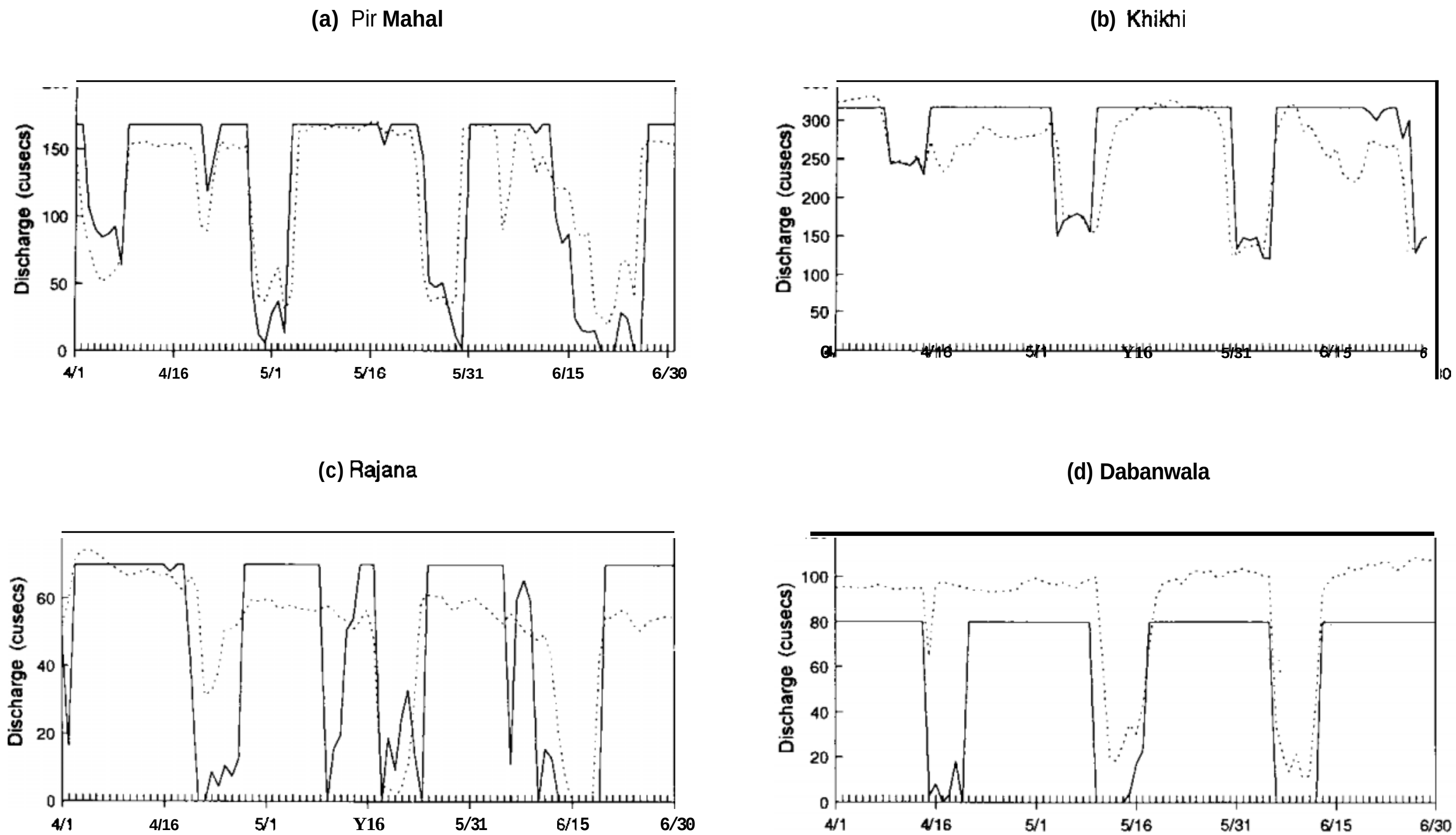
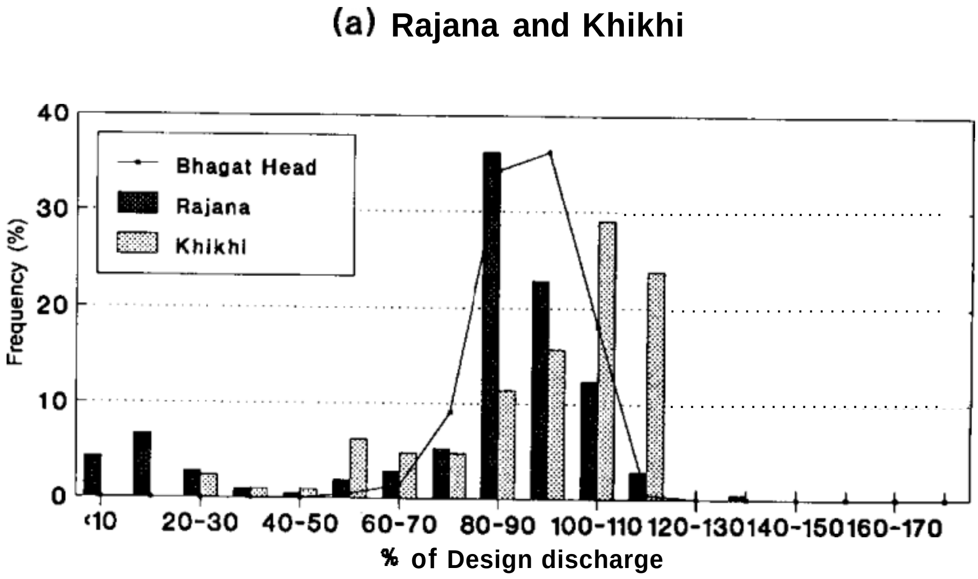


*Figure 5.15. Water distribution equity between canals, Bhagat Head Regulator, Lower Gugera Branch, Pakistan.*



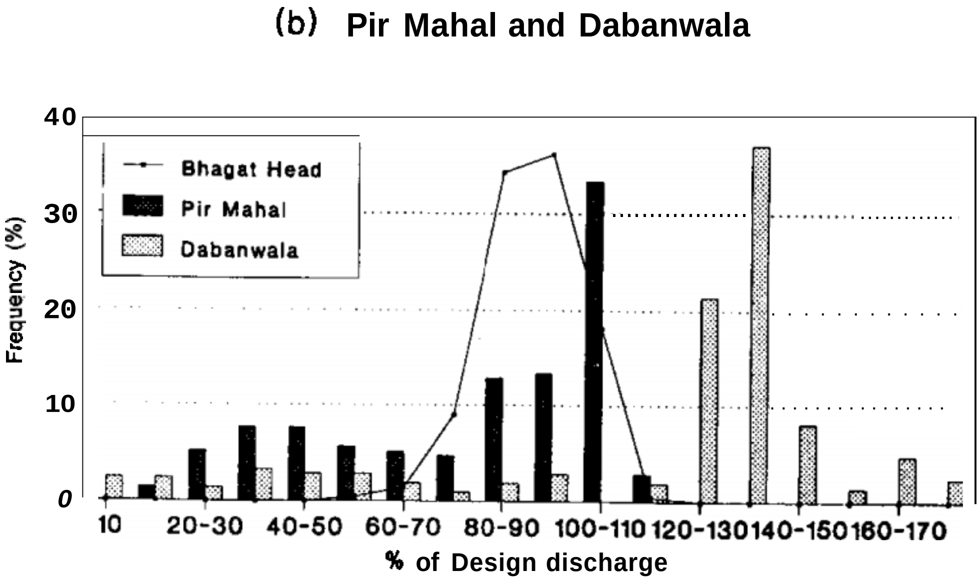
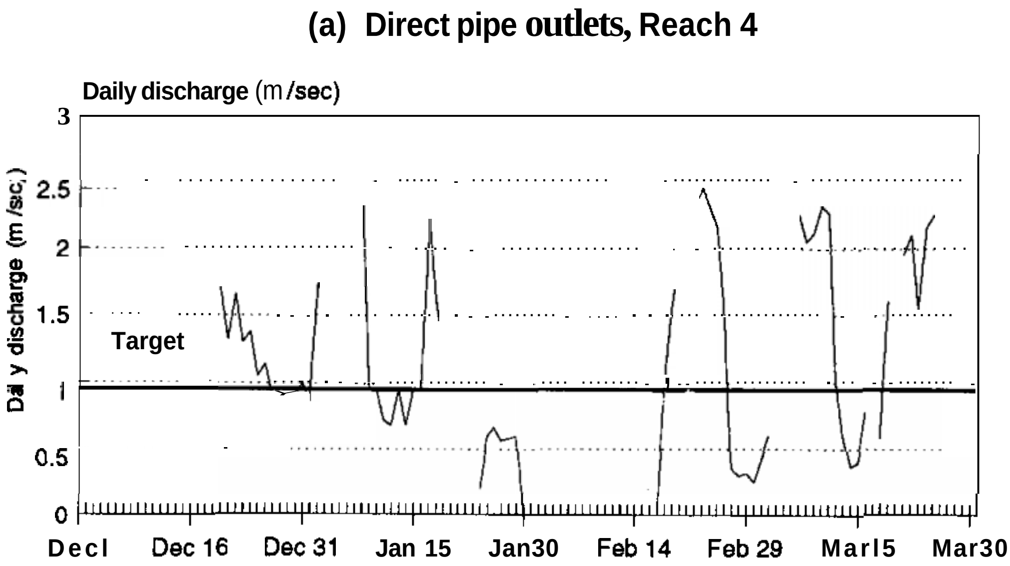



