Review of Selected Literature on Indicators of Irrigation Performance

(Research Paper)

Review of Selected Literature on Indicators of Irrigation Performance

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Cover: Graphs depict effect of irregular water delivery upon crop yield and water productivity and water distribution equity in the Lagar Distributary both of which illustrate performance points.

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Foreword

DR. P. S. Rao prepared the first version of this Review of Selected Literature on Indicators of Irrigation Performance as an input into a joint IIMI-IFPRI activity on irrigation performance. As IIMI's own Performance Program began to get organized, we realized that we needed a systematic review of the existing literature as a foundation for our own work.

We, therefore, requested Dr. Rao to update and further revise his original draft. He completed this revision late in 1992. Subsequently, I had the pleasure of working with him in Madras for a couple more days, incorporating the many comments and suggestions we had received.

Even before its publication, we at IIMI have already begun using this valuable resource. It brings together in one place brief summaries of, and cogent comments on, the major literature available since the early 1980s on irrigation performance. The emphasis is on water supply performance because that is what is emphasized in the literature. The paper therefore brings out the gaps, especially in terms of indicators for sustainability and social impact performance.

Dr. Rao and IIMI conceive of this volume as, in a sense, a first draft. We hope it will be used by researchers and research-minded irrigation managers as a basis for designing field programs to test the relative utility of different indicators under different conditions. We would very much welcome comments and suggestions on this text, as we hope that it could be substantially revised and updated based on progress over the next few years.

IIMI's Program on Assessing and Improving the Performance of Irrigated Agriculture is in its early stages. I have had the privilege of being its Acting Head during the period of transition to IIMI's new organization. I am glad that Dr. Rao's work will provide a firm foundation for the future direction of the program. IIMI is very grateful to him for this contribution.

Douglas J. Merrey
Acting Head, Program on Assessing and Improving the Performance of Irrigated Agriculture
May, 1993

Preface and Acknowledgements

THIS PAPER REVIEWS much of the irrigation management literature on performance indicators available up to 1992, with special reference to indicators on water delivery performance. It should be considered as a first attempt, a draft for the use of researchers and irrigation managers who could suggest ways it could be further improved. We would not only welcome comments, corrections, additions, and suggestions, but actively seek your reactions to this work. We plan to update and revise it after a couple of years of experience through the International Irrigation Management Institute's (IIMI's) Program on Assessing and Improving the Performance of Irrigated Agriculture and other programs which contribute to developing effective indicators of irrigation performance.

An earlier version of this paper was presented and discussed at an international meeting organized by the International Food Policy Research Institute (IFPRI) in Washington, D.C., in March 1991. Many useful comments were made at this meeting. The paper has since been thoroughly revised and updated. The first version was prepared while I was working as Visiting Professor at Anna University, Madras, as a voluntary contribution to the IIMI-IFPRI collaborative program on the assessment of performance of irrigation. The IIMI-IFPRI program was supported by the Ford Foundation. The present revision was made possible by the support of IIMI's Program on Assessing and Improving the Performance of Irrigated Agriculture.

I must acknowledge with thanks the help of Dr. Mark Svendsen, Dr. Khin Maung Kyi, and Mr. Charles Abernethy who provided references and papers which served as the basis for the first version of this review. Dr. Svendsen also provided editorial assistance at that time.

In December 1992, IIMI offered me the opportunity to update and revise the earlier version. The resulting draft was then the subject of very detailed comments and reviews. Dr. Svendsen and Mr. Abernethy provided very detailed comments and suggestions; Drs. C.M. Wijayaratna and R.Sakthivadivel offered less detailed but very useful and encouraging written comments. Dr. Hammond Murray-Rust commented through the media of discussions with Dr. Douglas J. Merrey, Acting Head of the Performance Program. I have carefully considered all of their suggestions, and have made use of many (but not all) of them.

While I thank Dr. Svendsen and IFPRI for agreeing to the publication of this greatly revised paper by IIMI, I must also thank Dr. Merrey who asked me to revise and update the first version for this publication, provided additional references for its updating, critically reviewed and edited the intermediate revised draft, and then spent two enjoyable and productive days with me in Madras finalizing this version. He has taken responsibility for finalizing the report on my behalf. Nevertheless, I take full responsibility for the contents of this review, including any errors or weaknesses that might be found. Finally, I must thank Mr. Kingsley Kurukulasuriya for diligently editing the final draft of this paper.

Comments and corrections may be sent to me through the Performance Program Leader at IIMI.

P.S. Rao
April 1993

CHAPTER 1

Introduction

THIS PAPER REVIEWS a set of selected literature on indicators of irrigation performance. Its purpose is to summarize and synthesize the most useful indicators described or used in recent reports and publications, and to provide a critical analysis as a first step toward creating a consensus on which indicators would be most useful for specified purposes. *The major audience for this paper will be researchers interested in the performance of irrigation systems.* It may also be of use to managers of irrigation systems who would not normally have the time to read research publications and may not have easy access to them. For this reason, some of the presentations in the review are more detailed than researchers might ordinarily expect. The paper should be read in conjunction with the framework for assessing irrigation performance developed by Small and Svendsen (1990, 1992). Both papers are products of a group of researchers involved in a special collaborative project on the assessment of performance of irrigation.

Abernethy (1989) presented a review of the indicators of the performance of irrigation water distribution systems at a Symposium on Performance Evaluation of Irrigation Systems held at the International Irrigation Management Institute (IIMI), Colombo, Sri Lanka, in November 1989. Abernethy's review paper and an early version of the paper on a framework for assessing irrigation performance (Svendsen and Small 1989) were also discussed at a workshop on Irrigation Performance held in Pangbourne, England, in February 1990. The convergence of opinion of researchers at these meetings suggested that indicators of performance should include not only the output indicators of the irrigation water delivery system but also some of the important indicators of the impacts of those outputs and rough indicators of overall system health. The present review reflects this emerging consensus.

The indicators reviewed in this paper deal primarily with the quality of irrigation service provided by the managers of the water delivery system, the agricultural production which is the output of the irrigated agriculture system, and to a limited extent, the economic benefits derived from the agricultural production that form the outputs of the agricultural economic system. The concepts and definitions of these systems and the conceptualization of irrigation in the context of nested systems are elaborated in the framework for assessing irrigation performance proposed by Small and Svendsen (1990, 1992). Other types of indicators — social, process, and sustainability — are dealt with wherever they are found to be part of some of the papers reviewed but the attention paid to them in this paper and indeed in the available literature on irrigation management is very limited.

Performance of irrigated agriculture is a very complex subject. The complexities are well-described in the literature, for example, Heermann et al. (1990), Chambers (1988), and Smith (1990). Irrigation systems often have a number of competing objectives and are assessed by interest groups with differing values and perspectives; a wide range of performance indicators is thus required. Any framework and any set of indicators of performance will only capture a part of the complex reality. It is therefore also important to say what the review does not deal with.

This review does not deal with the methodologies and measurements for determining the indicators or with the interpretation of the indicators in the context of diagnostic analysis of systems at various levels. Nor does it deal with the indicators for the performance of the managers and institutions responsible for the systems.

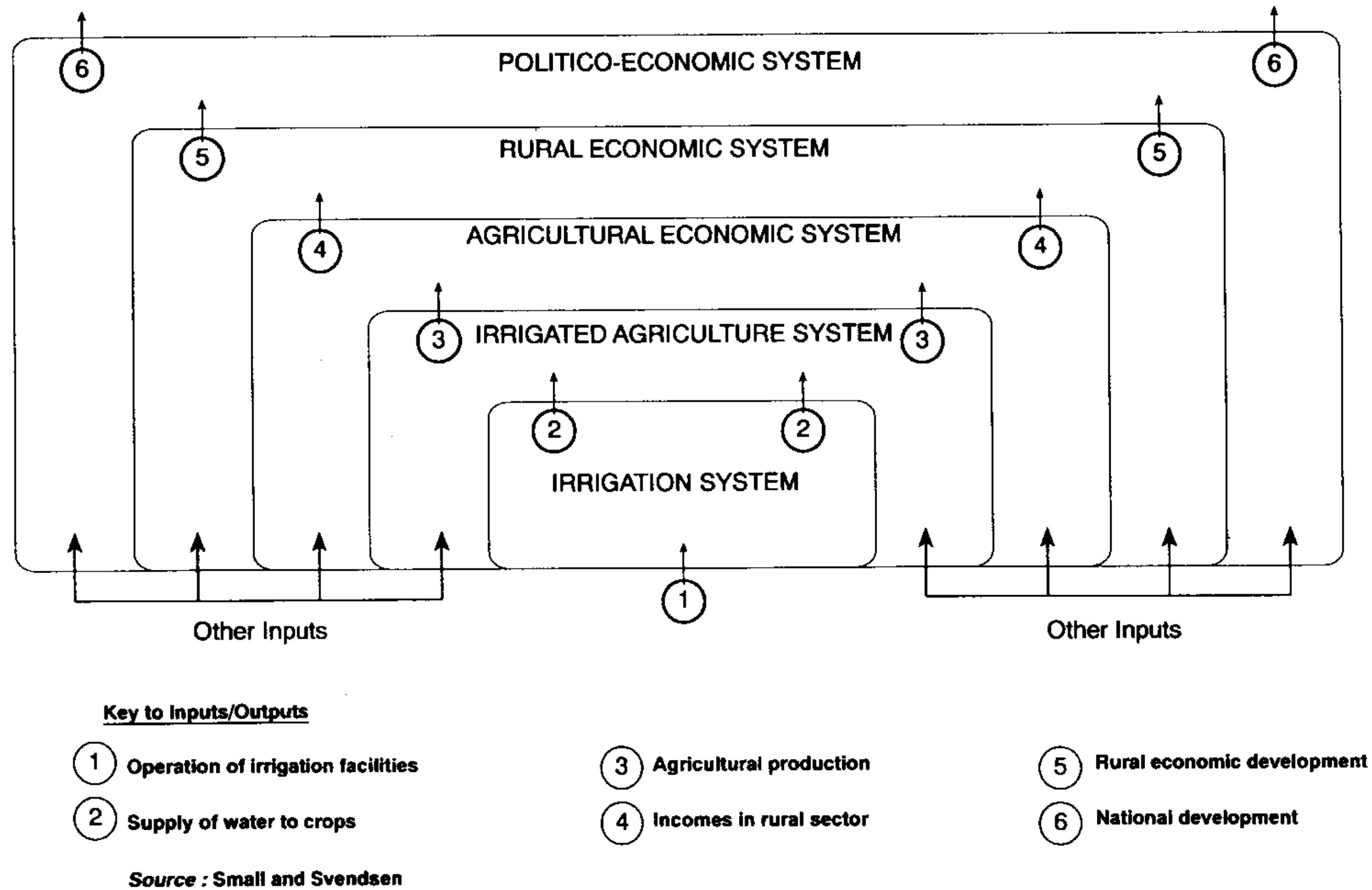
Performance indicators may be used for several purposes. Indicators can be used by system managers to compare actual results to planned targets. Or they may be used by researchers, investors, higher-level managers or policymakers to compare the performance of a number of systems with one another. In the latter case, the type of indicator used may be called a *comparator* after Abernethy (1993).

The framework of Small and Svendsen (1990, 1992) facilitates systematic comparative analysis of irrigation performance by specifying key terms and concepts very precisely. A key feature of the framework is its conceptualization in terms of nested systems (Figure 1). An irrigation system is defined as a set of physical and social elements used for the acquisition, control, delivery and dispersion to the crop root zones of water. Its output — water — is one of a number of inputs to the irrigated agriculture system. The outputs of this system — crops — in turn are an input to the agricultural economic system, and so on. Small and Svendsen concentrate their analysis on the performance of the irrigation system; this review also concentrates on the performance of the water delivery system, but includes discussion of a few key indicators of performance relevant to the other systems, particularly the irrigated agriculture system. Chapter 2 of the paper reviews selected specific publications, providing the reader with summaries of some of the most useful recent literature. We considered organizing the review according to the nested framework of Small and Svendsen. However, a number of the authors cover indicators that fall into several of the systems they define. Therefore, to preserve the integrity of each author's contribution, Chapter 2 discusses these contributions in chronological order, beginning with earlier literature and coming up to 1992. We also considered standardizing the terminology used by the various authors, but decided to retain the authors' own uses to facilitate reference to the original sources. Except for a few cases noted in the text, there were no exact equivalents among the authors.

Chapter 3 contains a discussion of the most important types of performance indicators. While the presentation in Chapter 2 aims at capturing the major contributions of the publications reviewed, the discussion in Chapter 3 concentrates on the problem of using that knowledge to address and resolve the difficult issues we face in performance assessment. Chapter 4 concludes with suggestions on the choice of a minimum set of indicators for irrigation performance. A list of performance indicators classified with respect to the system and authors is given in Appendix 2.

The review is limited, not exhaustive, and is confined to a selected set of literature in the English language.

Figure 1. Inputs and outputs: Irrigation in the context of nested systems.



Source: Small and Svendsen, 1992.

CHAPTER 2

Review of Significant Work

BOS AND NUGTEREN

BOS AND NUGTEREN (1990 [1974]) present the most widely accepted concepts and definitions of irrigation efficiencies. Their paper is the result of a joint effort by the International Commission on Irrigation and Drainage (ICID), New Delhi, the University of Agriculture, Wageningen, and the International Institute for Land Reclamation and Improvement (ILRI), Wageningen. These three organizations collaborated to collect information on irrigation practices in areas where small farms prevailed. A total of 29 National Committees of the ICID cooperated in this venture by submitting 91 sets of data covering as many irrigated areas. The results were first published in 1974.

Bos and Nugteren divide the overall project efficiency into various components so that the efficiencies associated with different components of the water delivery system — conveyance, distribution, and field application — can be separately stated. The following terms are used in the definitions:

V_c	=	Volume of water diverted or pumped from river,
V_d	=	Volume of water delivered to the distribution system,
V_1	=	Inflow from other sources,
V_2	=	Nonirrigation deliveries from the conveyance system,
V_3	=	Nonirrigation deliveries from the distributary system,
V_f	=	Volume of water delivered to the fields, and
V_m	=	Volume of water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle.

Conveyance Efficiency (e_c)

Conveyance is the movement of water from its source through the main and lateral or secondary canals or conduits to the tertiary offtake. The conveyance efficiency e_c is the efficiency of canal and conduit networks from the reservoir, river diversion, or pumping station to the offtake of the distribution system. It can be expressed as:

$$e_c = \frac{V_d + V_2}{Vc + V1}$$

Distribution Efficiency (e_d)

Distribution is the movement of water through the tertiary (distributary) and quaternary (farm) canals or conduits to the field inlet. Distribution efficiency e_d is the efficiency of the water distribution canals and conduits supplying water from the conveyance network to individual fields. It can be expressed as:

$$e_d = \frac{V_f + V_3}{V_d}$$

Field Application Efficiency (e_a)

Field application is the movement of water from the field inlet to the crop. The field application efficiency e_a is the relationship between the quantity of water furnished at the field inlet and the quantity of water needed to maintain soil moisture at the level required by the crop. This is an indirect way of establishing the field application efficiency, since the water used by evapotranspiration of a crop equals the amount of water needed to maintain the required soil moisture for the crop. The field application efficiency can be expressed as:

$$e_a = \frac{V_m}{V_f}$$

Tertiary Unit Efficiency (e_u)

The tertiary unit efficiency e_u is the combined efficiency of the water distribution system and of the water application process. In other words, it is the efficiency with which water is distributed and consumptively used within the tertiary unit. The tertiary unit efficiency can be expressed as:

$$e_u = \frac{V_m + V_3}{V_d}$$

If the nonirrigation deliveries are insignificant compared with the volume of water delivered to maintain soil moisture at the required level for the crop, we may write:

$$e_u = e_d \cdot e_a$$

The tertiary unit efficiency expresses the efficiency of water use downstream of the point where the control of water is turned over from the water supply organization to the farmers.

Irrigation System Efficiency (e_s)

The irrigation system efficiency e_s is the combined efficiency of the system of water conveyance and distribution:

$$e_s = \frac{V_f + V_2 + V_3}{V_c + V_1}$$

If the nonirrigation deliveries are insignificant compared with the volume of water delivered to the fields, which is often true, we may write:

$$e_s = e_c \cdot e_d$$

Overall Project Efficiency (e_p)

The separate assessments of conveyance, distribution, and field application efficiencies will indicate if and where remedial measures are required to improve the efficiency of water use in the project as a whole. The data used to assess the separate efficiencies can also be used to assess a project's overall irrigation efficiency.

The overall (or project) efficiency can be expressed as:

$$e_p = \frac{V_m + V_2 + V_3}{V_c + V_1}$$

This value represents the efficiency of the entire operation between river diversion or source of water and the root zone of crops. If the values of V_1, V_2, and V_3 are negligible compared with V_c and V_m, which is often true, the following relation holds:

$$e_p = e_c \cdot e_d \cdot e_a$$

Various efficiencies of irrigation water use are shown in Figure 2.

