PN-ACH-936

WORKING PAPERS ON IRRIGATION PERFORMANCE 3

ASSESSING SEASONAL IRRIGATION SERVICE PERFORMANCE

Rien Jurriëns

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

Working papers of the International Food Policy Research Institute encompass a wide range of subjects drawn from its research programs. The papers—primarily data analyses, historical descriptions, or case studies—contain information that IFPRI believes may be of interest to others. Working papers undergo informal review but do not necessarily present final research results.

ASSESSING SEASONAL IRRIGATION SERVICE PERFORMANCE

Rien Jurriëns

Working Papers on Irrigation Performance 3

International Food Policy Research Institute
Washington, D.C.

June 1996

CONTENTS

Foreword vii

Introduction 1

Part 1: The Concept and the Indicators

1. Performance Assessment Framework 5
2. Performance Targets and Indicators 10
3. Supply Performance Indicators 15
4. Variability Performance Indicators 19
5. Efficiency Performance Indicators 23
6. Summary of Approach and Indicators 26

Part 2: The Practical Application

7. The Tungabhadra Case 31
8. Irrigation Objectives and Targets 36
9. Irrigation Intensity Performance 41
10. Flow Delivery Performance 46
11. Water Use Performance 49
12. Uniformity Performance 52
13. Reliability Performance 58
14. Efficiency Performance 60
15. Summary and Conclusions 63

Glossary 67

References 69

TABLES AND ILLUSTRATIONS

Table 1 Framework and choices made 9

Table 2 Summary of targets and indicators 13

Table 3 Uniformity and reliability 19

Table 4 IIR and WUR as overall performance indicators 28

Table 5 Localized crops and planted area for Tungabhadra Left Bank Command Area 36

Table 6 Localized crops and planted areas, D36 canal 37

Table 7 Duties for Tungabhadra scheme 38

Table 8 Target and actual irrigation intensities for Left Bank Command Area, 1987/88 41

Table 9 Target and actual irrigation intensities for D36, 1987/88 42

Table 10 Summary of irrigation intensity performance, 1987/88 45

Table 11 Summary of flow delivery performance, 1987/88 48

Table 12 Target and actual water use for Left Bank Command Area 49

Table 13 Target and actual water use for distributary D36 50

Table 14 Water use performance for Left Bank Command Area (LBCA) and distributary D36 51

Table 15 Flow along D36 in *kharif* 52

Table 16 Calculation of flow uniformity ratio (FUR) along D36 in *kharif* (based on Irrigation Department targets) 53

Table 17 Flow along D36 in *rabi* 53

Table 18 Intensity uniformity ratio along D36 in *kharif* 54

Table 19 Irrigation Department (ID) and equitable distribution (ED) targets and resulting flow delivery ratios (FDRs) 55

Table 20 Comparison of flow uniformity ratios (FURs) 56

Table 21 Average supply to outlets for various canal reaches, September 1987 56

Table 22 Reliability performance, main canal and D36 58

Table 23 Realized irrigation efficiencies, 1987/88 61

Table 24 Realized irrigation efficiencies for various years 62

Table 25 Overall (scheme) operational efficiency ratios for various years 62

Table 26 Summary of performance indicators 65

Figure 1 Tungabhadra Project, Karnataka, India 31

Figure 2 Monthly rainfall and evapotranspiration, Left Bank Command Area 33

Figure 3 Command area of distributary D36 34

Figure 4 Main components of the research program 35

FOREWORD

The Working Papers on Irrigation Performance series was initiated by the International Food Policy Research Institute (IFPRI) in early 1992 to promote research, discussion, and thought on issues relating to the effectiveness and efficiency of irrigation systems in the developing world. This is not a new topic, but much of the work in this area is marked by a wide diversity of definitions, assumptions, approaches, and methodologies, which has rendered results incommensurate and nonadditive.

The purpose of this series is to provide a venue for more coherent and focused efforts to characterize irrigation performance and to understand its determinants and its impacts on national food production systems. The series consists of concept papers that provide a framework for approaching irrigation performance issues and case studies that represent applications of these principles to field situations.

The series is rooted in an activity carried out in conjunction with the International Irrigation Management Institute (IIMI) to develop a framework and methodology for assessing irrigation performance. Several of the papers in the series had their origin in that activity, though other papers are included as well. A fundamental criterion for inclusion in the series is consistency with the definitions and concepts presented in the first paper, which articulates a framework for assessing irrigation performance and provides the overall conceptual basis for the series.

The case study presented here is drawn from Indian experience and provides an excellent counterpoint to the Philippine study which preceded it in the series. The scheme providing the basis for the analysis is large, located in a semi-arid environment, grows a variety of crops, and is managed by a large, routinized, bureaucratic agency. In all these features, it contrasts, to some degree, with the Philippine case. The author, Rien Jurriëns, has worked for many years in the study scheme and brings with him a thorough familiarity with it and its mode of operation.

This is more than a case study, however. In the first part of the paper, the author places the study into the context of the performance analysis framework presented in Working Paper 1. Referring to recent literature on performance indicators, he then carefully constructs a set of indicators appropriate to the study situation and discusses the characteristics of the constituent indicators.

In the second part of the paper, these indicators are applied to an extensive set of performance data taken from the Tungabhadra irrigation system in South India. Throughout this section, enough interpretation of results is supplied to highlight the merits and limitations of the indicators and the methodology. It should be kept in mind throughout that the paper is intended more to develop and evaluate a set of performance indicators and methodologies than it is to provide a comprehensive depiction of the performance of the scheme.

Mark Svendsen
Series Editor

INTRODUCTION

Since the mid-1980s there has been a growing need for performance assessment in irrigation systems to address the widely observed gap between expectations and reality. For some time, much of the discussion has been of a qualitative, general nature, and it has become clear that there is a need for a set of measurable indicators to use in evaluating the performance of specific irrigation systems. Having a consistent set of indicators is a necessary first step in identifying problems and developing measures for improvement.

Consequently, considerable work has been done in recent years on developing indicators of performance. This work has been extensively summarized by Rao (1993) and others. Substantial progress has been made on the subject and valuable ideas and indicators have been developed. This paper is meant to be a next step in the discussions to address some of the shortcomings in the present state of the art. These can be characterized as follows.

For some time, discussions addressed the development of indicators alone. More recently, discussions about conceptual frameworks for performance assessment have been stimulated by the 1991 FAO workshop (FAO 1991) and the work of Small and Svendsen (1990, 1991, 1992). The next step would logically be the systematic incorporation of indicators into a framework. This paper presents a set of indicators in one complete package, using the framework outlined in Chapters 1 and 2. At the moment, such an "integrated" approach is also being taken by the International Commission on Irrigation and Drainage-International Irrigation Management Institute (ICID-IIMI) working group on performance assessment (Bos et al. 1994). The approach and scope in this paper differ in some respects from that one, although there are similarities as well.

Many performance parameters (the "quality" elements of performance) have been proposed, such as efficiency, reliability, and equity. And for most parameters, many indicators have been suggested. For example, proposed indicators of "equity" include the coefficient of variation, the Gini coefficient, Christiansen's coefficient, the interquartile ratio, and various others (see Gillott and Bird 1993). This paper discusses the advantages and disadvantages of the various indicators and addresses some of the problems noted in the literature.

Much of the existing work has some problems in practical application. It either concentrates on methodology development, with little attention paid to practical application, or it deals with long-term field research, where there is much more opportunity (time, money, and manpower) for collection of detailed data than there would be in normal operation. Moreover, to be operationally useful, indicators need to be readily available to managers who must make timely decisions about taking remedial measures or modifying operational practices. The purpose of this paper is to develop a set of indicators for practical management purposes, for which the required data can be collected on a routine basis by operational field personnel.

In the "early days" of irrigation management research, Bottrall (1977) and Chambers (1976) tried to classify performance parameters in different groups, each group having its own characteristics—for example, productivity, equity, convenience, stability, and cost-effectiveness. Although not explicitly stated, or systematically organized, this classification involved some notion of the different subsystems mentioned by Small and Svendsen (1992)

and addressed in the 1991 FAO workshop (irrigation systems, irrigated agriculture, agricultural economy, rural economy, and socioeconomy).

In conducting research, it is not always evident with which subsystem one is dealing. Often, performance parameters or indicators are discussed without making the distinction at all, or the subsystems are confused with one another. This paper is limited to a discussion of the water delivery service.

Performance assessment can take place over different periods of time. Much of the recent work on water delivery performance has dealt with monitoring the day-to-day operation of the system. This paper specifically deals with seasonal and annual performance.

In summary, the purpose and intended added value of the paper is

- to develop a complete set of indicators, consistently placed in a systematic framework, and
- to emphasize their practical application in irrigation system management.

Discussion is restricted to the seasonal performance of water delivery services.

It is not the purpose to develop completely new indicators, but primarily to organize, adapt, and select the best of the existing ones. Partially new indicators are introduced only where there are none that fits the proposed framework.

Part 1 discusses the framework and the proposed set of indicators. Part 2 is a practical exercise in performance assessment for an irrigation system in South India, largely based on field research and summarized in Jurriëns and Landstra 1990. The exercise was conducted to see whether the concept and indicators proposed in Part 1 are relevant, consistent, and workable in practice. A glossary of terms begins on p. 67.

The package presented here is primarily valid for large-scale, jointly managed, and supply-driven canal systems. In the latter, allocations are determined by an irrigation agency. Only some of the suggested indicators are applicable to on-demand systems.

PART 1

THE CONCEPT AND THE INDICATORS

1. PERFORMANCE ASSESSMENT FRAMEWORK

THE NEED FOR A FRAMEWORK

Numerous discussions have revealed how complicated the issue of performance assessment is. The subject can be dealt with effectively only with a well-defined concept or framework of what the performance assessment is and is not. This is in line with one of the first conclusions of the FAO workshop Improved Irrigation System Performance for Sustainable Agriculture: "A proper framework needs to be set up at the outset of any performance analysis defining the purpose, scope and type of the assessment required" (FAO 1991, 18). Small and Svendsen 1990 and Svendsen 1991 presented a framework, which was revised in Small and Svendsen 1992. Subsequently, in the context of an ICID-IIMI working group on performance assessment, Bos et al. (1994) elaborated on the Small and Svendsen framework for a somewhat different purpose, including sets of indicators for various subsystems.

This chapter reviews the Small and Svendsen framework and its variations and discusses some of its key elements. It is a mixture of Jurriëns 1991 and 1992 and the above-mentioned references. The reader may initially notice some differences among the various approaches; however, these are primarily related to the choices made within the framework about what to concentrate on, rather than to essential differences among the approaches.

The approach in this paper is to dissect the seasonal water delivery performance of an irrigation system assessment by answering three questions: (1) What is the purpose of this assessment? (2) What are the boundaries of the assessment? and (3) What is the content of the assessment?

THE MODEL AND THE PURPOSE OF PERFORMANCE ASSESSMENT

There are different views on the nature and purpose of performance assessment, and its detailed contents largely depend on the view one adopts. The choices made in this paper are outlined below.

Goal-Oriented Model

An essential point of departure is that "performance assessment" should be seen as determining the degree to which objectives or targets are realized. This goal-oriented approach to performance, or "management by objectives," differs from the "natural system model" (see Small and Svendsen 1992) and has been adopted in most of the recent work (FAO 1991; Murray-Rust and Snellen 1993; Bos et al. 1994). Moreover, it involves a quantitative procedure rather than a qualitative description of processes, results, and problems. The implication is that all indicators should be a comparison of a realized and a target value. This comparison may seem obvious, but often it is not explicitly and consistently applied. Here the comparison is made using a ratio of the realized value to the target value.

Previous Page Blank

Routine Assessment

Performance is analyzed for different reasons. It can be the subject of a specific research project, and performance analysis can also be part of the routine management of a scheme. In the first case, much more time, manpower, and money are usually available for data collection and analysis. In the management of an irrigation scheme, the necessary data must be easily gathered and quantifiable so as to serve the purpose of controlling the management process and its results.

Seasonal Results

Even when a performance assessment is made routinely every season, the purpose of the assessment may vary. It may

- concentrate on operation during the season with daily or weekly checks on the extent to which the operation is managed according to plans;
- address the final seasonal or annual results of operations; or
- compare the results of various seasons and years, to assess the need for structural operational or strategic changes.

Indicators are used primarily to evaluate either day-to-day operation or long-term performance. For daily operations, the term "operational monitoring" is more appropriate than "performance assessment."

The longer the time horizon, the more an assessment is a matter of strategic, rather than operational (executive), management. The objectives are different, as well as the purpose for which the results are used, and consequently also the contents of the performance assessment. The seasonal performance measurement discussed in this paper falls somewhere in between: it is the final result of daily operations during the season, but the conclusions can also be used for strategic management. Yet emphasis is on the operational side, dealing with the question, Are we doing things right? and not, Are we doing the right things? (as put by Murray-Rust and Snellen [1993]).[1]

Existing Schemes

This paper deals with the management of existing schemes rather than with the development of new projects (for example, their planning, design, and construction) or the performance of a sector (such as the irrigation sector).

---

[1]In discussing the rationale for performance analysis, Small and Svendsen (1992) distinguish between operational, accountability, intervention, and sustainability performance. A problem with this is that "accountability" itself can concern interventions, operations, or seasonal results; by the same token, "intervention" (a change in policy or practice) can also take place over the short or the long term, with performance assessment being undertaken before and after the intervention. It therefore seems more logical to make the above distinctions on the basis of time horizon, yielding the related concepts of operational and strategic management, which automatically include the other notions.

ANALYTICAL BOUNDARIES

In the management of existing irrigation schemes, there are many objectives to be realized, the nature and contents of which depend on the tasks to be executed, the complexity of the system concerned, and the responsible party.

Irrigation Service (Subsystem) Performance

The objective of irrigation can be narrowly defined as supplying water to crops; or it may be more broadly defined as contributing to farmers' welfare. This is suggested in the "nested end-means" framework of Small and Svendsen, who describe the results of an activity with a narrow purpose as the input to an activity with a broader purpose. Thus, for example, the results of irrigation activities are inputs to the agricultural subsystem, the outputs of which, in their turn, are inputs to the agricultural economic subsystem, and so on. In this paper the discussion of performance assessment is limited to the tasks carried out in the context of supplying irrigation service (irrigation per se), which narrows the possible objectives. Further, only the narrowly defined water supply task is dealt with: how water is made available for agricultural activities by capturing it from the source, distributing it through the system, and delivering it to the users. Other water-related tasks such as maintenance and drainage are not covered here.

These limitations are not meant to suggest that the water subsystem is more important than others. Each subsystem has its own characteristics and objectives, and a final and complete picture requires conducting similar assessments of the other subsystems as well. This approach was advocated in FAO 1991; Bos et al. (1994) propose different sets of indicators for various subsystems. This paper concentrates on water delivery, elaborating on the Bos et al. paper.

The Main System

The irrigation subsystem is itself made up of several components: the headworks, the system of main and secondary canals, the tertiary canals, and the individual farms. In this paper only water distribution through the main system and delivery to the tertiary units are addressed.

The main reason for this limitation is that a workable performance analysis must have a clear and well-defined set of objectives. Objectives and targets in the main system are primarily related to the water delivery, and the water entering the tertiary unit is the result of that activity. Below the tertiary inlet, the water is distributed over a relatively small area and is then primarily an input to be used for agricultural production. The objectives within the unit and on the farm are different from those of the main system; and therefore, the performance analysis and indicators would also be different.

Irrigation Agency

In large, jointly managed systems, such as those addressed in this paper, physical boundaries coincide with the boundaries of organizational responsibility. That is, a government agency or parastatal organization is usually responsible for water-related activities upstream from the tertiary inlet, while farmers are responsible for most activities downstream from the tertiary inlet. Performance analysis is simplified if boundaries on the analysis coincide with the responsibilities of one clearly defined party. If several parties are involved in management, their objectives and tasks may differ, and the performance analysis will be more

difficult. Consequently, performance assessment in this paper deals with the irrigation agency and the portion of the system that it controls.[2]

Thus, the operational management of the main system of water distribution is a narrowly defined intermediate between higher-level scheme management with broader objectives and lower farmer-level management, which also has broader agricultural, economic, and social objectives.

Assessment and Diagnosis

The process of improving irrigation system performance requires that various steps be taken. The first step is performance assessment, as discussed in this paper, which is a kind of fact-finding activity, concentrating on establishing *how well* the system performs. The second step is to analyze *why* it performs as it does—what are the reasons and causes, what are the determining factors? Third, one comes to the diagnosis phase, in which one identifies what should be done—that is, what remedial measures should be taken. This paper deals only with the first step, the performance assessment. The analysis of the determinants (the "why" question) is not, as such, part of performance assessment. Of course, the subsequent steps are important, but they are pointless without a proper performance assessment. A discussion of the subsequent steps would, of course, require a much longer paper. The discussion here is limited to the first step, however, for more systematic reasons. As stated above, this paper concentrates on water service performance. But because deficient performance in that field usually has reasons and causes that are outside that subsystem, related to the larger agricultural, social, and political systems, the "why" and "what" questions must address all the other (sub-)systems, a task that requires a completely different framework and approach from the one used here.

The established objectives or targets are accepted and used as the yardsticks for comparison in this analysis. An analysis of the objectives themselves can be important or even essential for understanding the scheme's performance and problems, but it is a separate activity not undertaken here. The performance assessment discussed here establishes the results; a diagnosis of the determinants of the measured performance would include other subsystems, and the management process itself, which includes target setting. Moreover, the people responsible for meeting the targets are often different from those setting the targets, and the two should therefore be evaluated separately. In this sense, one could see setting targets as a strategic management issue and realizing targets as an operational (executive) management issue. Again, the performance assessment discussed here addresses the question, Are we doing things right? and not, Are we doing (or trying to do) the right things?

The points made here are summarized in Table 1. The arrows indicate the choices made in this paper in the context of seasonal irrigation service performance assessment, as discussed in the preceding sections.

---

[2]In jointly managed systems, farmers often play a role upstream of the outlet, and the government may play some role below the outlet. In addition, performance problems may be strongly related to interactions where the authority of the two groups meets or overlaps (see, for instance, Jurriëns 1992). But this is a matter of problem diagnosis rather than of performance assessment itself.

Table 1—Framework and choices made

Framework	Options for Study	Choices Made
Model		
Goal-oriented		✓
Natural system		
Purpose		
Type	Research	
	Management	✓
Time horizon	Daily	
	During season	
	Seasonal/annual	✓
	More years	
Process	Planning/design	
	Construction	
	Management	✓
	Rehabilitation	
Management	Strategic	
	Operational	✓
Operational (management)	Planning (target setting)	
	Operation/monitoring	
	Performance assessment	✓
Boundaries		
Subsystem	Socioeconomy	
	Agriculture	
	Irrigation service	✓
Party	Government	
	Irrigation agency	✓
	Farmers	
Tasks	Nonwater tasks	
	Water tasks	✓
Water tasks	**Capturing and distribution**	✓
	Field water use	
	Maintenance	
Levels	Irrigation sector	
	Irrigation scheme	
	Main system	✓
	Tertiary unit	
	Farmers' fields	

Source: Based on Small and Svendsen 1992.
Note: Boldface type indicates the choices made.

2. PERFORMANCE TARGETS AND INDICATORS

TERMS, TYPES, AND REQUIREMENTS

In discussions of performance indicators, the many terms used are usually not well defined. For clarity, the terms used in this paper are outlined first.