*Figure 5.16. Effects of rotations by canal section on daily discharge, Tungabhadra Irrigation System, India, Rabi 1987–88.*



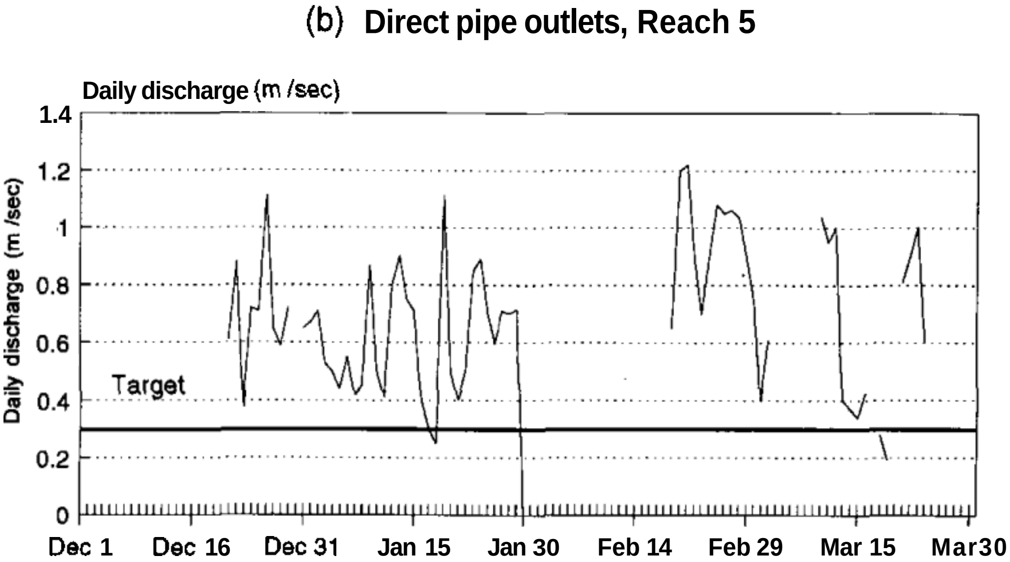



*Figure 5.17. Relative water supply, dry season, 1986, Kalankuttiya, Sri Lanka.*

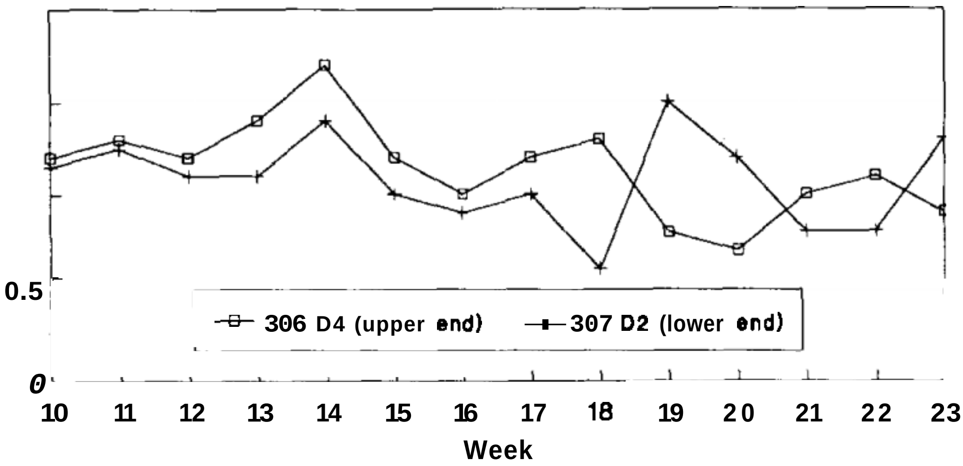


*Figure 5.18. Water disfribufion equity, Viejo Retamo, Argentina, 198849.*

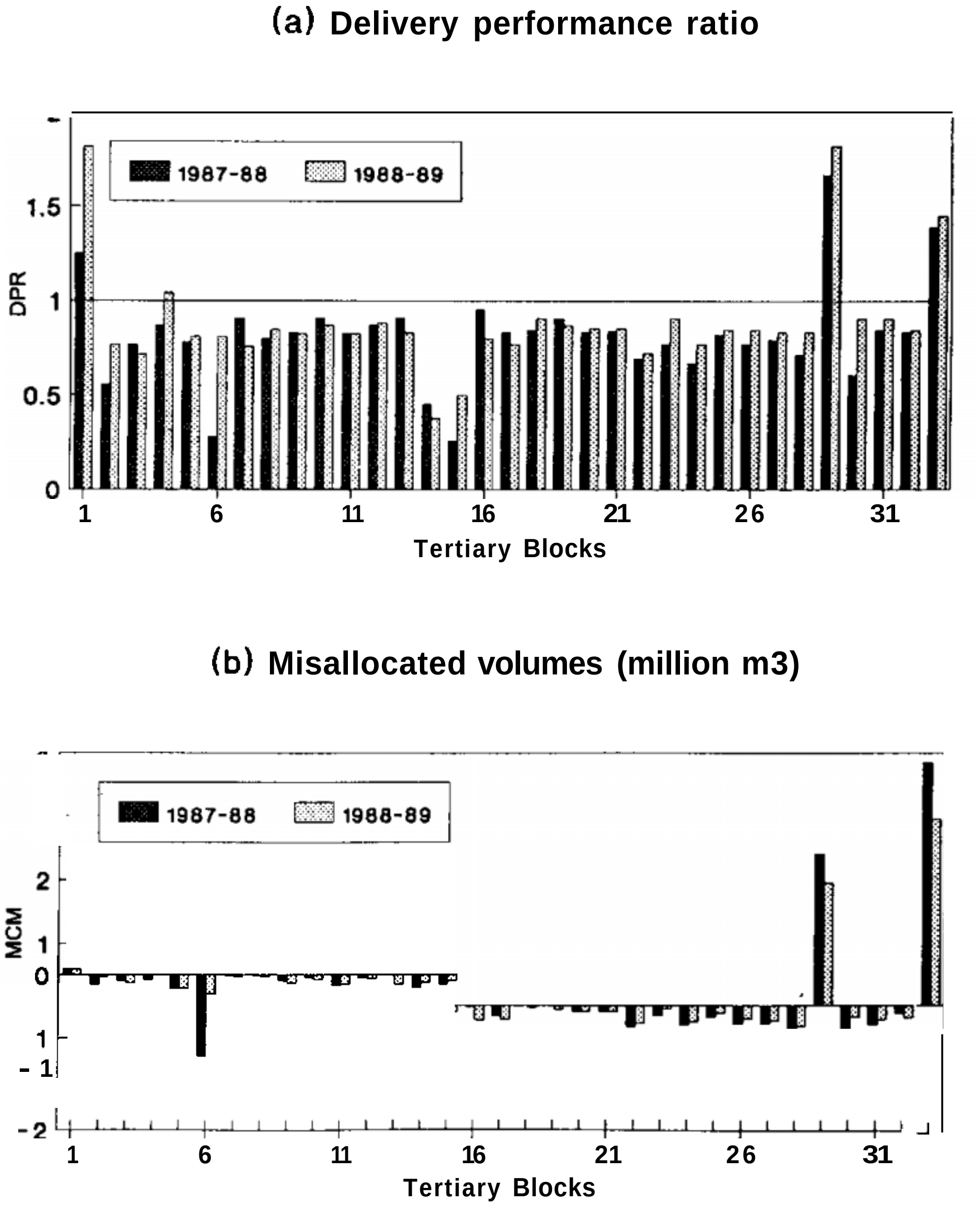


*Figure 5.19. Timing of cross-regular or gate operations to stabilize discharge in Main Canal, Kirindi Oya, Sri Lanka.*

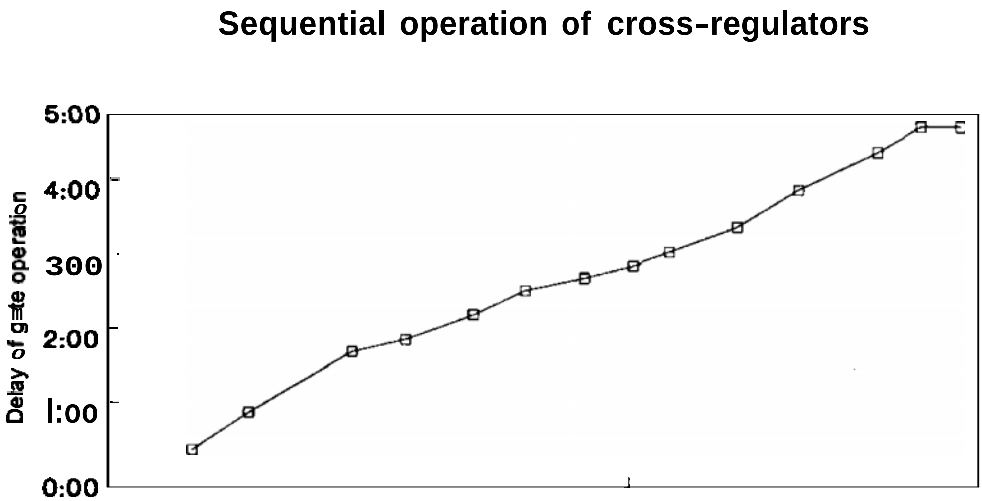



*Figure 5.20. Efficient operations rhrough computer simulation, Kirindi Oya, Sri Lanka.*