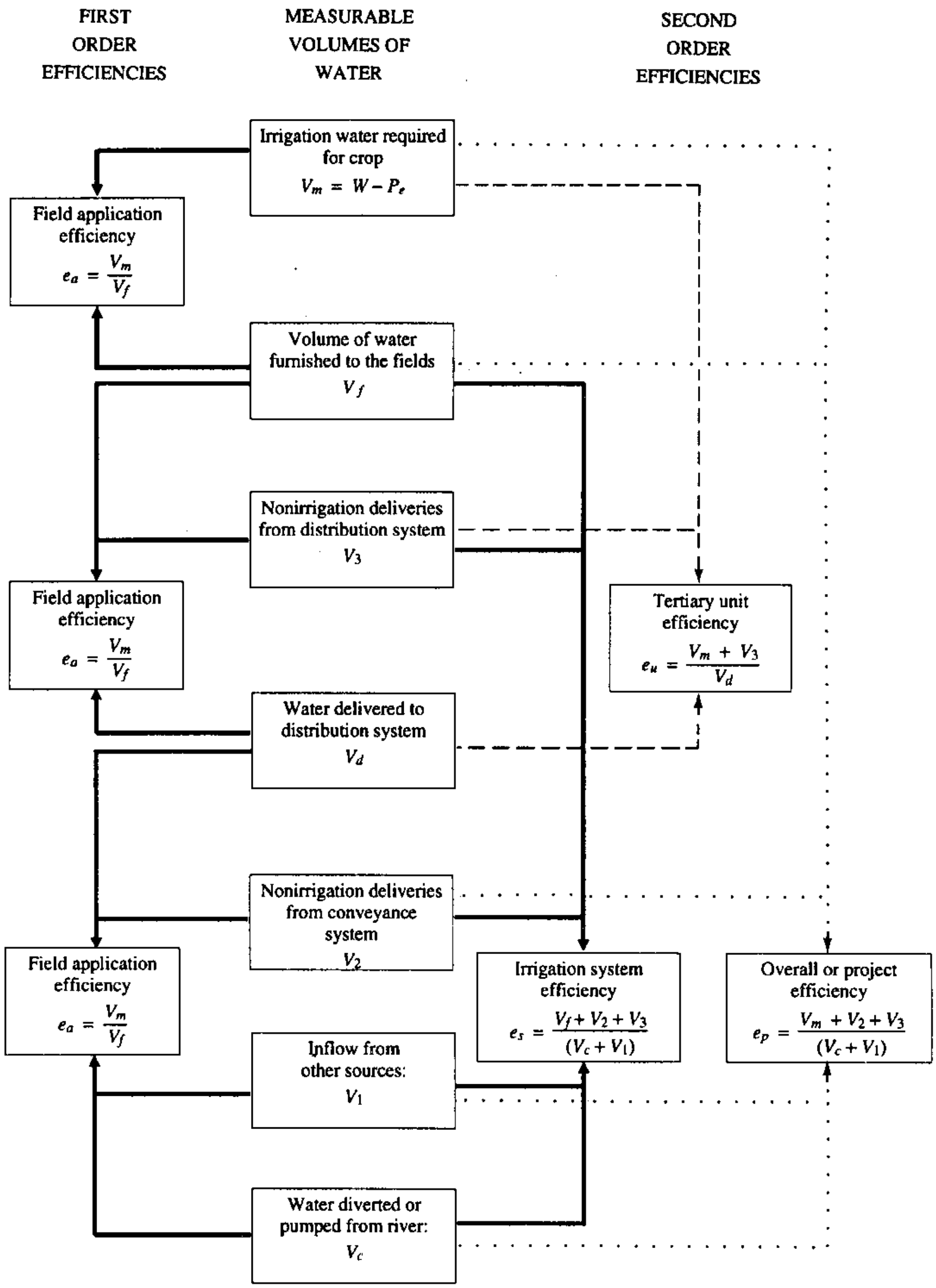
The results and analyses presented in this work by Bos and Nugteren are very comprehensive and cover a wide range of issues. For example, they also present systemic descriptors and process indicators such as the irrigation project staff as a function of the irrigated area, and the relationship of water charges to tertiary unit efficiency. This will remain a classic reference on the subject for a long time.

It is useful to note here that the terms proposed by the Irrigation Water Requirements Committee of the American Society of Civil Engineers (Jensen 1974), which are applicable to on-farm systems as well as to projects, are similar to those proposed by Bos and Nugteren. They are described in Jensen (1983).

LEVINE

Levine (1982) presents a detailed exposition of the *Relative Water Supply* (RWS) concept and its use as an explanatory variable for irrigation systems. It was first presented in 1974 and has been extensively used in the project on "Determinants of Irrigation Problems in Developing Countries." The concept has also been widely tested in the field by many of Levine's graduate students.

Figure 2. Various efficiencies of irrigation water use.



Source: Bos and Nugteren, 1982.

Two individual factors, the available water supply and the water "demand," are basic factors in irrigation planning, design, and operation. Individually, they are relatively difficult to use in attempting to understand system performance. Combined, they provide a variable with utility for both practical and theoretical applications. This variable, the Relative Water Supply (RWS), can be defined generally as the ratio of supply to demand.

Levine (1982) points out that the inverse of the RWS variable is a traditional "engineering efficiency" term used in irrigation, Water Use Efficiency (WUE). The fundamental difference between the concept of RWS and that of WUE is the difference in perspective that is engendered.

The RWS variable presents a *neutral* view of the relationship between the amount of water available or delivered and the amount utilized for crop production. The WUE variable, by contrast, has *value* connotations inherent in the term "efficiency," i.e., the higher the efficiency, the better it is. However, for a variety of reasons, a higher WUE is *not* necessarily better than a lower level, and in fact may be worse. In addition to its neutral character, the RWS variable lends itself to improved understanding and planning for the *behavior* of the major participants in the irrigation process — the irrigation managers or controllers and the farmers.

Two forms of the RWS variable have been found to be useful; the Theoretical Relative Water Supply (RWST) and the Actual Relative Water Supply (*RWSA*). RWST is defined as the ratio of water supply at the location of interest to the water "demand" associated with maximum production of the optimal crop or cropping pattern grown with appropriate cultural practices on the total irrigable area designed or intended to be served from that location. *RWSA* is defined as the ratio of water supply to the water demand associated with the crops actually grown, with the cultural practices actually used, and for the actual irrigated area. *RWSA* is derived from field observations and measurements. The implications of the various terms in the definitions and the methods of computing RWST and *RWSA* are elaborated in Levine (1982).

The RWS methodology has been widely applied and tested in rice irrigation systems, though in principle it can be applied to all types of systems. *RWSA* is computed by the following expression:

$$RWSA = \frac{IR + RN}{ET + S\&P}$$

where,	IR	=	Irrigation water supply,
	RN	=	Rainfall,
	ET	=	Evapotranspiration, and
	$S\&P$	=	Seepage and percolation.

RWSA can be calculated for a certain period — a week, a month, or a season. It is important to note that *RN* is the total rainfall for the period and that *S&P* are treated as a component of the "demand." *RWSA* can be calculated at any level in the system where the water supply can be measured — the main diversion points or the last control point regulated by the irrigation bureaucracy.

RWS has been used as an independent variable to study and explain the operations of the irrigation systems associated with different management behaviors. For example, consider the following cases:

i. Data from Taiwan suggest that these systems can produce a full crop when RWST is approximately 1.0 at the turnout level, serving approximately 50 ha, and when *RWSA* is approximately 1.0, under the following conditions: systems with control infrastructure (both physical and institutional) at the 10-ha level; 24-hour monitoring and operational control; specialist on-farm water distribution (common irrigator); effective communication within the system bureaucracy and between the system and the farmers; and farmer cooperation.

ii. When RWST is 2.5 or greater, systems with minimal operational control (main channel distribution) would still permit water distribution that should not be the limiting factor in crop production.

On the basis of case studies and observations, Levine (1982) proposes the hypothesis that each management pattern has a minimum RWST value which would permit the "optimum" production and which could result in an equal value for *RWSA*. This minimum value could be considered a *critical level,* for both RWST and *RWSA*. These could be used to evaluate system management.

This ability of RWS to serve as a useful tool in evaluating management implications is the most significant contribution of the concept. In addition to its potential role in evaluating management and equity, the RWS variable has proven useful for inferring the decision rules that characterize system operation. For example, data for some Javanese systems show a very high correlation between RWST and cropping decisions made. When RWST at the land preparation time was greater than 1.0, essentially the entire irrigable area was devoted to rice. At RWST values less than 1.0, there was a rapid decline in the fraction of the area cropped to rice. When RWST was below 0.8 there was practically no rice grown.

In order for an indicator like RWS to serve as a basis for comparative studies and analysis of irrigation systems in different regions or countries, it is necessary to use it in a standardized manner. That does not always seem to happen.

Some, for example, Weller et al. (1989) have used *RWSA*, substituting effective rainfall for total rainfall (*RN*). As the effective rainfall computation is not as unambiguous as the total rainfall, this makes it difficult to interpret *RWSA* as a tool for comparative study of the associated management implications. Abernethy (1989) argues that the "demand" element in the denominator be defined as only the *ET*, the amount needed to satisfy crop evapotranspiration. He gives a good reason to support the argument: for example, if percolation-reducing practices, such as puddling for rice, are not used, then the demand is higher and so RWS is lower indicating better management, which is not the true case. It is not clear, though, whether the error in the estimation of *S&P* is not higher than what the differences in puddling can cause. Abernethy has also referred to the difficulty of estimating *S&P* values. Levine (1982) mentions that, while the measurement of *S&P* is relatively simple in principle, the estimation of system values frequently presents difficulties. Since *S&P* constitute a site-specific characteristic, area-wide values are obtained through interpretation. Notwithstanding the significant problems in measurement and estimation of *S&P*, there is a good case for standardizing the methodology for the benefit of comparative studies.

GARCES

Garces (1983) develops a methodology to evaluate the performance of irrigation systems and applies it to Philippine national systems. He makes extensive use of nondimensional indices for evaluating each of the four broad interacting subsystems — water, human, environmental, and economic — of the total irrigation system. The desired qualities of the performance indicators identified are: that i) they be quantifiable; ii) the data be collected on a regular basis by the project management; iii) they be sufficiently robust to give an indication of system performance whether in a wet or a dry season; and that iv) they be applicable to all technical system types.

Water Subsystem

For the water subsystem, three water-based performance indicators are selected that can help rate the success in achieving the crop production objective. They are productivity, equity, and efficiency. Each of these "indicators" is to be assessed by one or more "descriptors."

Productivity. Productivity performance of the system is assessed by the following descriptors:

i. *Area Utilization* (*Au*), defined by the ratio of the harvested area (*AH*) and theoretically serviceable area (*TA*).

$$Au = \frac{AH}{TA}\ ,\ O \leq Au \leq 1$$

ii. a) *Yield: Rain-fed-Based* (*Yr*), defined as the ratio between the system's average yield (*IY*) and nearby rain-fed areas' average yield (*RY*).

$$Yr = \frac{IY}{RY}\ ;\ RY > O$$

For the dry season, when *RY* is often zero, the *RY* value for the "wet" rain-fed season can be used.

b) *Yield: Potential-Based* (*Yp*), which utilizes a potential yield (*PY*) for the area for comparison with *IY*. Potential yield is obtained from experiment stations or from demonstration plots in farmers' fields.

$$Yp = \frac{IY}{PY}, O \leq Yp \leq 1$$

c) *Yield: Top Yielders-Based* (*Yt*), which utilizes the highest farmer yields within the system. If *TY* is the average yield of 10 or 20 percent of the top yielders,

$$Yt = \frac{IY}{TY}, O \leq Yt \leq 1$$

iii. *Irrigation-Water Output* (*IWO*) is given by the expression

$$IWO = \frac{IY}{(W/A)}$$

where,	*IY*	=	Irrigated average yield for systems,
	W	=	Total volume of irrigation water per season, and
	A	=	Total area harvested.

IWO describes the productivity per unit of water supplied to the system in kg/mm per unit area or kg/m^3.

Equity. Equity achievement is described by the following descriptors:

i. *Production Distribution* (*PD*) uses the proportionality between the percentage of the total area planted corresponding to a section and the percentage of the total production that particular section contributes. By looking at the production deviations from the respective areas, one can assess a systems' equity.

$$PD = 1 - \sum_{s=1}^{n} | (\% As - \% Ps) |$$

$$= 1 - dp;$$

$$O \leq PD \leq 1$$
$$O \leq dp \leq 1$$

where, *As* = % of total area harvested contributed by section,

Ps = % of total production contributed by section,

n = Number of sections into which system is divided, and

dp = Absolute value of summation of deviations (shortages) of % total production from % total area harvested for each section into which the system is divided, in fractional form.

ii. *Flow Distribution* (*FD*) follows the same logic as the *PD* descriptor but utilizes information on flows going to each section.

$$FD = 1 - \sum_{s=1}^{n} | (\% As - \% Fs) |$$

$$= 1 - df;$$

$$O \leq FD \leq 1$$
$$O \leq df \leq 1$$

where, *Fs* = % of total flow received by section.

iii. *Production Flows Distribution* (*PFD*) combines the information on production and flows from the above equations for *PD* and *FD* to define

$$PFD = 1 - \sum_{s=1}^{n} | (\% Ps - \% Fs) |$$

$$= 1 - dpf;$$

$$O \leq PFD \leq 1$$
$$O \leq dpf \leq 1$$

Efficiency. Efficiency of water use is considered for two clearly distinguished periods of a cropping season: i) land soaking and land preparation (LS and LP), and ii) from planting to terminal drainage (crop water requirement period, CWR).

i. *Land Preparation Span* (*LPS*) descriptor is given by the expression

$$LPS = \frac{TLPS}{ALPS}, O \leq LPS \leq 1$$

where, *TLPS* = Targeted or programmed *LPS*, and
LPS = Actual *LPS* in days.

ii. For the crop water requirement period, *Relative Water Supply Actual* (*RWSA*) is used as a descriptor. This is the same as the one described by Levine, noted earlier.

Human Subsystem

For the human subsystem, the indicator suggested is *response.* It reflects the ability of the human subsystem to react to the dynamic process of decision making and subsequent implementation, leading to the achievement of a set of predetermined irrigation-oriented goals.

There are two descriptors:

i. *Response Capacity* (RC), which seeks to relate the preparedness and versatility of the project staff to plan, address, and resolve the day-to-day operation and maintenance matters of the system.

ii. *Farmers' Satisfaction* (FS), which is the degree of satisfaction perceived by the farmers with the irrigation system as a descriptor of system performance.

The descriptors are qualitative in nature and their assessment involves either survey methods using questionnaires, or informal or open-ended interviews with farmers and key informants.

Environmental Subsystem

The environmental subsystem uses "impact on the environment" as the indicator. The three descriptors are:

i. *Waterlogging* (W): percentage of area affected; frequency of occurrence (seasonal basis); and magnitude of production loss.

ii. *Soil Toxicities* (ST): percentage of area affected, severity of the condition; and magnitude of production loss.

iii. *Irrigation Water Quality* (WQ): water quality standards for irrigation are well-defined and readily available. The particular setting of each system should be analyzed to determine what importance the water quality issue might have in the performance of the system.

Economic Subsystem

For the economic subsystem, the strategy followed in the identification of an economic indicator is to look for a suitable element which can convey a message of economic stability in the short- and long-run time frames and which can be monitored on a seasonal basis. The indicator "cost recovery" is used. The ability to generate resources to cover the costs of regular operation and maintenance is important for system sustainability.

The descriptors are:

i. *O&M Financing* (*OMF*), which can be defined as that portion of the *O* and *M* expenses that is self-generated by the irrigation system.

$$OMF = \frac{AC}{OME}$$

where, AC = Amount collected as service fee, and

OME = *O* and *M* expenses during the period.

ii. *Threshold Level* (*TL*), which is the fraction of the maximum collectible that would equal the *O* and *M* expenses of the system.

$$TL = \frac{OME}{MC}$$

where, MC = Maximum collectible, a function of fee level and area benefited.

iii. Percentage Collected (*PC*), which is the percentage of the total amount due that is actually collected.

$$PC = \frac{AC}{MC}$$

The three descriptors are interrelated:

$$OMF = \frac{PC}{TL}$$

The approach and methodology developed by Garces are important contributions to the search for performance indicators for evaluation of irrigation systems using data regularly collected by the agencies in the Philippine rice systems.

MERRIAM AND OTHERS

Merriam et al. (1983) describe the methods for evaluating irrigation systems and practices which include sprinkler systems of various types, furrow irrigation, border-strip irrigation, and basin irrigation. Procedures are described to measure and determine the potential efficiency of the systems as designed and the actual efficiency that is obtained with present management. A precise terminology is required to make and interpret the measurements. In order that all comparisons have a common basis, the three performance parameters — potential application efficiency, actual application efficiency and distribution uniformity — are based on the average depth of water infiltrated or stored in the quarter of the area receiving the least amount of water. The low-quarter (LQ) concept was developed by the USDA Soil Conservation Service and is recommended as the standard for comparing alternative conditions. For some uniformity studies, Christiansen's uniformity coefficient may be used.

Definitions of Performance Parameters

Application Efficiency (AE) is the ratio of the average depth of the irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percent.

Actual Application Efficiency of Low Quarter (AELQ) is the ratio of the average low-quarter (LQ) depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percent. The average LQ depth infiltrated is the average of the lowest one-fourth of the measured values where each value represents an equal unit of area and cannot exceed the soil moisture deficiency (SMD). Values of AELQ indicated both the uniformity of water distribution and adequacy of irrigation. When LQ is less than SMD or the desired management-allowed deficiency (MAD), under-irrigation is indicated. The numerical value of the LQ average depth indicates the adequacy of irrigation.

Potential Application Efficiency of Low Quarter (PELQ) is the efficiency that is obtainable, expressed as a percent, when the average LQ depth of irrigation water infiltrated and stored just equals MAD. PELQ is a measure of how well the system can apply water if the management is optimal. The difference between PELQ and AELQ is a measure of management operations. Low PELQ values indicate design problems. This is the only efficiency term that should be used to compare systems or methods.

Distribution Uniformity (DU) is the ratio of the average LQ depth of irrigation water infiltrated to the average depth infiltrated, expressed as a percent. DU indicates the magnitude of distribution problems.

Many of these and other measures described by Merriam, Shearer and Burt have been widely used in the evaluation of sprinkler systems of irrigation. Their application to Third World irrigation is necessarily limited to a few systems only; but the concepts and the ideas may have relevance in stimulating further thinking on performance measures.