Performance has many qualities, some of which are timeliness, adequacy, predictability, reliability, efficiency, and equity. These are commonly referred to as "parameters." This is a broad term, and to be more specific and measurable, a parameter must be expressed in what is here called a "measure." For instance, water delivery can be expressed in flow rates or volume, and adequacy can be expressed in water depth or volume per hectare. (Thus, for each measure different units can often be used and must be indicated as well.) Finally, a performance "indicator" is defined as the ratio of two values of the measure, the realized value and the target value.

Past discussions have addressed which parameters, measures, and indicators should be used to describe the performance of irrigation, or of specific elements of irrigation, such as water delivery. Some of these, such as timeliness and reliability, are not easily quantifiable. Others are inconsistent with the delineation of performance assessment outlined, such as quality of life, productivity, sustainability, and profitability, because they refer to broader systems.

A comprehensive overview of water-related indicators is provided by Rao (1993). Mohtadulla (1993) nicely summarizes the many aspects of selecting the appropriate indicators. Requirements of a good indicator are presented by Abernethy (1986) and Bos et al. (1994). The following criteria are found in most lists and characterize the indicators developed in this paper.

- Indicators should address the seasonal results of the water delivery service.
- Indicators should be related to explicit targets and should always be the ratio of the realized and the target value of the measure concerned.
- Indicators should be quantifiable: both the target and the result have to be given as a quantity.
- Indicators should be practical, in the sense that the required information can be collected routinely and cost-effectively and that calculation of the indicator is relatively easy.
- Indicators should (to the degree possible) be objective and discount any personal bias of the persons doing the data collection or calculation.
- Indicators should be transparent and "communicable," meaning that they can be easily understood by all interested parties (farmers, managers, government), without too much scope for different interpretations.
- Indicators should be plentiful enough to provide a reasonable insight into the complete performance (as defined), but not so plentiful that the picture becomes muddied.

- Together, indicators should provide guidance as to which elements should be addressed in the subsequent analysis and problem diagnosis.

TARGETS AND RELATED INDICATORS

As discussed, performance indicators are the ratio of measured target values. In developing these indicators, two important distinctions are required.

- Supply and supply variability. The first concerns the quantities of water to be supplied; the second concerns the variability of the supply aspects in space and time.
- Achievement and efficiency. Achievement refers to the actual amount of water supplied and to supply variability; efficiency deals with the losses involved in the process.

In line with this, three types of targets are discussed: supply targets, variability targets, and efficiency targets. Each has its own parameters, measures, and indicators.

Water Supply Targets and Indicators

Any agency operating a supply-driven canal system is usually judged by both its clients and its superiors on one or more of the following basic criteria:

- the area that, at the end of the season, has been provided with irrigation water;
- the amount of water that area has received; and
- the flows and volume delivered at specific locations in the system.

These three factors are interrelated: knowing two of them makes it possible to calculate the third. For instance, the flow targets for seasonal operation are based on areas targeted and how much water they have been allocated. Alternatively, when the irrigated area and delivered flows are known, the water use can be calculated.

It is not possible to say which one of the three is the most important.[3] That may vary for different schemes. Sometimes the area served and the amount of water to be delivered are formally stated and nothing is said about the target water use. Or, even though canals are designed to carry specific flows based on specific areas and water requirements, target areas may not be explicitly given.

These three targets, which determine the supply performance parameters for seasonal performance assessment, are called (areal) extent, adequacy, and (flow) delivery. The corresponding measures are irrigation intensity, water use, and flow delivery. The resulting indicators, which are elaborated on in Chapter 3, are termed: *irrigation intensity ratio* (*IIR*); *flow delivery ratio* (*FDR*); and *water use ratio* (*WUR*).

A good preliminary evaluation of supply performance could be made using two indicators, from which the third could be derived. Yet in the remainder of this paper, all three indicators are discussed because one could be more useful than another in a specific scheme.

[3]Therefore, the sequence in which the targets and indicators are treated here is not important The sequence will be determined in practice, depending on the priority of the scheme targets. Here, however, the approach and the indicators are the focus, not the sequence.

Moreover, having information on all three enables one to check their consistency. If they do not correspond, something is wrong, either with the targets or with the data collected.

Variability Targets And Indicators

It is often said that the purpose of an irrigation agency is, apart from supplying quantities of water, to do so in an equitable and reliable way. And sometimes—for example, in Pakistan and India—the scheme managers mention equitable distribution as the first objective. But even when the target distribution is not equitable, it is useful to know to what extent the realized distribution deviates from the targeted one.

All three supply indicators concern average or total seasonal quantities. Equity and reliability, however, concern the variability of these supply quantities in either space or time. In principle, supply indicators can be determined for different scheme levels: primary level (main canal inlet), secondary level, or tertiary level. Lower-level values give information about spatial distribution at the higher level. Also, the indicators can be determined for different time periods such as seasons, years, months, or weeks. Emphasis here is on seasonal performance, but shorter period values give information about fluctuations during the season. The term "uniformity" is used here to indicate the spatial distribution. For time variability the term "reliability" is used. For uniformity, the measure can be either flow or intensity. Reliability concerns only flow. The resulting indicators, further discussed in Chapter 4, are the *flow uniformity ratio* (*FUR*), the *intensity uniformity ratio* (*IUR*), and the *flow reliability ratio* (*FRR*).

Efficiency Targets and Indicators

Indicators discussed under the two preceding categories measure achievement. Efficiencies are usually about how much water has been lost. Some losses are inevitable, or at least they cannot be reduced by better operational management. One of the problems in common considerations of efficiency is that no distinction is made between avoidable and unavoidable losses. If the task is to analyze the performance of management, unavoidable losses should be excluded from considerations of operational efficiency. Also, sometimes some (operational) losses should be accepted to make operation easier. Consequently, in line with the other indicators, an efficiency indicator should be the ratio of a realized value to a target value of the efficiency. The measure involved would be the irrigation efficiency, or the ratio of the sum of total volume delivered at a certain level (heads of secondary or tertiary canals, for example) to that delivered at a higher level (primary or secondary canal heads, for example). The ratio of realized to target values of these measures would be an indicator of operational efficiency.

Discussion Of Targets And Indicators

The discussion in Chapters 1 and 2 clearly involves the notion of accountability. Performance indicators, and consequently targets, should be chosen so that a well-defined body (an irrigation agency) can be made accountable for its performance on well-defined objectives (targets).[4] The targets are given here so that the agency's performance can in principle be "measured" by how well they are realized. Of course, one can think of other

[4]This could also have been given as a requirement in the list of criteria. This was not explicitly done, because the requirements mentioned there are in fact consequences of this overall requirement

accountability measures, such as the number of farmers' complaints. Although complaints can be useful, making an accurate performance assessment still requires that one know what these complaints are about (for example, water flow, quantity, reliability) and that they be quantified. Thus, one would have to use the parameters described above.[5]

To be relevant, a parameter should at least (1) relate to irrigation supply and (2) be within the control of the agency. When it is no longer clear to what extent an indicator is related to canal water supply, such as when there is high rainfall or extensive groundwater pumping, there is a problem. The more supplementary water supplies increase, the more difficult it becomes to separate the quality of the agency's service from other factors. This condition applies to all of the indicators discussed here. Therefore, these indicators are primarily valid for conditions without substantial rain or groundwater pumping. They could be used in such circumstances, but their use and relevance, and possible modifications required would need further study.

In principle, several of the indicators can be calculated for different locations and levels in the system. Yet, for reasons of cost and practicality it is necessary to limit the number of locations and to select the most appropriate ones. Emphasis in this paper is on higher system levels. An example for one distributary is given in Part 2.

Finally, the issue of indicators is related to the discussion of "standards," against which the measured values of the indicators can be compared (Small and Svendsen 1992). In this sense, a performance indicator can be seen as an objective degree of target achievement, after which a comparison of the indicator with the standard (another value of the same indicator) can lead to a value judgment about system performance, such as good, acceptable, or poor. Such standards can be established for a system, region, or country, or even worldwide. This approach makes superfluous the discussion of whether to use general or site-specific standards, because either can be used in this approach. Table 2 summarizes this discussion.

Table 2—Summary of targets and indicators

Target	Parameter	Measure	Indicator	
Area	Extent	Intensity	Irrigation intensity ratio (IIR)	Water supply
Flow	Delivery	Flow	Flow delivery ratio (FDR)	
Water use	Adequacy	Water use	Water use ratio (WUR)	
Spatial distribution	Uniformity	See Chapter 4	Flow uniformity ratio (FUR)	Variability
			Intensity uniformity ratio (IUR)	
Time distribution	Reliability	See Chapter 4	Flow reliability ratio (FRR)	
Efficiency	Operational efficiency	Irrigation efficiency	Operational efficiency ratio (OER)	Efficiency

[5]Although the indicators should be measures for accountability, a complication is that the irrigation service performance can never be equated with the quality of the agency's performance. A poor delivery performance does not automatically mean that the quality of the management or operators is poor, because poor delivery can be due to factors beyond their control. This complication is unavoidable and can be dealt with in three ways: (1) targets and indicators can be chosen such that interference by other parties or external factors is limited as much as possible; (2) an assessment of poor delivery performance should be treated as descriptive only;and (3) the complete set of indicators can be examined to provide information for further analysis.

SUMMARY OF TERMINOLOGY

To make it easy to understand and remember the meaning of the various indicators, the following notation system is used. Each indicator is the ratio of the actual to the target value of the measure, with the subscripts *r* and *t* for realized and target, respectively. The indicator is abbreviated with three letters: the last one always is the *R* of "ratio," and the first two letters indicate the measure involved:

- Achievement indicators—supply targets

  II for irrigation intensity
  FD for flow delivery
  WU for water use

- Achievement indicators—variability targets

  FU for flow uniformity
  IU for intensity uniformity
  FR for flow reliability

- Efficiency indicator

  OE for operational efficiency

A fourth letter can precede these three when necessary to avoid confusion. This can be an *O* for the entire or overall scheme, a *P* for primary (main) canal, an *S* for secondary, an *M* for main system (primary and secondary system), or a *T* for tertiary level. These terms and others are presented in a glossary beginning on p. 67.

3. SUPPLY PERFORMANCE INDICATORS

IRRIGATION INTENSITY PERFORMANCE

For professional irrigation system management in supply-driven schemes, one of the first targets to be set is the size of the area to be irrigated in one season or in an agricultural year. All interested parties should know where irrigation water is supposed to be delivered. In addition, sound operation during the season requires flow targets to be set, which are usually based on the size of targeted areas. Conversely, the area irrigated during a season may be the first parameter to give an indication of the quality of the irrigation service. Yet, it is surprising how little attention it is given in the literature. The term "irrigation intensity" is used here to mean the ratio of irrigated area to total irrigable area.[6]

For performance assessment, the realized intensity is compared with the target intensity of the system. An intensity figure of, for instance, 60 percent may seem low, but when, as is the case in many schemes in India and Pakistan, the target intensity is low—say, 50 percent, because of design assumptions and limitations in water availability—a 60 percent result would be very good. The irrigation intensity ratio would therefore be defined as follows:

$$\textit{Irrigation intensity ratio } (IIR) = II_r/II_t,$$

where II_t is the target intensity and II_r the realized intensity. This is, of course, the same as the ratio of the realized and targeted areas, but when the latter is calculated one does not see the intensity figures.[7] In principle, this ratio can be determined for the entire scheme (scheme IIR or OIIR) or for the command area of a secondary canal (SIIR).

Some major complications arise in determining the seasonal irrigation intensities. They concern (1) the definition of "irrigated," (2) the types of crops irrigated, and (3) the annual results for crops with growing seasons that span more than one irrigation season.

The first point deals with how to determine whether a piece of land is irrigated. Is the criterion the total amount of water received, the number of irrigations, or something else? This question is discussed in more detail in Chapter 9.

The second point refers to the use of the number of hectare-days of irrigation instead of simple intensity, as suggested by Levine (1982). From a practical standpoint, problems with the collection of the required data may make this difficult. In addition, if the hectare-days concept is meant to distinguish between crops of different duration, this does not seem to deal with performance. If one knows how much area is irrigated, why is it necessary to know for how long? The management knows which crops are grown and tries to adapt the supply of water to that, taking into account the growth periods. If the system failed, that would be

[6]Care should be taken not to confuse cropping intensity (which may also include rain-fed crops) with irrigation intensity. Smith uses the term "intensity of utilization," which refers to the average number of irrigated crops per year (FAO 1991, 25).

[7]This may seem an academic observation, but it is not. Although one may know how much of an area is irrigated, one still does not know much unless one also knows how much of the area is irrigable. If one knows the ratio of irrigated to targeted area, one still does not know the target intensity and thus may miss relevant information.

evident from the water delivery and water use performance, not primarily from the intensity performance. If the system were "underused" for part of a season or year because crops with short growing seasons were planted, this would be a matter of agricultural and economic interest, but not of water delivery performance.

Knowing what types of crops are planted is also useful when there are many different crops with no clear irrigation seasons. But then, as well, the above reasoning would apply. The target is to supply water to specific areas, and performance is to be measured against that goal and not against crops grown. Where there are many crops of different durations and no specific irrigation seasons can be distinguished, the solution is to consider annual results only.

When there clearly are different irrigation seasons, the next question is What about two-season or perennial crops? This can be dealt with in two ways. Suppose that a scheme includes a net irrigable area of 100,000 hectares, of which 60,000 hectares are to be irrigated with a one-season crop in each season, and 40,000 hectares are planted with a two-season or perennial crop. One approach says that the annual irrigable area is 160,000 hectares, because the 40,000 hectares under the two-season crop are counted only once (as one irrigated crop). According to another approach, the annual irrigable area is 200,000 hectares because the same crop is counted twice (once in each season). The approach used is a matter of choice and does not make much difference as long as it is clearly indicated. And as long as the same approach is used to arrive at both targeted and realized intensities, the results are the same. Examples are given in Part 2.

Regardless of the foregoing, there is yet another complication. The *IIR* can be determined for one season and for the agricultural year, which often has two irrigation seasons. Suppose an annual intensity of 160 percent is reported. The problem is that this may consist of the same land (80 percent of the irrigable area) being irrigated twice (leaving 20 percent without irrigation at all), or of 100 percent of the land being irrigated in the first season and 60 percent in the second season (60 percent with double irrigation and no land without any irrigated crop). The two results are quite different, and what is really happening cannot be deduced from the 160 percent figure alone. A more complete picture would be provided by separate seasonal intensities and *IIR*s, along with another performance indicator, the annual *irrigation coverage ratio* (*ICR*):

$$\textit{irrigation coverage ratio } (ICR) = IA_i / IA_t.$$

The IA_i is defined as the land area that has had at least one irrigated crop, and IA_t as the area (number of hectares) to be irrigated at least once. The difference between the value of this indicator and 1 would represent the land that had no irrigated crop at all. In fact, this *ICR* is a rough indicator of uniformity, which is discussed in more detail in Chapter 12. It is stressed that IA_t should relate to the actual target area to be irrigated, which does not necessarily equal the total command area.[8] Finally, it is noted that this *ICR* is relevant only when looking at annual results that include two or more seasons. For one season, the *ICR* equals the *IIR* and is not needed.

[8]In this way one takes into account situations where there are rotations over the years, as there are, for instance, in parts of Tamil Nadu or Indonesia, where, because of water shortage, every year a different part of the system is not irrigated.

FLOW DELIVERY PERFORMANCE

However vague targets in irrigation system operation may sometimes be, there is usually some idea of the magnitude of flows to be delivered at specific times and locations in the system or of the total seasonal volume to be supplied. In fact, a supply-driven system requires such flow targets. Therefore, the actual flows should be monitored. A logical performance indicator would then be the *flow delivery ratio*:

$$\textit{flow delivery ratio } (FDR) = Q_r / Q_t,$$

where Q_t is the target amount of water to be delivered at a certain location and Q_r the amount actually delivered. Q can be expressed in cubic meters (m^3) per season or in liters per second (l/s) or in cubic meters per second (m^3/s) as an average over the period concerned.

Many scholars have used this indicator under different names (although usually for daily operation and research purposes). Bhutta and VanderVelde (1993) called it the "delivery performance ratio" (DPR), Kelley and Johnson (1991) the "management performance ratio" (MPR). The term "flow delivery ratio" is used here only because it is consistent with the rest of the terminology in this paper. Directly derivable from the FDR is a measure called "misallocations," giving the ratio of the difference between measured flows (Q_r) and target flows (Q_t) and the target itself: $(Q_r - Q_t)/(Q_t)$, used by Bos et al. (1991). The FDR can be determined for the primary (system), secondary, or tertiary levels. Practical applications are discussed in Chapter 10.

WATER USE PERFORMANCE

Information on "irrigated" areas (which was used in the computation of the IIR) does not give insight into the actual amount of water supplied to those areas, and information on flow (included in the FDR) does not automatically say how much area is irrigated with that flow. Therefore, the two should be combined to measure the amount of water actually used for the areas irrigated. In this sense it is proposed to apply the water use ratio:

$$\textit{water use ratio } (WUR) = WU_r / WU_t,$$

or the ratio of actual water use (WU_r) to target water use (WU_t) for the irrigated areas. Both parameters are expressed in volume per unit area (cubic meters per hectare [m^3/ha]), but can be converted to millimeters or liters per second times hectares (l/s × hectares) as an average over the period concerned.

The WUR can be determined for each season or for the entire year. The seasonal WUR does not pose problems; because it concerns amounts of water applied to irrigated areas, one can see that $WUR = FDR/IIR$. A determination of the annual WUR, however, presents the same problem as determining the intensity, at least when two-season crops extend across two distinct seasons and there has been "double irrigation" on the same land. First , the two-season crops should be counted only once, because they occupy the same land (number of hectares). Second, the realized annual irrigated area used in the calculation should then be the land that actually received irrigation water. In other words, when two seasonal crops are grown on the same piece of land, the number of hectares concerned should be counted only once (because the WUR is not about water use by crops but about water use on land). This would be in line with the idea of the ICR, and in this case the annual $WUR = FDR/ICR$. Calculation examples are given in Chapter 11.

Finally, one important remark has to be made with respect to water use and "adequacy." Various studies (FAO 1991; Francis 1990; Small and Svendsen 1990; Weller 1991; and others), all based on Levine 1982, use a parameter called "relative water supply" (RWS). Although their definitions differ slightly, they have in common that the RWS relates the actually supplied water with some form of crop requirements, thus giving a measure for adequacy.

This adequacy measure compares supplies with crop requirements, while the adequacy measure proposed above compares supplies with targets. Thus, it is seen that this RWS is a special case of the WUR when the target WU_t aims to meet the full crop water requirements. In the context of this paper, the WUR is a more general performance indicator. RWS does not work well when applied to "protective" irrigation schemes in India and Pakistan, where the targeted supply is not sufficient to meet the full crop water requirement. With an RWS of less than 1, the FDR can then still be equal to 1. In such cases, the RWS can be useful in assessing the adequacy of the target, but the result would only provide information on how the system is designed and planned, not on its operational performance.

LOCATIONS AND LEVELS CONSIDERED

As said earlier, these indicators could theoretically be determined for different levels in the system. For systematic performance assessment of a large command (either a total scheme or a secondary canal command), however, the following considerations apply.

The IIR can be easily determined for the entire command area under consideration (OIIR or SIIR). The simplest determination of the FDR can usually be made for either the entire scheme (OFDR) or a secondary canal (SFDR) at the inlet of a command area. This would give an indication of the extent to which the planned supply was being received. But the FDR should in principle also be determined at the tertiary inlet level (TFDR), which is the "output" level of the agency's water service. To this end, one has to know quite accurately all tertiary inflows over the season. Few experienced irrigation experts can provide examples of systems where this is really known. There are, then, two possible approaches to estimating tertiary inflow. One is to use seasonal measurements at a limited number of representative locations. The other is to gather detailed measurements at all locations, but only at some crucial moments during the season. Practically speaking, both of these approaches require data collection efforts that are beyond the capability of most operating agencies.