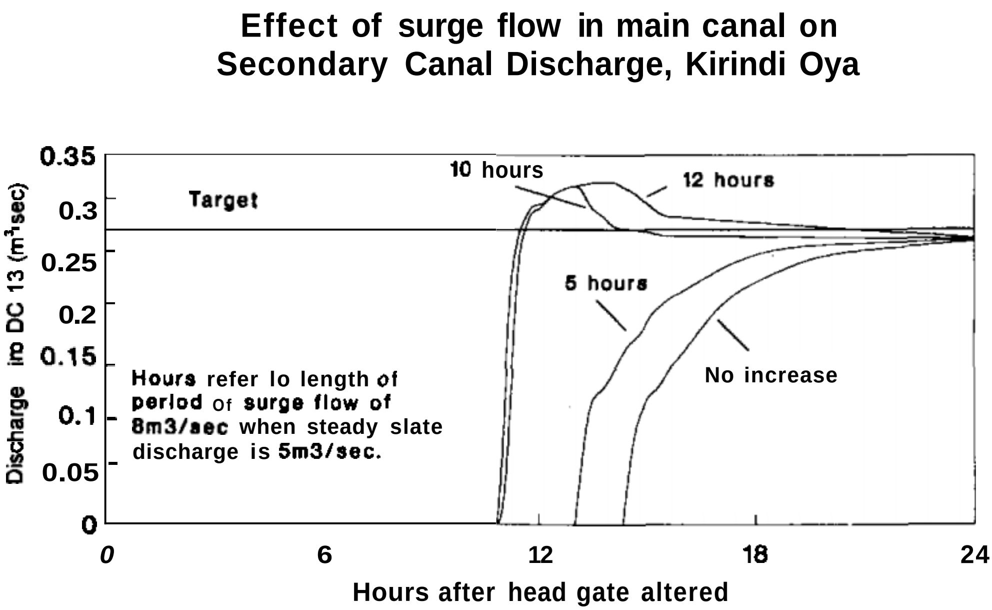



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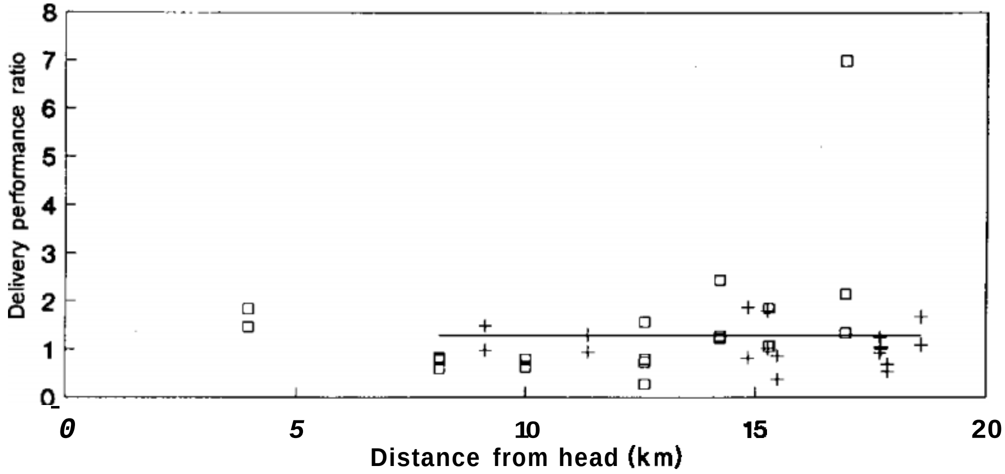
*Figure 5.21. Water distribution equity, Way Jepara, Indonesia, wet season, 198849.*

(a) Water distribution equity




(b) Design impact on equity

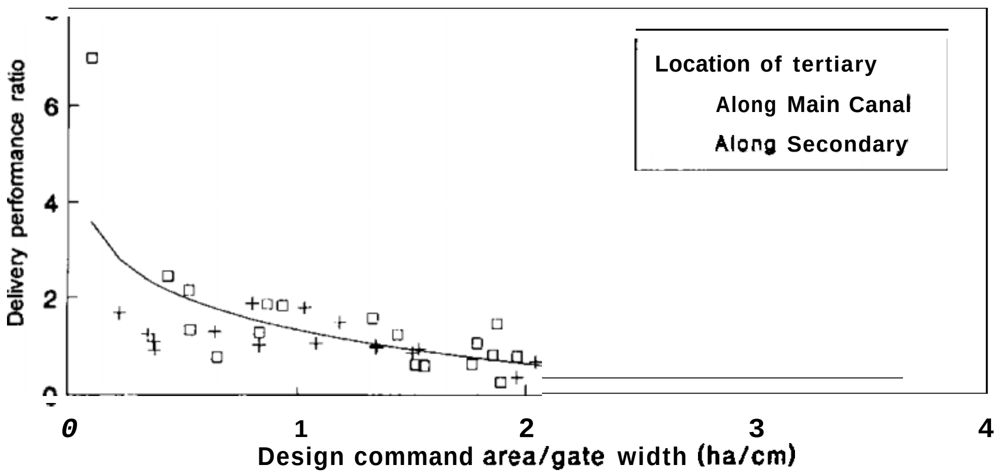


*Figure 5.22. Gate widths and design command area: two examples from Indonesia.*

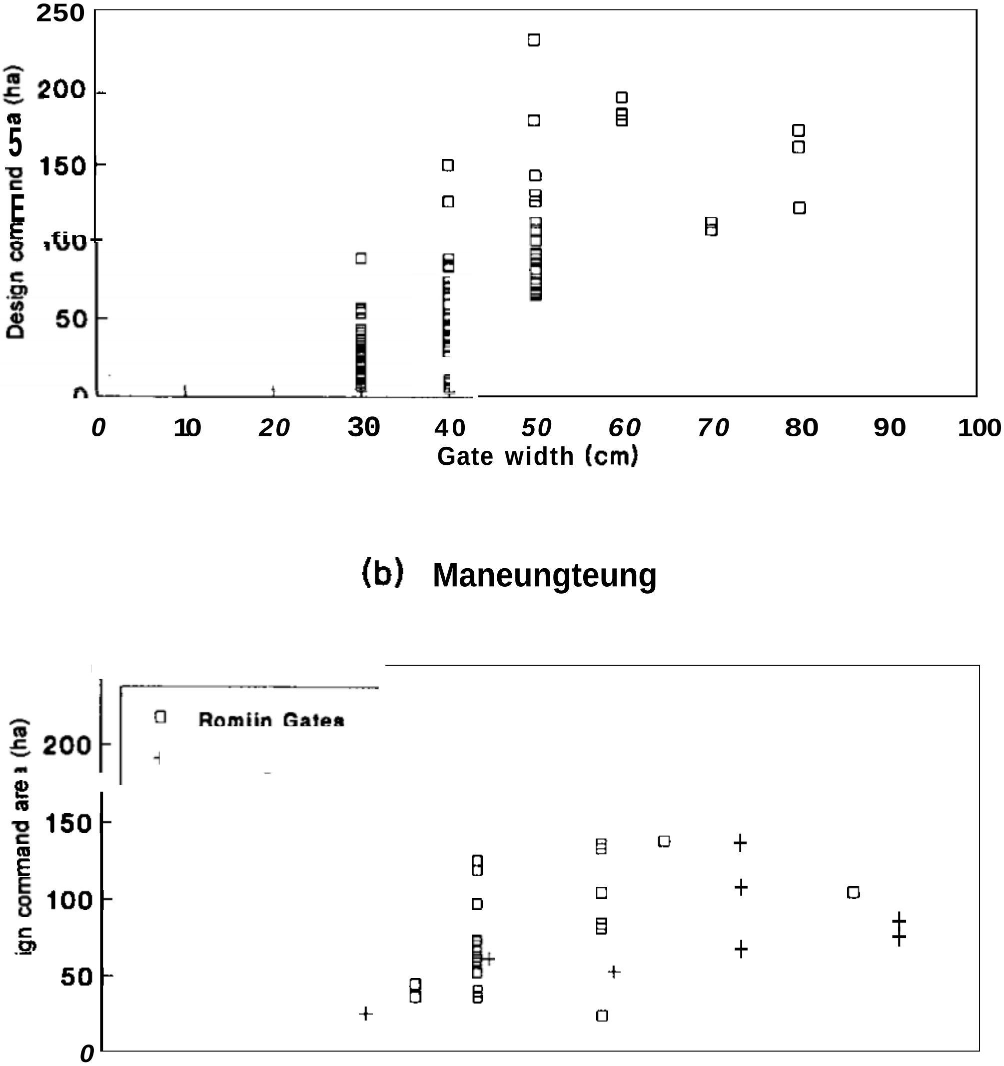
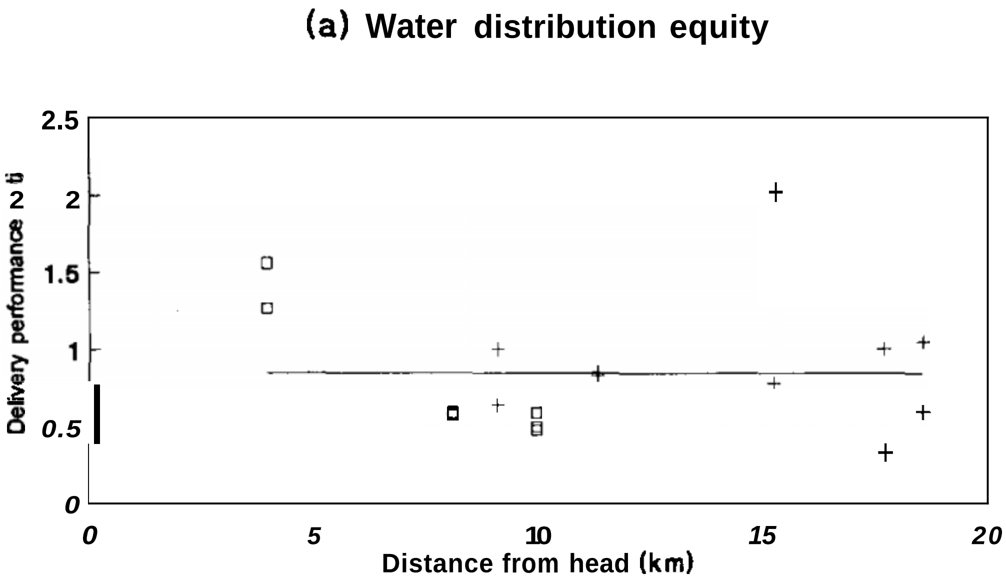