SECKLER AND OTHERS

Malhotra et al. (1984) illustrate a methodology for monitoring the performance of large-scale irrigation systems using a case study of a *warabandi* system of northwest India. An important contribution of their study is the use of "wetted area" as an indicator of water supply for a farmer's field in a water-deficient system. This can be observed easily in the field. They define the "net wetted area" (NWA) as the area of farmer's land that is wetted *at least once* in an irrigation season; the "total wetted area" (*TWA*) is the NWA multiplied by the number of irrigations that the area receives. The area of every individual farmer that can be irrigated is measured and recorded. This area is called the "cultivable command area" (CCA). In the case study of the warabandi system, the predicted outputs are: a) NWA is equal to one-third of CCA; and b) *TWA* is equal to 133 percent of CCA. By measuring the actual outputs of NWA and *TWA* it is possible to determine if the results of the warabandi system are within an acceptable range of error. Malhotra et al. define "allocative efficiency" as the coefficient of determination between the wetted area after a watering on each farm (NWA), and the farm area (CCA). This will be 1.0 when there is perfect equity, in the sense that every farmer receives a share proportional to the size of his holding.

Seckler et al. (1988), in a continuation of the analysis of the earlier study (Malhotra et al. 1984), develop a performance index for managerial effectiveness. They conclude that the coefficient of determination previously proposed is not a valid index of performance and suggest using a new index defined in terms of the concept of "Management by Results" (MBR). In MBR, the results (R) are defined as the relationship between the predicted outputs (P_o) of the system, as specified by its objectives, and the actual results (A_o) obtained from operation of the system. The results are expressed as a ratio, $R = A_o/P_o$. If the system is performing perfectly, $A_o = P_o$, and $R = 1.0$. Of course, in the real world, perfection is impossible, and satisfactory results are defined within a predetermined range of error of plus or minus a certain percentage.

The "total error" (*TE*) for the warabandi system is calculated by Seckler et al. using an index developed by Theil for similar problems. This index is defined as:

$$TE = \frac{\sqrt{\sum (TWA * - TWA)^2}}{\sqrt{\sum (TWA *)^2}}$$

where *TWA* and *TWA** are the actual and targeted total wetted areas; *TWA* is the observed value and $TWA^* = 1.33 \times CCA$.

In their study, the total error is 20 percent, which means that the warabandi system under study is performing at 80 percent effectiveness with respect to the *TWA** objective function. The authors claim the Theil index has many desirable characteristics that are elaborated in the paper.

The approach used in these studies is a major and significant contribution to the thinking on performance and performance indices at system level in water deficient environments.

LENTON

Lenton (1984) defines water delivery performance (WDP) to serve as an indicator of performance of an irrigation system to monitor productivity and equity. The general approach followed is to define the criteria at the individual farm level and then proceed up the system, at higher and higher levels of aggregation, in order to define performance criteria appropriate for the outlet (turnout), minor, distributary, branch and system level. This is to be achieved by suitable statistical procedures for sampling and estimation.

Using the notation indicated in Figure 3, one appropriate measure of WDP to take into account the quantity and timing of water delivered to a farm can be defined as follows:

$$WDP_i = \sum_{t=1}^{n} \frac{K(t)\ V_i(t)}{V_i^*(t)}$$

$$V_i(t) \leq V_i^*(t)$$

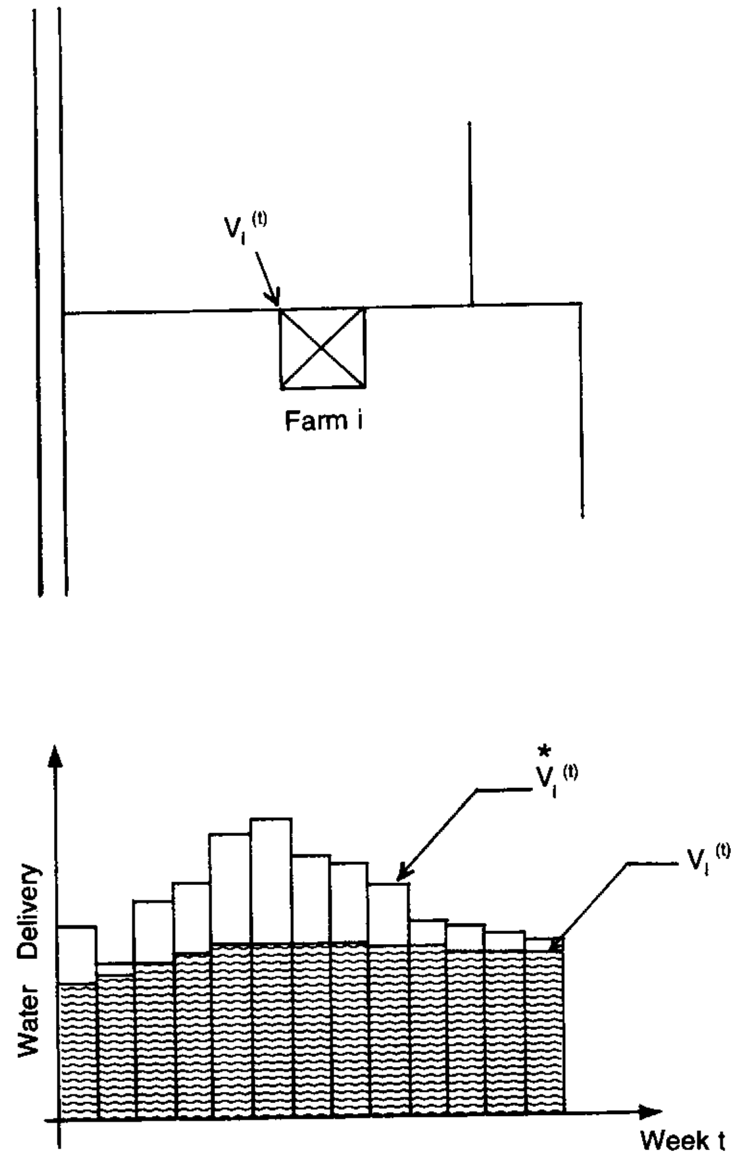
$$\sum_{i}^{n} K(t) = 1$$

where, $V_i(t)$ = Volume of water delivered to farm *i* during the week (or other time period) *t* of cropping season,

$V_i^*(t)$ = Target volume of water to be delivered to farm *i* during the week *t* of cropping season, calculated for actual crops grown and existing conditions of soil, rainfall, and other sources of water, and

$K(t)$ = Weighing factor indicating the relative importance of water at different stages of crop growth.

Figure 3. Water delivery to the farm.



$V_i^{(t)}$ = Volume of water delivered to farm *i* during week (or other time period) *t* of cropping seasons.

With water delivery performance defined in this way, WDP_i would equal *one* if the water delivered to the farm during each week of the cropping season is equal to the target water delivery, and *zero* if water is never delivered during any of the weeks of the cropping season. If water is delivered at the wrong times and/or in the wrong amounts, WDP will vary between zero and one.

WDP_i as defined here assumes that if water delivered is greater than target water delivery, water delivery performance is not affected. Lenton also suggests a modification to the definition of WDP_i which explicitly accounts for the harmful effects of overirrigation. It can be expressed by the following:

$$WDP_i = \sum_{t=1}^{n} \varepsilon_i(t)$$

where,
$$\varepsilon_i(t) = \frac{K(t)\, V_i(t)}{V_i^*(t)}, \text{ if } V_i(t) \le V_i^*(t)$$

$$= \frac{K(t)\, V_i^*(t)}{V_i(t)}, \text{ if } V_i(t) > V_i^*(t)$$

The concept and definitions of water delivery performance are a major contribution to the thinking on performance indicators which combine the effects of adequacy and timeliness with appropriate weights attached to critical periods of crop growth. It is easy to communicate to the managers of the system and it is easy to compute.

ABERNETHY

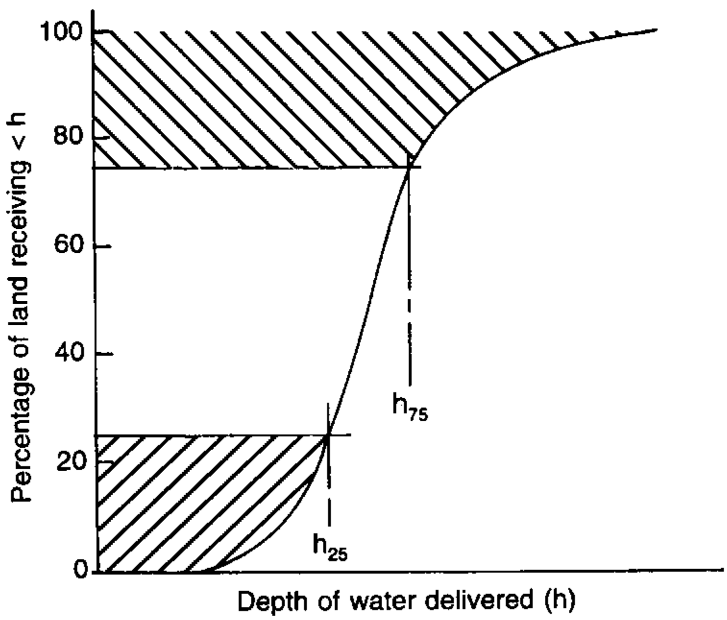
Abernethy (1986) deals with performance measurement in canal water management and makes two important contributions regarding measurement of equity and relative potential yield. He defines two measures of equity, I_1 and I_2. Figure 4 illustrates the difference between I_1 and I_2. The interquartile ratio (IQR) I_1 is defined as h_{75}/h_{25}, h_{25} being the depth of water such that one quarter of all the land receives less than this, and h_{75} is the lower limit of the most favored quarter. However, when there is a relatively small set of available values of h (which is usually the case) then h_{25} and h_{75} are not sharply defined, and I_1 becomes rather volatile. For this reason, he prefers to take the average depth of water received by all land in the best quarter, divided by the average depth received in the poorest quarter, (i.e., the average for the shaded area in the Figure 4), which he terms I_2, *modified interquartile ratio.* He illustrates the computation of I_1 and I_2 for some cases and compares them with other inequity measures like the coefficient of variation, and Christiansen and Gini coefficients. The virtue of the ratios I_1 and I_2 is that they are easily understood by almost anybody and hence are easily communicated to agency personnel.

The concept of relative potential yield is illustrated by using some observations from Kaudulla to quantify the effects of irregular water delivery upon crop yield and water productivity. First, a water demand curve is developed (Figure 5). This should be done on a daily basis, using data from climatic observations to construct an evapotranspiration curve, say, through the Penman formula. Next, some form of soil storage and percolation model is used to calculate a pattern of intermittent water inputs that will maintain sufficient water in the root zone to satisfy crop needs, downward percolation, and direct evaporation to atmosphere. (Holmes [1983] describes these steps for the case of a rice system). Then, the actual history of water issues to the field is compared with this ideal requirement. Using crop-water response tables such as those of Doorenbos and Kassam (1979), calculations can be made of how much yield is lost due to the occasions when water deliveries fall below requirements. The excess supply of water at other periods implies a waste of water, and therefore, a reduction of the productivity of the water used. Taking all these things together, Abernethy calculates (for the particular patterns of crop demand and water delivery shown in Figure 4) the relative yield Y_r (that is, yield relative to what would be achieved if the delivery and demand curves matched precisely) as 88 percent, and the relative water productivity, P_r, similarly defined, as 66.8 percent.

Figure 4. Definition of interquartile ratios.

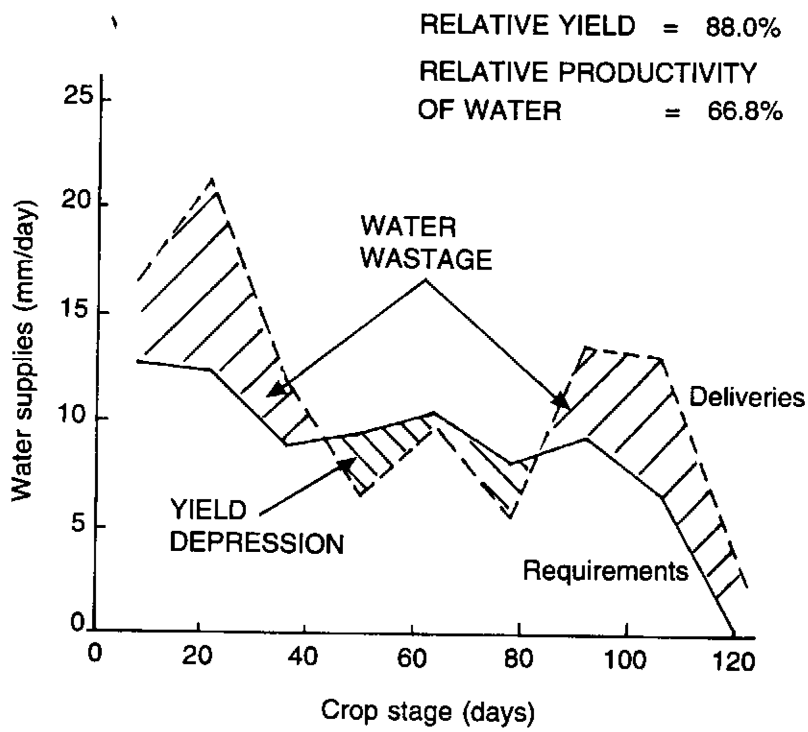
$$I_1 = h_{75} / h_{25}$$

I_2 = upper/lower shaded areas



Source: Abernethy, 1986.

Figure 5. Effect of irregular water delivery upon crop yield and water productivity.



Source: Abernethy, 1986.

This means (without any consideration of how the farmer uses the water in his field) the system is supplying water to him in such a way that the best productivity he can achieve will be 33.2 percent less than it could be under a water delivery system that accurately matched crop requirements. Abernethy suggests that this seems to be a meaningful way of quantifying the effect of a water delivery schedule. It enables the interpretation of scheduling in output terms, but without the distortion of extraneous factors (fertilizers, pests, prices, etc.) that make it unsafe to use actual production as the measure.

SAMPATH

Sampath (1988) reviews equity measures for irrigation performance evaluation and deals with the analytical issues involved in developing and using practical measures of equity for evaluating irrigation project performance. Deriving from the economic literature on equity in income distribution, the paper discusses the usefulness of seven axioms for equity measures in evaluating the robustness of seven different positive measures of equity such as range, the relative mean deviation, the variance, the coefficient of variation, the standard deviation of logarithms, the Gini coefficient and Theil's information measure. Based on the fulfillment and nonfulfillment of different axioms, the paper discusses the relative merits and demerits of the seven different measures of equity. On the basis of this critical evaluation it concludes that Theil's information measure is more useful than the others since it fulfills many of the important axioms in addition to being amenable to decomposition analysis.

Theil's measure is based on the notion of entropy in information theory. Sampath shows how it can be applied in the irrigation context for the warabandi system which is analyzed in Seckler et al. (1988).

Let y_i be the fraction of total TWA for the ith unit cultivable command area (CCA) where i varies from 1 to n. The entropy of TWA shares is then defined as

$$H(y) = \sum_{i=1}^{n} y_i \log \frac{i}{y_i}$$

which is the weighted average of the logarithms of the reciprocal of each TWA share, weights being the respective TWA shares. The upper limit of $H(y)$ is log n, which is reached when all unit CCAs get equal TWA, and the minimum of $H(y)$ is zero, which represents one unit CCA receiving all the TWA. Therefore, $H(y)$ can be regarded as a measure of irrigation equality. Thus, Theil's measure of inequality is obtained by subtracting $H(y)$ from its own maximum value:

$$\log n \ H(y) = \sum_{i=1}^{n} y_i \ \log n \ y_i$$

which varies from zero to log n.

It may seem objectionable that the upper limit, log n, increases when the number of CCA units increases. For example, when an irrigation system consists of two CCA units, we have a maximum inequality in irrigation distribution whenever one CCA unit gets all the water and the other gets nothing. In this case the value of the index is log 2. But when the system consists of, say, 2,000 CCA units and one CCA gets all the water while the remaining 1,999 units get no water at all, then it is natural to expect that an inequality measure reflects the greater severity of the problem of equity. That is what the Theil's index does; it will now equal the logarithm of 2×10^3. In contrast, the normalized measures will indicate the level of inequality as unity in both cases thereby implying the problem of equity is the same in the two-unit case and in the two-thousand-unit case. This is claimed to be one of the important advantages of Theil's measure.

PLUSQUELLEC

The World Bank recently carried out a 3-year comparative study on the performance of large-scale gravity irrigation systems in selected countries of Asia, Africa, and Latin America. A series of case study reports has been published by the Bank. Plusquellec (1989, 1990), for example, describes the performance of two irrigation systems in Colombia, and of the Gezira Irrigation Scheme in Sudan, respectively. These studies focus on the extent to which the design of the irrigation system fosters effective water management and provides equitable, reliable, and timely water distribution to farms; they analyze water efficiencies, the effectiveness of maintenance, and cost recovery. Some of the studies also focus on project-specific issues. For example, the case study of the systems in Colombia also analyzes the extent to which farmers' organizations have taken responsibility for operating and maintaining the systems and helping to recover costs.

Although the comparative performance study carried out by the Bank was limited to the data available in the projects without field research, supplemented by field visits and farmer surveys, it contains a wealth of information. A large number of useful lessons can be drawn on many dimensions of performance and on various types of performance indicators — output, outcome, and process indicators. Appendix 1 illustrates the types of data collected and the chief characteristics of two irrigation systems in Colombia (Plusquellec 1989). The performance indicators include, among others, efficiency of water distribution, environmental impact, staff requirements for operation and maintenance, recovery of water charges, and O&M costs.