A similar reasoning applies to the WUR. Determination of the OWUR or SWUR is not usually difficult. For the TWUR, however, one will often be faced with the same practical problems outlined above. It is noted that the earlier mentioned direct relation between IIR, FDR, and WUR is valid only when they all refer to the same level.

4. VARIABILITY PERFORMANCE INDICATORS

The supply performance indicators (IIR, WUR, and FDR) may not be conclusive in all aspects. Abundant reference has been made to the now famous head-tail differences. Often, average figures on intensity, delivery, or water use mask uneven distribution: overirrigation in part of the area and underirrigation elsewhere. In many schemes, therefore, "equitable" water distribution is an important, if not always clearly specified, target. In any case, for a complete performance analysis, it is useful to analyze this "equity" aspect, and most of the current writings on performance include equity indicators as well.

However equity is defined, it generally has to do with spatial variability in the supply (or availability) of irrigation water. Because the resulting variability is to be compared with a target distribution that may not be equitable, it seems better not to talk about equity performance or an equity indicator, but instead to use the term "(distributional) uniformity."

There can be variations in spatial distribution as well as variations in flow over time. Reliability, predictability, and timeliness are indicators often mentioned in this respect. Most of these indicators are not yet well established (as observed and illustrated, for instance, throughout FAO 1991). However, the core concept has to do with variability in available (delivered) flow over time. "Reliability" would thus refer to temporal variability and "uniformity" to spatial variability.

To be consistent with the concept of FDR, IIR, and WUR, uniformity should concern water delivery (in terms of cubic meters or average liters per second), irrigation intensity (in percent), or the derived water use (average l/s ha). Determining the degree of uniformity requires taking these measures at various locations in the system at the same time (in this case, after the season). By its nature, reliability can only concern variations in daily, weekly, or monthly flow values and not in land or water use, as with uniformity. Because reliability concerns temporal variability, it can be determined for one specific location only, which can be the inlet of the main, secondary, or tertiary canal (see Table 3). The next section discusses statistical elements of variability that bear on the development of the respective indicators.

THE STATISTICAL ELEMENTS OF VARIABILITY

In recent literature much attention has been given to the uniformity (equity) and reliability issues, both in general and in relation to performance indicators. Some proposed indicators have been taken from the discipline of statistics, such as the standard deviation,

Table 3—Uniformity and reliability

	Uniformity	Reliability
Measure	Flow or irrigation intensity	Flow
Location	Along main or secondary canal	At inlets or along main, secondary, or tertiary canals
Time	End of season	At different times during season
Reference unit	At canal inlets or reaches	Weekly or monthly

the coefficient of variation, and variance. Others have been theoretically or empirically derived for a specific purpose, such as Theil's measure, the Gini coefficient, and the Christiansen uniformity coefficient. Rao (1993) and Abernethy (1986, 1990) review many of them. Abernethy suggested the modified interquartile ratio (MIQR), which has since been used and advocated by many authors. This is the ratio of the water received on the best-supplied quartile of the land area to that received on the worst-supplied quartile. Recently, Gillott and Bird (1993) gave a detailed review and comparison of all of the indicators discussed here.

Gillott and Bird conclude that the MIQR is simple to understand but that it is insensitive to a large part of the data (what happens between the two extreme quartiles). Theil's measure is difficult to interpret and tends to change more than the other indicators when the uniformity changes. The other coefficients behave similarly, but preference is given to the coefficient of variation (CV), because it responds most credibly to "transfers" (moving a value, such as a volume of water, from one place to another in the distribution series). In line with this, as in Clemmens and Bos (1990) and Bhutta and VanderVelde (1993), the use of the CV is advocated here.

The standard deviation $STD(x)$ of a series of observations (x_i) with average $\bar{x}$ is defined as

$$STD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}},$$

and the coefficient of variation (CV) as

$$CV = \frac{STD}{\bar{x}}.$$

Use of the CV instead of the STD has the advantage that variations over a series are explicitly compared with the average of that series. This makes sense because a certain variation around a high average is less important than the same variation around a lower average. Subsequently it is proposed that $(1 - CV)$ be used as the parameter and not the CV itself. Using only the CV, it would not be possible to have a ratio comparing the actual CV with the target CV if the latter value were zero (perfectly uniform). Using $(1 - CV)$ yields a parameter value of 1.0 with completely uniform distribution and an indicator value of 1.0 with perfect performance according to target uniformity. Finally, it is consistent with the general approach in this paper that better performance gives higher values of the indicator.[9] Accordingly, because a performance indicator is always the ratio of the measured to the target value of a parameter, the following general uniformity indicator is proposed:

$$\textit{uniformity ratio} = (1 - CV)_r/(1 - CV)_t.$$

This implies that a target value for $(1 - CV)$ should be set. In most irrigation systems, this is not explicitly done. The solution could be to use $CV = 0$ or $(1 - CV) = 1$ as a target or, if this

[9]The consequence of this approach is that it may result in negative values of the indicator, but this should not be a problem. It shows directly that the standard deviation is higher than the average.

is not realistic, to use some other target value of (1 – *CV*), based, for instance, on average results over a number of recent years. This target should not be confused with the magnitude of target flows themselves (the latter are included in the FDR discussed earlier). Another issue is that the above still does not say to which factor the variability (STD, CV) should be applied. This is elaborated upon in the next section.

UNIFORMITY INDICATORS

First, it must be decided for which factor variability should be determined. Most authors look at the variability of the measured flow rates. But it is also possible to look at the uniformity of the irrigated areas, thus distinguishing between "water uniformity" and "land uniformity." Both are discussed below.

For water uniformity, the FDRs in the analysis are used instead of the actual measured flows. Because the target flow may vary along the canal length, using the actual flow variations would neglect possible differences in target flow and thus not give a correct picture of the real operational performance. When targets at different measurement points are equal, using variations of actual flows and of FDRs will produce the same result. Thus, the following uniformity indicator can be used when considering variability of flows:

$$\textit{flow uniformity ratio } (FUR) = [1 - CV(FDR)]_r/[1 - CV(FDR)]_t,$$

where $CV(FDR)$ is the coefficient of variation of the *FDR*s, calculated as the ratio of $STD(FDR)$ and average $\overline{FDR}$.

The above is valid as long as the spatial elements on which the variability is determined are equal. Often this will not be the case when flow distribution uniformity along a canal is analyzed. Usually there will be a limited number of measurements along the canal, and normally the measurement locations will not divide the canal into exactly equal reaches. It would then not be correct to give the FDR of a short reach the same weight as that of a long reach. It is common, therefore, to use the weighted values of the elements involved. Here it is proposed to use the reach length as the weighting factor, because using the areas served would introduce another source of variability. The weighting will be done in the average FDR and not in the standard deviation, which will be taken from the actual FDRs.[10] The flow uniformity ratio would then be

$$FUR = [1 - CV_w(FDR)]_r/[1 - CV(FDR)]_t,$$

where $CV_w(FDR) = STD(FDR)/\overline{FDR}_w$, CV_w is the weighted coefficient of variation, *STD* is the standard deviation of the actual *FDR*s, and the weighted average $\overline{FDR}_w$ is the sum of the reach *FDR*s times the reach lengths, divided by the total canal length. This may seem complicated, but the calculation examples given in Chapter 12 illustrate that it works quite easily.

Likewise, the uniformity of irrigated areas can be assessed by using irrigation intensity as a parameter. The indicator concerned would be the

$$\textit{intensity uniformity ratio } (IUR) = [1 - CV_w(IIR)]_r/[1 - CV(IIR)]_t,$$

[10]The author is grateful to a reader of an earlier draft of this paper for this suggestion. He clearly demonstrated that the latter would give incorrect results.

with a similar measure as above:

$$CV_w(IIR) = STD(IIR)/\overline{IIR}_w,$$

based on the weighted coefficient of variation of the *IIR*s. The latter is the ratio of the standard deviation of the actual *IIR*s divided by the weighted average *IIR*, calculated as above. For the weighting factor, it is again proposed to use the relative reach length, because this enables a direct comparison of FUR and IUR. Examples of both indicators are given in Chapter 12.[11]

RELIABILITY INDICATOR

In the literature, a few examples are found of a possible reliability indicator. Clemmens and Bos (1990) propose the standard deviation of the ratios of actual to target flows (called FDRs in this paper). Bhutta and VanderVelde (1993) use the coefficient of variation of flows during the season. For the reasons mentioned above, use of (1 – *CV*) is advocated here as a reliability measure. Thus, the derivation is similar to the one for uniformity. One could thus establish the following definition:

$$\textit{flow reliability ratio } (FRR) = [1 - CV(FDR)]_r/[1 - CV(FDR)]_t,$$

where the *CV* is calculated from measured *FDR*s averaged over a certain time period (such as a week or a month) and at a certain location. As for uniformity, using *FDR*s works in situations where target flows vary over the season. If they do not vary, actual flows can be used as well. In this case, it is usually easy to consider equal time spans, so that no weighted average is necessary.[12] Calculation examples are given in Chapter 13.

LOCATIONS AND LEVELS

Just as for the supply indicators, it has to be specified for which locations and levels in the system the F(I)UR and FRR are be determined. There is some difference between the uniformity and reliability indicators.

The FUR or IUR should be determined for the tertiary inlet level only. Here, the same practical problems will arise as with the FDR and WUR. Chapter 12 explains in detail how to come to aggregate values, including the application of the weighting procedures described above.

The FRR can be determined for both the "input" level (the head of the command area considered [OFRR or SFRR]) or the "output" level (the tertiary inlets [TFRR]). At the tertiary level, the same practical problems arise as with the FDR and WUR.

---

[11] For reasons explained in the same chapter, a water-use uniformity indicator is not useful.

[12] Again, in calculating the average and standard deviation of the FDRs, the target flow value is eliminated and is not included in the final CV. One could reason that reliability has to do not only with fluctuations but also with the average. A tertiary unit must be able to rely on getting a flow that is of the planned magnitude. Getting much too little in a reliable way does not make much sense Therefore, it could be suggested that the final result of (1 – *CV*) should be multiplied with the average FDR. However, this is not advocated here because it would not be in line with the considerations on uniformity, and it would mix up different targets; the FDR already includes the larger flow. It might be useful, however, to combine various indicators, and this is discussed in Chapter 8.

5. EFFICIENCY PERFORMANCE INDICATORS

Much has been written about the various efficiencies that can be calculated for a system, and often they are treated as the only indicator of performance.[13] But achieving a certain efficiency is seldom the primary or ultimate target of system managers. The distinction made by Small and Svendsen between achievement and efficiency targets seems logical, in the sense that the real targets must be achieved with a targeted use of the resources. Thus, realizing a certain efficiency can be a necessary condition for a particular level of performance, such as when available water is limited and it is necessary to irrigate a certain area, or when it is necessary to limit water losses to avoid waterlogging and salinization problems. Although widely described, efficiency is one of the most complicated indicators and is therefore discussed in more detail below.

A low efficiency may indicate that a number of things are wrong. But it does not say what is wrong, whether the failings are important, or which targets have or have not been realized. Moreover, there is a question of when a result should be seen as poor. These and other questions related to the notion of efficiency have recently been discussed by Small (1992). Some complications and solutions are discussed below, looking first at the main system alone (not including the tertiary canal level).

MAIN SYSTEM EFFICIENCY PERFORMANCE

This measure of efficiency concerns the losses between the main canal head and the tertiary inlets. The related indicator would then be the *main system operational efficiency ratio* (*MOER*):

$$\textit{main system operational efficiency ratio } (MOER) = (IE_r/IE_t)_M,$$

where IE_r = realized irrigation efficiency and IE_t = target efficiency, both defined as

$$IE_M = \Sigma Q_T/Q_P,$$

in which IE_M = main system irrigation efficiency, ΣQ_T = total volume delivered to all tertiary inlets, and Q_P = total volume delivered at the primary (main) canal head. (The *P* for primary canal is used here because the *M* is already used for main system.)

The above can be simplified when it is realized that flow targets at various locations in the system are based on assumed (targeted) efficiencies. If performance were perfect, all FDRs would be unity. Consequently, the operational efficiency ratios can simply be calculated as the ratio of the two FDRs at the levels concerned:

[13]The efficiencies discussed in this chapter are irrigation efficiencies, as defined by Bos and Nugteren (1974). They do not refer to other types of efficiencies, such as water use efficiency and yield per cubic meters of water, which are more a part of the agricultural subsystem than of the water service subsystem.

$$MOER = FDR_T/FDR_P,$$

where (P) represents the FDR at the main canal head and (T) is the aggregate FDR for tertiary canal inlets.

Whereas the common irrigation efficiencies will always be less than 1, this need not be the case with the OERs. When the OER is less than 1, one does not automatically know whether this is due to unrealistic target efficiencies or to imperfect operational performance. And when the OER is greater than 1, apparently the target efficiency can be set higher. Thus, some professional expertise is necessary to interpret the resulting performance indicators, but this is true for all indicators.

A practical problem is that it is difficult to assess the actual seasonal main system efficiencies without knowing, quite accurately, the level of all tertiary inflows. As is true for the FDRs, this information is often not available. The same approach could be followed as indicated in Chapter 3. This procedure computes seasonal values of the indicator. However, in practice, efficiency at a critical time during the season may be far more important than efficiencies achieved during other periods.

OVERALL EFFICIENCY PERFORMANCE

According to the framework provided in Chapter 1, performance assessment should not include the tertiary unit level. The water losses occurring within the tertiary unit or on the field would then be excluded, as would the potential evapotranspiration (ET_p), which relates to the crop level. Nevertheless, this section discusses overall scheme efficiency, including tertiary unit and farm level, for two reasons. One is that most readers would find it unacceptable not to do so because the overall efficiency is a standard measure of performance. Second, an overall efficiency measure can provide useful additional information when it is considered together with the WUR or the MOER. There are at least two complications in applying the system efficiency measure.

First there is the complication of rainfall. Standard practice is to calculate the overall irrigation efficiency with the formula $IE = (ET_p - R_e)/I$, where R_e is effective rainfall and I is the total (main) canal supply. In this case, efficiency can be low during rainfall, when canal flows are not adapted. But is such low efficiency (and implied waste) avoidable? And how much of the rain is used for irrigation and how much of the canal water? (The answers to these questions would affect the value of R_e). The R_e figure used in the calculation is highly arbitrary and will often not equal the actual operational value, but it nevertheless strongly affects the result. It seems logical to make two calculations—one with full rainfall and one without rain—and to compare the results. Admittedly, this comparison would give only a broad impression of the effect of rainfall on the indicator values, but more than that is simply not possible when applying this formula. Yet another possibility would be to apply the formula $IE = ET_p/(R + I)$, which would yield yet another result. Examples are given in Chapter 14.

Second, the role of ET_p in the efficiency definition is a problem. Not only is the real value often not known with precision, but more important, in reality ET_p may not be achieved, and the actual ET_a may be less than ET_p. This may happen at tail-ends of systems designed for full irrigation or, as in Indian and Pakistani systems designed for protective irrigation, throughout the system. The calculated efficiency may then not reflect the actual water losses. In this respect, the practice applied by the World Bank National Water Management Project in several Indian schemes is interesting. Data are usually available for irrigated crops and areas and for actual main canal releases. Water requirements are calculated for the crops

and areas actually irrigated, and these are compared with the actual supply. For the scheme concerned, a "realistic" target efficiency value is assumed, say 50 percent. If the calculated value of the ratio is 20 percent, one can be sure that considerable water losses have occurred (but one still does not know whether they have occurred at the level of the main system, the tertiary unit, or the field). If the calculated ratio were 80 percent, it would be evident that there must have been considerable underirrigation and that the area effectively irrigated must have been much smaller than the official figures. If calculated efficiency ratios were on the order of 40 to 50 percent, one could say that neither over nor underirrigation had occurred. Some sample calculations are presented in Chapter 14.

Taking into account the above discussion, it is proposed to use

$$\textit{overall operational efficiency ratio } (OOER) = (IE_r/IE_t)_O$$

as an indicator of efficiency performance. IE_t is the target value and IE_r the realized irrigation efficiency for the overall (entire) scheme (O). (The S of "scheme" cannot be used because it is already used elsewhere for "secondary.") Where rainfall cannot be neglected, IE_O could be calculated with the formula $IE_O = ET_p/(R + I)$. Using this formula for IE avoids the problem of what value to use for R_e, but it still includes total rainfall, which is unpredictable and should not be part of the performance indicator (either target or realized). It seems most logical, therefore, not to include rainfall at all and to compare only water requirements with irrigation supply.

Some may disagree with the approach suggested here and, indeed, it has some problems. Yet it has some advantages over the common determination of efficiency. First, the above-defined OERs compare the actual efficiency with some target value. This is not only consistent with the requirements discussed in Chapter 2, but it also excludes unavoidable losses. In this respect, efficiency, as commonly defined, is not really an indicator of operational performance. It is fair to say that a low efficiency figure can be a symptom of many kinds of problems in the scheme, but does not necessarily indicate problems with the system operation. This approach may well increase the number of systems in which high performance efficiency is found, and this seems realistic in the sense that it is not fair to blame managers and operators for losses they cannot control. A second advantage of this approach is that it seems to deal effectively with underirrigation.

6. SUMMARY OF APPROACH AND INDICATORS

Part 1 began by describing the scope and contents of seasonal performance assessment of operational management in irrigation systems. Briefly, the seasonal results of water distribution in the main system and delivery to the tertiary units are compared with preseason targets. Targets are considered as given facts; their adequacy or correctness is not considered in this performance assessment. Also, why results differ from targets is not investigated in this context.

Performance is portrayed by various indicators, all giving the ratio of realized to target values of the measures of various parameters. Two different types of indicators are discussed—those dealing with achievement (effectiveness) and those dealing with efficiency (resources used to realize targets). Of the achievement indicators, there are three supply indicators dealing with irrigated areas (intensities), water delivered, and water used on irrigated areas. Two types of variability indicators are suggested, concerning uniformity of distribution over the area and reliability of distribution over the season. With respect to operational efficiency, the most important element is that the actual results should be compared with targets, thus eliminating unavoidable losses.

Proposed supply indicators of achievement are as follows:

$$\textit{irrigation intensity ratio } (IIR) = II_r/II_t,$$

where II_t is the target intensity and II_r the realized intensity;

$$\textit{irrigation coverage ratio } (ICR) = IA_i/IA_t,$$

where IA_i is the land area (number of hectares) that has had at least one irrigated crop and IA_t the target area (number of hectares) to be irrigated for at least one crop;

$$\textit{flow delivery ratio } (FDR) = Q_r/Q_t,$$

where Q_t is the target amount of water to be delivered at a certain location and Q_r the amount actually delivered (both primarily in cubic meters but easily converted to average liters per second); and

$$\textit{water use ratio } (WUR) = WU_r/WU_t,$$

where WU_r is the realized and WU_t the target water use on the irrigated areas (both in cubic meters per hectare but easily converted to millimeters or average liters per second times hectares (l/s ha).