*Figure 5.23. Design impacts on water distribution equity, Way Jepara, Indonesia, dry season, 1988.*



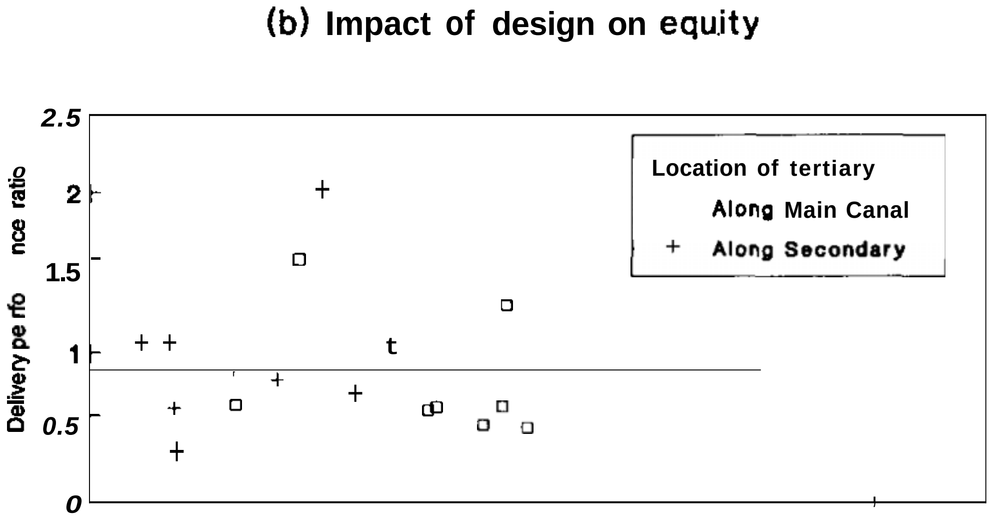
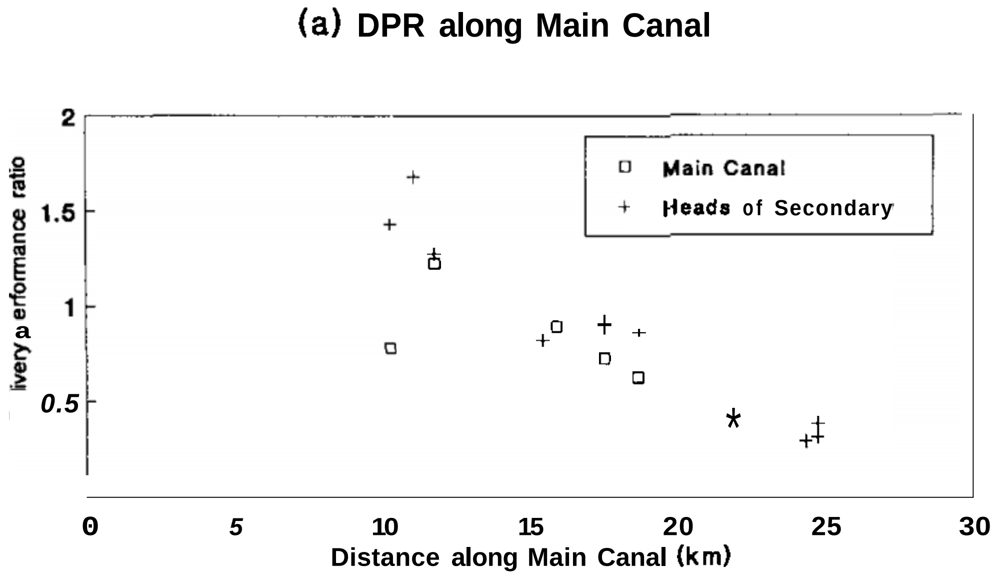



*Figure 5.24. Water distribution equity, Maneungteung, Indonesia, wet season, 1988.*



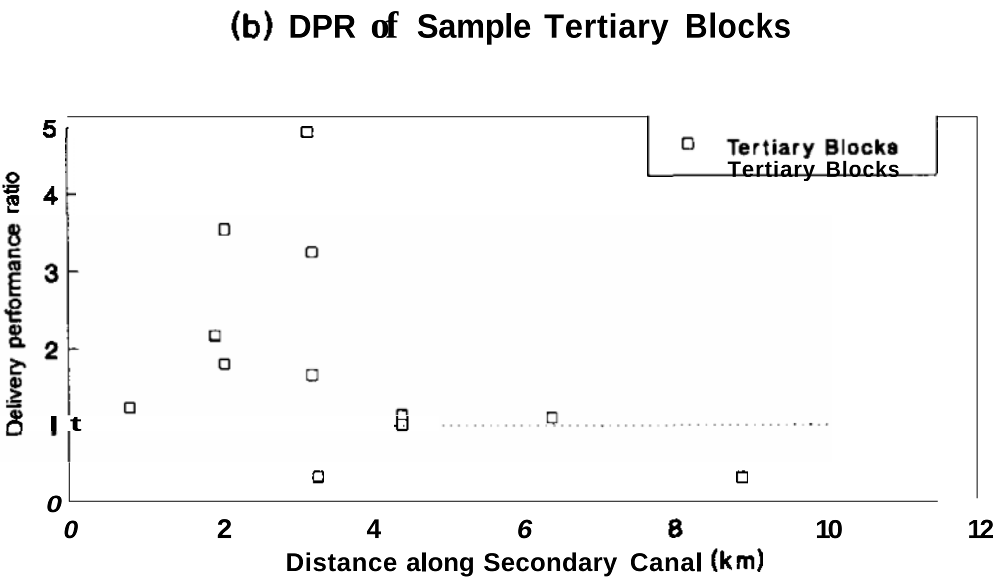
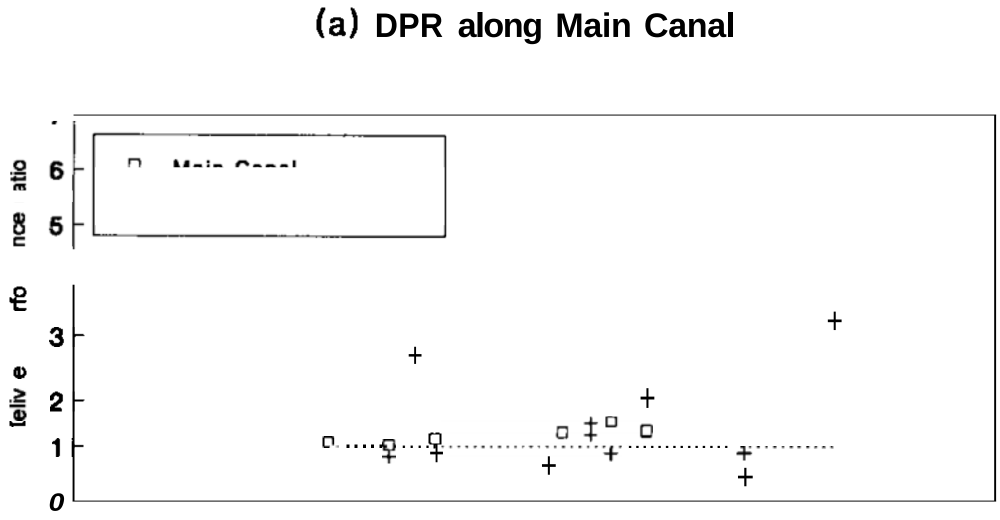



*Figure 5.25. Water distribution equity, Maneungteung, Indonesia, dry season, 1988.*



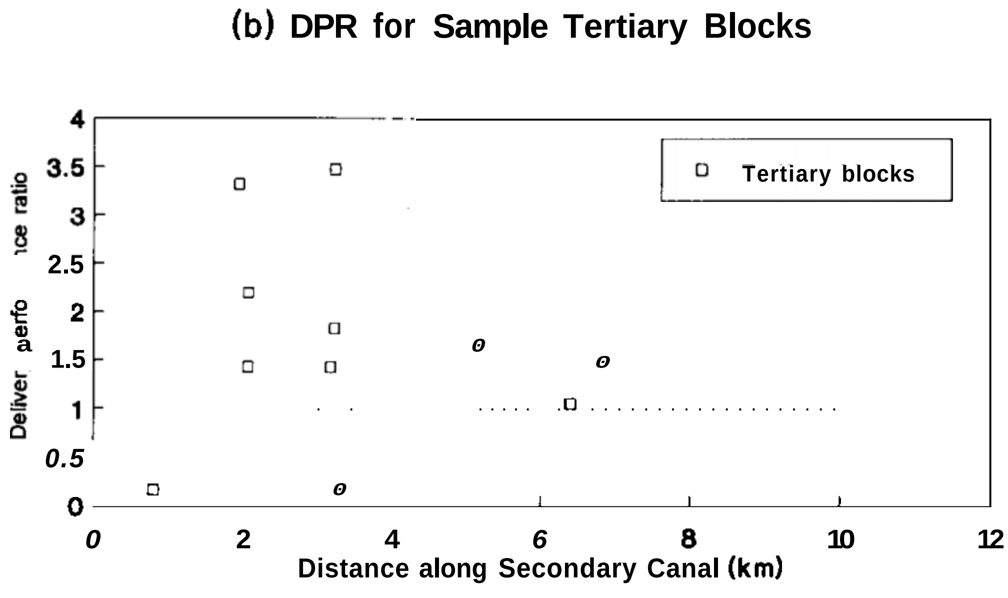



*Figure 5.26. Changes in equity during rotational irrigation, Maneungteung Irrigation System, Indonesia.*