Based on the practical experience of the comparative studies, Plusquellec offered some comments at the irrigation performance workshop held in Pangbourne, U.K., in February 1990, which are very instructive. He pointed out that:

> *it is relatively easy to collect from a project agency a series of data on the physical environment (climatic and hydrological data, physical infrastructure), on agriculture production, on staff and on O&M costs of an irrigation project. These data can be obtained from agencies performing relatively well within a short time. However, the greatest difficulty is found in obtaining and interpreting data on water supply. Few projects have information on volumes of water delivered to each farm unit, not even to each tertiary unit. When these data exist, these are often too unreliable for analytical uses. The cases of Morocco, and to some extent of Coello District in Colombia or Yaqui Project in Mexico where water is delivered volumetrically to each farmer are rather unique in developing countries. In most cases, what could be obtained are the volumes delivered to large sections of projects (such as the four sectors of about 25,000 ha of the Upper Pampanga Project in the Philippines). In these cases, without further field **research** and **monitoring** there is no possibility to determine the water use efficiency at conveyance, distribution, and field level. At best, an educated guess of overall efficiency can be determined. Needless to say that the other indicators of quality of water service — equity, timeliness, and reliability — cannot be determined and only a qualitative and subjective judgement can be made.*

The studies carried out by the Bank have been very useful for initiating more focused research on performance indicators, but it is not very encouraging to learn that, except in a few systems, the basic measurements and data do not exist for assessing the quality of irrigation service. The challenge is much bigger than simply identifying performance indicators for the quality of irrigation water deliveries.

Plusquellec et al. (1990) present the results of assessment studies of the performance of gravity irrigation projects in six countries in different climatic and social environments, with respect to their original objectives in terms of water availability, water use efficiencies, equity of water distribution, cropping intensity and crop yields, and project economic rates of return. The main characteristics of the projects, the water use efficiencies, and the economic rates of return of the projects are given in Tables 1 to 3. An important conclusion is the need for more realistic assumptions in the adoption of design standards, especially irrigation efficiency which affects the cropping intensity, the overall productivity of the project and its economic viability. The overall performance of irrigation projects in economic terms has been less satisfactory at full development than anticipated at either appraisal or completion of their investment phase, although their social impact has been substantial and their contribution to food security and poverty alleviation is not in doubt.

Table 1. Main characteristics of projects.

Country	Projects	Irrigation area (ha)	Average farm size (ha)		Annual rainfall (mm)	Storage capacity / Annual flow (mm^3)	Project completion (year)	Main crops
Morocco	Doukkala gravity} Doukkala sprinkler}[1]	18.65 32.12	2.00 2.00		305	2320/500	1980	sugar beet, wheat, vegetables, forage
			Private	Ejido				
Mexico	Sinaloa[2] Yaqui Panuco	105,00 220,00 131,000	13.70 21.60 38.40	8.60 9.00 9.10	550 270 900	1610/1350 6130/2497 940/6680	1982 1984	wheat, soybean sorghum, vegetables wheat, cotton, soybean maize, sorghum, safflower pastures
Philippines	Upper Pampanga	103,00	2.90		1,850	1753/2000	1977 1981	paddy
Thailand	Lam Pao	48,000	2.40		1,360	900/1760	1981 1985	paddy, groudnut
Colombia	Coello R.U.T.	27,187 9,742	16.20 5.70		1,350 1,123	(run of rive) (pumping)	1953 1973	rice, cotton, sorghum sorghum, soya
Sudan	Gezira	882,00	8.00		160 to 470	2880/50,000	1965	cotton, soybean, wheat

1 Includes the two bank-financed projects: Doukkala I and II.

2 Includes the two bank-financed projects: Sinaloa I and II.

Source: Plusquellec et al., 1990.

Table 2. Water use efficiencies (%).

	Conveyance and distribution efficiency			Field application efficiency			Overall irrigation		
	Appraisal estimate	Actual	Actual as % of appraisal	Appraisal estimate	Actual	Actual as % of appraisal	Appraisal estimate	Actual	Actual as % of appraisal
Sinaloa	74-80	67	(87)	70	55	(79)	52	37	(71)
Panuco	75	54	(72)	70	48	(69)	52	26	(50)
Doukkala	86	73-75	(86)	75	67	(75)	64	49	(77)
Doukkala	85	72	(85)	60	58	(97)	50	42	(84)
Yaqui	61	61	(100)	70-75	55	(76)	43-46	38	(85)
Coello	–	65	–	–	45	–	–	30	–
Gezira	–	93	–	–	75	–	–	70	–
Upper Pam	–	NA	–	–	NA	–	58	36	(62)
Aurora-Penara	–	NA	–	–	NA	–	39	36	(92)
Lam Pao I	–	NA	–	–	NA	–	55	28	(51)
Lam Pao I	–	NA	–	–	NA	–	58	28	(48)

NA = No field data available for separate calculations of conveyance distribution efficiency and field application efficiencies.

Source: Plusquellec et al., 1990

Table 3. Project economic rate of return (%).

	Appraisal	Completion	Impact evaluation	
			(1)	(2)
Upper Pampanga	13.0	14.0	8.9	11.7
Aurora-Penaranda	17.0	8.6	2.6	4.5
Lam Pao I	25.0	18.0	15.0	19.0
Lam Pao II	26.0	11.0	9.0	10.0
Sinaloa I	12.0	11.0	9.0	–
Panuco	20.0	11.4	7.0	–
Doukkala I	11.4	20.5	11.0	–
Doukkala II	11.0	18.0	10.0	–

(1) Using rice prices estimated at impact evaluation.
(2) Using rice prices estimated at completion.
Source: Plusquellec et al., 1990.

MAO ZHI

Mao Zhi (1989), in his paper *Identification of causes of poor performance of a typical large-sized irrigation scheme in South China,* describes an index system which consists of twelve techno-economic indices of performance of an irrigated-agriculture system. The indices of the Zhanghe Irrigation Scheme (ZIS) before rehabilitation are presented and the causes of the unsatisfactory values of these indices are analyzed. The effects of the rehabilitation of the scheme are illustrated by comparing the values of the indices before and after rehabilitation in 1980.

ZIS is the largest system in Hubei Province in South China and serves an irrigation area of 174,000 ha. The Zhanghe Reservoir is designed for multipurpose uses, but is mainly used for irrigation. The main crops in Zhanghe Irrigation District are rice, wheat and cotton. The multiple cropping index is about 2. Rice is planted over 86 percent of ZIS and wheat on 73 percent of the rice fields after harvest. The average evaporative demand is 1,353.1 mm and rainfall is 937.7 mm which is distributed in a highly irregular pattern both between years and during each year.

The following index system consists of twelve techno-economical indices grouped into three categories for analyzing the performance of ZIS.

Indices of Irrigation Water Utilization

i. Efficiency of utilizing irrigation water resources S (%)

$$S = \frac{W_p}{W_d} \times 100$$

where, W_d and W_p are the design and actual annual quantity of irrigation water diverted from water sources in the same years (m^3 $year^{-1}$).

ii. Gross annual irrigation water quota M (m^3 ha^{-1} year^{-1})

$$M = \frac{W}{A}$$

where, W is the actual total gross annual quantity of irrigation water (m^3 year^{-1}). A is the actual irrigation area (ha).

iii. Irrigation application efficiency E†

$$E = \frac{W_f}{W_h}$$

where, W_f is the total volume of water delivered to the points of use in field by the irrigation canal system (m3); Wh is the total volume of water diverted from the headwork for irrigation (m^3).††

Indices of Irrigation Area and Engineering Aspects of System

iv. Efficiency of actual irrigated area F (%)

$$F = \frac{A}{A_d} \times 100$$

where, A is the actual, and A_d is the design irrigated area (ha).

v. Percentage of area provided with field irrigation and drainage system D (%)

$$D = \frac{A_{fa}}{A_{fd}} \times 100$$

where, A_{fd} and A_{fa} are the design and actual area provided with the field irrigation and drainage system (ha).

vi. Efficiency of facilities in good condition G (%)

$$G = \frac{N_g}{N} \times 100$$

where, N is total number of facilities for irrigation or drainage of the same category; N_g is the number of the facilities in good condition (safe, integrated, functioning normally and attaining the design standards).

† This should not be confused with "field application efficiency" as used by Bos and Nugteren (1990).

†† W_p, W and W_h seem to refer to the same thing, though it is not certain from the text.

Indices of Economic Benefit

vii. Yield per unit area y (t ha^{-1} year^{-1})

$$y = \frac{Y}{A}$$

where, Y is the total annual yield (t year^{-1}) of crops in A (ha).

viii. Yield per unit quantity of irrigation water y_w (kg m^{-3})

$$y_w = \frac{Y}{W}$$

where, the unit of Y is kg year^{-1}

ix. Income from irrigation water charges per unit area i (yuan† ha^{-1} year^{-1})

$$i = \frac{I_w}{A_d}$$

where, I_w is the actual total annual income from irrigation water charges (yuan year^{-1}).

x. Irrigation benefit per unit area b (yuan ha^{-1} year^{-1})

$$b = (y - y_o)\ c + (y' - y_o')\ c' - h$$

where, y and y_o are the annual yields of crops per unit area (t ha^{-1} year^{-1}) with and without irrigation respectively, y' and y_o' are the annual quantities of by-products per unit area with and without irrigation (t ha^{-1} year^{-1}), c and c' are the costs of agricultural product and by-product (yuan t^{-1}); and h is the annual expenditure per unit area for irrigation (yuan ha^{-1} year^{-1}).

xi. Irrigation benefit per unit quantity of irrigation water b_w (yuan m^{-3})

$$b_w = \frac{b}{M}$$

xii. Percentage of financial self-sufficiency J (%)

$$J = \frac{I}{H} \times 100$$

where, H is the total annual expenditures which include salary, administrative expenses and current expenditures (yuan year^{-1}), and I is the total annual income from water charges and the diversified economy (yuan year^{-1}).

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† The Chinese unit of currency. In 1992, one yuan=US$0.178.

Performance Evaluation of ZIS

The values of the twelve indices on ZIS before rehabilitation are given in Table 4. A comparison of the values of the twelve indices before and after rehabilitation is given in Table 5. Mao Zhi's paper is a remarkable and commendable contribution for a number of reasons: 1) the indicators of system performance are described as per the design, as actually obtaining (mean and ranges), and

Table 4. The values of the twelve indices on Zhanghe Irrigation System (ZIS) before rehabilitation.

No.	Names, symbols, and units of indices	Values of indices			
		During 1976–1980 on ZIS		Design	Normal level or standard level
		Ranges	Average		
1.	Efficiency of utilizing irrigation water resources $S(\%)$	75–93	88	100	95
2.	Gross annual irrigation water quota M (m^3 ha^{-1} $year^{-1}$)	6,400 -7,300	6,900	4,620 -5,700	5,000 -6,000
3.	Irrigation application efficiency E	0.43 -0.53	0.48	0.65	0.60
4.	Efficiency of actual irrigation area F (%)	55–98	91	100	100
5.	Percentage of area provided with field irrigation and drainage system D	10–30	20	100	100
6.	Efficiency of facilities in good conditions G (%)	75–90	82	100	98
7.	Yield per unit area y (t ha^{-1} $year^{-1}$)	4.68 -5.76	5.16	6.00	6.00
8.	Yield per unit quantity of irrigation water y_w (kg m^{-3})	0.65 -0.82	0.75		1.15
9.	Income from irrigation water charges per unit area i (yuan ha^{-1} $year^{-1}$)	7.2 -12.5	10.1		30
10.	Irrigation benefit per unit area b (yuan ha^{-1} $year^{-1}$)	371 -477	420		600
11.	Irrigation benefit per unit quantity of irrigation water b_w (yuan m^{-3})	0.053 -0.065		0.061	0.85
12.	Percentage of financial self-sufficiency J (%)	25–38	33		100

Source: Mao Zhi, 1989.

the normal or standard level of performance expected is given (Table 4); 2) the indicators measure the performance of a large system on many dimensions — water use efficiencies, area irrigated, yields, productivities of land and water, irrigation water charges, and the financial self-sufficiency of the agency; and 3) the improvements in performance after rehabilitation (Table 5) are not only due to physical and structural changes but also due to policy changes resulting in increased incomes from irrigation water charges and higher financial self-sufficiency of the irrigation agency.

Table 5. Comparison of the values of the twelve indices on ZIS before and after rehabilitation.

No.	Names, symbols, and units of indices	Average values of indices on ZIS		Values of the ratio (A)/(B)
		Before rehabilitation (1976/80) (B)	After rehabilitation (1985/87) (A)	
1	Efficiency of utilizing irrigation water resources *S* (%)	88	100	1.14
2	Gross annual irrigation water quota *M* (m^3 ha^{-1} $year^{-1}$)	6,900	5,850	0.85
3	Irrigation application efficiency *E*	0.48	0.60	1.25
4	Efficiency of actual irrigation area *F* (%)	91	100	1.10
5	Percentage of area provided with field irrigation and drainage system *D* (%)	20	95	4.75
6	Efficiency of facilities in good conditions *G* (%)	82	100	1.22
7	Yield per unit area *y* (t ha^{-1} $year^{-1}$)	5.16	7.65	1.48
8	Yield per unit quantity of irrigation water y_w (kg m^{-3})	0.75	1.31	1.75
9	Income from irrigation water charge per unit area *i* (yuan ha^{-1} $year^{-1}$)	10.1	55.6	5.50
10	Irrigation benefit per unit area *b* (yuan ha^{-1} $year^{-1}$)	420	588	1.40
11	Irrigation benefit per unit quantity of irrigation water *b* (yuan m^{-3})	0.061	0.101	1.66
12	Percentage of financial self-sufficiency *J* (%)	33	105	3.18

Source: Mao Zhi, 1989.

This, then, is an example of the mix of indicators for assessment of the performance and general health of an irrigation system. The indicators used cut across Small and Svendsen's nested subsystems. A time series of such indicators can provide a basis for examining the sustainability of a system.

CLEMMENS

Clemmens (1990) describes a method of evaluating and understanding water delivery performance of a system before rehabilitation. The paper seeks to separate conceptually the two components of water delivery performance at an offtake: first, how accurate is the preparation of the water delivery schedule (delivery schedule performance)? and second, how did the system deliver water with reference to the schedule (operations performance)? When measurements of volumes V (or discharges Q) are taken at any point in the system, there are three values that should be considered:

V_A : The actual volume of water delivered (measured),

V_I : The volume that the operators intended to supply as per the schedule, and

V_R : The volume needed downstream of the point (obtained from agronomic requirements of the crops and losses in conveyance).

The three terms can be related as follows:

$$\frac{V_A}{V_R} = \frac{V_I}{V_R} \times \frac{V_A}{V_I}$$

$\frac{V_A}{V_R}$ is a measure of the overall delivery performance — the actual volume delivered divided by the required volume.

$\frac{V_I}{V_R}$ is a measure of how well the intended volume in the schedule matches the downstream requirements. (V_I could be considered as either the design volume for the season or the volume intended relative to supply available, depending on what is being evaluated). The ratio can evaluate the delivery-schedule part of the operational plan.

$\frac{V_A}{V_I}$ is a measure of the delivery system's ability to supply water according to the schedule. The statistics associated with this ratio can be used to evaluate the performance of the system and its management at delivering water.

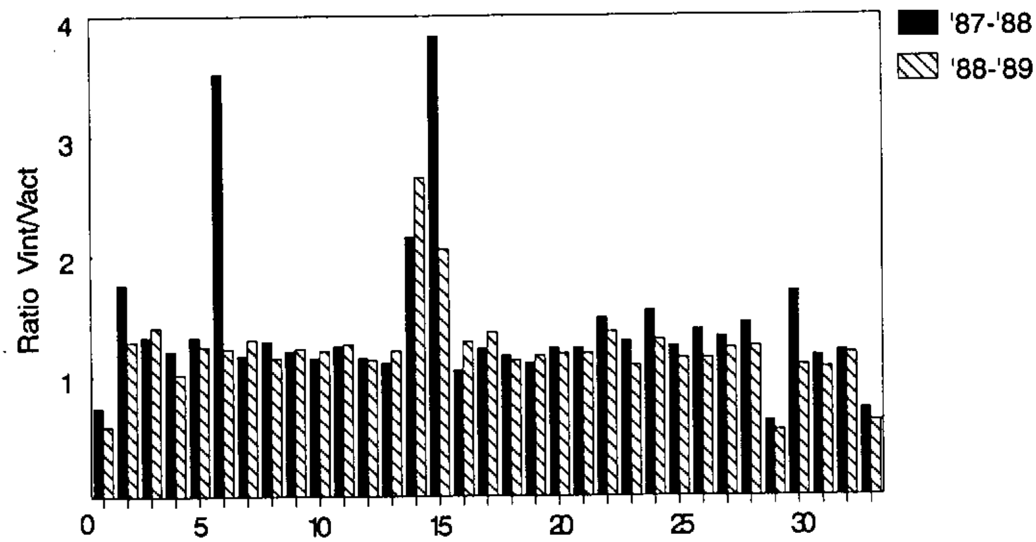
Clemmens' approach is useful in determining the extent to which the causes of poor performance relate to the inadequate estimation of water requirements and improper preparation of water delivery schedules or to the inability of the physical or management system to operate according to the schedule to deliver the intended supply. However, it will not determine whether the main cause of poor performance is physical system limitation, operational problems, or management.

The paper also proceeds to analyze the adequacy of supply at the outlets on a lateral by sampling and by assuming that the frequency distribution is normal for the ratio of actual to intended flows (Q_A/Q_I). This is probably of only academic interest at this stage when we do not, as yet, have empirically determined frequency distributions that are shown to be nearly normal.

Clemmens and Bos (1990) provide a more detailed exposition of the same concept and the use of statistical relations to express equity, adequacy and reliability from the measurement of these ratios. The use of the statistical methods is illustrated well with examples for the case of normal distribution.

Bos et al. (1991) also demonstrate the use of the average seasonal values of the ratio of "intended" and "actual" volumes of water delivered to the tertiary units in a performance evaluation of the Viejo Retamo Secondary Canal of the Rio Tunuyan Irrigation Scheme in Mendoza Province, Argentina. The results are shown in Figure 6. The ratio $V_{intended}/V_{actual}$ shows that most of the areas are about equally supplied with water, and that only a few units are "out of line."

Figure 6. Average values of the ratio $V/_{intended}/V_{actual}$.



Source: Bos et al., 1991.

MOLDEN AND GATES

Molden and Gates (1990) describe a number of performance measures for use in evaluation and design of new or rehabilitated irrigation water delivery systems. Performance measures are introduced as functions of defined state variables and are used to indicate the state of system performance relative to objectives of adequacy, efficiency, dependability, and equity of water delivery. Two examples are presented to illustrate the concepts introduced.