The following variability achievement indicators are proposed:

$$\textit{flow uniformity ratio } (FUR) = [1 - CV_w(FDR)]_r / [1 - CV(FDR)]_t,$$

in which $CV_W(FDR) = STD(FDR)/\overline{FDR}_W$, where $STD(FDR)$ is the standard deviation of the actual FDRs, and CV_W the weighted coefficient of variation, being the ratio of STD to the weighted average $\overline{FDR}$. This $\overline{FDR}_W$ is the sum of the FDRs for the different canal reaches times the corresponding reach lengths, divided by the total canal length. $(1 - CV)_t$ is a target value, ideally unity, but is more realistically determined on the basis of historical data.

$$\textit{intensity uniformity ratio } (IUR) = [1 - CV_W\,(IIR)]_r/[1 - CV(IIR)]_t,$$

with the weighted CV_W of the IIRs, as defined above, and where $(1 - CV)_t$ is the target value.

The above uniformity ratios refer to spatial variability, the following to temporal variability:

$$\textit{flow reliability ratio } (FRR) = [1 - CV(FDR)]_r\,/[1 - CV(FDR)]_t,$$

where the CV is calculated from measured FDRs over a certain time period (such as weekly or monthly) and at a certain location.

For efficiency, it is more difficult to find a valid, adequate, and practical indicator. Taking into account the complications involved, use of the following is suggested:

$$\textit{operational efficiency ratio } (OER) = IE_r\,/IE_t,$$

where IE_r is the realized and IE_t the target irrigation efficiency.

These ratios can be determined for different levels: (1) for the canal system between the main canal head and tertiary inlets (MOER) and (2) for the overall scheme (OOER). In the first case, the MOER can be determined by the ratio of the FDRs concerned:

$$MOER = FDR_T/FDR_P,$$

with subscripts P and T for inlets of primary (main) canal and tertiary units, respectively. The OOER is the ratio of target and realized scheme irrigation efficiency (IE) with the IEs calculated as $IE = ET_p/(R + I)$, where R is total rainfall and I is scheme irrigation supplies.

Sample calculations for an actual canal system are provided and discussed in Part 2, which is intended to assess the relevance and practicality of the approach and indicators proposed in Part 1.

The above list perhaps includes too many indicators when one wants to have a quick idea of a system's performance or to compare the performance of one system with that of another. It might then be useful to have one or two primary "overall" indicators. Rather than developing a new indicator or combination of indicators, however, it seems simpler and more justified to use the IIR and the WUR as the two essential indicators, dealing with performance in terms of the extent and amount of irrigation supply.

As stated in Chapter 2, performance indicators are related to targets, and there are three types of primary targets: land (to be irrigated), water (to be supplied), and water (to be used) per unit of land. One could reason that the water to be supplied follows from the water to be used on the land to be irrigated. Consequently, the latter two could be seen as the essential targets. If there are figures on the related IIR and WUR, they provide information about the third parameter (water supplied, or FDR). Further analysis involving the distributional parameters and the related indicators (FUR, FRR) and operational efficiency (OER) may shed light on the possible causes of underperformance. Thus, WUR

and IIR provide a quick impression of performance, because they are most directly related to the essential targets. Table 4 provides an illustration of this reasoning.

Table 4—IIR and WUR as overall performance indicators

IIR	WUR	FDR	Performance	Causes
Low	Low	Very low	Bad; widespread underirrigation	Low FUR and IUR: water shortage or low OER
Low	High	O.K. or low; depends on values	Poor; head-tail difference	Low FUR and IUR: low OER
High	Low	Low	Insufficient; uniformly underirrigated	High FUR: low OER or water shortage
High	High	High	Good	High FUR, FRR, OER
= 1	= 1	= 1	Perfect	FUR = FFR = OER = 1

Part 2

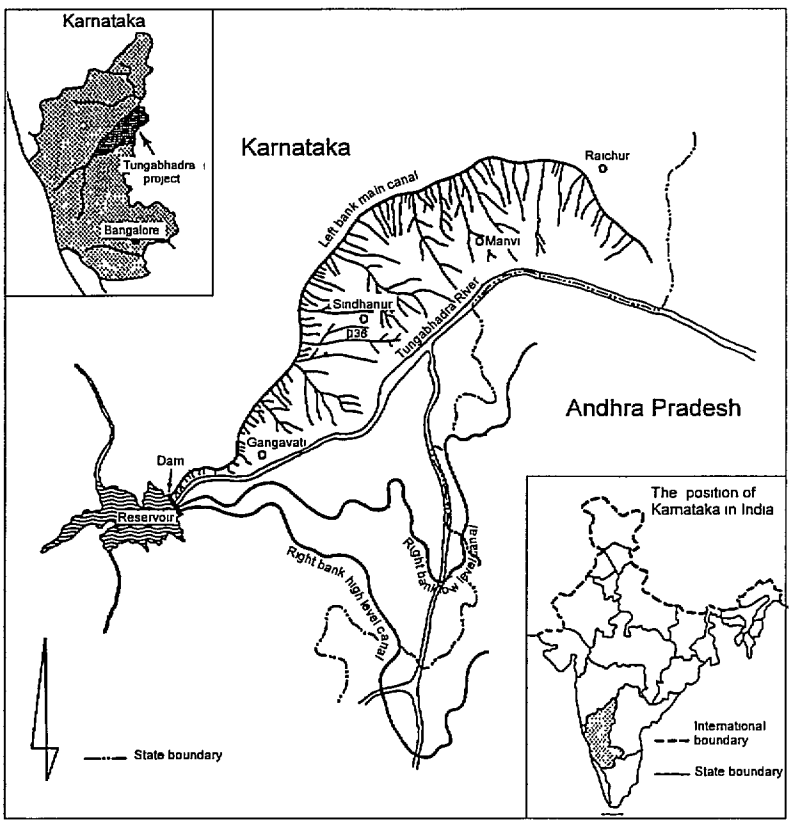
THE PRACTICAL APPLICATION

7. THE TUNGABHADRA CASE

This second part of the paper presents a practical application of the concepts and indicators for assessing seasonal water delivery presented in Part 1 using the Tungabhadra Project in Karnataka State, South India, as an example. Research was carried out in this scheme under the Tungabhadra Irrigation Pilot Project (TIPP) from 1986 through 1990 by the International Institute for Land Reclamation and Improvement (ILRI), in collaboration with the Tungabhadra Command Area Development Authority and the Irrigation Department. The analysis presented here focuses on part of this research as it relates to performance assessment. More details on the research approach are given in Jurriëns 1990, and details of the research results may be found in many TIPP research reports, in Jurriëns and Landstra 1990, and in some of the other references given in this paper.

The Tungabhadra Irrigation Project is located about 300 kilometers north of Bangalore, the capital of Karnataka State (see Figure 1). It is an interstate project with a command area of 360,000 hectares in Karnataka and 150,000 hectares in Andhra Pradesh. Water was

Figure 1—Tungabhadra Project, Karnataka, India



Previous Page Blank

first released in 1954. Three main canals supply irrigation water to the area from a reservoir behind a dam on the Tungabhadra River. Two of these canals are on the right bank of the river, one at a high level and one at a low level. They supply water to 116,000 hectares in Karnataka and continue into Andhra Pradesh. The main canal on the left bank serves about 244,000 hectares, entirely in Karnataka. The right and left bank areas form separate command areas with considerably different characteristics and problems. In this paper, only the Left Bank Command Area (LBCA) is considered.

More detailed information about the LBCA is given in the next section. Chapter 8 then reviews the general system objectives and the derived operational targets, as well as their implications. This provides the background needed to fully understand the subsequent chapters, which deal with the performance indicators introduced in Part 1.

Each chapter starts with calculations of the indicator concerned and continues with discussions of the practical aspects, including a review of targets used and collection of the required data. The final chapter summarizes the conclusions and makes recommendations for further research.

THE TUNGABHADRA SYSTEM

This section provides basic information about the Tungabhadra system useful for understanding the subsequent performance assessment. For more detailed information, see Jurriëns et al. 1987 and Jurriëns and Landstra 1990.

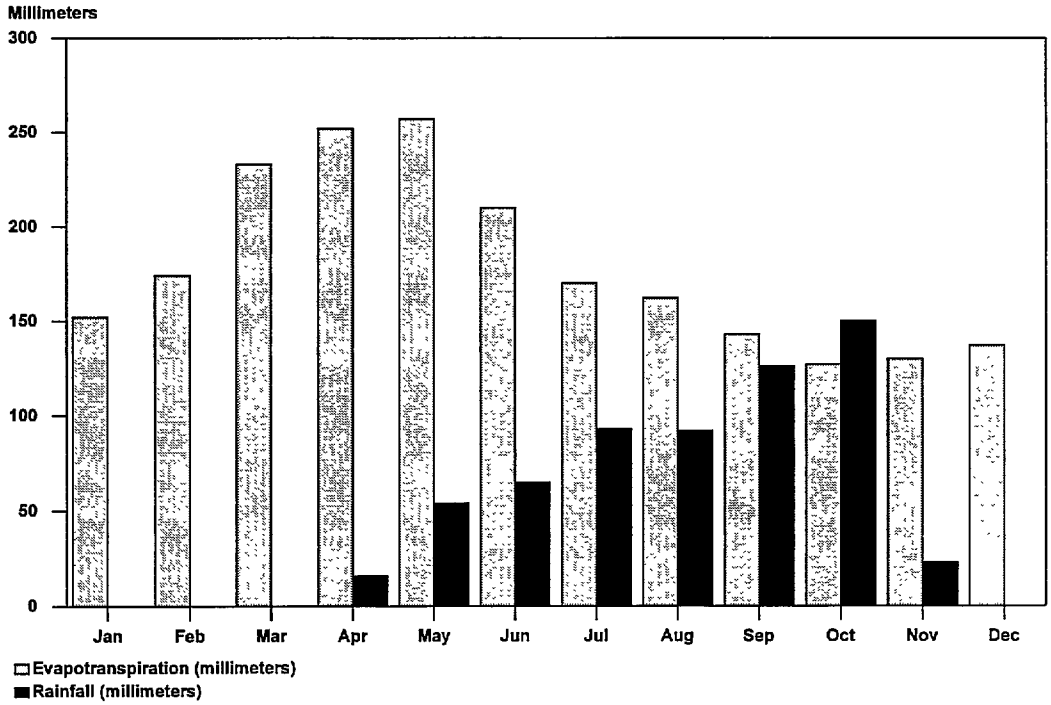
The Left Bank Main Canal is a 227 kilometer contour canal. With a maximum capacity of 102 cubic meters per second, it supplies water to 85 secondary canals, called distributaries in India. These distributaries vary in length from 1 to 65 kilometers and cover command areas of from 50 to 35,000 hectares. The main canal is entirely lined, and the distributaries are largely unlined. The offtake structures from main to secondary canals are culverts (round concrete pipes), placed at the level of the canal bed and provided with vertical steel slide gates. In the main canal there are four cross regulators, but these are mainly used to enable dewatering reaches of the canal for maintenance and repair and not to control the water level.

The topography of the area is undulating. The distributaries are situated on well-defined ridges, approximately perpendicular to the main canal, with slopes toward the Tungabhadra River on the order of 0.2 to 0.5 meters per kilometer. Soils in the area are mainly black cotton soils; red soils cover only some 15 percent of the area. The depth of the black cotton soils is mostly limited—less than 1 meter over about 50 percent of the area. The subsoil usually consists of "murram," a weathered rock soil layer of varying thickness, with varying composition, structure, and permeability.

The average annual rainfall is about 600 millimeters, but it is highly erratic and varies from 300 to 1,200 millimeters. Normally, 90 percent of the annual precipitation falls between June and October. Figure 2 shows the average monthly rainfall and evapotranspiration. Average monthly evapotranspiration varies from about 130 millimeters in October and November to about 250 millimeters in April and May. Deficits occur in most months.

Crops grown in the scheme are paddy, cotton, sugarcane, "garden crops" (vegetables, spices, and fruits) and "light crops" (crops that require little water). Light crops include cereals (wheat, sorghum, millet, maize), pulses (cow peas, red gram, bengal gram), and oil seeds (sunflower, groundnut, sesame, linseed). High-yielding varieties of rice are cultivated, and hybrid varieties of cotton and some grains are common. There are officially two irrigation seasons: the wet season (*kharif*) from July to October and the dry season (*rabi*) from November to April.

Figure 2—Monthly rainfall and evapotranspiration, Left Bank Command Area

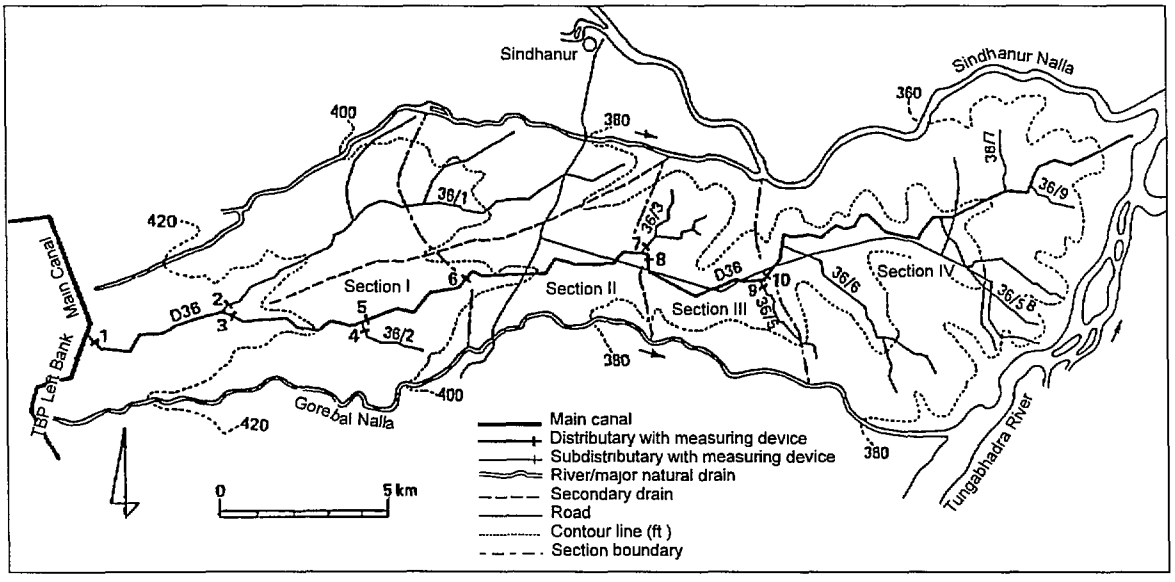


In the Tungabhadra Irrigation Pilot Project, research was done on various aspects of the reservoir, main canal, and LBCA, but emphasis was on the command area of distributary D36 as a pilot area, which is depicted in Figure 3. The D36 distributary takes off at kilometer 75 from the main canal, which is at one-third the actual length of the main canal, but at about half of the length that normally supplies some irrigation water to the distributaries. The D36 canal is about 39 kilometers long and serves a command area of 18,200 hectares. The canal is mostly unlined. It does not have cross regulators, but there are numerous drop structures to limit the hydraulic gradient to 25 centimeters per kilometer, which act as a partial level control. The distributary command of D36 is bounded by two large *nalas* (natural drains); the land slopes from the distributary to these *nalas* at about 5 to 15 meters per kilometer.

The main D36 canal has eight subdistributaries ("minors") of varying lengths and sizes. In the area, there are about 200 tertiary units (*chaks*), varying from about 20 to 150 hectares, of which 100 take off directly from D36 itself and 100 from the minors. The offtake structures of the "direct" *chaks*, called outlets, are gated circular concrete pipes at bed level. Those from the minors are ungated. Watercourses (capacity > 1 cusec = 1 cubic foot per second = about 28 liters per second) and field channels (capacity < 1 cusec) within the *chaks* are largely unlined, and there are usually not many structures within the *chak*.

Farm sizes are generally small, most of them from 2 to 5 hectares, and most are cultivated by their owners. There are no formal water users' organizations in the scheme, but farmers are formally represented through farmers' unions on the Tungabhadra Board and in the annual meetings of the Consultative Irrigation Committee, where irrigation matters and problems are discussed. Furthermore, farmers exert strong informal influence through the farmers' unions.

Figure 3—Command area of distributary D36

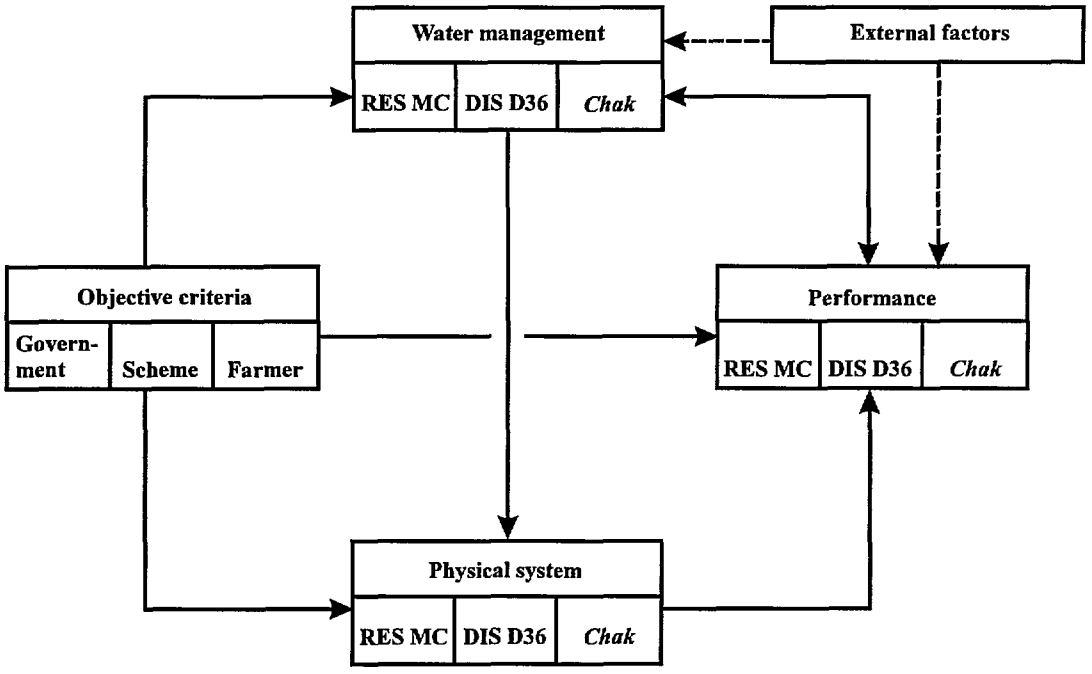


Reservoir operation and water distribution in the main system are the responsibility of the Irrigation Department. Formally, the department also has some responsibilities for water management in the tertiary unit (the *chak*), but in practice water affairs within the *chak* are organized by the farmers concerned. The Command Area Development Authority, Tungabhadra Project, is responsible for various matters at the farmers' level, such as agricultural support, extension and cooperation, construction of small works, introduction of *warabandi* (fixed turn rotational distribution), and drainage and reclamation of waterlogged and salt-affected lands.

Figure 4 depicts the main components of the research program. This figure illustrates that performance is assessed (at different levels) by identifying and comparing results and objectives. The differences observed between objectives and actual performance can then be explained from an analysis of the objectives themselves, the management practices, and the physical system properties, including the interactions among these components. The work of management to achieve the objectives is affected by the properties and limitations of the physical system, and together they affect the performance.

As mentioned earlier, emphasis here is on performance assessment, with due attention to an analysis of the objectives and targets themselves. Management and aspects of the physical system are touched on only in passing.

Figure 4—Main components of the research program



Notes: RES MC stands for "reservoir main canal"; DIS/D36 is distributary D36.