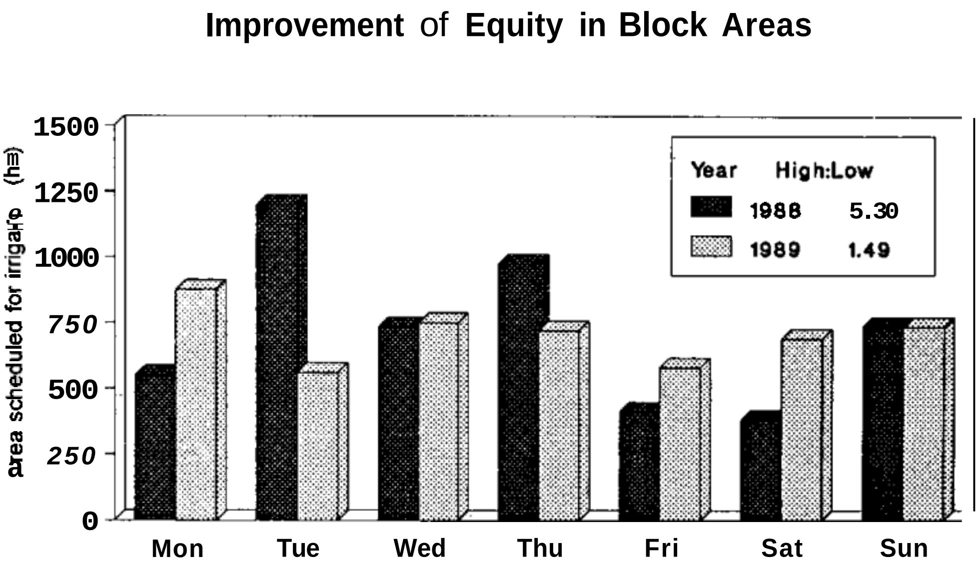



*Figure 5.27. Changes in management inputs during rotational irrigation, Maneungteung Irrigation System, Indonesia.*

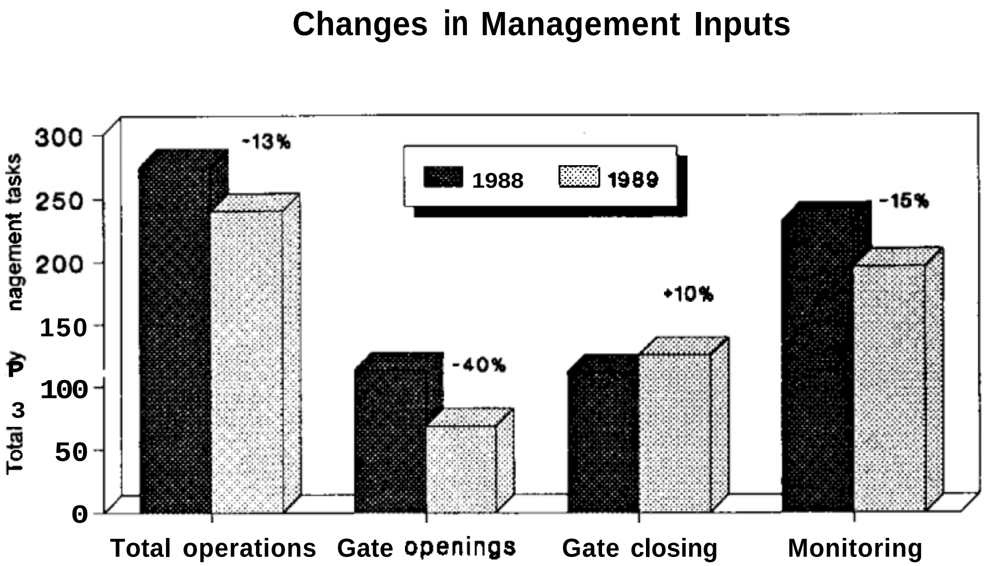
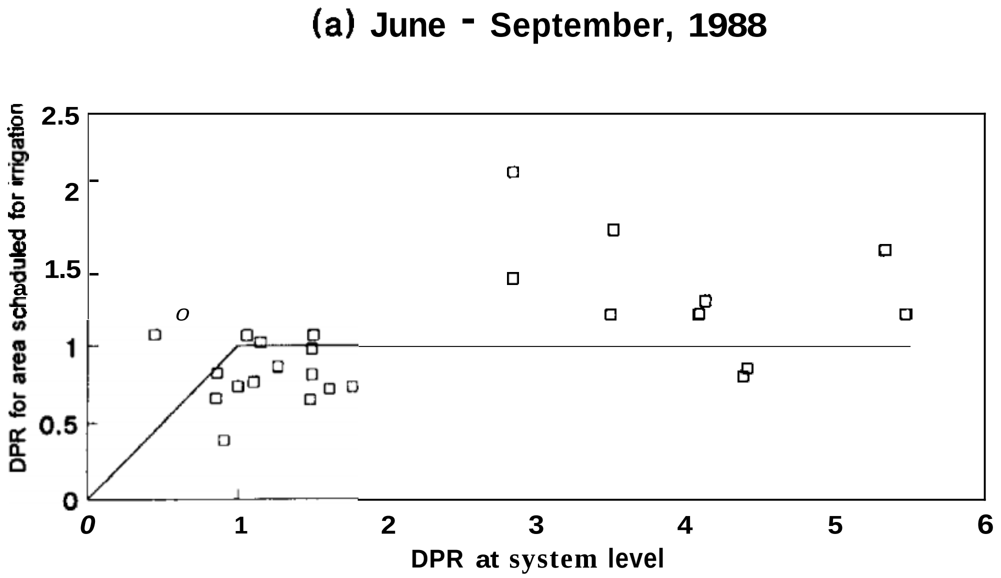
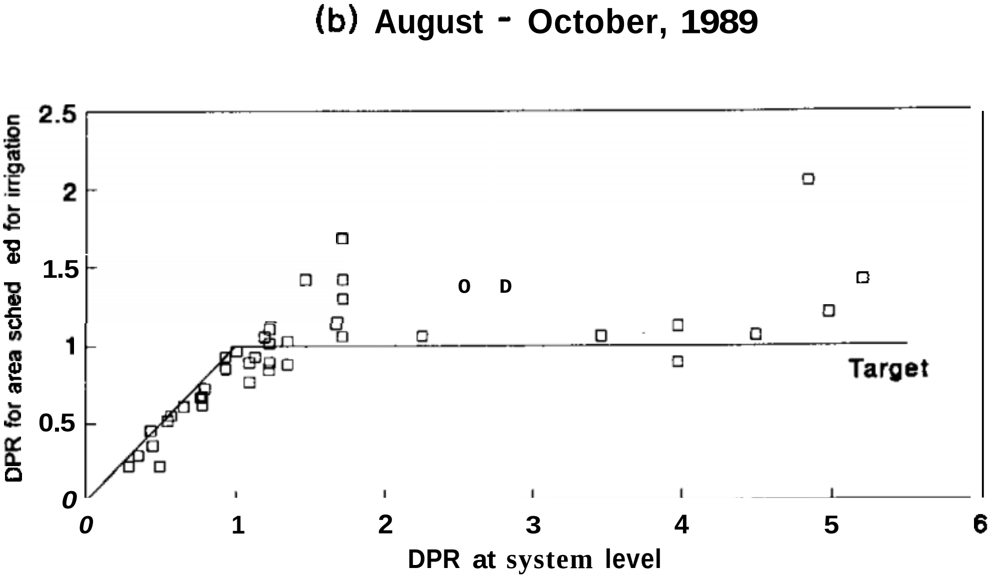


*Figure 5.28. Improvement in water delivery performance, Maneungteung Irrigation System, Indonesia.*



# CHAPTER 6

# Lessons Learned from the Case Studies

## LACK OF EVIDENCE OF AN EFFECTIVE PERFORMANCE ASSESSMENT FRAMEWORK

NONE OF THE case studies contained any evidence of an effective assessment framework which would help managers improve over the levels of performance reported in the previous two sections. That does not mean to say that none of the systems have such a framework it might be there, but is unreported.

Further, and this is equally telling, most of the case studies are reports of specific research activities that were themselves instrumental in collecting the data presented. This indicates that the operating personnel and the managers do not have access to data of sufficient quantity or reliability to assess performance and diagnose ways of improving it.

Which of these two conditions needs to be addressed first if performance is to be improved is difficult to determine: data collection programs without a framework appear doomed to die through lack of relevance; a framework is of little value unless there are good data to be used.

## LACK OF CLEARLY STATED OBJECTIVES

Most of the case studies did not identify the objectives for which the systems were being managed. This reflects in part the lack of a framework that stresses the importance of having clearly stated objectives, but it is also because outsiders impose their own understanding of what the objectives ought to be on the systems being studied.