One of the important contributions of the paper is to further subdivide conceptually the second question addressed by Clemmens (1990): how did the system deliver water with reference to the schedule? The two questions are: is the physical system capable of delivering the scheduled quantity of water; and, if so, is the system operated to deliver the water as per the schedule? Thus, the contributions to water delivery performance of both structural and management components of the system are identified and separated.

The major state variables which determine water delivery system performance may be defined in terms of an amount of water, denoted Q, which may refer to either rate, volume, frequency, or duration of water delivery. The focus in the paper is on rates and volumes of water delivery. At a point X in the system and a time t, the following four state variables are defined:

$Q_D(X,t)$	:	Actual amount delivered by the system,
$Q_R(X,t)$	:	Amount of water required for consumptive and other uses downstream of the delivery point X,
$Q_S(X,t)$	:	Amount specified in the water delivery schedule, and
$Q_d(X,t)$	:	Amount of water which could be delivered by the system, given perfect operation according to the given schedule.

Twelve performance measures are defined relative to four water delivery system objectives. Each measure is a function of selected state variables of the system and is related to either actual field performance, performance relative to structural contributions, or performance relative to management contributions. The four performance objectives considered are adequacy, efficiency, dependability and equity. Adequacy relates to the desire to deliver targeted amounts of water needed for crop irrigation to delivery points in the system. Efficiency is the conservation of water resources in the delivery process or the prevention of over-delivery. Dependability is defined as the achievement of temporal uniformity in the ratio of delivered amounts of water to targeted amounts. Equity, as related to the water delivery system, is defined as spatial uniformity of the ratio of the delivered amounts of water to the targeted or potentially deliverable amounts.

Table 6. Matrix of water delivery system performance measures relative to system objectives.

System objective	Actual	Structural contribution	Management contribution
Adequacy	$P_A = 1/T\sum_T (1/R\sum_R pA)$	$P_{AS} = 1/T\sum_T (1/R\sum_R pAS$	$P_{AM} = 1/T\sum_T (1/R\sum_R pAM)$
Efficiency	$P_F = 1/T\sum_T (1/R\sum_R (pF))$	$P_{FS} = 1/T\sum_T (1/R\sum_R (pFS))$	$P_{FM} = 1/T\sum_T (1/R\sum_R (pFM))$
Dependability	$P_D = 1/R\sum_R CV_T(Q_D / Q_R)$	$P_{DS} = 1/R\sum_R CV_T (Q_d / Q_s)$	$P_{DM} = 1/R\sum_R CV_T (Q_D / Q_d)$
Equity	$P_E = 1/T\sum_T CV_R (Q_D / Q_R)$	$P_{ES} = 1/T\sum_T CV_R (Q_d / Q_s)$	$P_{EM} = 1/T\sum_T CV_R (Q_D / Q_d)$

Notes: CVT = Temporal coefficient of variation (ratio of standard deviation to mean) over the time period T.

CV_R = Spatial coefficient of variation over the region R.

$P_A = Q_D / Q_R$ if $Q_D \leq Q_R$ = 1, otherwise $P_F = Q_R / Q_D$ if $Q_R \leq Q_D$ = 1, otherwise

$P_{AS} = Q_d / Q_s$ if $Q_d \leq Q_s$ = 1, otherwise $P_{FS} = Q_S / Q_d$ if $Q_s \leq Q_d$ = 1, otherwise

$P_{AM} = Q_D / Q_d$ if $Q_D \leq Q_d$ = 1, otherwise $P_{FM} = Q_d / Q_D$ if $Q_d \leq Q_D$ = 1, otherwise

Source: Molden and Gates, 1990.

Next >>

The summations in Table 6 indicate an average of discrete functions of comparative ratios of state variables over a region or subregion, R, served by the delivery system for a time period T. Arithmetic averages are employed for evaluating the measures. However, a weighted average expression could be used when it is desirable to assign water delivery priorities differentiating among values of crops, farm sizes, or critical periods of crop growth. This could be accomplished through the use of relative weighing coefficients associated with each point value of the function of the state variables.

Extensive field measurements were made during 1986 to evaluate the performance of two water delivery systems, Minneriya and Kaudulla, in north-central Sri Lanka. The results are presented in Table 7 and in Figures 7, 8 and 9. The performance standards useful to judge the performance as good or fair or poor, are given in Table 8.

Table 7. Summary of performance measures for Minneriya and Kaudulla systems.

Measure	Minneriya		Kaudulla	
	Farm turnout	Canal headgate	Farm turnout	Canal headgate
P_A	0.84	0.79	0.80	0.85
P_F	0.78	0.82	0.72	0.70
P_E	0.66	0.64	0.83	0.76
P_D	0.48	0.59	0.70	0.55

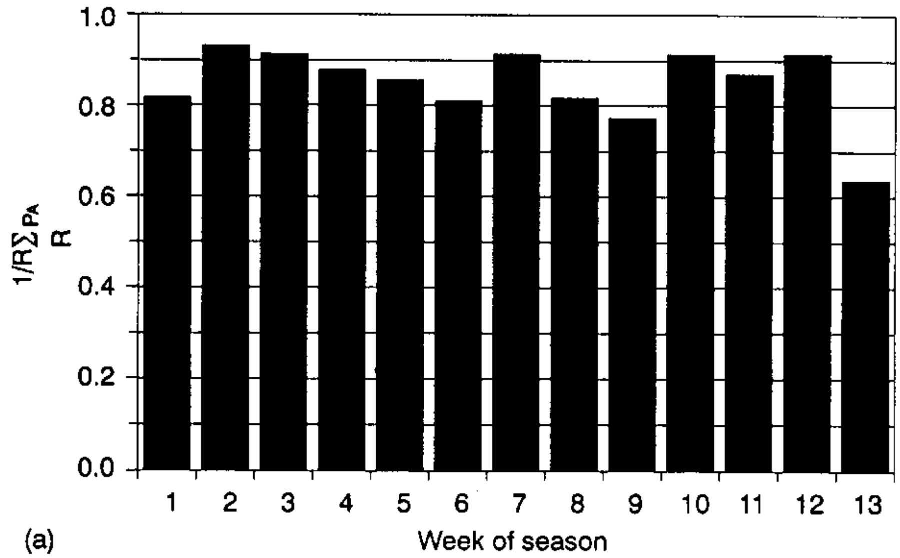
Source: Molden and Gates, 1990.

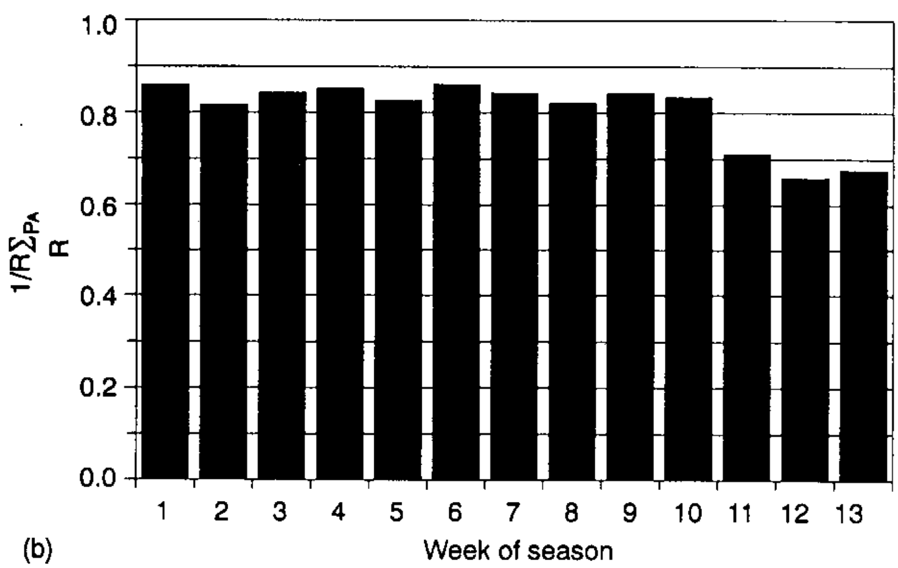
Table 8. Example performance standard.

Measure (1)	Performance classes		
	Good (2)	Fair (3)	Poor (3)
P_A	0.90–1.00	0.80–0.89	
P_F	0.85–1.00	0.70–0.84	
P_E	0.00–0.10	0.11–0.25	0.25
P_D	0.00–0.10	0.11–0.20	0.20

Source: Molden and Gates, 1990.

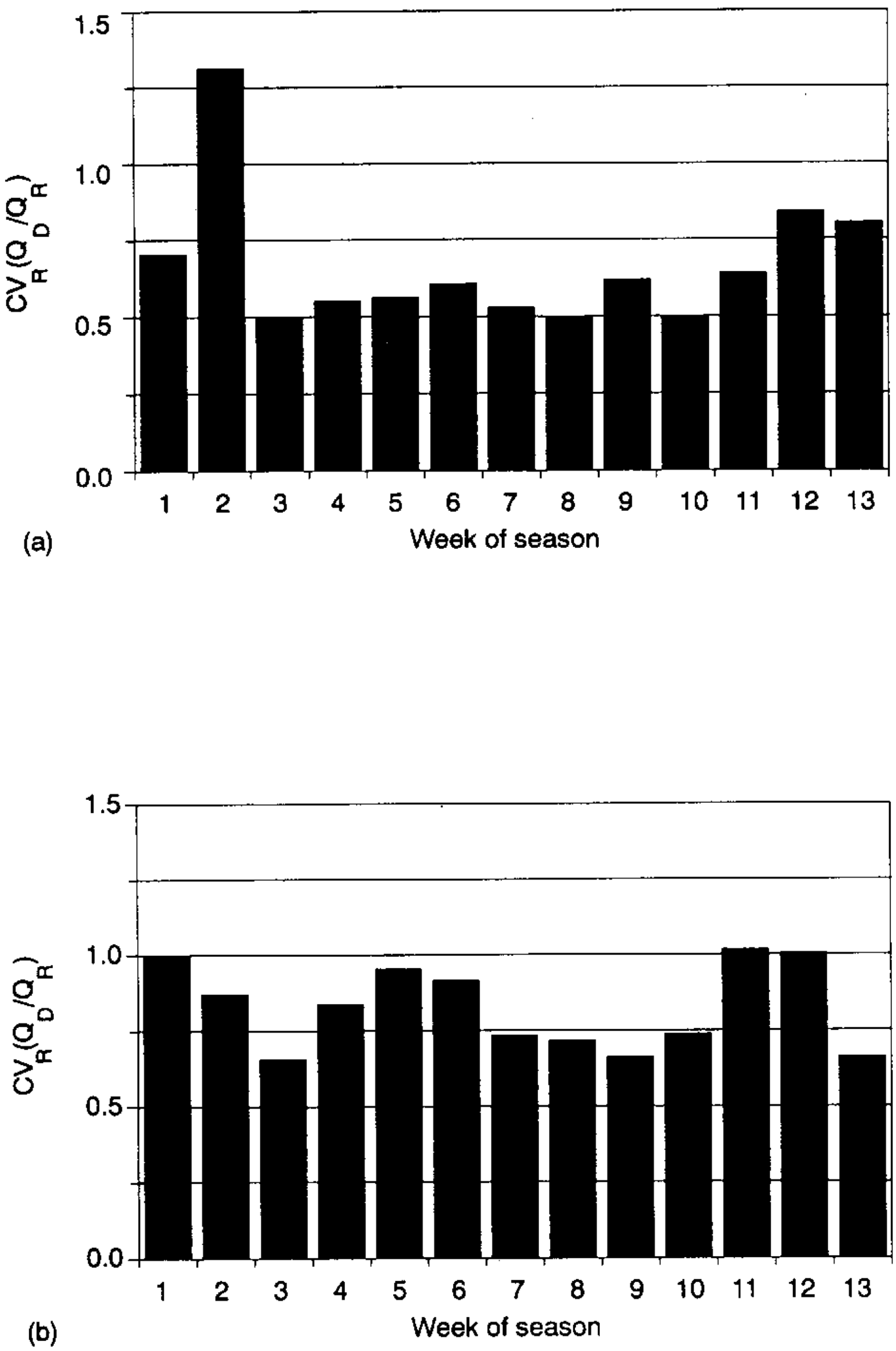
Figure 7. Plot of the spatial average value of P_A for (a) Minneriya and (b) Kaudulla.





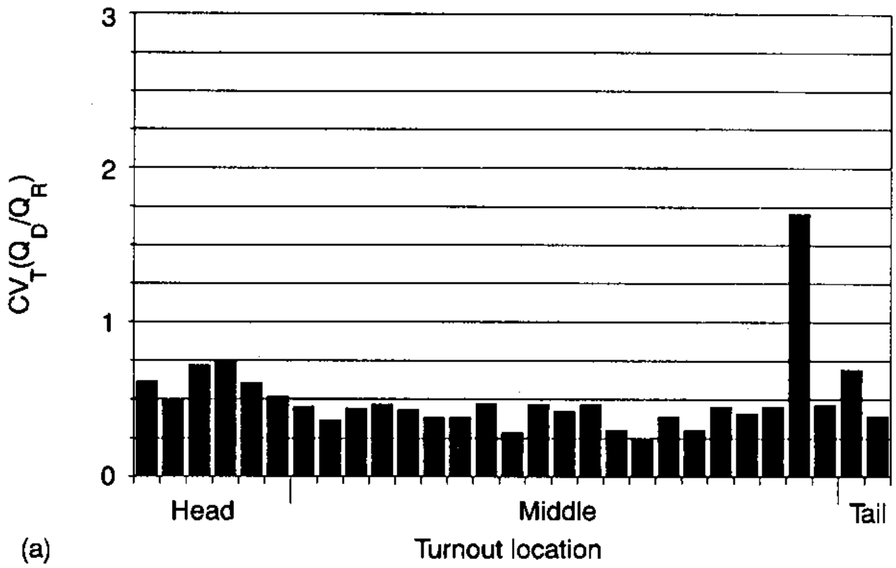
Source: Molden and Gates, 1990.

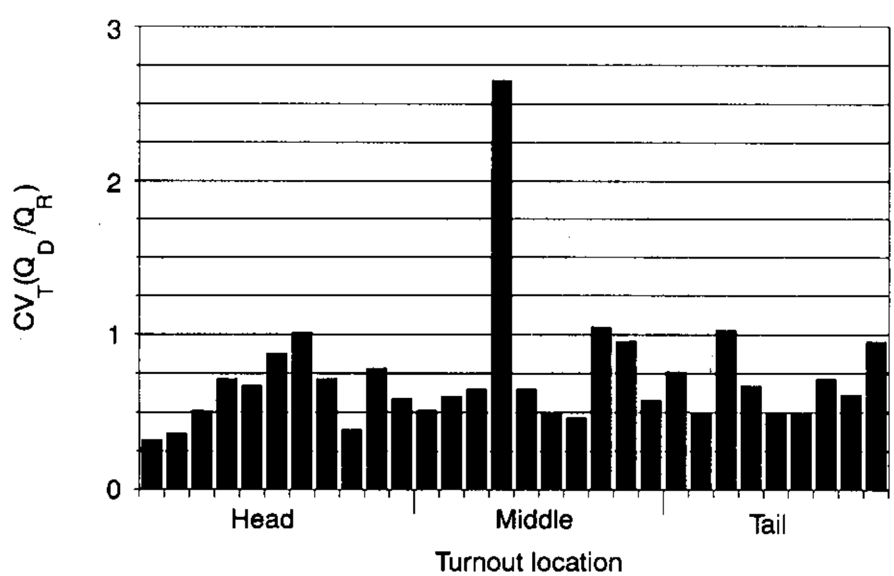
Figure 8. Plot of $CV_R(Q_D / Q_R)$ for (a) Minneriya and (b) Kaudulla.



Source: Molden and Gates, 1990.

Figure 9. Plot of $CV_T(Q_D / Q_R)$ for (a) Minneriya and (b) Kaudulla.





Source: Molden and Gates, 1990.

A comprehensive data set was not available to allow estimation of performance measures for actual field conditions or for structural and management contributions. The application of the proposed methodology is illustrated by constructing a hypothetical water delivery system using computer simulation. A summary of performance measures is presented in Table 9 and Figures 10, 11 and 12.

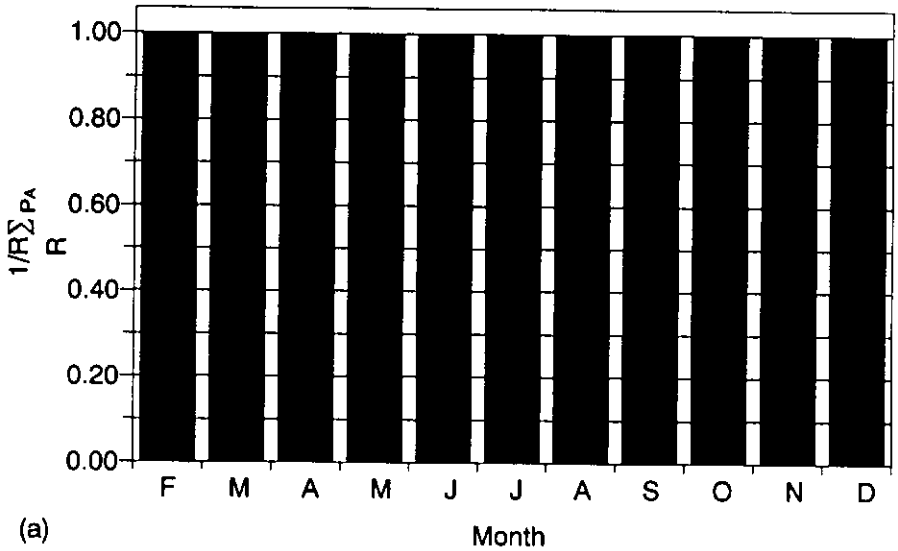
The paper deserves careful attention, particularly because of its attempt to distinguish physical and managerial factors affecting performance. Field data are used to illustrate the concepts and to compute the performance measures.