8. IRRIGATION OBJECTIVES AND TARGETS

This chapter analyzes the irrigation objectives in the Tungabhadra Scheme so that the results can be compared with the targets. The Tungabhadra Scheme was originally designed for "protective irrigation," which means that a rather limited amount of available water is thinly spread over as large an area as possible to benefit as many farmers as possible. Hence the primary objective is not maximum agricultural production per unit of land, but rather protection against total crop failure for a large number of farmers. The limited amount of water provided by irrigation supplements the average annual rainfall of 600 millimeters. But, as noted above, rainfall is erratic, and no rain at all falls in the *rabi* season.

Theoretically, protective irrigation is to be achieved through two operational targets: (1) low irrigation intensity, and (2) low unit water supply (water requirements). Both were thought to be facilitated by the policy of "localization," which prescribes for both seasons which crops are to be grown in which areas. In this explanation, intensity and localization are treated together.

IRRIGATION INTENSITIES AND LOCALIZATION

Table 5 shows the localized crops and areas. A certain piece of land is to be irrigated for one crop in the wet season (*kharif*), for one crop in the dry season (*rabi*), or for a two-season crop. The total irrigable command being 243,900 hectares, it is seen that the target irrigation

Table 5—Localized crops and planted area for Tungabhadra Left Bank Command Area

Season and Crops	Area	Percent of Total
	(hectares)	
Kharif		
Paddy	21,100	
Light	89,300	46
Subtotal	110,400	
Two seasons		
Sugar	8,400	
Cotton	30,000	
Garden	6,300	18
Subtotal	44,700	
Rabi		
Paddy	. . .	
Light	88,800	36
Subtotal	88,800	
Total	243,900	100

Source: Basic data from Tungabhadra Irrigation Pilot Project research, 1986–90, International Institute for Land Reclamation and Improvement.

Note: . . . indicates a nil or negligible amount.

intensity for the entire scheme is 100 percent for one agricultural year (two seasons). The localization pattern or crop zoning is such that every piece of land is to receive irrigation water for one crop per year. The land to be irrigated under a *kharif* crop will not receive water in *rabi* and conversely.

The idea is that localization of large areas for "light crops" makes protective irrigation feasible (Karnataka, Planning Department 1976). It is observed that the objective of protective irrigation and the 100 percent intensity include a notion of "fairness" in that each piece of land is to have one irrigated crop per year, but it does not imply complete equity because different crops require different amounts of water, and provide different returns.

Another purpose of localization initially was that the areas to be cultivated with certain crops could be selected to avoid waterlogging, salinity, and waterborne diseases (Rao 1974). For this reason, patterns were prepared in minute detail, taking into account topography, soils, village locations, and the like.

There is a localization pattern for each distributary and, within the distributary command, for each *chak*, and even for each "survey number" (cadastral unit). The figures for the different *chak*s may vary, but the basic idea remains the same (see Jurriëns and Landstra 1989). Table 6 gives a localization plan for the D36 area, similar to that of Table 5, showing that 40 percent of the area is to be irrigated under one crop in *kharif*, 20 percent under a two-season crop, and 40 percent under one crop in *rabi*. The irrigable command is 18,196 hectares; the annual target intensity is 100 percent, localized in such a way that each piece of land is to have one irrigated crop per year.

DUTIES

In India, water requirements are expressed as "duties," indicating the area to be irrigated by a unit flow size, given in acres per cusec (1 cusec = 1 cubic foot per second = 28.3 liters per second). Of course, with one cusec at the main canal head, less land can be irrigated than with one cusec at the distributary head. Duties are therefore always to be given

Table 6—Localized crops and planted areas, D36 canal

Season and Crops	Area	Percent of total
	(hectares)	
Kharif		
Paddy	503	
Light	6,776	40
Subtotal	7,279	
Two seasons		
Sugar	. . .	
Cotton	2,870	
Garden	816	20
Subtotal	3,686	
Rabi		
Paddy	. . .	
Light	7,231	40
Subtotal	7,231	
Total	18,196	100

Note: . . . indicates a nil or negligible amount.

for a specified level, and the differences between the levels must account for the intermediate losses. The duties for the two levels that have been officially adopted in the scheme are given in Table 7. The inverse values, converted to l/s × ha, are added.

Duties are meant to supplement rainfall, and consequently they differ for the same crops in *rabi* and *kharif*. Moreover, because target duties are considered averages for the crop season, no indications for peak requirements and seasonal fluctuations are given.

THE BASIS FOR THE OPERATIONAL TARGETS

There is no explicit mention in any of the early scheme documents of how the operation of the water distribution was visualized. Some implicit ideas, however, can be deduced from the foregoing theoretical points of departure (localized crops, areas, and duties), and by taking into account the characteristics of the physical system.[14] The scheme was designed to enable simple operation with very few interventions in the distribution of the limited water supply. Four points must be kept in mind when evaluating the actual planning and operational procedures.

1. The design flows for the various levels (main canal, distributaries, and *chak*s) must be based on the downstream localized cropping pattern and the corresponding duties. The localized areas for the various crops are divided by the corresponding duties for the level concerned. These required flows per crop are then added, taking into account the crop calendars. In this way, the design flows for every distributary, minor, and *chak* were determined long ago and can be found in various scheme documents. Because all the elements that are used to determine these flows are fixed as basic scheme policy elements, the resulting design flows are still valid. Operational target flows are always equal to these design flows, and consequently they do not have to be recalculated each season. The target inlet

Table 7—Duties for Tungabhadra scheme

	Main Canal Head		Distributary Head	
Crop	Duty	Allowance	Duty	Allowance
	(acres/cusec)	(l/s.ha)	(acres/cusec)	(l/s.ha)
Kharif				
Paddy	55	1.27	65	1.08
Light	150	0 47	175	0.40
Sugar	75	0.93	90	0.78
Cotton	120	0.58	140	0.50
Garden	100	0.70	115	0.61
Rabi				
Paddy	40	1.75	45	1.56
Light	120	0.58	140	0.50

[14]This discussion is based on a logical interpretation of the design concept and confirmed by many scheme documents, engineers, managers, and operators in the field.

flow given for D36 is 5.86 cubic meters per second. According to the concept of localization and duties described above, different targets would have to be set for *kharif* and *rabi*. In the actual system operation this is not done, however, and the same target of 5.86 cubic meters per second is used for both seasons.

2. Theoretically, according to the above procedure, the outlet flows and corresponding canal flows should vary over the season, depending on the localized crops and duties and crop calendars. In practice, this is not done, however. Authorities attempt to keep the canal flow constant, for which three reasons are commonly given: the high duties (which mean low supply in addition to rainfall per unit area), the differing crop calendars over the command area, and the absence of proper level-control structures (the drops function as such only when the canal is running at about the discharge for which it was designed). If target flows and levels varied over the season, all gates would have to be operated continuously, which would make any effective control impossible.
3. No *chak* or minor is entirely localized for one season only, meaning that outlets are rarely closed and that canals run continuously in both seasons. Only if there is very high rainfall is an outlet, minor, or an entire canal completely closed for a short period.
4. Considering the above, the formal intention of Irrigation Department staff, therefore, is that all outlets should always be open to target (design) flows. This is all the more necessary because there are no proper rating curves for partial gate closure. The settings for all outlets have been predetermined (with an approximate formula, assuming the design water surface elevation in the canal) and are marked with paint on the gate winch.

IMPLICATIONS OF THE SCHEME OBJECTIVES

The official scheme objectives and targets are in various respects in conflict with the views and wishes of the farmers. Indian farmers are free farmers; they want to decide for themselves which crops to cultivate. Hence they may wish to grow paddy or cotton on lands localized for light crops. Such so-called "crop violations" have become common as increasing numbers of migrants from the Andhra Pradesh plains have settled in the scheme area since the early 1950s. These people were used to irrigation and paddy cultivation and want to continue farming in the way that is familiar to them. Moreover, in the first decade of the scheme before construction was completed, farmers were encouraged to grow rice to make good use of the then abundantly available water. Consequently, they came to see paddy cultivation as their established right.

Moreover, farmers want to grow a crop in both seasons. It is common for farmers to feel that when part of a certain area (survey number or *chak*) is localized, the entire area is entitled to irrigation, no matter the season. This is in essential conflict with the official localization. But for the farmer, it is both desirable and logical to irrigate the land in both seasons. The outlet is always open, and water flows continuously in the watercourse because in the *chak* there is always some land localized for the season at hand. So when a farmer who is not localized for that season sees water passing, he wants to use it as well. If he does so, serious water-use problems arise from the fact that an area localized for light crops in *kharif* is in fact irrigated in both seasons instead of only one. This problem is perhaps even more serious than that of irrigating paddy instead of cotton in only one season.

The official duties cause other problems. No one knows how they were initially established, but everybody agrees that over the years they could not be realized. In other words, they did not cover the actual crop water requirements. This was confirmed by calculations of actual crop water requirements based on the theoretical FAO method (FAO 1976) using local climatic data, crop calendars, and so on (see Jurriëns and Landstra 1989). Knowing this from practical experience as well, new duties were proposed several times by various local officials and research stations, but for reasons that are unclear, they were not officially accepted and the original duty values shown above are still the official ones. Of course, farmers do not care about all this; they want sufficient water for their crops, and thus they try to take more water than is allocated according to the duties.

Problems also arise where suitable irrigable land was not localized initially, for reasons that often cannot be reconstructed. The farmers do not understand why one piece of land is localized and a similar piece is not. Consequently, much nonlocalized land is cultivated and irrigated. The irrigation of nonlocalized land is classified by the Irrigation Department as "unauthorized irrigation."

An individual farmer thus has many good reasons for trying to take more water than officially allowed: to cultivate paddy instead of a light crop; to irrigate all the land in both seasons instead of only part of the land in one season; to supply water according to actual crop needs instead of according to the official duties; and to irrigate irrigable but nonlocalized land. These conflicts between formal scheme objectives and farmers' wishes are at the root of the major problems in scheme performance, as is illustrated in the following chapters.

The performance assessment in the following chapters is done for the year 1987/88, because for that year the required data were most complete and consistent. The primary objective of the analysis is to show a practical application of the concept and indicators discussed in Part 1, illustrating their merits as well as their deficiencies.

9. IRRIGATION INTENSITY PERFORMANCE

INTENSITY PERFORMANCE INDICATORS

This chapter analyzes the irrigation intensities for the Tungabhadra case along the lines discussed in Chapter 3, first for the entire LBCA and subsequently for distributary D36. In Chapter 3, the indicator for intensity performance was defined as the ratio of realized (II_r) to targeted (II_t) irrigation intensity:

$$\textit{irrigation intensity ratio } (IIR) = II_r / II_t.$$

Because there are two distinct seasons, this chapter also takes a look at the irrigation coverage ratio (ICR), which was defined in Chapter 3 as

$$\textit{irrigation coverage ratio } (ICR) = IA_i / IA_t,$$

where IA_i is the land area that has had at least one irrigated crop and IA_t the area that is targeted to get (at least) one irrigated crop.

Left Bank Command Area

The target intensities, according to the localization, were given in Table 5 as 46 percent of the entire command area for *kharif* crops, 18 percent for two-season crops, and 36 percent for *rabi* crops. Actual results for the year 1987/88 are presented in Table 8.

The table shows that for the whole year the realized irrigation intensity was 83 percent (two-season crops counted only once). Because the annual target was 100 percent, the annual irrigation intensity ratio (annual IIR) was 83 percent. Figures for the two seasons separately are a bit more complicated. As discussed below, the targets for both seasons were

Table 8—Target and actual irrigation intensities for Left Bank Command Area, 1987/88

Crop	Target		Realized	
	(hectares)	(percent)[a]	(hectares)	(percent)[a]
Kharif	110,400	46	97,428	40
Two-season	44,700	18	19,848	8
Subtotal	155,100	64	117,276	48
Rabi	88,800	36	85,080	35
Two-season	44,700	18	19,848	8
Subtotal	133,500	54	104,928	43
Yearly total	243,900	100	202,356	83

[a]Percent of total irrigable command area (243,900 hectares).

set as the sum of the seasonal and the two-season crops. Thus, the target for *kharif* was 110,400 + 44,700 = 155,100, or 64 percent of the total command; for *rabi* it was 88,800 + 44,700 = 133,500, or 54 percent of the total command (the sum of the two target intensities for the two seasons then was (46 + 18) + (36 + 18) = 118 percent. For the *kharif* season, the realized 48 percent intensity means a seasonal IIR of 48/64, or 76 percent. The 43 percent of the command that had been irrigated in *rabi* means that the IIR was 43/54, or 79 percent.

Unfortunately, there is no detailed information about where the irrigated and nonirrigated lands are located. But it may be assumed that the land irrigated under *rabi* crops (85,080 hectares) is largely the same land as that irrigated already under *kharif* crops (97,428 hectares). This is because the farmers who are in a position to take the required water (localized or not) in *kharif* will also do that in *rabi*. This was indeed observed in many places in the field and supported by the detailed data. This would mean that the 117,276 hectares under *kharif* and two-season crops would have had at least one irrigated crop and 126,624 hectares (243,900 – 117,276) would have had no irrigated crop at all. This would yield an irrigation coverage ratio (ICR) of 48 percent (117,276/243,900 = 0.48), meaning that about half the irrigable land did not have an irrigated crop at all. If the above assumption is not completely correct, and the *rabi* intensity included some "new" land irrigated in *rabi* that was not irrigated in *kharif*, the ICR figure would increase.

Distributary D36

Table 9 displays similar information for the D36 command, for the same year. The realized annual intensity appeared to be 79 percent, which was, at the same time, the annual IIR because the annual target was 100 percent. When looking at the separate seasons, the picture is again different. As above, both seasonal and two-season crops are used to calculate the seasonal intensities. Thus, the *kharif* target is 60 percent and the *rabi* target is 60 percent as well. Table 9 shows that, for *kharif*, the realized intensity is 48 percent, giving a seasonal IIR of 80 percent (48/60 = 0.80). Figures for *rabi* are 46 percent and 76 percent (46/60 = 0.76) respectively.

More land is irrigated in the *kharif* season: 8,840 hectares, or 48 percent of the total irrigable command. In the case of D36, detailed figures are available for all individual *chaks*. These are not given here, but they suggest that in *rabi* about 500 hectares were irrigated that were not irrigated in *kharif*. These figures would indicate that the area having had at least one irrigated crop was on the order of 8,840 + 500 = 9,340 hectares. This would yield an ICR of

Table 9—Target and actual irrigation intensities for D36, 1987/88

Crop	Target		Realized	
	(hectares)	(percent)[a]	(hectares)	(percent)[a]
Kharif	7,279	40	5,889	32
Two-season	3,686	20	2,951	16
Subtotal	10,965	60	8,840	48
Rabi	7,231	40	5,482	30
Two-season	3,686	20	2,951	16
Subtotal	10,917	60	8,433	46
Yearly total	18,196	100	14,322	79

[a]Percent of total irrigable land (18,196 hectares).

51 percent (9,340/18,196 = 0.51), which would mean that about half the command did not get any irrigation at all.

PRACTICAL PROBLEMS AND DISCUSSION

Targets

The foregoing text described two different approaches to finding target intensities. The 100 percent target is used to find the annual intensity because it is in line with the localization purpose of the scheme, that every piece of localized land is to have one irrigated crop. In this case, any two-season crops should then be counted only once. When calculating the intensity for separate seasons, two-season crops are counted in both seasons, because these crops are still on the land in *rabi* and should be irrigated as well. Although this may seem somewhat confusing, this dual approach is the most logical because it is most in line with the actual objectives and targets.[15]

Data Collection

In the Tungabhadra case, the Irrigation Department collects all basic data on irrigated areas for every survey number. For the entire scheme and for the D36 command, seasonal and annual figures were obtained from the scheme files within a few weeks, but several problems occurred in the further processing:

- Data obtained from the Irrigation Department appeared to differ substantially from those collected by the Department of Agriculture. The reasons for this could not clearly be traced. Irrigation Department data have been used here.
- In all cases, the figures on total annual irrigated area appeared to include double counting of the two-season crops. As explained above, this was acceptable in calculating seasonal results, but not for annual totals.
- Basic data on localized and irrigated areas were available at survey-number level, requiring further processing of all data. This involved aggregating the data by *chak*, minor, and distributary. Because many survey numbers appear to be located in two adjacent *chak*s, data on irrigated areas had to be divided over the two *chak*s. This was not only a laborious job, but the outcome depended heavily on the skill of the

[15]A slightly easier approach to finding the annual intensity would be to use 118 percent for the annual target as well. There is no problem in doing so, as long as the same approach is used for the realized intensities in determining the IIRs.

Yet another issue concerns the definition by Murray-Rust and Snellen (1993, 17) of the overall performance of main system managers, which depends on two criteria; one of these is the efficiency with which services are provided, which they define as follows:: "the degree to which services offered by the main system managers respond to farmers' needs, within the limitations imposed by national policies and objectives and by overall resource availability."

This is a general statement, and the above tries to make this more specific. In addition, emphasis should be on the second part, the limitations. Main system water delivery is the agency's responsibility, and targets are, in the first place, the agency's targets. Logically, they should meet the farmers' needs to the degree possible, but often they cannot meet all farmers' wishes. Nevertheless, it is always important to communicate with the farmers (clients) in setting targets. But this is primarily a matter of target setting and not of performance assessment, which starts only after targets have been set and can be compared with results achieved (see also Small and Svendsen 1993, which discusses values and goals in line with Chambers 1988, Chapter 2).

officer doing the job. It was therefore concluded that, to enable routine performance assessment of this type, it would be necessary to collect data on irrigated areas per *chak* and restructure the documentation to make relevant processing easier.

Another difficulty in determining irrigation intensities and IIRs is defining when a piece of land is "irrigated." Is it irrigated, for example, when it has received a certain total amount of water over the season, or when it has received a certain number of irrigations? In practice, it is difficult to include a notion of adequacy or sufficiency in this definition, and this question requires further study. The data used in this paper are discussed below.

In Tungabhadra, the normal Irrigation Department practice is to term a piece of land "irrigated" when, during the survey, there is a crop on the land that evidently must have been supplied with canal water. Crops grown purely on rain or on pumping from groundwater or the river are not counted. In the D36 command, there is land along the Tungabhadra River, at the far end of the canal system, that canal water never reaches and that is irrigated with water pumped from the river. This land is not included in the Irrigation Department statistics on irrigated areas. One could argue that this land could therefore be subtracted from the target area to be irrigated by the canals. But one could also argue that the pumping is a response to the system's failure to meet its targets and that this land should therefore be included in the target as nonirrigated land in the realized intensity figure. The situation would become still more complicated where there is substantial conjunctive use from canals and pumping (of either surface or groundwater). This complication does not arise in the Tungabhadra Left Bank Command Area, however.

In the Tungabhadra case, the issue is further complicated by the way in which data on irrigated areas were collected. Common practice in India is the "joint inspection." Various parties involved (Command Area Development Authority, Irrigation Department, and Revenue Department) go together into the field some time before harvest and register the land on which there is an irrigated crop. In spite of the detailed work and the effort put into it, considerable errors can be made in estimating the exact area. But it has also been observed that sometimes severe water shortage occurs at the end of the season, after the joint inspection has taken place, which results in considerable yield reductions or even total crop failure. The official figures on irrigated areas, recorded during the inspection, however, still include these lands and give an overly optimistic picture.