This highlights a particular dilemma for observers attempting to make judgments about performance. The most commonly cited objectives, including many of those used in this study, are more global in nature: equity, reliability and adequacy are all seen to some extent as universal to the evaluation of water delivery performance. System managers may have an entirely different set of local objectives. Unfortunately, if they are not clearly expressed, they will be ignored in external assessment, and a different set of objectives used in any evaluation of the level of performance actually achieved.

The combination of the lack of an effective performance assessment framework and a set of relatively short-term research-oriented case studies means that there is little information on the long-term trends of performance in any of the systems studied. Short-term studies give little opportunity to see if performance is improving or declining, and the lack of long-term performance indicators in the assessment process means that adverse and even irreversible changes are simply not being monitored.

## TARGET AND OBJECTIVE MISMATCHES

In the majority of case studies some shortfall is reported either in achieving targets, in fulfilling objectives, or in both. It is obvious that without accurate data such shortfalls are inevitable, but it may be precisely because of adverse institutional pressures than system operators do not wish to report "bad news."

The first step in the diagnosis framework presented in Figure 2.3 is to check whether appropriate data exist. It is essential that data collection be undertaken openly and objectively if realistic assessment of performance is to rake place. The fact that shortfalls in meeting targets or objectives are reported should not initially be any cause for alarm or discrimination: it is when those shortfalls are viewed as persistent that evaluation must become more critical.

Assuming data exist, and this is not the situation in all of the case studies, then the diagnosis can proceed to assessing whether the defined targets, if met, would actually meet the objectives. The examples from both Gal Oya and Maneungteung suggest that even when targets were met they did not meet the stated or presumed objectives for the system: in other words, the targets themselves included significant inequity of water distribution while the system-level objective was stated as being to achieve equity.

Some of the case studies show the opposite: cases where objectives have been fulfilled even though component targets may not have been fulfilled. Way Jepara shows fairly high levels of equity, but the operational targets were not met. Perhaps this is because water conditions were highly favorable (supply far exceeding demand) so that there was no incentive to precisely meet targets. Certainly efficiency of water use was very low, an example of where the second part of the definition of performance is relevant.

Whichever scenario is considered, however, it is obvious that there is little concern with better matching the system-level objectives with operational targets. At this stage of the diagnosis it may not be possible to say which should be modified in the future, but it is clear that the system is inherently out of synchrony and this can only perpetuate the situation where performance is lower than it could be.

There is some evidence to suggest that operational targets are institutionalized, and remain static even if external or system-level objectives change. Such rigidity is the hallmark of bureaucratically administered systems rather than of performance-oriented management systems.

The worst case, and regrettably the one that seems to typify most of the case studies is that neither objectives nor targets were met to any great degree of precision. It may be that in most cases the managers are neither "doing things right" nor "doing the right thing." This does not mean to say the systems are catastrophes, but it does mean that there is tremendous potential to improve performance.

## ASSESSMENT OF OPERATIONAL PERFORMANCE

In the lower part of Figure 2.3 possible courses of action are addressed when neither objectives are fulfilled nor targets achieved. A basic conclusion here is that when neither objectives are fulfilled nor targets 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, if objectives or targets are not being fulfilled nor targets being achieved.

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 fulfill more ambitious sets of targets.

A simple example comes from Kirindi Oya New, and more complex, irrigation designs proved initially to stress the management capacity of the irrigation agency. Once appropriate training, associated with computer modeling, took place, it proved possible to manage the system much more effectively.

A conclusion that can be drawn at this stage is that where there appears to be widespread deficiency in both the physical system and the management conditions, the most effective first steps will be to focus more on improving management rather than going for a technological solution.

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 2.3 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 for 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.

The case study of rotations at Maneungteung, West Java, exemplifies this point. By improving objectives, implementation and monitoring through involvement of both agency staff and farmers, significant performance improvements resulted.

Rehabilitation and modernization, for example, are legitimate strategies to improve output from a system, but should only be advocated under a specific set of conditions. This condition is when evaluation determines that 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 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.

The case studies from Pakistan appear to suggest very strongly that management improvements, particularly the management of maintenance, are essential in improving overall water delivery performance. More complex technological solutions are less likely to be effective if the capacity to maintain simple infrastructure is inadequate.

Assessment of operational performance is in large measure a site-specific activity. What is being assessed is the degree of achievement of specific hydraulic and other targets, and their capacity to meet the system-specific objectives.

Under these conditions. therefore, the primary motivation of a manager will be to increase performance in absolute terms for that system. based on a time series view of actually achieved performance. A good example would be the improvement of equity of water distribution: if this is a system objective and the manager consistently improves the achieved level of equity this is good performance irrespective of the situation encountered in any other system.

## ASSESSMENT OF PERFORMANCE BETWEEN SYSTEMS

It is more difficult and perhaps impossible to make many definite conclusions about the relative performance of different systems. Nevertheless, the overall environment in which an individual system is being operated must be taken into account when decisions have to be made in respect of where to invest for improved performance in the future.

The case studies are too diverse in both physical design and managerial environment to be definitive. Nevertheless, in respect of certain objectives that concern decision makers at levels higher than the individual system, the following observations can be made based on the available evidence.

### Equity

Fixed division systems generally outperform gated systems in respect of equity: this is not a surprising conclusion insofar as equity is largely built into the system, but it suggests that when managers have greater operational flexibility at their disposal they do not use it to achieve greater equity. Indeed, there is some evidence that the flexibility is not utilized because design assumptions on how gates will be operated are not fulfilled: approximations in design dominate equity of water distribution rather than precise operational control.

### Reliability

In terms of reliability, subsystems within larger *fixed* division systems often outperform subsystems in larger *gated* division systems. However, this depends on the quality of main system management: if there is good control at the system head and if maintenance is properly managed, then the fixed control infrastructure is effective in delivering water reliably.

It is much more difficult to make any conclusions concerning either reliability or equity for small systems because there are less data available. In general, small systems are "self-monitored" by water users, and there is less need to develop a long-term written historical database. It is widely assumed that smaller systems achieve higher levels of performance than larger ones: the evidence in the case studies discussed here is simply inadequate to come to any conclusion in this regard.

## Adequacy

Assessing adequacy is also extremely difficult. In most fixed division systems it is an explicit objective not to give farmers as much water as they would like to have or could use. The principle behind many fixed division systems is to share inherently scarce water among as many users as possible. Adequacy can only be evaluated in terms of individual cropping decisions.

The evidence suggests that in larger gated division systems despite the relatively greater investment in physical infrastructure, adequacy is not met. This is true for the Sri Lankan, Indian and Indonesian examples where there are big differences between water deliveries and estimated demand. In all cases studied there appears to be no technical reason why these differences occur, and the obvious deduction is that management is weaker than required to effectively operate the infrastructure provided.

One conclusion to be drawn from this is that investment decisions need to be guided as much by the evaluation of organizational and infrastructural capacity to manage systems as by the physical precision implied by selecting more complex technology. Where management is weak then provision of a complex system is not necessarily the best investment policy: simplicity in rules for operation and maintenance and simplicity in design of structures may result in better performance. The corollary of this argument is that, as indicated above, upgrading control infrastructure can probably only be justified if the management capacity already is in place to take full advantage of it.

# CHAPTER 7

# Propositions for Improving Performance

THIS SECTION OFFERS a set of propositions 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 and 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 propositions are divided into four sets, the first dealing with objective setting, the second with operational management, the third with information management and the fourth with management conditions.

These four activities are not sequential. A properly managed organization relies on a continuous cycle of planning, implementation, and review 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.

## 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. Thus, there is little or no opportunity for stabilization of management inputs.

***System-level objectives must be based either on past experience from that system, or from system facing similar design and management conditions, rather than on assumptions about what ought to be achieved in more generic terms.***

It is common to find in the preparation of projects, whether system- or sector-oriented, that objectives are developed which do not conform to 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 system 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 different levels of performance is, however, quite legitimate. The case studies indicate that no clear distinction is made between performance assessment relating to specific objectives of managers and assessment of the impact of current management strategies on other aspects of performance. 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 of the impacts of current management actions.***

There are many reasons why objectives do not match system design. In some cases there is a need to justify initial investments based 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. It is easy and probably inappropriate to criticize managers of systems in these countries for low water use efficiencies or for 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 contradictory. 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, panicularly 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: policymakers, planners, managers and users, rather than only of 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 for 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.

***One way of improving performance is by strengthening farmer parricipation in the annual or seasonal planning process and developing operational plans and targets.***

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 in accordance with objectives set by the agency alone. This is obvious for the smaller systems, such as those of Nepal and lava, but appears equally true for Viejo Retamo and, briefly, for Maneungteung. 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, but 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.

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 held 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.

Once objectives have been clearly defined the next task is to transform these into clear quantitative operational targets that are required of each individual within the hierarchy. Operationalization clearly includes both the structure of the decision-making 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 only 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 for the secondary impacts of irrigation on sustainability or income distribution. In some respects this is not only because the responsibilities of any particular group do not cover these objectives, but because 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 handed down from 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 on 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 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 the 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 shares 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 it enables 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.

## 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 do 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 do not mean any 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 have 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 to and not embarrass colleagues mean 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 the use of existing computer models to assess alternative operational and maintenance strategies. Such models enabling testing of different scenarios without jeopardizing agricultural output facilitate speedy processing of datacollected through routine monitoring activities. In many cases the technology exists but the institutional conditions do not.

## INSTITUTIONAL AND OTHER MANAGEMENT CONDITIONS

The final set of propositions relates to the institutional conditions within which systems are 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 then evaluating performance based on an assessment of the degree of achievement of those targets becomes an abstraction.