Table 9. Summary of performance measures for the hypothetical water delivery system.

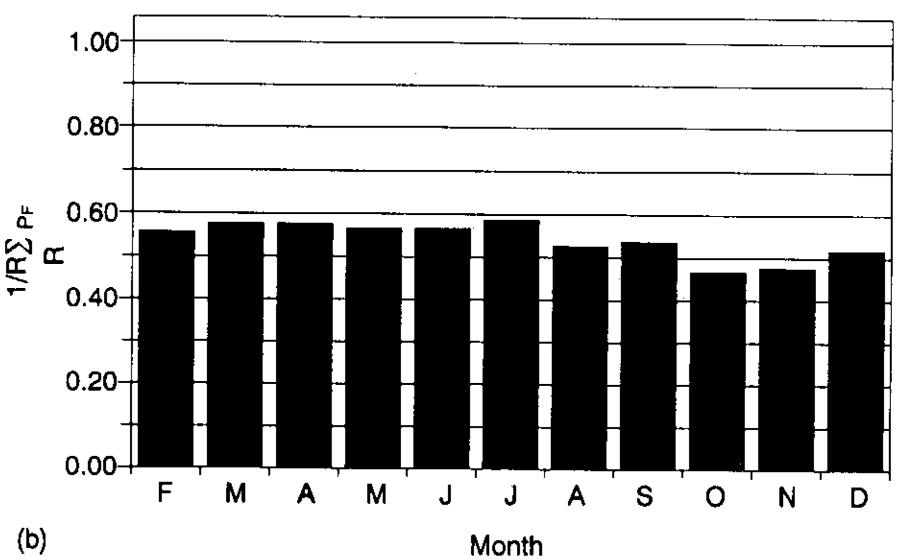
Measure	Canal headgate	Farm turnout
P_A	1.00	1.00
P_{AS}	1.00	0.92
P_{AM}	1.00	1.00
P_F	0.54	0.54
P_{FS}	1.00	0.95
P_{FM}	0.54	0.53
P_E	0.26	0.30
P_{ES}	0.01	0.20
P_{EM}	0.26	0.50
P_D	0.11	0.10
P_{DS}	0.01	0.12
P_{DM}	0.11	0.15

Source: Molden and Gates, 1990.

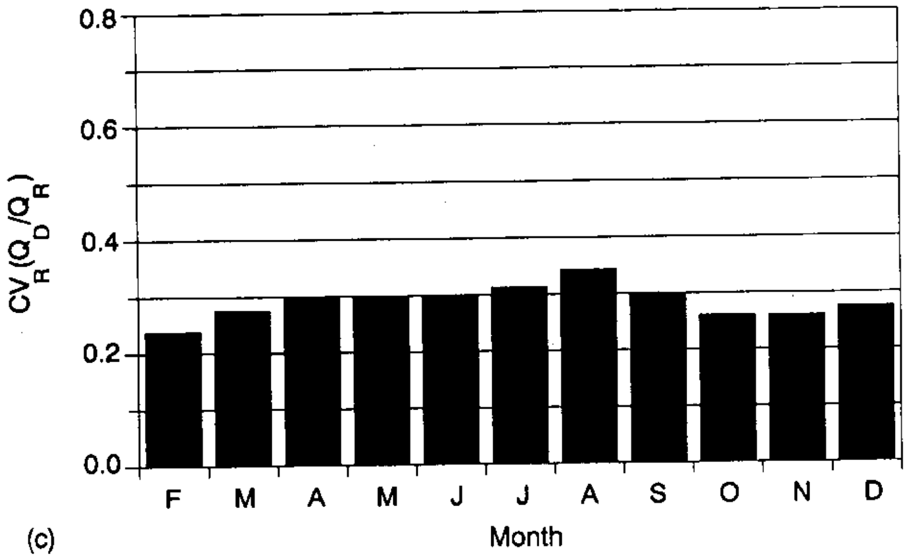
Figure 10. Plots of the spatial averages of (a) p_A *,(b)* p_F *and (c)* $CV_R(Q_D / Q_R)$.



(a)

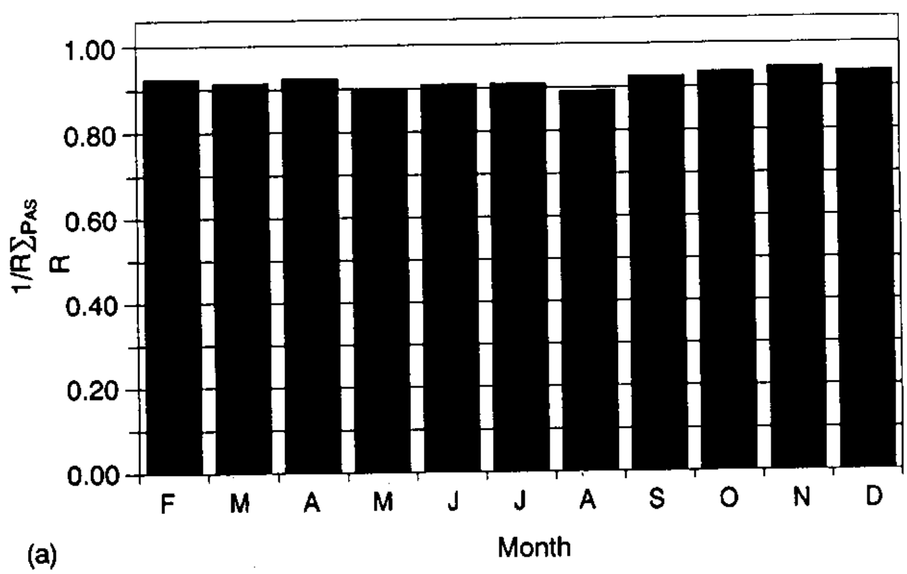


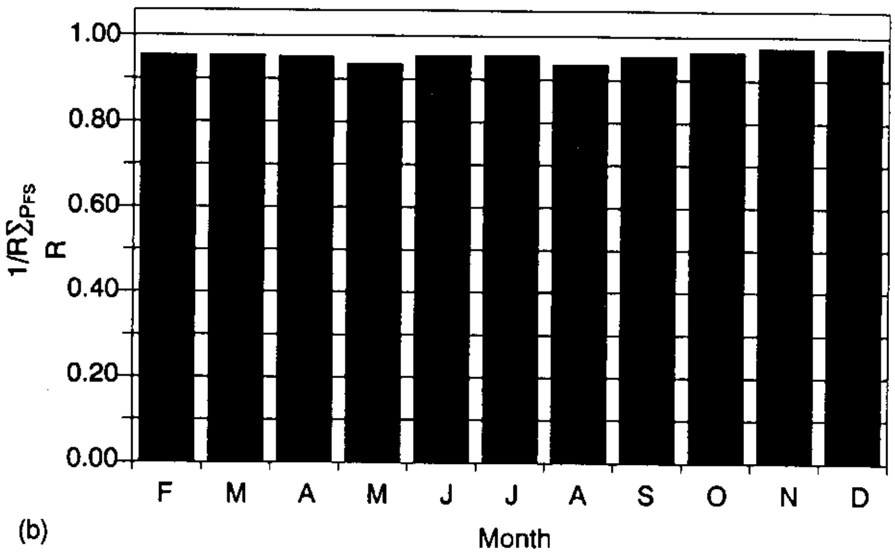
(b)



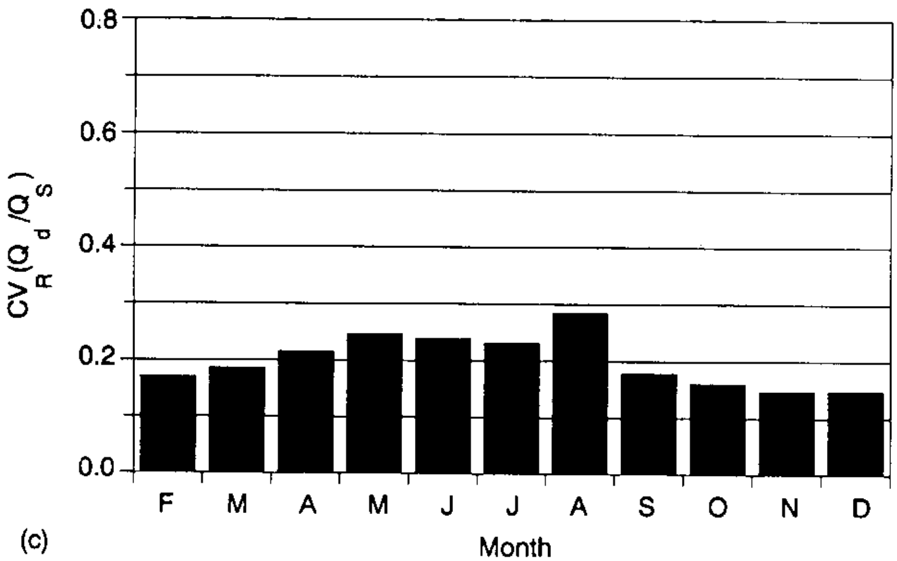
Source: Molden and Gates, 1990.

Figure 11. Plots of the spatial averages of (a) P_{AS} and (b) P_{FS} and of (c) $CV_R(Q_d / Q_S)$.





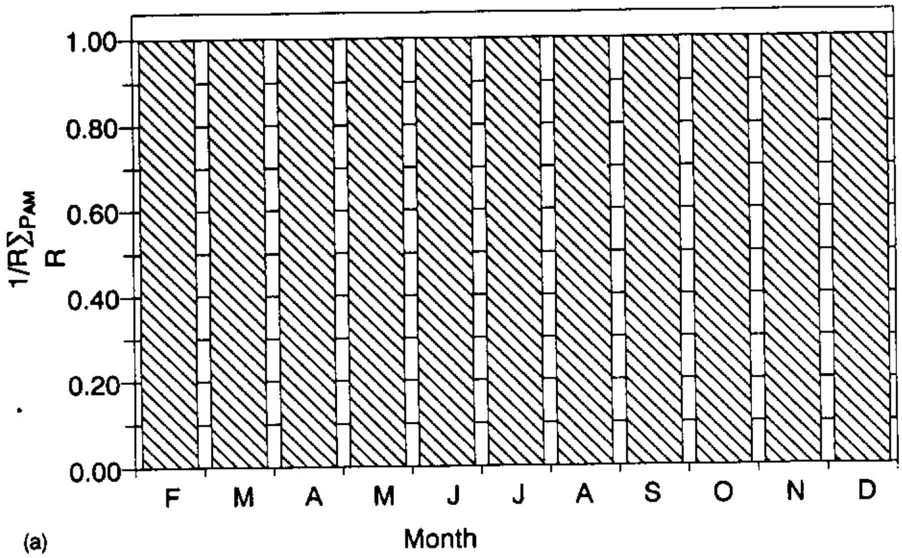
(b)



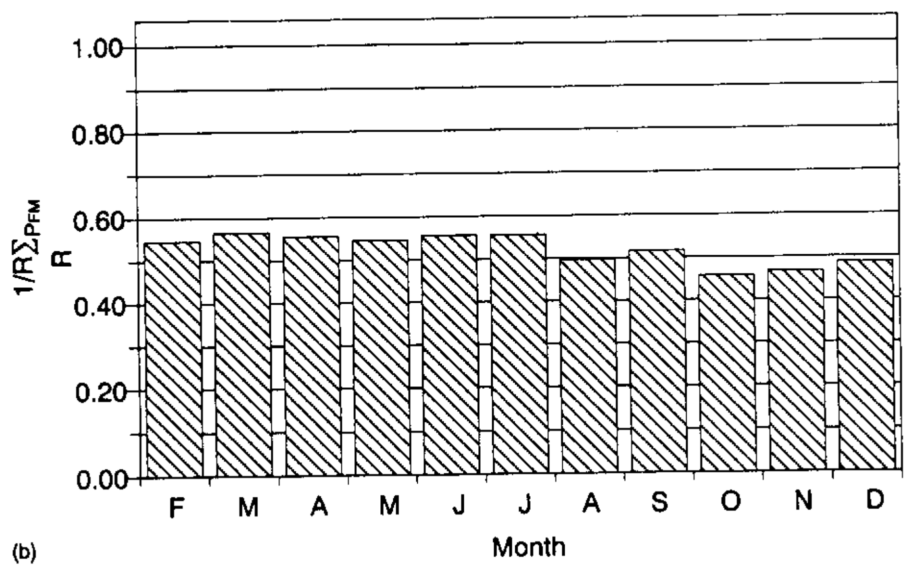
(c)

Source: Molden and Gates, 1990.

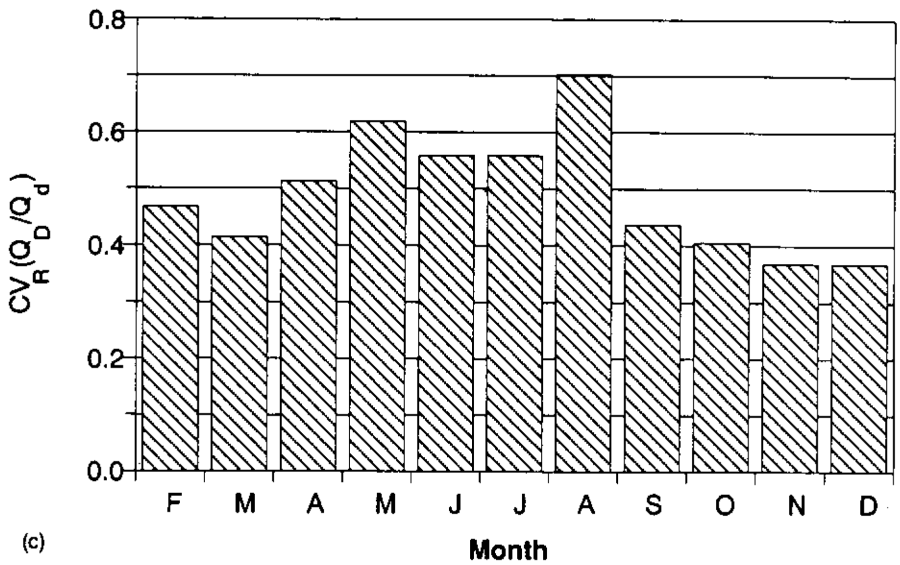
Figure 12. Plots of the spatial averages of (a) P_{AM} and (b) P_{FM} and of (c) $CV_R(Q_D / Q_d)$ for hypothetical system.



(a)



(b)



(c)

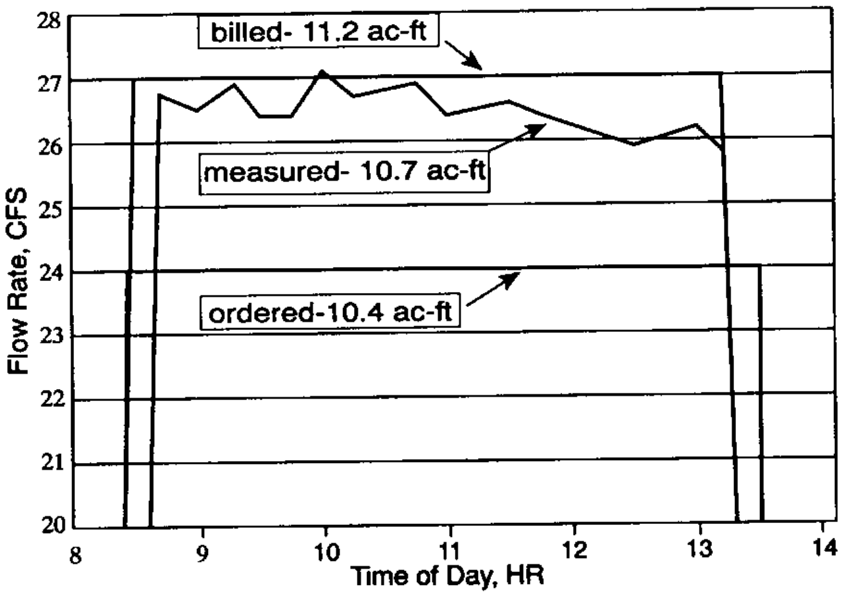
Source: Molden and Gates, 1990.

PALMER

Palmer (1990) describes, in a short and very interesting paper, a study on how well an irrigation district in the United States was able to meet farmer demand. The district serves 55,000 acres (22,267 ha) of farmland through a network of concrete-lined canals. In the study, water deliveries were monitored along two lateral canals and compared to the orders and bills for these events. One monitored lateral was at the upstream end of the district and the other at the downstream end. The two were operated by different ditch riders. The upstream lateral had 10 monitored turnouts while the other had 12. To contrast seasonal operating differences, two 3-month periods were studied and 225 deliveries were recorded, or about 75 percent of all deliveries occurring at these turnouts. An example of the study data is shown in Figure 13.