Conceptual Aspects

The foregoing practical problems could be solved by establishing adequate definitions and procedures for data collection. "Irrigated area" should refer to land that has produced a reasonable crop, and the practice of data collection should be geared to that. These problems also raise conceptual issues: It can be argued, for example, that irrigated area has to do with adequacy and yields and cannot be used as a single indicator. Here, yield level is used as a threshold criteria to qualify an area of land as irrigated. Subsequently, for a complete diagnosis, the results could be analyzed in combination with information about yields and water use. Only the combined information provides a complete picture.

A second conceptual issue relates to the relevance of the IIR as a performance indicator, as discussed in Part 1. In the Tungabhadra case, there is a clear target, and the picture is not confused by substantial groundwater pumping. Also, the rainfall in *kharif* is such that the field staff collecting the data are generally able to distinguish between purely rain-fed crops and those that have been irrigated. Furthermore, the seasonality aspect is not disruptive. There are clearly two seasons, with a small overlap of only about one month. As long as the data are not collected in this period, the seasonal figures are valid.

SUMMARY AND DISCUSSION OF RESULTS

Results of the intensity performance analysis are summarized in Table 10, for both the LBCA and D36. It is notable that the total irrigated area had never been as large as in the year under consideration here. For instance, the total was about 135,000 hectares in 1984 and 161,000 hectares in 1985; the average over the period 1970–87 was 152,000 hectares. The high figure for 1987/88 is therefore somewhat surprising and could indicate serious underirrigation in this year. This is discussed in Chapters 11 and 14.

A further conclusion from the analysis is that intensity performance, both for the entire scheme and for D36, is not perfect, but it does not look too bad. However, additional information indicates a serious distribution problem. ICR figures, although indicative, suggest that large parts of respective commands have not had any irrigated crop at all. Remote sensing analysis carried out under the TIPP for the year 1988/89 confirmed this picture, strongly indicating the inequity in water distribution in the Tungabhadra Scheme, which is further analyzed in Chapter 12.

It is clear that there must be sound standards and procedures for data collection on irrigated areas. In this particular case, it is evident that data collection on irrigated land needs to be improved and that a better definition of what is actually "irrigated" is required. Data on irrigated areas may not yet be very accurate, but they do give a good indication of how much area has been served by irrigation water and to what extent the targets have been realized.

Results show the relevance of relating actual outcomes to targets and the particular importance of the ICR, which can provide additional information to the IIR. However, more information about the location of the irrigated land is needed in order to interpret the ICR more accurately. Furthermore, when there are two irrigation seasons as well as two-season crops, it makes sense to count the two-season crops for both seasons in determining the seasonal intensity, but only once for the annual intensity.

Table 10—Summary of irrigation intensity performance, 1987/88

	Kharif	*Rabi*	Year
Left Bank Command Area			
Target	155,100	133,500	243,900
Irrigated	117,276	104,928	202,356
Irrigation intensity ratio	0.76	0.79	0.83
Irrigation coverage ratio			> 0.48
D36			
Target	10,965	10,917	18,196
Irrigated	8,840	8,433	14,322
Irrigation intensity ratio	0.81	0.77	0.79
Irrigation coverage ratio			> 0.51

10. FLOW DELIVERY PERFORMANCE

DELIVERY PERFORMANCE INDICATOR

In Chapter 3 the indicator for flow delivery performance was defined as

$$\textit{flow delivery ratio } (FDR) = Q_r / Q_t,$$

where Q_t is the target amount of water to be delivered at a certain location and Q_r is the actual delivered amount. Q can be expressed in cubic meters or liters per second (seasonal average). The flow delivery performance for the entire LBCA and for the D36 distributary is assessed below.

Left Bank Command Area

The target annual allocation was 2,200 million cubic meters (MCM). In the year under consideration, the total withdrawal by the Left Bank Main Canal was 1,837 MCM, yielding a main canal (primary) flow delivery ratio (PFDR) of 84 percent. The estimated seasonal targets were 1,200 MCM for *kharif* and 1,000 MCM for *rabi*. Actual delivery was 962 MCM in *kharif*, giving an FDR of 80 percent, and 875 MCM in *rabi*, giving an FDR of 88 percent.

Distributary D36

Actual measured total flow into D36 for the year considered was about 60.25 MCM for *kharif* and 54.45 MCM for *rabi*, totaling 114.70 MCM. The annual target was 130 MCM, 65 MCM for each season. Although these targets are only estimates, one can conclude that D36 did get less than its planned share, with an FDR of about 88 percent for the year (in line with the main canal FDR)—93 percent for *kharif* and 84 percent for *rabi*. Details on FDRs for the various canal reaches and per month are discussed in Chapters 12 and 13 respectively.

PRACTICAL PROBLEMS AND DISCUSSION

Targets

According to the official arrangements on the use of the Tungabhadra reservoir waters by the different canals, the Left Bank Main Canal is entitled to an annual use of 102 thousand million cubic feet or 2,890 MCM. However, because of siltation in the reservoir and other problems, the targeted 2,890 MCM has not been realized since 1965, the first year for which data were available. The average for the entire period, for instance, was 2,125 MCM. For this reason, the target releases are set every year anew, depending on the level of the reservoir. These yearly targets should be used to assess performance.

In years with normal reservoir levels, releases are targeted before the season at a constant rate of about 95 to 100 cubic meters per second during the middle of each season and somewhat less for the first and last months. The annual total would then come down to

some 2,200 MCM. In line with the actual planning practices, a realistic division for the LBCA is 55 percent for *kharif* and 45 percent for *rabi*, or working targets of about 1,200 MCM for *kharif* and 1,000 MCM for *rabi*.

For the D36 distributary as well, it is difficult to determine the total target flow because no official target volume is given. The design inlet flow of D36 is said to be 5.86 cubic meters per second, and Irrigation Department staff indeed use this as the target flow. If the plan not to consider the validity of the targets is adhered to (for further discussions, see Jurriëns 1989), one only has to determine the length of the irrigation periods for *kharif* and *rabi*. Formally, the total cropping period could be 10 months (2 months per year for canal closure for maintenance), which in practice often includes time for a summer crop, although this was in conflict with the official plans. The total target flow would therefore be some 155 MCM. Because the flow is always less in the first and last months of the year, the working target is about 0.85 × 155 = 130 MCM. Again, the division between *kharif* and *rabi* is not known, but taking into account the localization and duties for D36, target delivery would be about the same: 65 MCM for each season. Instead of presenting the total volume in MCM, one could use the target flow in cubic meters per second and compare that with the average measured flow. Here, volumes are used because they have to be determined anyway for the subsequent computation of the WUR.

Data Collection

For the entire scheme, flow and volume delivered at the main canal inlet (from the reservoir) are determined on the basis of daily gauge readings. The only source of errors could be in the rating curve used, which is not frequently calibrated. But generally in India, the closer to the dam, the better and more frequent the flow data collected.

For the distributaries, data are often less reliable. In the Tungabhadra case, inlet flows are measured only on the bigger distributaries. For D36, this was done using a standard rating curve for the pipe inlet. Measurements taken by a device built behind the inlet for the research program (see Jurriëns and Ramaiah 1989) revealed that this rating curve yielded values that were too high. Consequently, values recorded in the official Irrigation Department documents are higher than the ones from the measuring device used here. Yet data needed for the flow delivery performance are often easier to collect and more available and reliable than data on irrigated areas, as discussed in the previous chapter.

The biggest problem concerns the flows at the tertiary inlet level. These are not recorded on a routine basis. For the entire scheme, consequently, nothing can be said about the tertiary flow delivery ratio (TFDR). More information about inlet flows for the D36 distributary level was available, thanks to the special measurement program. Still, this information was insufficient to determine (aggregate) TFDRs. Chapter 12 on uniformity discusses some of the available information on tertiary inlet FDRs.

Conceptual Problems

Targets (for instance, cubic meters per second or monthly volumes) can be modified during the season because of the changing water availability in the river or reservoir. In the Tungabhadra scheme, this is done regularly. The question, then, is whether to determine monthly values of the FDR with changing targets or to stick to the preseason targets and determine one seasonal FDR value. The disadvantage of the latter is that unexpectedly poor water availability during the season will produce a low FDR, for which management cannot be blamed. However, changes during the season are usually seen as operational measures

and not clearly documented as new targets. Here only the preseason targets are used, because this is consistent with the seasonal approach for the other indicators.

In the Tungabhadra scheme, it is common that at one location the *kharif* crop is still to be harvested while somewhere else a *rabi* crop is already on the land. Neither the end of the *kharif* season nor the start of the *rabi* season is well defined. But in this overlap period, actual canal flows are usually less, because water requirements are low. Consequently, from the flow figures it is usually possible to make a reasonable division between *kharif* and *rabi*, and errors are relatively small. The end of the *rabi* season is obvious because that is when the canals are closed for maintenance.

SUMMARY AND DISCUSSION OF RESULTS

Practical problems in determining annual and seasonal FDRs are related to both target and actual flow rates, both for the main canal and D36. The preseason targets for the main canal are not found in official scheme documents and, therefore, are not always easily traced. Estimates made above are in line with what was observed for recent years. The same procedure would provide indications of the division between *kharif* and *rabi* target volume, which is also not officially given. For the D36 distributary, the design flow is used as a target, with some reduction at the beginning and end of the year.

Calculation of actual flows and volumes for the PFDR (LBCA) or secondary (S)FDR (D36) is rather simple because inlet flows are measured daily. Although a variety of minor practical problems were faced in this respect, resulting errors will be smaller than for intensities. Insufficient data were available to determine the TFDRs.

Taking into account these uncertainties and approximations, results for 1987/88 are summarized in Table 11. The low FDR for the main canal is due primarily to the low water level in the reservoir in this year. Since 1973, releases have not been more than 2,000 MCM. In 1987, the total withdrawal by the Left Bank Main Canal was only 1,837 MCM. Over the year, D36 got somewhat less than the level targeted, but more than its relative share (88 percent compared to 84 percent for the LBCA), primarily because of relatively high *kharif* delivery.

Table 11—Summary of flow delivery performance, 1987/88

	Kharif	*Rabi*	Year
		(million cubic meters)	
Main canal			
Target	1,200	1,000	2,200
Delivered	962	875	1,837
PFDR	0.80	0.88	0.84
D36			
Target	65	65	130
Delivered	60	54	115
SFDR	0.93	0.84	0.88

Note: PFDR is the primary flow delivery ratio and SFDR is secondary flow delivery ratio.

11. WATER USE PERFORMANCE

WATER USE PERFORMANCE INDICATORS

In Chapter 3, an indicator for water use performance was defined as

$$\textit{water use ratio } (WUR) = WU_r / WU_t,$$

or the ratio of actual to target water use on the irrigated areas. Both could be expressed in cubic meters per hectare, which can be converted to millimeter depth or average l/s ha.

The figures on irrigated area and delivery can also be used to compute the WUR. As discussed earlier, this calculation does not yield new information but can nevertheless provide another look at the results. This is illustrated in the subsequent analysis, first for the entire scheme and then for D36.

Left Bank Command Area

Results for the LBCA are summarized in Table 12. Taking the earlier assumed 2,200 MCM as annual target supply, the assumed 55/45 division for seasonal supply, and the target figures for the irrigated area, the target use figures would be 1,200 MCM on 155,100 hectares or 775 millimeters for *kharif*, and 1,000 MCM on 133,500 hectares or 750 millimeters for *rabi*. Using the figures from the previous chapters for actual irrigated area and delivery, it is seen that, the actual use has been 962 MCM on 117,276 hectares, or 820 millimeters, for *kharif*, and 875 MCM on 104,928 hectares, or 835 millimeters, for *rabi*. This gives a WUR of 820/775 = 1.06 for *kharif*, and a WUR of 835/750 = 1.11 for *rabi*.

For the total year, the target use is 2,200 MCM on 243,900 hectares, or 900 millimeters. The actual water use was 1,837 MCM and the amount of land that actually received irrigation water was 117,276 hectares, an actual annual use of 1,837 MCM on 117,276 hectares or 1,565 millimeters. Thus, the annual WUR = 1,565/900 = 1.74.

Table 12—Target and actual water use for Left Bank Command Area

Water Use	*Kharif*	*Rabi*	Year
Target			
Delivery (million cubic meters)	1,200	1,000	2,200
Irrigated area (hectares)	155,100	133,500	243,900
Use (millimeters)	775	750	900
Realized			
Delivery (million cubic meters)	962	875	1,837
Irrigated area (hectares)	117,276	104,928	117,276
Use (millimeters)	820	835	1,565
Water use ratio (WUR)	1.05	1.11	1.74

Table 13—Target and actual water use for distributary D36

Water Use	*Kharif*	*Rabi*	Year
Target			
Delivery (million cubic meters)	65	65	130
Irrigated area (hectares)	10,965	10,917	18,196
Use (millimeters)	590	595	715
Realized			
Delivery (million cubic meters)	60	54	115
Irrigated area (hectares)	8,840	8,433	9,340
Use (millimeters)	680	645	1,230
Water use ratio (WUR)	1.15	1.09	1.72

Distributary D36

Detailed figures for D36 yield similar results, summarized in Table 13. According to the assumptions made earlier, the target use for *kharif* is 65 MCM on 10,965 hectares, or 590 millimeters; for *rabi* (counting the full two-season localization), it is 65 MCM on 10,917 hectares, or 595 millimeters. Actual *kharif* delivery was 60.25 MCM on 8,840 hectares, or 680 millimeters, giving a WUR of 680/590 = 1.15. Actual *rabi* delivery was 54.45 MCM on 8,433 hectares, or 645 millimeters, giving a WUR of 645/595 = 1.0. Looking at the full year, the target use would be 130 MCM/18,196 hectares = 715 millimeters. In reality, 115 MCM was supplied to 9,340 hectares, an annual use of 1,230 millimeters. The corresponding annual WUR is 1,230/715 = 1.72.

PRACTICAL PROBLEMS AND DISCUSSION

Targets and Data Collection

For this purpose, the same data are used as in the previous sections for intensity and delivery performance. Hence, no new problems have to be discussed here. It is only to be observed that the scheme's initial target delivery of 2,890 MCM would mean an average planned water use on the irrigated land of $2{,}890 \times 10^6/243{,}900 = 11{,}844$ cubic meters per hectare, or 1,184 millimeters (at main canal head level). Because of the low reservoir, the present lower target has been adopted.

Conceptual Aspects

There are no special problems associated with calculating the seasonal WUR. It is logical to count the two-season crops for both seasons because they indeed use water in both seasons. The seasonal WUR could be calculated directly as WUR = FDR/IIR. For *kharif* for the LBCA, for instance, this would yield WUR = 0.80/0.76 = 1.05, as calculated in Table 12.

However, as discussed in Chapter 3, complications arise when determining the annual WUR, particularly when, in the second season, there are crops on the same land used in the first season; that land is not localized for the second season; and another part of the total planned area does not get any water at all. In such situations, only the land area that has had at least one irrigated crop should be used in the calculations. Thus, the annual WUR is related to the ICR and can be calculated directly as WUR = FDR/ICR. For the LBCA, the

WUR would be 0.84/0.48 = 1.75; for D36, WUR = 0.88/0.51 = 1.73 (the difference between these figures and those in Tables 12 and 13 is due to rounding).

SUMMARY AND DISCUSSION OF RESULTS

The practical problems associated with determining the WUR are the same as those for irrigated area and delivery. Separate analysis for *kharif* and *rabi* can only be indicative because of the uncertainties involved in delivery, as outlined in Chapter 12. Estimates of the various WURs are given in Table 14.

Two-season crops also have to be counted for *rabi* when determining water use. For the individual seasons, this is in line with the procedure used for calculating the IIR. For the annual WUR, only land with at least one irrigated crop should be considered.

In spite of the uncertainties involved, the WUR figures give rise to some interesting observations. For the seasonal WUR, it is seen that, in both *kharif* and *rabi*, water use is not much more than the targeted amount. This is surprising because it was expected that water supplies would not be sufficient to cover crop water requirements and that, consequently, farmers would try to take more than allowed. Moreover, in the field, high losses were measured in the drains during *kharif*.

One reason for the lower-than-expected WURs is that, particularly in *rabi*, yield was low and crop failures occurred. This points at an overestimation of the "irrigated" area and thus an underestimation of the actual water use necessary to obtain a good yield. This suggests that yield figures, although not a performance indicator for main system water distribution per se, could provide useful additional information for assessing other indicators (see also Chapter 6 and Chapter 14). A second factor is that in 1987 *kharif* rainfall was very high (1,190 millimeters), which offset the lower irrigation supply.

Another observation is that the annual WUR yields much higher results. This clearly reflects the double irrigation on the same land, in conflict with the objectives. Instead of the targeted 100 percent of the land being irrigated with 900 millimeters of water, about 50 percent of the land was irrigated with 1,565 millimeters!

As was discussed in Chapter 4, the water use and WURs calculated above give information about operational performance, but they do not provide insight into the adequacy of the delivery, because the target is not to deliver the total crop water requirements. This is discussed further in Chapter 14.

Table 14—Water use performance for Left Bank Command Area (LBCA) and distributary D36

	LBCA			D36		
Water Use	***Kharif***	***Rabi***	**Year**	***Kharif***	***Rabi***	**Year**
Target	775	750	900	590	595	715
Realized	820	835	1,565	680	645	1,230
Water use ratio (WUR)	1.05	1.11	1.74	1.15	1.09	1.72

12. UNIFORMITY PERFORMANCE

The irrigation coverage ratio (ICR) discussed in Chapter 9 indicated a rather nonuniform water distribution, at both scheme level (along the main canal) and distributary level. At scheme level, this cannot be further explored because no detailed data are available for distributaries other than D36. For the D36 command, various required data are available, and the uniformity aspect can be further explored. Both flow uniformity and intensity uniformity are discussed below.

FLOW UNIFORMITY PERFORMANCE

For flow delivery uniformity, the following indicator was proposed in Chapter 4:

$$\textit{flow uniformity ratio } (FUR) = [1 - CV_W\,(FDR)]_r/[1 - CV(FDR)]_t,$$

where CV_W, the weighted coefficient of variation, is the ratio of the *STD* and the average weighted *FDR*, the latter being the sum of the reach *FDR*s times the reach length, divided by the total canal length. The nominator is the realized value and the denominator the target value.

For the D36 canal, supplies to all individual minors and outlets could not be determined because of the many practical problems involved. But flows were measured by measuring devices at various locations in the D36 canal itself, dividing the canal into reaches, and the total outflow on these reaches could thus be determined and compared with targets. Resulting FDRs for the various reaches and for the *kharif* season are given in Table 15.

Considering all the uncertainties involved, the results are only indicative, but they may nevertheless give a reasonable impression of what happens along the canal. Reach 5 ends at about kilometer 25 on the canal, and the entire canal is 39 kilometers long. FDRs on the first 25 kilometers are evidently much higher than on the last 14 kilometers.

Thus, Table 15 gives a clear picture of the considerable nonuniformity along the canal. But, as discussed in Chapter 4, the problem is to quantify this in a logical and workable indicator. Ideally, the FDRs for all reaches would be 1, resulting in a calculation of $(1 - CV)_r$, = 1. This is not necessarily absolute equity, but uniformity compared to target.

Table 15—Flow along D36 in *kharif*

	Reach					
Flow	1	2	3	4	5	6
	(liters/second)					
Target	1,530	760	473	1,228	500	1,370
Measured	1,498	713	464	1,238	766	547
Flow delivery ratio (FDR)	0.98	0.94	0.98	1.01	1.53	0 4

In Table 16 one sample calculation of the FUR is given for the *kharif* season, using official ID flow targets. It is seen in the table that the canal reaches vary in length. As explained in Chapter 4, to determine the flow uniformity ratio, the weighted CV_w is then used, that being the ratio of the standard deviation *STD* of the *FDR*s and the weighted average $\overline{FDR}_w$. For this example, the target $(1 - CV)_t$ is assumed to be 1 so that $(1 - CV)_r$, calculated in Table 16, equals the *FUR*.