Large irrigation agencies, particularly those where salaries, promotions, 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 are 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 it has 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 requires that patience and understanding are present to tolerate false starts and mistakes during this process.

Irrigation management always occurs 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 will 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 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.

# CHAPTER 8

# Sustaining Irrigation Performance

## LONG-TERM ASPECTS OF PERFORMANCE

CHAPTERS 4 AND 5 largely focused 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 intra-seasonal 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 output indicators do not show trends. Monitoring and information management requirements to determine trends are 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.

## SUSTAINABILITY OF PERFORMANCE WITHOUT EXTERNAL CHANGE

All of the case studies included in Chapters 4 and 5 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.

## Waterlogging, Salinity and Soil Degradation

The case studies suggest that system managers are not very concerned with whether the physical resource base of their 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 into Lake Qarun are reduced to avoid the rise of water level above a specified limit. Other case studies are less encouraging.

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 8.1). If deliveries are reduced during periods of low evapotranspiration the water table level can be kept below danger 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. Yet, at least as far as the case study is concerned, there is no evidence that the management guide has been adopted.

Environmental concerns are of great importance to sustainability of agriculture in Pakistan. At one level, current output performance is relatively disappointing as indicated by cropping intensities, cropping patterns or yields. There is some evidence that wheat yields per unit of water in Pakistan are highest when farmers have access to a 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 important, however, is the question of salinity resulting from under-irrigation. 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 to 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 et al. 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.

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 are completely and independently responsible for private shallow tubewell development and management.

There has been a technological fix to the problem, once it had arisen, through the installation of drainage systems, 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 allows a sustainable balance between short-term output targets and long-term sustainability to be pursued.

## Health

There are increasing concerns with the impact of irrigation on the 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 for maintaining production rather than as an integral part of the objective set to be considered when drawing up shorter-term plans for water allocation and distribution.

## 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 of water 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 be actually 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 at 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 to find land abandonment at the ends of many canals, 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, subsystem and system levels. 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 little evidence that these gains were 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; this 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.

## 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.

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

## Competition for 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 resource allocations 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 nonagriculture sectors such as domestic 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 (Lansing 1991).

## 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.

## Changes in Agricultural Demand

Changes in government policies towards the agriculture 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 fanners 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 forresponse 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 systems 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 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 becauseextensive 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.

## 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 leveled 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 policymakers 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-financingface 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 have toundoubtedly change because they will have to be more responsive to the needs of the users who will foot the bill.

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 the performance of systems. However, it is too early to find good data following these changes.

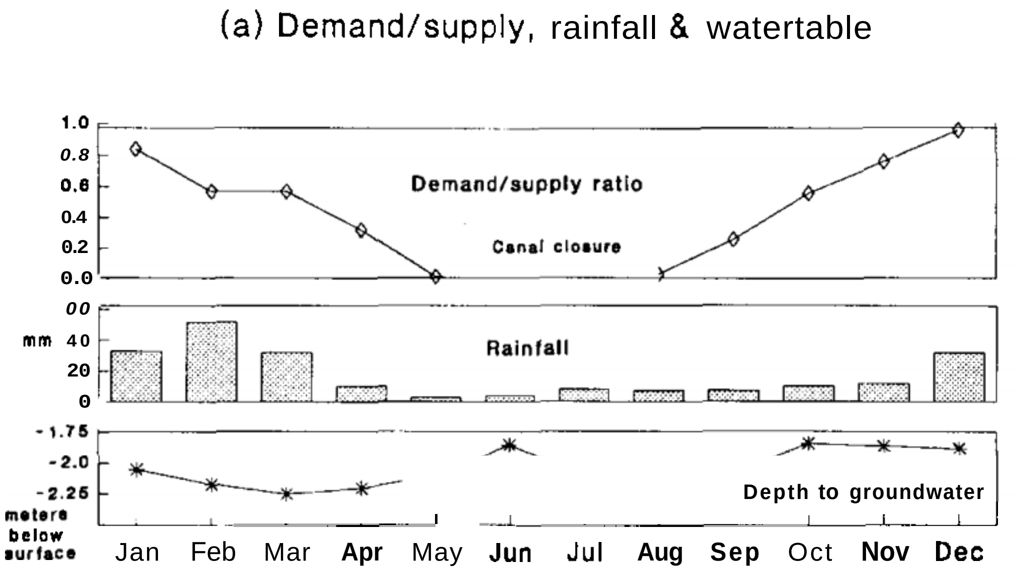
## Competition for Land or Labor

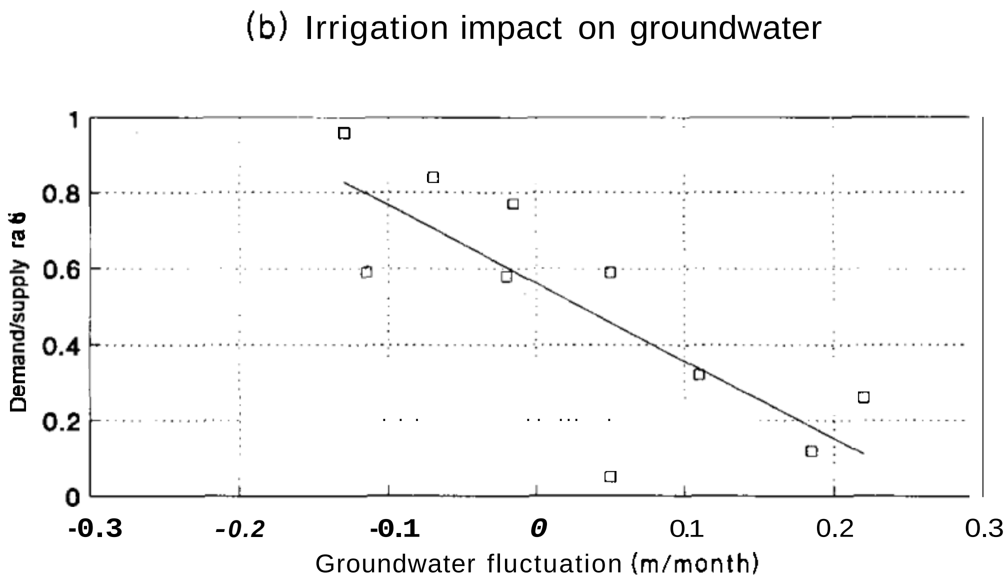
One final exampleofexternalchangeiscompetitionfor non-water resources, notably for land and for labor.

In the Maneungteung case, actual irrigated land was about 10percent less than officially reported. This is symptomatic of the tremendous demand on land for housing and other nonagriculturalpurposes. Similartrendscankseeninall 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 king 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.

*Figure. 8.1. Effect of irrigation management on groundwater, Viejo Retamo, Argentina.*



# CHAPTER 9

# Conclusions

GIVEN THE DIVERSE nature and expectations of the case studies included in this paper it is difficult to come to definitive conclusions. Nevertheless, it is possible to make a number of general conclusions that have relevance for future activities.

***The case studies show little evidence of performance-responsive management being undertaken by the various agencies concerned.***

The evidence from the majority of the case studies is that irrigation system are not managed in response to performance. Where operational or maintenance rules are indicated in the case studies, they are most often routinized rather than made in response to actual field conditions. Virtually none of the case studies indicate the actual objectives of operating the system, thereby removing a major component of the performance assessment process.

There is strong evidence that actual conditions do not coincide with the stated targets in most of the case studies. However, given the data available, it is hard to distinguish between those cases where the mismatch between desired and actual conditions is deliberate, in response to legitimate changes at field level, and those cases where it is the result of poor control.

***Where irrigation managers do not state their objectives clearly, they run the risk of having objectives imposed on them by others.***

Most of the case studies describe performance in terms of a general set of objectives that are assumed to apply more or less universally. This is certainly true of indicators that refer to equity, reliability and adequacy. These may not necessarily be the objectives for a particular system, although they are of interest in a comparative sense.

This difference between the objectives of an individual system and those at a wider level is an important one. Clearly, it would be impossible to expect every system to contribute equally to the national goals, although the total sum of their contributions should approximate the wider objectives. An important task for managers ought to be to distinguish clearly between those objectives they see as being of local or site-specific importance and those which are part of the wider sector view.

In assessing individual system performance, those responsible for undertaking performance assessments should try to determine which objectives are priorities at system level. If they do not succeed in identifying local objectives (and the authors here may be guilty in this respect) then assessment will be based on the imposition of wider objectives rather than on those objectives actually viewed as important at the system level.

***The case studiesprovide lirrle or no information on the instirurional or organizational condirions in the systems described: it is very difficult ro make a rrue assessment of design-management interactions wirhour such information.***

Most of the case studies describe the physical design of the system (although this had to be supplemented by personal knowledge in several cases) but few describe the management conditions in any form at all. It is therefore easy to fall into the trap of linking performance too much to the physical conditions and ignoring the contribution of the management structure to actual performance achieved.

In many countries, including those represented in the case studies. governments spend less and less in real terms on system operation and maintenance. This means that managerial capacity is likely to be weaker than in the past, and this must affect performance. While it may be assumed that the organizational structure and institutional conditions are designed to match the management requirements of a particular design, there is some evidence to suggest this is not the case: many of the State Irrigation Departments in India and Pakistan are more or less similar in structure and purpose even though the system designs vary significantly.

***Simple designs and simple operational rules rend to result in performance ar least as good as that in complex systems, and may even ourperform them in absolute terms.***

In a more positive light, one conclusion that appears to emerge from the case studies is that simplicity tends to lead to better performance. This is true both for simple physical designs and for simple operational rules and targets: where they are combined it is easier to meet targets.