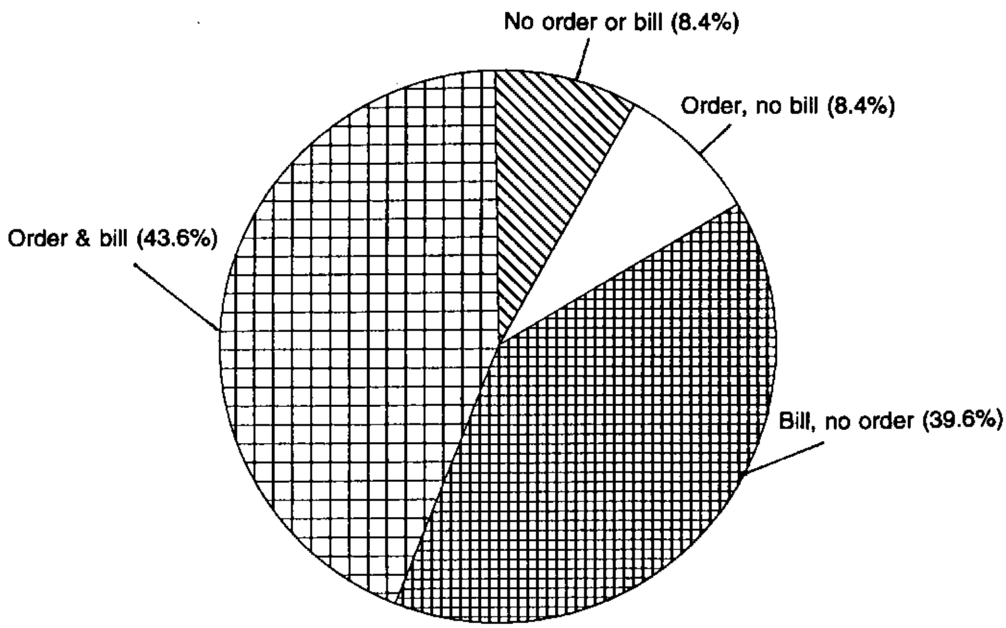
District rules require that farmers order water at least four days before the desired delivery date. The dispatcher collects water orders into reports which the ditchriders use to schedule deliveries. The district does not later compare water orders with actual deliveries or bills. Ditchriders record delivery flows and times on a set of loose cards for the billing department. Bills are sent to farmers twice yearly. An analysis of the data for the two laterals is presented in Figures 14 and 15. These are examples of process indicators that measure the performance of the internal workings of the agency in the water delivery and accounting.

Figure 13. Ordered, measured and billed hydrographs with corresponding volumes, for a single farm delivery.



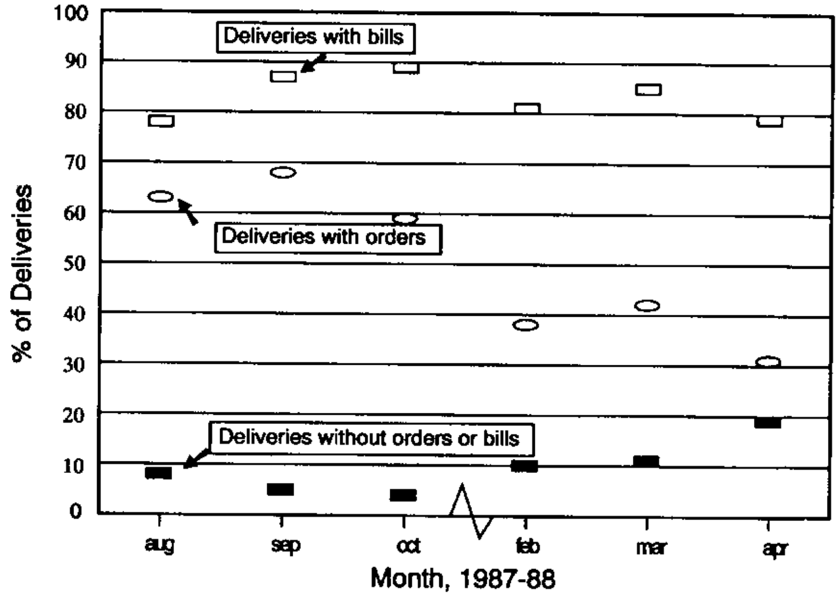
Source: Palmer, 1990.

Figure 14. Percent of measured deliveries with corresponding orders and/or bills, for all data.



Source: Palmer, 1990.

Figure 15. Completeness of accounting for district deliveries, by month, for all data.



Source: Palmer, 1990.

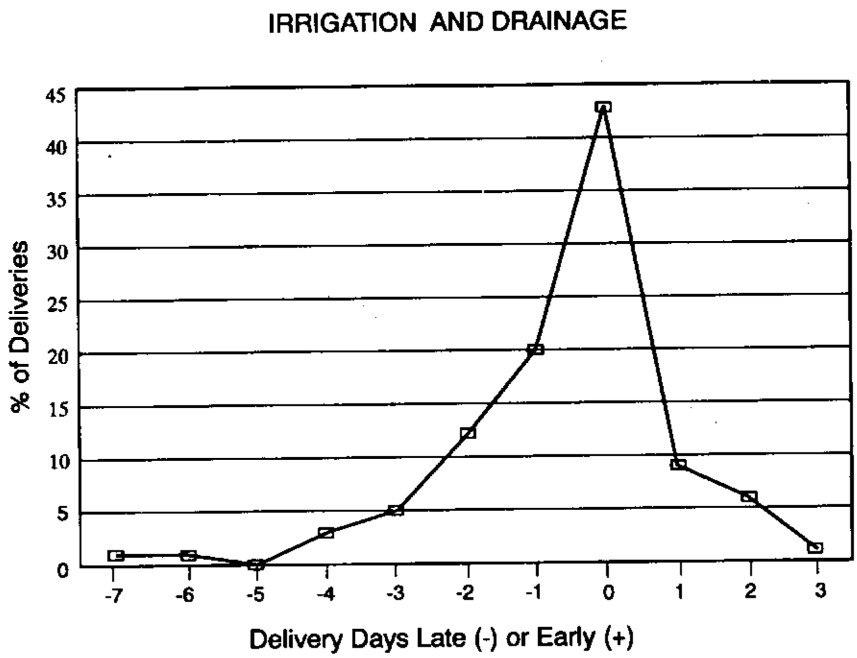
Under district rules, deliveries can be made up to one day earlier or one day later than requested. Timeliness is thus defined as the days between the ordered and the actual delivery dates. Seventy-two percent of deliveries occurred within one day of the ordered date (Figure 16). Figure 17 breaks down the data by lateral and time period.

One measure of how closely the flow provided by the district matches the rate and volume desired by the farmer is the delivery adequacy. For this study, intended flows were assumed to be the same as ordered flows. Adequacy is thus defined as the ratio of volume or average flow rate measured to the volume or flow rate ordered. Figure 18 shows the ranked distribution of adequacy values for those measured deliveries with corresponding orders. Adequacy can also be defined to measure the accuracy of district billing records with respect to deliveries. Bill-based adequacy, then, is the ratio of measured flow rates or volumes to the corresponding billed quantities (Figure 19).

One recommendation of the study is that action research in working districts is needed to devise and test more accurate ordering, scheduling, delivery and billing methods. The paper is instructive for the way the data on timeliness and adequacy are presented to illustrate the performance of the irrigation system under study.

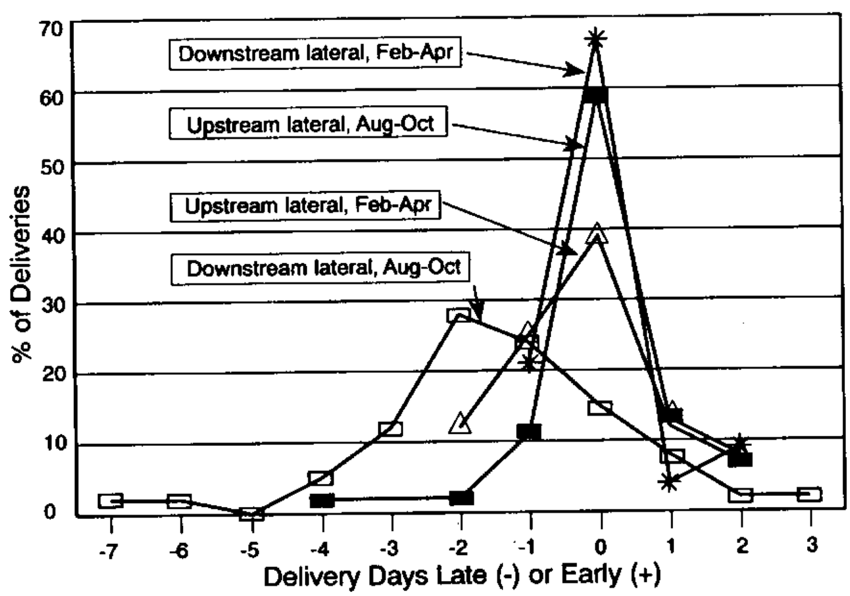
Palmer et al. (1991) also provide a detailed account of the research and analysis of the same case study. Some more insights gathered from the research are also reported in this paper.

Figure 16. Timeliness of deliveries with corresponding orders, days late or early, for all data.



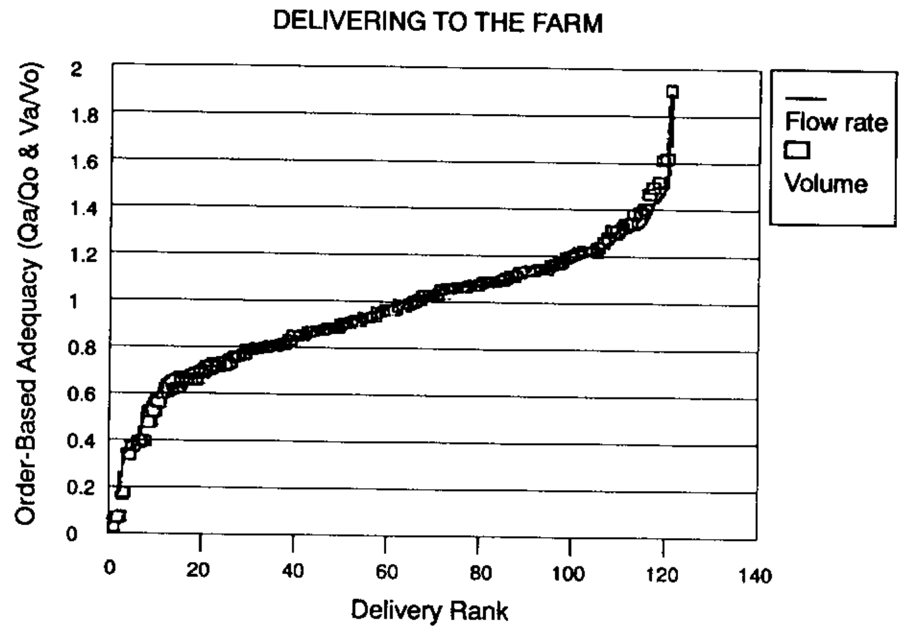
Source: Palmer, 1990.

Figure 17. Timeliness of deliveries with corresponding orders, days early or late, by lateral and time period.



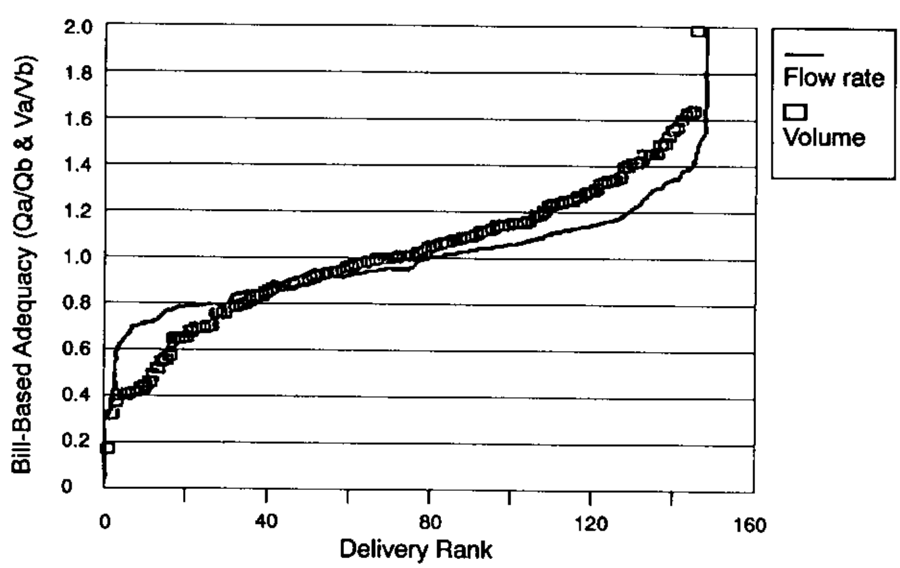
Source: Palmer, 1990.

Figure 18. Order-based adequacy of flow rate and volume for all measured deliveries with corresponding orders.



Source: Palmer, 1990.

Figure 19. Bill-based adequacy of flow rate and volume for all measured deliveries with corresponding bills.



Source: Palmer, 1990.

HYDRAULIC RESEARCH WALLINGFORD

Hydraulic Research Wallingford has been conducting research in collaboration with national irrigation agencies in many countries on performance assessment and improvement of irrigation systems. Some of the results of the research are reported in papers by Weller (1991), Goldsmith and Makin (1991), Makin et al. (1991) and Bird (1991).

Weller

An irrigation water management research program was implemented by Hydraulics Research Wallingford in collaboration with the National Irrigation Administration (NIA) of the Philippines on the Porac Area of Porac Gumain River Irrigation System (PGRIS), (Weller 1991). The objectives of the study were to monitor the response of the main canal network to changes in water availability and assess its capability to deliver crop water requirements to subareas jointly managed by NIA staff and existing Irrigator Associations. The paper presents an analysis of the response of the main system to the varying irrigation demands, and assesses the conjunctive use of groundwater with surface water and the potential of computer models to assist management with the preparation of the annual irrigation schedules.

The paper has some very interesting and useful information on instrumentation for discharge measurement and accuracy of water-level sampling. Initially, manual gauging methods were used in the research but it soon became clear these were not able to detect all the changes in flow, particularly at night. Hence, automatic gauging methods — capacitive water-level sensors, data loggers, and data transfer to cassettes with interrogation by a microcomputer once a week — were introduced. The loggers could record readings at hourly intervals for up to 10 days. One important outcome of the automatic data records was that some estimate of the accuracy of the traditional manual sampling of water levels could be made. Error populations for each sampling rate and for the range of time were generated and an estimate of the errors at the 95 percent confidence level obtained as shown in Figure 20. The findings are surprising. With a sample rate of one reading per day at the head of the Main Canal East, for example, the error in the total discharge computation per day can be as high as 44 percent, and even over a seven-day period it is still 13 percent. This has very important implications when schedules for rotational issues are drawn up.

The performance indicators used in this research included the following:

* Project efficiency and its component efficiencies: conveyance efficiency, distribution efficiency, and field application efficiency as defined in Bos and Nugteren (1990),
* Relative Water Supply (*RWS*),
* Christiansen's coefficient (*UCC*), and
* Specific yield.

Relative Water Supply (*RWS*) is used as an indicator of the adequacy of the irrigation water deliveries and is defined as:

$$RWS = \frac{Irrigation\ Delivery + Effective\ Rainfall}{Evapotranspiration + Seepage\ \&\ Percolation}$$

The use of effective rainfall in the numerator is significant. Levine's (1982) definition of *RWS* uses total rainfall.

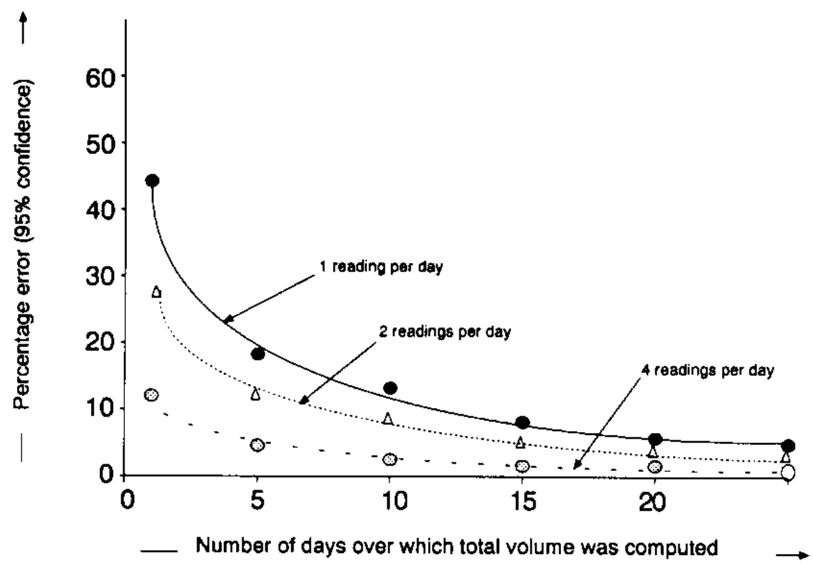
Christiansen's coefficient is used to measure the spatial uniformity of irrigation water distribution. This parameter has the advantage that it is easy to compute, has a finite range, and does not require a distribution to obtain it.

In generalized form it can be expressed as

$$UCC = 1 - \frac{\sum_{1}^{n} (|X_i - \bar{X}|\, a_i)}{(\sum_{1}^{n} a_i)\, \bar{x}}$$

where, X_i = Depth of irrigation delivered to incremental area a_i,
$\bar{X}$ = Mean depth of irrigation water, and
n = Number of incremental areas.

Figure 20. Accuracy of manual gauge reading versus sampling rate.



Source: Weller, 1991.

The maximum value of *UCC* is 1.0 which indicates completely uniform spatial distribution of irrigation water. *UCC* values reported in the study varied between 0.66 and 0.86.

Specific yield† is used for productivity assessment and is defined as the weight of crop per unit volume of water.

$$\text{Specific yield } (\text{kg}/\text{m}^3) = \frac{A_c \bar{Y}}{V_T}$$

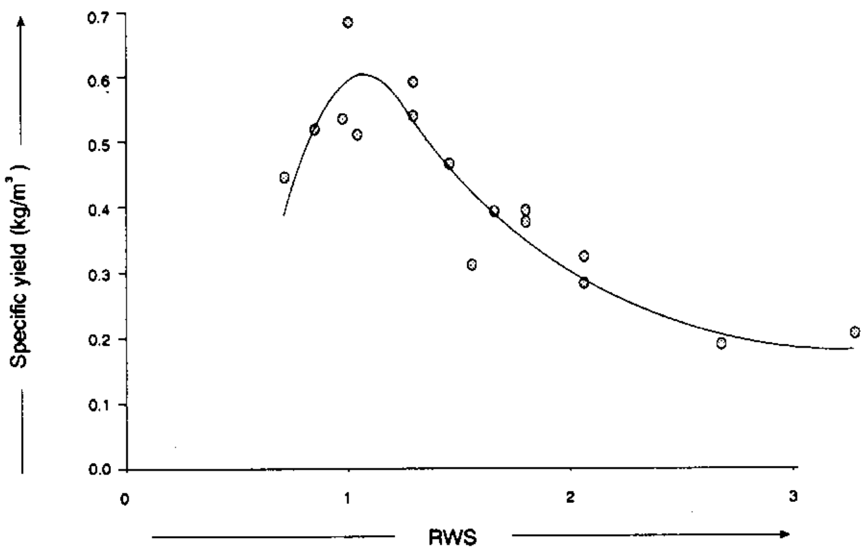
where, Ac = Cropped area (ha),

$\bar{Y}$ = Mean yield (kg/ha), and

V_T = Total volume of water supplied in a season (M^3).