The product of *FDR* and reach length for each reach is given in the final column of Table 16. The weighted average of these values is 0.84; the standard deviation of the *FDR*s in column 2 is 0.33. The CV_w, then, is 0.39, the $(1 - CV)_r = 0.61$, and the $FUR = 0.61$. These calculations can be made using a calculator or spreadsheet program. It does not matter whether the lengths are in meters or kilometers, because the dimensions are eliminated in the further calculations.

Table 17 gives the results for the *rabi* season. Processing of the *FDR*s yields an *STD* of 0.32: $\overline{FDR}_w = 0.91$, $CV_w = 0.35$, $(1 - CV_w)_r = 0.65$, and, for the target $(1 - CV)_t = 1$, $FUR = 0.65$.

D36 INTENSITY UNIFORMITY PERFORMANCE

Flow uniformity performance, discussed in the previous section, concerns uniformity in water flows (water delivery). Intensity uniformity performance concerns the amount of land irrigated, as measured by the intensity uniformity ratio (IUR):

Table 16—Calculation of flow uniformity ratio (FUR) along D36 in *kharif* (based on Irrigation Department targets)

Reach	Length L_i	*FDR*	*FDR* x L_i
	(kilometers)		
1	5.409	0.98	5.30
2	3.109	0.94	2.92
3	3.079	0.98	3.02
4	9.174	1.01	9.27
5	4.542	1.53	6.95
6	13.977	0.40	5.59
Total length	39.290		
STD (*FDR*)		0.33	
$\overline{FDR}_w$			0.84

Note: $CV_w = 0.33/0.84 = 0.39$; $(1 - CV)_r = 0.61$; $FUR = 0.61/1 = 0.61$

Table 17—Flow along D36 in *rabi*

	Reach					
Flow	1	2	3	4	5	6
			(liters/second)			
Target	1,530	760	473	1,228	500	1,370
Measured	1,509	659	404	1,390	760	686
ID FDR	0.99	0.87	0.85	1.21	1.52	0.5

Note ID FDR is the flow delivery ratio determined by the Irrigation Department.

$$\textit{intensity uniformity ratio } (IUR) = [1 - CV_w\,(IIR)]_r/[1 - CV(IIR)]_t.$$

Table 18 shows the realized intensities on the various canal reaches. These should be compared with the target intensities. The CV_w is determined using the *IIR*s. For the calculations here, irrigated and localized areas are used, giving the same results as when using intensities. This gives the *IIR*s, indicated in the table.

Table 18 shows that on the first 25 kilometers of the canal the intensities are higher than the target and on the last 14 kilometers (reach 6) they are much less. Using the same calculation procedures as in Table 16, the results are as follows: $STD = 0.40$; $\overline{IIR}_w = 0.84$; $CV_w = 0.48$; $(1 - CV_w)_r = 0.52$ and thus, assuming $(1 - CV)_t = 1$, the $IUR = 0.52$.

This is less than the above-calculated *FUR* of 0.61, meaning that distribution of irrigated areas is less uniform than the distribution of flow deliveries. The many reasons for this cannot be discussed in the context of this paper. The point here is that determining and comparing the various indicators not only aids in evaluating performance but also suggests questions for further study relating to reasons behind the observed results.

PRACTICAL ASPECTS AND DISCUSSION

Targets

The actual target to be used for the FUR or IUR is not the target flow or target intensity, but the target value for $(1 - CV)$, which is the measure for uniformity. Here that value is ideally 1, but historical data suggest the use of a value of less than 1. Either FDRs or IIRs can be used to determine $(1 - CV)$ values.

There were substantial problems associated with determining the target values for flow and intensity, particularly for the reach outflows. Determining the area targets for the IIR was less problematic because the localized areas for the various reaches could be determined. For flow uniformity analysis, the targets set by the Irrigation Department itself should be used, as given in Table 15. But analysis of these targets revealed that they did not correspond with the official duties and localized crops and areas (see Jurriëns 1989). Equitable distribution (ED) targets were calculated as well, based on a completely equitable distribution (equal liters per second per hectare), to see how this would affect the results. The corresponding FDRs are given in Table 19. It is seen that this yields entirely different FDRs. The processed results would be $STD = 0.56$, $\overline{FDR}_w = 0.97$, $CV_w = 0.57$, and $(1 - CV) = 0.43$. The latter is considerably less than the 0.61 calculated with the ID flow targets.

Table 18—Intensity uniformity ratio along D36 in *kharif*

	Reach					
Distributary	**1**	**2**	**3**	**4**	**5**	**6**
Length (meters)	5,409	3,109	3,079	9,174	4,542	13,977
Localized (hectares)	3,073	682	544	1,668	949	4,158
Irrigated (hectares)	3,365	949	686	1,963	1,144	734
Irrigation intensity ratio (IIR)	1.09	1.39	1.26	1.18	1.21	0.18

Table 19—Irrigation Department (ID) and equitable distribution (ED) targets and resulting flow delivery ratios (FDRs)

Target and Results	Reach					
	1	2	3	4	5	6
ID target	1,530	760	473	1,228	500	1,370
ED target	1,628	361	288	993	502	2,200
Measured	1,498	713	464	1,238	766	547
ID FDR	0.98	0.94	0.98	1.01	1.53	0.40
ED FDR	0.92	1.98	1.61	1.25	1.53	0.25

Data Collection

The above calculations illustrate an important problem related to the uniformity indicator, namely, that many data points are required. In the Tungabhadra case, for intensity this was mainly a problem of collection and processing. For flow uniformity, the problem is more serious, because data on flows should be available at various points along the canal. Measuring individual outlets will often be a problem, and if this is the case, the above approach of using total outflows on canal reaches could then be followed. Then, though, the difference between two measurements will also include seepage losses. In the Tungabhadra case, these losses were small compared to the flows through the outlets, and when losses are about the same over the canal length, this aspect can be ignored in evaluating the uniformity of outlet flows.

Still, however, flows must be measured at a number of locations along a canal. In many irrigation systems, this will not be standard practice—certainly not on secondary canals. Under the TIPP research project, measurement structures were built in the D36 canal, or existing drop structures were converted into measurement structures, so that the above indicators could be determined. For routine performance assessment, it would be useful to have at least 5 to 10 measurement locations on a main canal, depending on the number of outlets.

Conceptual Aspects

The foregoing results, as summarized in Table 20, show the following:

- Figures for *kharif* and *rabi* are slightly different, in line with the different distribution of the FDRs. Apparently the somewhat higher FDR on the long tail reach for *rabi* results in a lower CV and, consequently, a little higher FUR value.
- Using other targets would clearly affect the resulting indicator.
- A less uniform distribution results in a lower FUR value.

These results and conclusions support the relevance and adequacy of the proposed indicator, including the weighting procedure.

Finally Table 21 shows the water use on the various canal reaches for one month, determined by the ratio of seasonal reach outflow and area actually irrigated per reach. It is interesting to see that the results in terms of l/s ha do not vary much along the D36 canal. The explanation is simply that farmers adapt the area they irrigate to the water availability;

Table 20—Comparison of flow uniformity ratios (FURs)

	Reach							
Season	1	2	3	4	5	6	*CV*	1 – *CV*
Kharif (ID)	0.98	0.94	0.98	1.01	1.53	0.40	0.39	0.61
Rabi (ID)	0.99	0.87	0.85	1 21	1.52	0.50	0.35	0 65
Kharif (ED)	0.92	1.98	1.61	1.25	1.53	0.25	0.57	0.43

Table 21—Average supply to outlets for various canal reaches, September 1987

	Actual Water Use			Target		Ratio
Reach	Quantity	Irrigated Areas	Use	Localized	Target Use	Actual/Target Use
	(million cubic meters)	(hectares)	(l/s × hectare)	(hectares)	(l/s × hectare)	
1	5.01	3,365	0.58	3,073	0.39	1.49
2	2 14	949	0.87	682	0 45	1.93
3	1.59	686	0.89	544	0.38	2.34
4	3.98	1,963	0.78	1,668	0.38	2.05
5	2.23	1,144	0.75	949	0.37	2.03
6	2.02	734	1.06	4,185	0.47	2.25

that is, they irrigate as much land as possible with the water available from the system. Apparently, one needs about 0.7—0.9 l/s × ha (at canal outflow level) for acceptable irrigation. In Table 15 it was seen that FDRs along the canal varied considerably. Farmers determined which areas were to be irrigated on the different reaches in rough accordance with the FDRs.

The ratios of actual to target use for this month are more uniform than the FDR or IIR values. This illustrates that the water use measure is not, by itself, a relevant one for determining uniformity indicators. (It also appears that the ratios in the last column are much higher than the values found in Chapter 11 for the season. Reasons for this are not discussed here, because they are both complicated and beyond the scope of this paper. The same applies to some deviating figures for reaches 1 and 6. The table is given primarily to show that determining some simple indicators and ratios gives rise to interesting questions for further analysis.)

SUMMARY AND DISCUSSION OF RESULTS

The uniformity performance ratio results for the FUR and IUR are summarized below.

	Kharif	***Rabi***
FUR	0.61	0.65
IUR	0.52	. . .

The above sections show that the proposed uniformity indicators are workable and yield consistent and relevant information. Use of (1 – *CV*) for the FDRs or IIRs and the weighting procedure was shown to be easy.

The low FUR values are primarily due to very low supplies to the last part of the canal. Variations on the first half of the canal are limited. Data and results on the IIR deviate slightly from those for the FUR. The use of an indicator for water use uniformity is not very relevant because the result will often be a quite uniform distribution, due to the fact that farmers adapt their irrigation practices to the available water on the basis of a certain requirement per hectare. This is illustrated by the use figures (l/s × ha) and ratios given in Table 21 for one month.

The main problem with determining the ratios is that the data must be available, which may not always be the case. Having measurements at sample locations in the canal may give sufficient indication of the uniformity. With respect to data collection, the same problems were already mentioned for the actual irrigated areas and flow targets.

13. RELIABILITY PERFORMANCE

The last variability (achievement) indicator discussed here is reliability, which provides an indication of fluctuations over time. As discussed in Chapter 4, it can be determined for one location only and, in all cases, it relates to flows. In Part 1, the following indicator was proposed:

$$\textit{flow reliability ratio } (FRR) = [1 - CV(FDR)]_r / [1 - CV(FDR)]_t.$$

MAIN CANAL AND D36 FLOW RELIABILITY

For the main canal inlet, monthly flow values are available, which are used to calculate reliability (see Table 22). The result is an average FDR of 0.82, a standard deviation of 0.25, a CV of 0.31; consequently $(1 - CV)_r = 0.69$. With a target value for $(1 - CV)_t$ of 1, the FRR would be 0.69. In practice, such a target may be unrealistic, and a somewhat lower value may be used, based on historical figures.

Next, the FRR is calculated for the D36 inlet (measuring device MD1) for which daily measurements were taken and from which monthly averages can be calculated. These can then be converted into FDRs by using a target of 5,860 liters per second. The average FDR is 0.91 and the standard deviation 0.16, giving a CV of 0.18 and an FRR of $(1 - CV)_r = 0.82$, for a target of $(1 - CV)_t = 1$. The same table gives the results for the canal measuring device MD10 at kilometer 25, showing an FRR of 0.68, indicating a lower reliability than for the canal inlet. It is noted that in the latter two cases, where the target is the same for all time intervals,

Table 22—Reliability performance, main canal and D36

	Main Canal		D36 at MD1		D36 at MD10	
Month	Actual	FDR	Actual	FDR	Actual	FDR
July	157	0.86	5,697	0.97	178	0.13
August	233	1.01	5,671	0.97	441	0 32
September	247	1.07	6,624	1.13	868	0 63
October	208	0.90	4,410	0.75	592	0.43
November	104	0.45	3,731	0.64	657	0.48
December	79	0.34	4,347	0.74	692	0.51
January	215	0.94	5,717	0.98	801	0.58
February	134	0.58	6,463	1.10	792	0.58
March	257	1.12	6,028	1.03	674	0.49
April	173	0.95	4,484	0.76	470	0.34
Average		0.82		0.91		0.45
STD		0.25		0.16		0.14
CV		0.31		0.18		0.32
FRR[a]		0.69		0.82		0.68

Note: MD is measuring device.

[a]Assuming a target of $(1 - CV)_t = 1$.

the same results would have been obtained by using the average standard deviation and CV for the measured flows instead of FDRs.

When FRRs for separate seasons are determined, for instance for the D36 inlet, the following results are obtained. For *kharif*, the average is 0.89, the STD is 0.17, the CV is 0.20, and the FRR is 0.80. For *rabi* the results are 0.92, 0.15, 0.16, and 0.84 respectively. It is seen that in spite of the declining flows near the end of *rabi*, the overall reliability in *rabi* has been somewhat better than in *kharif*. It is not necessary to use a weighted average as was done with the uniformity indicator, because the time intervals used to determine the FDRs are the same over the entire period.

PRACTICAL ASPECTS AND DISCUSSION

For the determination of the FRR, the FDRs are to be used, for which target flows are required. In this case, monthly totals are used. The problem here again is that these target flows are not well defined (see Chapter 10). In line with actual practice (of target setting and operation), 180 MCM in July and April and 230 MCM in the other months are used here as flow targets, together yielding the total 2,200 MCM annual target. For D36, the official target flow is used for all periods.

Regular flow measurements are required for the location concerned. Usually, this will not be a problem for the main canal or major secondary canals. It will be more difficult to get frequent routine measurements of tertiary inlet flows. Even under the TIPP research project it was impossible, for various practical reasons, to get regular and frequent measurements on a substantial number of tertiary inlets. The irregular measurements on some inlets suggested a much lower reliability than for the canal flows (see Jurriëns 1992) .

Conceptually, the reliability indicator is similar to the uniformity indicator. The resulting FRR (FUR) does not indicate when (or where) a low or high value occurs, and two different distributions over the season (or area) may yield the same FRR (or FUR). The weighting problem will usually not arise with the FRR, because when detailed data are available, they can be processed in periods of the same length. Another aspect is that the length of the period affects the resulting FRR value. Extremes of daily values are leveled out in the monthly averages, and because the CV is included in the FRR, using daily values will usually yield lower FRR values than monthly values will. It is therefore recommended to indicate the period used.

14. EFFICIENCY PERFORMANCE

In Chapter 5, two types of efficiency performance indicators were proposed, defined as follows:

main system operational efficiency ratio (*MOER*) = $(IE_r/IE_t)_M$, and

overall operational efficiency ratio (*OOER*) = $(IE_r/IE_t)_O$.

Both are the ratio of the realized to the target value of an irrigation efficiency for the main system and overall scheme, respectively. This chapter consists of two parts, one discussing the actual irrigation efficiencies realized, and the second reviewing the problems involved in establishing target values.

REALIZED IRRIGATION EFFICIENCIES

Unfortunately nothing can be said about the realized main system efficiencies in the Tungabhadra case, which involve the losses between the main canal inlet and the tertiary inlets. Doing detailed flow measurements on tertiary inlets is not a routine practice in the scheme. The Tungabhadra Research Project recorded flows on measurement structures in the D36 distributary only. It was impossible, however, to continuously measure all individual tertiary offtakes on the distributary, let alone for the entire scheme. Consequently, no information is available on the MOER.

Somewhat more can be said about the total scheme efficiency performance. The analysis that follows is partly in line with the World Bank approach, as discussed in Chapter 5. To that end, data on canal releases and actual irrigated crops and areas are needed, which are available in the Tungabhadra case. Using crop water requirement calculations, the ratios of the requirements to the supplies are calculated.

But even applying this approach to the Tungabhadra scheme is problematic. A determination of real crop water requirements can only be indicative because uncertainties are involved in both crop calendars and crop coefficients. Estimates, including the uncertain data for crops and areas cultivated, yield a total annual requirement of some 1,530 MCM at crop level. With the delivery of 1,837 MCM the calculated efficiency is 83 percent (1,530/ 1,837 = 0.83). This clearly points to considerable underirrigation, which was confirmed by field observations, and partly explains the very high figures recorded for irrigated areas. It was mentioned in Chapter 11 that in the year 1987/88, which is analyzed in this sample case, the total annual irrigated area was about 202,000 hectares, whereas the average for the period 1970–87 was about 150,000 hectares.

The above figures are for the entire year and do not count rainfall. More information is obtained from seasonal values and when rain is taken into account. Actual supply in *kharif* was 960 MCM plus rainfall of 1,400 MCM, which together give 2,360 MCM. With an estimated water requirement in *kharif* of 655 MCM, the "efficiency" is 28 percent (655/2,360 = 0.28). This confirms the field experience of considerable losses in *kharif*. Actual use in *rabi* was 850 MCM. With an estimated water requirement of 875 MCM in *rabi*, the efficiency is 97 percent

(850/875 = 0.97), which indicates considerable underirrigation or an overestimation of the well-irrigated area.

Similar calculations for D36 yielded efficiency values of 32 percent in *kharif* (requirement = 52 MCM, supply = 60 MCM, and rain = 100 MCM) and 80 percent in *rabi* (requirement = 68 MCM, supply = 54 MCM). The conclusions to be drawn from this are similar: First there were substantial underirrigation and yield reductions in *rabi*, as was observed in the field, and second, irrigation within the tertiary unit is usually much more efficient in *rabi* than in *kharif*, because in *rabi* there is no rainfall and water is more limited.

In the above, the full rainfall in *kharif* is included. When rain is not counted, the *kharif* result for the LBCA is 70 percent (655/960) instead of 28 percent, and for D36 87 percent (52/60) instead of 32 percent. The reason for the big differences is that canal flows are not changed when rain falls. Theoretically, the high duties include the assumption of effective use of additional rainfall. Practically, given the large areas and rainfall that varies in spatial occurrence, duration, and intensity, reducing irrigation deliveries in response to rainfall would be too complicated, especially given the system's limited control capacity. Moreover, the reservoir is often full during *kharif*, so even if one succeeded in saving water by reducing canal deliveries, the saved water would disappear over the reservoir spillway. The above results are summarized in Table 23.

In the foregoing, efficiencies were calculated with the formula $E = ET_p/(R + S)$, or the ratio of requirements to total supply, the latter including rainfall. This seems logical, because it shows how much of the supplied water is eventually used by the crop. It differs, however, with the common definition using the formula $E = (ET_p - R_e)/S$. As explained in Chapter 5, a problem here is that there is no obvious value for effective rainfall (R_e). Moreover, for both LBCA and D36, the total rain was more than ET_p, yielding a negative efficiency if total rain were used in this formula.

TARGET IRRIGATION EFFICIENCIES

The difficulty of determining actual efficiency has been discussed above. Determining target values to come to an operational efficiency ratio is even more difficult. To illustrate this, realized efficiencies for the entire scheme for various years are given in Table 24 (from Jurriëns and Wolters 1993).

Table 24 shows that results vary over years and between seasons. If rain is not counted for *kharif*, efficiencies vary roughly from 30 to 70 percent for this season, and from 35 to 80 percent for the year. When *kharif* rain is taken into account, efficiencies are considerably lower—20 to 30 percent for *kharif* and 20 to 35 percent for the year. In *rabi*, efficiencies are always higher than in *kharif*, roughly in the range of 50 to 95 percent.