The counterargument is that simple targets may be too modest and may be too inflexible. This is undoubtedly true. Nevertheless, the evidence suggests that where the systems have a high density of operable control structures, or a complex set of operational procedures, or both simultaneously. overall performance is no better and is frequently worse than where design and management conditions are simple.

This study concludes that increasing the control potential of an irrigation system without addressing managerial capacity is highly unlikely to lead to improved performance. Conversely, improving management of a system can lead to performance improvement without any physical improvements whatsoever. The more successful case studies reinforce this conclusion strongly.

***The prospects for sustaining performance improvements into the future are weak if there is no institutionalized framework for responding effectively to acrually achieved performance.***

All of the case studies are short-term snap shots of conditions over one or two seasons: no long-term studies are reported. There is some circumstantial evidence that performance improvements resulting from such short-term managerial intervention may not be sustained. The reason for this is almost inevitably the consequence of the lack of a performance assessment framework within agencies than enables managers to rapidly identify deviations from the implementation plan and take appropriate remedial action both in the short term and within the annual or seasonal planning time frame.

***Few of the case studies show any evidence of concern for sustaining the physical resource base necessary for productive irrigated agriculture.***

Few case studies show evidence of managers using long-term indicators of the overall condition of physical resources. In the cases reported by ILRI in Egypt and Argentina, and IIMI in Pakistan, references are made to waterlogging and salinity; all other case studies show a short-term focus only.

It is arguable that a system manager may find it extremely difficult to manage for both the short term and the long term. Even if this is true, however, there is little sign that long-term monitoring activities are fed back into the annual or seasonal planning activity in such a way as to modify existing water or crop allocations or areas authorized for cultivation.

## Opportunities for the Future

*Many* of the conclusions given above require verification. The use of secondary case studies that contain insufficient information will, in the long run, need to be replaced by a set of more focused 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.

Future studies need to move well beyond the main focus reported here of canal operations and maintenance: this focus was dictated in large measure by the inconsistency between case studies on the depth and breadth of information on other aspects of system management conditions and performance in respect of agriculture or economic development. Similarly, future studies have to include greater concern for environmental and social conditions which have the capacity to undermine agricultural stability if they are not made part of the objective set for system managers.

The paper has attempted to address the shortfalls that exist in current management practices in relation only lo water delivery in the canal system. There can be little doubt that what is required in the future is the implementation of a performance-responsive framework that managers and planners can use, and a parallel set of more consistent and more focused performance case studies in a range of physical and institutional environments. If this combination of intervention and knowledge improvement can be undertaken, then we are confident that this will be the basis for more sustainable, performance-oriented irrigation management in the future.

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# Glossary

This glossary provides definitions of the objectives and performance-related indicators used throughout the text.

## Objectives

This report refers to three primary objectives for an irrigation system. 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

Adequacy 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 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 lands to their 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

Equity 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 standard 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 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 time 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. Unreliable supplies are likely to prove a major and insurmountable constraint to high agricultural output.

## 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 *Rarw* (DPRJ. 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 hy 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 "lnterquartile Ratio" refers to Abernethy's modified interquartile ratio that compares the average of the top *25* percent of values in a range with the average of the lowest *25* percent of values (Abemethy *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 (RWSJ. The indicator RWS, developed hy 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, hut with values at or close to 1.0 management inputs themselves will not necessarily compensate for the relative scarcity of water.

***Water Availability* Index *(WAI)*.** The indicator WAI, 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 rice 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).

# 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 lava, Indonesia
3. The Fayoum. Egypt

## Submerged Orifice Systems

4. Upper and Lower Gugera divisions of the Lower Chenab Canal, 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, Mahaweli System H, Sri Lanka

## Gated Division, Gated Cross-Regulation

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

### *Case Study #1: Six Farmer-Managed Systems in Nepal*

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 Terai lowlands south of the Himalayas and three in the hill region of the Himalayan foothills

The three Terai systems are all established run-of-the-river systems that were scheduled for rehabilitation and possible expansion. Two of them, Laxmipur (I 34 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 an 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 when 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, with 1.5 km, while each of the other two is 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 of perceived need for water

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*[The authors gratefully acknowledge the assistance of the IIMI Nepal Office in providing access to these data prior to submission of the final evaluation report. and to assistance provided by the Departmen: 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-managed system in West Java Built in more or less its present form by fanners some hundred 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 of them have now been replaced by concrete sections that still maintain the same proportions of crest length for main and offtake canals. In the sleeper 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 fewer 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 1970s, 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 Shall-Scale Irrigation Turnover Program to assess the needs for physical and organizational upgrading prior to handover of full operations and maintenance responsibilities to fanners

## Reference:

International Irrigation Management Institute. 1989c. 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 maferial. The study was funded as part of a larger grant from the Asian Developmenf Bank and fhe Ford Foundafion, Jakarta.]*

## *Case Study #3:* The *Fayoum, Egypt*

The Fayoum Depression, southwest of Cairo, has a gross irrigated command area of 150,000 ha of 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 (each 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 percent of the total land is desert and annual rainfall is a b u t 10 mm.

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

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### *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 Mananwala. 45 km long 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 33,119 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 the 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 the use of such stop logs.

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

When there is sufficient water. particularly in the 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.

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### Case *Study #5: Mudki and Golewala Distributaries, India*

The design of the systems of the Indian Punjab is almost identical to that 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 significant 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 percent of Full Supply Discharge that is permitted under current operational rules.

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

The 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 the 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 irrigate 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 to several hundred years. The main canal passes through several of these reservoirs, making it possible lo control releases at several different locations. The main and secondary canal system is controlled through a series of undershot regulator gates, some venical, 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 channels are gated culvens. There is a wide range of command areas of distributary channels, from 4 lo 500 ha, with each distributary channel 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 the tail-end areas there has been a little tobacco and vegetable cultivation, but if water is insufficient for rice cultivation then land is normally left fallow. Annual cropping intensities were about 150 percent. Water allocations were on the basis of 1,300 mm of water for wet-season rice, and 1,800 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 have become very different from those described above.

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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*

The Tungabhadra Pilot Irrigation Project straddles the borders of Kamataka 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 delivery 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 percent cropping intensity in the** wet season (of which only **20** percent is to be rice), **37** percent in the dry season (none of which is supposed to be rice). plus **18** percent of perennial crops. notably sugar and cotton. Although this should result in an annual cropping intensity of 100 percent over two seasons, actual cropping intensity is about **67** percent, of which one third is rice.

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### *Case Study #8: Hakwatuna Oya, Sri Lanka*

Hakwatuna Oya is a 2, LOO-ha reservoir-backed system in northcentral Sri Lanka. The system is divided into two pans, 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 Canal System, approximately I3 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 somewhatlonger, approximately 20 km in total, but is subdivided into three branches with a bifurcation structure at the head of each subbranch. 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 6-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.

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## *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 to 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 and has 176 distributary canals totaling at least 2,800 km, and a Full Design Discharge of 310 $m^3$/sec.

The total length of the canal is over 250 km, terminating at Bhagat Head Regulator in the Lower Gugera Division. Along this length there is one major regulator at Buchiana where Burala Rranch 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 the Lower Gugera Branch and require major and rapid attention when they do occur.

Most offtakes from the 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 the year.

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## *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 cause 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, thesituationismoredifficult 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 a higher degree of water distribution equity and thus higher production and income for water users.

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### *Case Study #11: Kalankuttiya, Mahaweli System H, Sri Lanka*

Kalankuttiya Branch Canal of Mahaweli System H was completed during the 1970s. The main canal is 1 1 km long, serving 20 secondary offtakes. The total command area is 2,040 ha

Discharges in lhecanal arecontrolled from a small reservoirsupplemented by issues from the upstream portions of the integrated Mahaweli network. This enables plans to be drawnup onaseasonal 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 arc 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 completcd to encourage cultivation of non-rice crops in the dly season, particularly on lighter textured soils, in an effort to avoid water shortages. This strategy has been partially successful, panicularly for chili cultivation.

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*[The authors are grateful lo 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 **4,890** 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 headstmcture. 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. Themtations' turns move sequentially down the canal. and are controlled by a gatekeeper employed by the federated water user association.

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

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

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## *Case Study #13: Kirindi Oya, Sri Lanka*

The Kirindi Oya System in southern Sri Lanka has a command area of 12,900 ha, including 4,500 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.

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## 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 were not irrigable due to the collapse of a siphon on the smaller Right Bank Canal.

The system conforms to the current design guidelines of the Department of Public Works in Indonesia Along the main canal there are a series of wntml 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 of *Romijn* type, 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 percent of the area is scheduled for irrigation, again only for rice. However, there is a well-implemented program where 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 the Directorate of Irrigation I, Department of Public Works, and the Lampung Provincial Irrigation Service.

### Reference:

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## *Case Study #15: Maneungteung Irrigation System, Indonesia*

The Maneungteung Irrigation System is east of Cirebon, West Java. Served by a weir in the Cisang Garung River at Cikeusik and an 8-km long main canal to the headofthe system, the total irrigated area is 7.611 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 thetailendandafewsecondaries whichdonot 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 2,400 ha, is dominated by sugarcane cultivation, up to 50 percent of the total area at any one time. The eastern two-thirds. however, have only about 20 percent of sugar cultivation, much more wet-season rice, and extensive onion cultivation that relies on hand irrigation from trenches dug into rice fields and filled by 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 the Directorate of Irrigation 1, Department of Public Works. and the West Java Provincial Irrigation Service.

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