Table 23—Realized irrigation efficiencies, 1987/88

Scheme	Without Rain	With Rain
LBCA		
Year	0.83	0.63
Kharif	0.70	0.28
Rabi	0.97	0
D36		
Kharif	0.87	0.32
Rabi	0.80	0

It is also seen that the larger the irrigated area, the higher the efficiency. There could be at least two explanations for this. One is that when water management is more efficient, more area can be irrigated. The other is that the more area one tries to cover, the less the water use per hectare will be, and the result will be underirrigation and yield reductions. In that case, both irrigated areas and efficiencies are overestimated. The high values for 1987/88 must point at considerable underirrigation (yield reductions were recorded), and the low values in 1980/81 may point to real losses and inefficient water use. This analysis is supported by the supply figures for the irrigated areas: 910 millimeters in 1987 and as much as 2,120 millimeters in 1980.

RESULTS AND DISCUSSION

These figures show that it will be difficult to select a reasonable target value for the scheme efficiency. If, for illustration purposes, a target value of 45 percent were used (not counting rain), the resulting OOERs would be as indicated in Table 25.

The complications involved in finding a proper indicator for operational efficiency performance are clear. For scheme efficiency, the above approach could be followed when no data are available on system losses (both target and actual). When rain is taken into account, total rainfall should be used, so that the results clearly indicate whether there has been overirrigation or underirrigation. Efficiency values on the order of 40 to 50 percent might suggest a reasonable balance in the Tungabhadra case.

Table 24—Realized irrigation efficiencies for various years

Year/Season	Irrigated Area	Releases	Efficiency Without Rain	Rain	Efficiency With Rain
	(hectares)	(MCM)		(millimeters)	
1980/81					
Kharif	64,920	1,327	0.27	. . .	0.21
Rabi	. . .	1,138	0.47	. . .	. . .
Year	116,350	2,465	0.36	650	0.21
1985/86					
Kharif	102,940	1,189	0.46	. . .	0.30
Rabi	. . .	932	0.81	. . .	. . .
Year	161,680	2,121	0.61	600	0.33
1987/88					
Kharif	117,280	962	0.68	. . .	0.28
Rabi	. . .	875	0.96	. . .	. . .
Year	202,360	1,837	0.81	1,190	0.36

Note: . . . indicates not applicable.

Table 25—Overall (scheme) operational efficiency ratios for various years

Year	*Kharif*	*Rabi*	Year
1980	0.60	1.04	0.80
1985	1.02	1.80	1.36
1987	1.51	2.13	1.80

15. SUMMARY AND CONCLUSIONS

Part 2 began with brief descriptions of the Tungabhadra scheme and the research carried out under the Tungabhadra Irrigation Pilot Project. The scheme objectives were outlined and the resulting implications for operational procedures and targets were discussed. It was then described how the farmers' wishes and practices are in conflict with the initial protective design concept and its inherent localization and duties. This conflict is the basis of most of the scheme's problems. Part 2 continued to explore the specified performance indicators for this concrete situation, in line with discussions in Part 1.

With respect to the performance indicators, a distinction was made between achievement and efficiency indicators; achievement indicators include three indicators directly related to water supply and three indicators related to variations in spatial and temporal uniformity. The supply indicators are

- *water delivery*: flow delivery ratio (FDR);
- *irrigated area*: irrigation intensity ratio (IIR) and irrigation coverage ratio (ICR); and
- *water use*: water use ratio (WUR).

The variability indicators are

- *areal variability*: flow uniformity ratio (FUR) and intensity uniformity ratio (IUR); and
- *time variability*: flow reliability ratio (FRR).

Finally, two operational efficiency indicators were discussed:

- the main system efficiency ratio (MOER); and
- the overall efficiency ratio (OOER).

The various indicators were determined for both the entire LBCA and the distributary D36, for the entire year and for the *kharif* and *rabi* seasons separately. For all cases, the targets and the realized values of the various measures had to be determined. As far as the workability and relevance of the approach are concerned, the following can be concluded from the detailed discussions.

In many instances, because targets are not well defined, it is difficult to conduct a sound performance analysis. Target areas to be irrigated are often specified, but water to be delivered and water to be used per hectare are less likely to be so.

For the Tungabhadra scheme the total annual volume to be delivered is specified but is not realistic. For D36 the target is not well defined. In all cases it is difficult to divide annual targets into separate targets for *kharif* and *rabi*. As a result, the corresponding water use targets are also not well defined. The analysis not only underlines the importance of setting clear targets for all relevant parameters, for each season, but also shows that carrying out a performance analysis even without explicit targets is useful in understanding some basic scheme characteristics and management problems.

In the Tungabhadra scheme, no specific targets are set for uniformity and reliability. For the calculation examples, $(1 - CV)_t = 1$ is used for both indicators. When more historic information is available, this could be used to set lower, more realistic targets.

It was shown to be difficult to set adequate targets for operational efficiency. This may be easier in other schemes where the problem of substantial underirrigation is less serious and efficiencies are more uniquely related to losses.

Significant problems can be involved in collecting the required data on actual realizations. All indicators are based in some way on measured flows or irrigated areas. The accuracy of the indicators depends on the accuracy of the basic data. Flows can be measured, though in practice there often is no reliable routine measurement program. At a minimum, inlet flows of distributaries should be measured daily. Measurement of all tertiary inlets will often not be possible. In this case, flows should be measured at a number of locations on the secondary canals.

Determining which areas were actually irrigated is a major problem. There should be clear procedures describing when, where, and how to collect the data and who is responsible for collecting it. It is recommended that areas irrigated be recorded more than once per season. There should also be guidelines for defining "irrigated land." As indicated, supplementary information on crop yields and efficiencies can aid in the interpretation of the basic indicators.

Determining the IIR is in principle simple, and there are no conceptual problems for the seasonal indicators. For the annual IIR, any two-season crops should be counted only once. The ICR can provide useful additional information about nonirrigated areas, particularly in the case of unplanned double cropping on the same land. Use of the FDR can be useful in understanding the IIR results. The WUR, which can also be derived directly from the FDR and IIR (or ICR), also appeared to be useful. For the annual WUR, two-season crops should be counted for both seasons.

Variability indicators related to uniformity and reliability were also assessed. To analyze spatial variability, the FUR was determined on the basis of FDRs for each canal reach; where the $FUR = (1 - CV)_r/(1 - CV)_t$, CV is the ratio of standard deviation of the individual values to the average.

However, if canal reaches are of different lengths, the weighted CV_w should be used (using the weighted $\overline{FDR}$, which is the sum of the reach *FDR*s times reach lengths, divided by the total canal length). A similar determination of the IUR can provide interesting additional information. Applying the uniformity concept to water use is not useful because it does not reflect inequity in water delivery or irrigated area.

Reliability can be seen as uniformity or variability over time. An FRR can be calculated in the same way as the FUR using FDRs, where the $FRR = (1 - CV)_r/(1 - CV)_t$ with the CV calculated using the *FDR*s for the separate time spans. When equal time spans are used, no weighted average is needed.

For the operational efficiency indicators, a distinction is made between MOER pertaining to the main system losses between the main canal inlet and the tertiary inlets, and an OOER, which also includes tertiary unit and field losses. In both cases actual efficiencies should be compared with target values to exclude unavoidable losses. The MOER is often difficult to determine because the data required for that purpose are usually missing. For the OOER, the realized scheme efficiency can be calculated on the basis of calculated crop water requirements for the crops and areas actually irrigated, and the actual scheme supply. Here as well, it is useful to calculate separate values for the two seasons and for the entire year. To take rainfall into account, total rainfall should be added to the canal supply. This procedure

can provide additional information about the degree of under- or overirrigation and thus about the validity of the figures for irrigated area and water use.

A summary of the indicators computed is given in Table 26. Together, all of the indicators, however approximate, are useful in identifying major problems in the scheme. Some of the underlying reasons for the problems are immediately obvious. For the Tungabhadra case, these figures were interpreted as follows, first for the entire LBCA.

Realized supply has been approximately 80 percent of targeted supply. Moreover, the FRR indicates that the water supply fluctuated considerably over the year. Consequently, the IIRs, being on the same order of 80 percent, are not too bad, particularly so because the intensity targets were based on initial delivery targets that were much higher than the present ones. In *rabi* they are even very high. But these figures mask two important facts.

First, distribution over the area is inequitable. The annual irrigated area includes much double irrigation on the same land, in contrast to the intended single crop irrigation. The ICR shows that, as a result, perhaps half of the command had no irrigated crop at all. In each season, the WUR has not been much higher than the target, but the high annual figure underlines the double irrigation on the same land.

The second fact not expressed in the intensity figures is that considerable underirrigation occurred in large parts of the scheme. This is confirmed by the high efficiency figure and by the low observed yields. Together with the FDR and WUR results, this is in line with the observation that target allocations do not meet actual water requirements.

This problem can be anticipated from an analysis of the design objectives (see Chapter 10). It is aggravated by the low water availability in the reservoir. The combination of the above figures illustrates that insufficient water is available in the reservoir to realize all initial targets of irrigation intensity and water use. Apparently, the D36 distributary is sufficiently upstream on the main canal not to be strongly affected by the water shortage. Supply to D36 has been less than targeted, but by roughly the same proportion as the reduction in main canal supply. For *kharif*, supply to D36 has even been relatively higher than that to the main canal. Fluctuations have been somewhat less than for the main canal.

The realized irrigation intensities are less than targeted, but still on the order of 75 to 80 percent. Here as well, the low ICR shows that double irrigation is widespread, and a large part of the area is not getting an irrigated crop at all. For D36 this is confirmed by the low FUR

Table 26—Summary of performance indicators

	Scheme			D36		
Ratio	Annual	*Kharif*	*Rabi*	Annual	*Kharif*	*Rabi*
Supply						
IIR	0.83	0.76	0.79	0.79	0.81	0.77
ICR	>0.48	...	...	0.51	...	...
FDR	0.84	0.80	0.88	0.88	0.93	0.84
WUR	1.74	1.05	1.11	1.72	1.15	1.09
Variability						
FUR	n.a.	n.a.	n.a.	n.c.	0.61	0.65
IUR	n.a.	n.a.	n.a.	n.c.	0.52	n.c.
FRR	0.69	n.c.	n.c.	0.82	0.80	0.84
Efficiency						
OOER[a]	0.83/0.63	0.70/0.28	0.97	n.c.	0.87/0.32	0.80

Notes: n.a. indicates not available; n.c. indicates not calculated. ... indicates not applicable.

[a]Realized overall irrigation efficiency, not compared with target; first value without rain, second value including rain.

figures, indicating a nonuniform distribution along the canal. Here as well, the high efficiency figures point to serious underirrigation, at least in *rabi*. Overall, water use results are similar to those for the LBCA.

In conclusion, the approach outlined in Part 1 and applied in Part 2 seems to provide a systematic and workable methodology for effective operational performance analysis in large, supply-driven canal systems. It yields a useful description of system performance, while raising important questions relating to the causes of observed performance levels. Some of the complications discussed are perhaps related to the specific nature of the Tungabhadra system and similar schemes with low design intensities and allocations and may not be faced in simpler systems. Still, it is possible to come to several conclusions.

First, clear targets must be set for the various parameters. Second, this approach requires a systematic and consistent monitoring system, primarily of irrigated areas and flows. In particular, flow monitoring along secondary canals will have to be improved in many cases. Obviously, the more one wants to know, the more one has to measure. This applies most to the uniformity indicators. Computerized recording and processing procedures can greatly facilitate the data collection process. Third, the approach followed is primarily valid for supply-driven systems without substantial additional water supplied by rain or groundwater pumping. For demand systems only a few indicators may be relevant, and for systems with additional supply, the indicators will provide only a rough indication of operational performance. For these systems, study is needed to develop an appropriate set of indicators. Further study is also needed on how to deal with the intensity indicator where there are many crops grown in a scheme, where there is more than one crop per year on the same land, and where there is no clear division of seasons. The same applies to the question of how to determine aggregate scheme values for the tertiary inlet level for the FDR, FRR, and MOER. Finally, further study will be required to determine how to overcome some of the problems mentioned with the operational efficiency indicators.

GLOSSARY

Chak	Tertiary unit
Cusec	A flow of one cubic foot per second
CV	Coefficient of variation
Distributary	Secondary canal
D36	Distributary used as an example in this paper
Duty	Area that can be irrigated with a unit flow size (in cubic feet per second)
ED	Equitable distribution
FDR	Flow delivery ratio
FRR	Flow reliability ratio
FUR	Flor uniformity ratio
ICR	Irrigation coverage ratio
IIR	Irrigation intensity ratio
IUR	Irrigation uniformity ratio
LBCA	Left Bank Command Area
l/s ha	Liters per second per hectare
Kharif	Wet season (approximately July to October)
Light crops	Crops that require little water (grains, pulses, oilseeds)
Localization	Designation of areas to be irrigated, with crops and seasons prescribed
MCM	Million cubic meters
Minor	Subsecondary canal
MOER	Main system operational efficiency ratio
OER	Operational efficiency ratio
Outlet	Tertiary inlet

PFDR	Primary flow delivery ratio
Rabi	Dry season (approximately November to April)
Reach	A section of a channel
RWS	Relative water supply
SFDR	Secondary flow delivery ratio
STD	Standard deviation
TIPP	Tungbhadra Irrigation Pilot Project
Waranbandi	Rotational distribution within the tertiary unit with fixed turns for every irrigator, with a duration proportional to the holding size
WUR	Water use ratio

REFERENCES

Abernethy, C. L. 1986. *Performance measurement in canal water management.* ODI/IIMI Network Paper 86/2d. London: Overseas Development Institute/International Irrigation Management Institute.

———. 1990. *Indicators of the performance of irrigation water distribution systems.* Colombo, Sri Lanka: International Irrigation Management Institute.

Bhutta, M. N., and E. J. VanderVelde. 1993. Performance of secondary canals in Pakistan Punjab: Research on equity and variability at the distributary level. In *Advances in IIMI's research 1989–1991.* Colombo, Sri Lanka: International Irrigation Management Institute.

Bos, M. G., and J. Nugteren. 1990. *On irrigation efficiencies.* 4th ed. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.

Bos, M. G., W. Wolters, A. Drovandi, and J. A. Morabito. 1991. The Viejo Retamo secondary canal. *Irrigation and Drainage Systems* 5: 77–88.

Bos, M. G., D. H. Murray-Rust, D. J. Merrey, H. G. Johnson, and W. B. Snellen. 1994. Methodologies for assessing performance of irrigation and drainage management. *Irrigation and Drainage Systems* 7 (4): 231–261.

Bottrall, A. F. 1977. *Some basic problems of evaluating irrigation management.* Discussion Paper 1/77/2. London: Overseas Development Institute.

Chambers, R. 1976. *Criteria for evaluating and improving irrigation management.* Workshop on Choices in Irrigation Management. Paper D2. London: Overseas Development Institute.

———. 1988. *Managing canal irrigation: Practical analysis from South Asia.* Cambridge: Cambridge University Press.

Clemmens, A. J., and M. G. Bos. 1990. Statistical methods for irrigation system water delivery performance evaluation. *Irrigation and Drainage Systems* 4: 345–365.

FAO (Food and Agriculture Organization of the United Nations). 1976. *Crop water requirements.* Irrigation and Drainage Paper 24. Rome.

———. 1991. *Improved irrigation system performance for sustainable agriculture.* Proceedings of the Regional Workshop, Bangkok, October 22–26, 1990. Rome.

Francis, M. 1990. Performance assessment in the Sudan's Gezira System. *ODI Bulletin* (April): 7–10.

Gillott, P. W. K., and J. D. Bird. 1993. A quantitative review of adequacy and equity indicators for irrigation system distribution. Hydraulic Research, Wallingford, U.K. Mimeo.

Jurriëns, M. 1989. Operational target discharges. *WAMANA* (January): 34–41.

———. 1990. An approach to research on irrigation system management. ILRI Annual Report. 70. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.

———. 1991. Conceptual framework of irrigation system management. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. Mimeo.

———. 1992a. *Monitoring of irrigation system operation*. Proceedings of the International Conference on Advances in Planning, Design and Management of Irrigation Systems as Related to Sustainable Land Use, September 14–17, 1992, Leuven, Belgium.

———. 1992b. Interactions between main system and tertiary units. In *Irrigators and engineers*, ed. G. Diemer and J. Slabbers. Amsterdam: Thesis Publishers.

Jurriëns, M., and W. Landstra. 1989. Water distribution: Conflicting objectives of scheme management and farmers. In *Irrigation: Theory and practice*. Proceedings of the International Conference, Southampton, England.

———. 1990. *Tungabhadra irrigation pilot project*. Final Report. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.

Jurriëns, M., and V. Ramaiah. 1989. *Water distribution in a secondary irrigation canal: Results of a measurement programme*. ILRI Reprint No. 55. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.

Jurriëns, M., and W. Wolters. 1993. Can protective irrigation be more efficient? Paper presented at the International Conference on Hydrology and Water Resources, New Delhi, India.

Jurriëns, M., V. Ramaiah, and J. G. v. Alphen. 1987. *Irrigation water management in the Tungabhadra Scheme, India*. ILRI Reprint 50. Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.

Karnataka, Planning Department. 1976. *Report on re-examination of cropping pattern under TBP Left Bank Canal*. Bangalore, India.

Kelley, T. G., and S. H. Johnson. 1991. Monitoring operations performance in large-scale public irrigation systems in Indonesia. *Water Resources Bulletin* 27 (3): 495–507.

Levine, G. 1982. *Relative water supply; An explanatory variable for irrigation systems*. Technical Report No. 6. Ithaca, N.Y., U.S.A.: Cornell University.

Murray-Rust, D. H., and W. B. Snellen. 1993. *Irrigation system performance assessment and diagnosis*. Colombo, Sri Lanka: International Irrigation Management Institute.

Mohtadullah, K. 1993. Performance of irrigation systems. Keynote Address 4. 15th Congress of the International Commission on Irrigation and Drainage, The Hague, The Netherlands.

Rao, P. A. 1974. A monograph on agricultural planning and development of irrigated cultivation under T. B. Raichur District. Bangalore, India. Mimeo.

Rao, P. S. 1991. A note on the proceedings of the Seminar on Indicators of Irrigation Performance, held in Washington, D.C., March 18–19, 1991, by the International Food Policy Research Institute. Mimeo.

———. 1993. *Review of selected literature on indicators of nutrition.* Colombo, Sri Lanka: International Irrigation Management Institute.

Small, L. E. 1992. *Evaluating irrigation system performance with measures of irrigation efficiencies.* ODI Irrigation Management Network Paper 22. London: Overseas Development Institute.

Small, L. E., and M. Svendsen. 1990. A framework for assessing irrigation performance. *Irrigation and Drainage Systems* 4 (4): 283–312.

———. 1991. Choosing a perspective for assessing irrigation performance. In *Improved irrigation system performance for sustainable agriculture*. Proceeding of the Regional Workshop, Bangkok, October 22–26, 1990. Rome: Food and Agriculture Organization of the United Nations.

———. 1992. *A framework for assessing irrigation performance*. Working Paper on Irrigation Performance No. 1. Washington, D.C.: International Food Policy Research Institute.

Weller, J. A. 1991. An evaluation of the Porac River irrigation system. *Irrigation and Drainage Systems* 5: 1–17.

Working Papers on Irrigation Performance

1. *A Framework for Assessing Irrigation Performance*, by Leslie E. Small and Mark Svendsen, 1992.

2. *Assessing Effects of Policy Change on Philippine Irrigation Performance*, by Mark Svendsen, 1992.

Rien Jurriëns is a senior irrigation expert with the International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands.

72