The computed values of specific yield are shown plotted against RWS in Figure 21. The fitted curve in the figure suggests that specific yield in PGRIS attains a maximum value of about 1.1 at RWS. The maximum specific yield recorded was 0.68 kg/m^3.

Figure 21. Specific yield of rice from PGRIS.



Source: Weller, 1991.

† This is the same as Garces' "irrigation-water output" and Mao Zhi's "yield per unit quantity of water."

Goldsmith and Makin

Goldsmith and Makin (1991) describe a recent field study of the performance of a warabandi system in the Indian Punjab and illustrate some of the practical aspects of carrying out a rapid performance assessment. This study was a collaborative project between Hydraulics Research Wallingford and the Irrigation and Power Research Institute, Amritsar.

The field measurement program lasted for 24 days during February and March 1988 in Ferozepur District of Southwest Punjab. The study area included the command areas of two distributaries, Mudki (30,894 ha) and Golewala (28,727 ha). Both distributaries and the majority of water courses had been lined over the past eight years before the study commenced. Measurements were made of flows, losses and water levels in order to give estimates of equity of supply, adequacy of supply, and seepage and conveyance losses at both distributary and watercourse levels.

The study quantifies the performance of the distributaries in terms of water control objectives and conveyance efficiencies. For example, the measured interquartile ratio (IQR) of 1.35 for Golewala Distributary is considered very good in terms of the equity in water distribution; the conveyance efficiency was found to be 53 percent at the time of the study but it was expected that this might fall to 42 percent without improved maintenance of lining. These results are reported to have had an effect on the watercourse lining and maintenance policy in the state.

The paper makes recommendations on what to measure and how to measure. One important recommendation is that all measurements should be planned with due consideration of the need for compromise between speed and accuracy; and that measurements should not interfere with the normal operation of the irrigation system and should try to cover as large a sample of canals and watercourses as practicable in the time available.

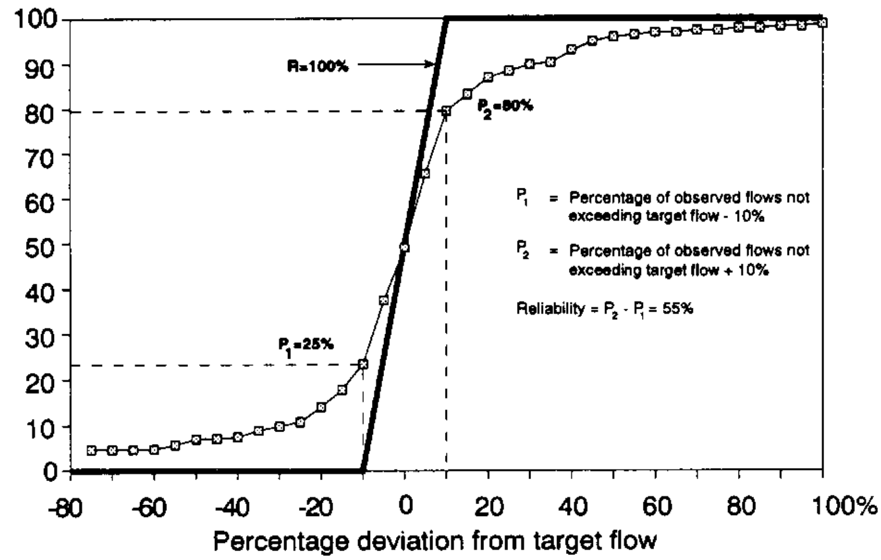
Makin, Goldsmith and Skutsch

Makin et al. (1991) describe the results of a research project initiated in 1987 by the Royal Irrigation Department (RID) in Thailand and Hydraulics Research Wallingford to investigate methods to improve water management at the Kraseio Project in Thailand. The introduction of computer-assisted irrigation scheduling to this 20,000-ha smallholder rice and sugarcane irrigation project has provided an opportunity for continuous performance assessment.

The Kraseio Project has been operated for two seasons, incorporating simple performance indicators, namely: actual versus targeted supply, and equity, reliability and adequacy measures. Over these two seasons, the value of regular feedback of performance information has been demonstrated, in terms of increased awareness by project staff of operating constraints and their ability to quantify project performance. The provision of weekly information on performance is exerting an influence on the management of the system thus enabling timely response to operational problems.

One of the contributions of the paper is the analysis of reliability of flows at the head of one of the canals (IR) as shown in Figure 22. The observed flow is considered reliable if it lies between $\pm$ 10 percent of the target flow. It will be seen that only 55 percent of the observed flows were found to be reliable. The reliability index at the head of the canal is thus defined as 55 percent. The causes of the unreliability are discussed in detail in the paper. Action was taken to alleviate the problem of unreliability.

Figure 22. Typical analysis of reliability from Kraseio (Head 1R Canal).



Source: Makin et al., 1991.

Bird

Bird (1991) reports the results of the collaborative research between Hydraulics Research Wallingford and the Irrigation Department of Sri Lanka in Hakwatuna Oya Irrigation Scheme in Sri Lanka. The paper supports the view that the introduction of monitoring and evaluation of water distribution systems as a part of the day-to-day management activity is a desirable step in the improvement process and can be done at little cost.

One aim of the study was to improve the standards of main system management within the constraints of the existing physical infrastructure through the provision of timely performance data. A microcomputer was installed at the project office to store and analyze rainfall, flow and field wetness data, and to provide performance reports on a regular basis. Early results suggested that the timely processing of an increased level of data collection was effective for both the identification of problems and the quantification of potential for improvement. Particular emphasis was given to providing the necessary software tools and training such that routine monitoring and evaluation became an accepted and sustainable proposition.

The paper makes a good contribution to the analysis of issues involved in deciding on the start and finish dates of the *maha* (wet) irrigation season in the irrigation scheme; that is, the preseason planning. Storage in the reservoir at the end of September and the occurrence of rainfall in September and October are two important factors in the preseason planning. There is generally a tradeoff between waiting for sufficient rain to start land preparation and the penalty of waiting too long thus pushing the end of the season into the warmer and drier months of February and March. Delaying the start of land preparation until the beginning of November would take advantage of the rainfall to "wet up" the system and possibly reduce the land preparation issues by 50 percent. This would, however, be at the expense of additional issues at the end of the season. What would be the net effect of these two factors on the overall saving of water in the reservoir at the end of the season? The paper addresses these issues for the two maha seasons in 1988–89 and 1989–90.

The paper uses coefficient of variation as an indicator to study variability of flows in the Right Bank Canal. It also uses the interquartile ratio (IQR) to express the inequity of water issues from the Right Bank Canal.

VANDER VELDE

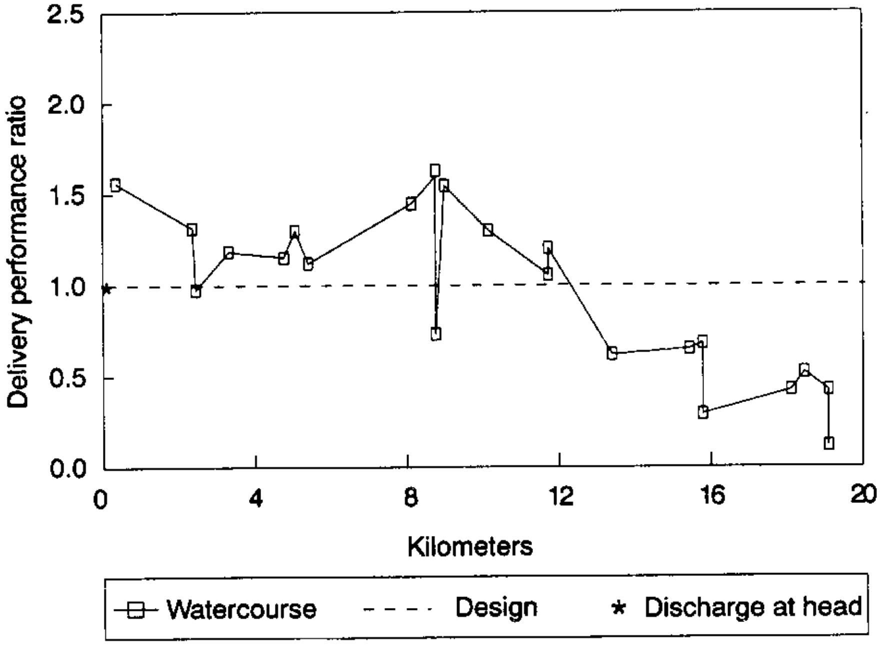
Vander Velde (1991) presents results of research conducted by the International Irrigation Management Institute (IIMI) in the assessment of the performance of selected secondary canals of the Lower Chenab Canal (LCC) System in Pakistan and discusses opportunities for improvement at the distributary level.

The field research has been concentrated in two subdivisions within the command of the Gugera Branch Canal which takes off from the LCC main canal. In Farooqabad Subdivision, Mananwala and Lagar distributaries have been the focus of detailed and sustained performance monitoring and assessment. Mananwala Distributary has a design discharge of 5.24 (m^3/s) and a culturable command area (CCA) of 27,157 ha; and Lagar Distributary has a design discharge of 1.08 (m^3/s) and CCA of 6,578 ha. In Bhagat Subdivision, performance studies were conducted on Pir Mahal Distributary (4.67 m^3/s design discharge and CCA of 14,891 ha) and on Khiki Distributary (9.66 m^3/s design discharge and CCA of 33,119 ha). Farooqabad Subdivision is at the head of the Gugera Branch Canal and Bhagat Subdivision is at the tail end.

The performance indicators used for studying the performance of the distributary canal are: delivery performance ratio (DPR); the interquartile ratio (IQR); and the coefficient of variation (CV).

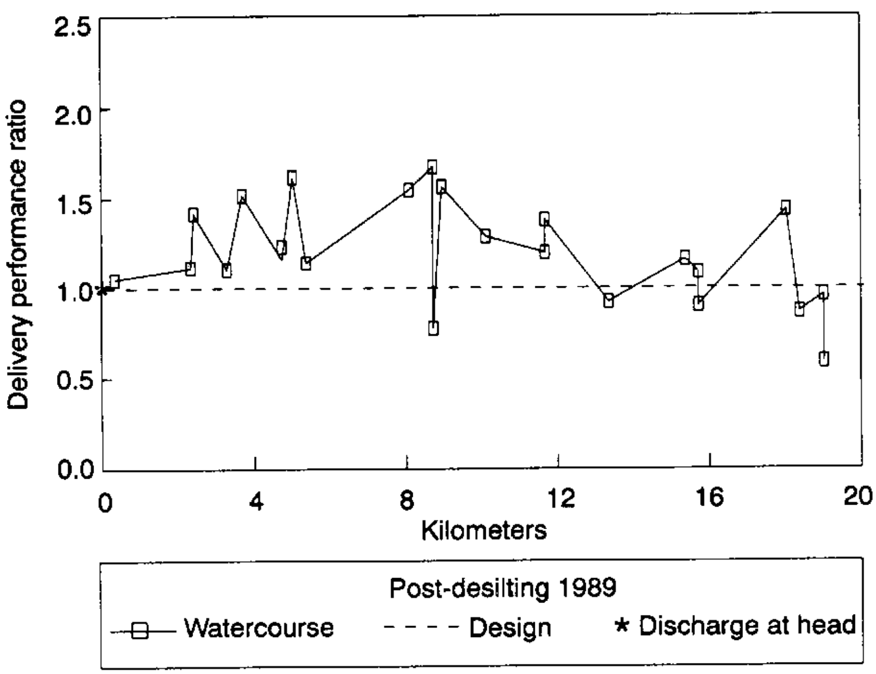
Delivery performance ratio (DPR) is defined as the ratio of actual discharge to design discharge. This is the same as the ratio of actual discharge to intended discharge defined by Clemmens (1990) if the canal is intended to be operated at the design discharge, which is, in fact, the case in the selected distributaries. If the DPR is unity throughout the length of the canal and throughout the season, the canal performance is achieving the expectations intended in the design. The variation of DPR along the Lagar Distributary before and after desilting is shown in Figures 23 and 24, respectively. It shows very clearly the improvement in water distribution equity achieved at the tail end of the distributary after desilting.

Figure 23. Lagar Distributary: Water distribution equity.



Source: Vander Velde, 1991.

Figure 24. Lagar Distributary: Water distribution (Post-desilting, 1989).



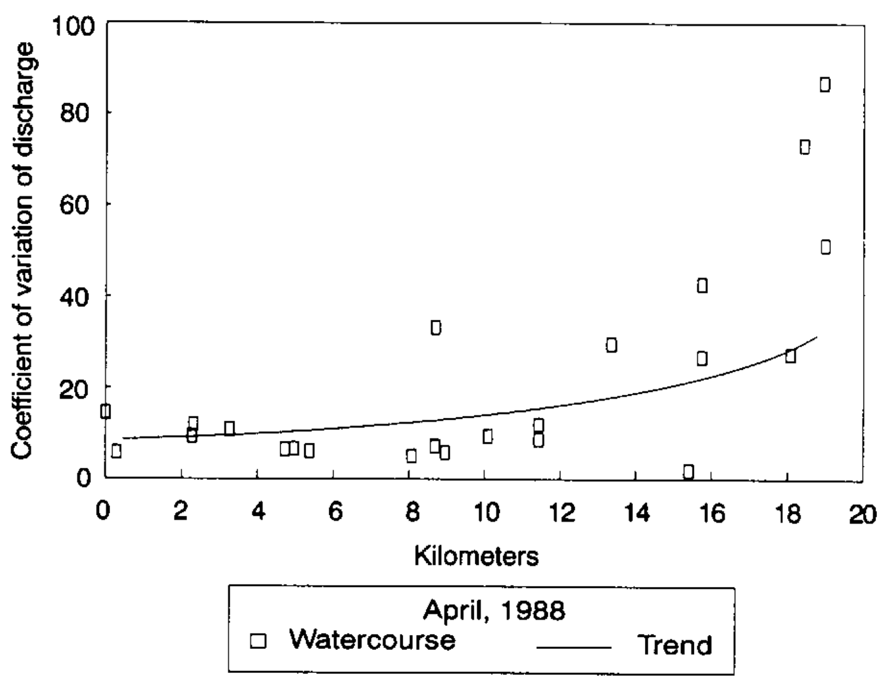
Source: Vander Velde, 1991.

The degree of inequity experienced by irrigators is demonstrated through the interquartile ratio (IQR) suggested by Abernethy (1986). This measure compares the performance of the poorest performing quartile of watercourse outlets to that of the best performing quartile served by the channel. In this study, IQR has been *modified* and applied both for quartile groups comprising all outlets in the Lagar Distributary and for all surveyed outlets in each quartile length along the Pir Mahal Distributary. In either case, the first quartile comprised only outlets located along the upper reach of the distributary and the fourth quartile included only outlets in the tail reach of the distributary. It is claimed that such a distance-based quartile grouping is justified in the context of the observed relationship between the outlet discharge and physical distance between the outlet and the distributary head gate. It has been demonstrated that selective maintenance and desilting in Lagar Distributary improved the water distribution equity and that, under full supply conditions, the IQR between head-end and tail-end outlets was reduced from more than 5:1 to about 1.5:1 or 2:1. It should be emphasized that this version of "modified IQR" is different from Abernethy's version.

The variability of surface water supplied to the heads of outlets along distributaries is indicated by the coefficient of variation (CV) of discharge as shown in Figure 25. The increasing CV indicating increased variability of discharge to outlets with increasing distance from the distributary head is quite pronounced. The relationship is logical and consistent with expectations, especially given the hydraulic conditions of channel flow described in detail in the study.

The paper contains very useful insights and is a significant contribution to the understanding of performance assessment and improvement of large canal systems.

Figure 25. Lagar Distributary: Variability in outlet discharge.



Source: Vander Velde, 1991.

CHAPTER 3

Performance Indicators

THE CHOICE OF performance indicators and other connected issues of importance in studies on performance assessment are discussed in this chapter. It draws upon some of the concepts, methods and procedures summarized in the previous chapter and upon Appendix 2 which provides a systematic list of indicators for various levels of irrigated agriculture systems and the appropriate references.

Small and Svendsen (1990, 1992) discuss the importance of setting goals for an evaluation process, the criteria of evaluation, the levels of evaluation, and the perspectives of different constituents (planning agency, farmers, and managers of irrigation operating agency) on the evaluation based on their respective values and goals. They also discuss the different purposes of performance assessments and the types of performance measures — process, output and impact measures.

It is necessary to emphasize here that the concept of performance is closely linked to the existence of goals and targets for achievement (Seckler et al. 1988; Abernethy 1989). The goals may be explicit or implied; but the choice of any parameter as an indicator of performance is based on the premise that enhancement of that parameter is a desirable thing. The identification of goals is not a simple, objective process. Abernethy (1991) discusses the goals, target setting and institutional context in irrigation organizations and also the indicators of performance.

In this chapter are described the choice of performance indicators and some of the issues that emerge in using them, starting with the irrigation water delivery system and then moving up to the irrigated agriculture system and the agricultural economic system.

WATER DELIVERY SYSTEM

There appears to be reasonable agreement in the literature that irrigation water delivery should be evaluated on the dimensions of adequacy, timeliness, and equity. Sometimes, other terms are also used: efficiency in water use, predictability and reliability of water supply. These are, however, not separate but are associated with adequacy and timeliness. Water quality may be an additional important dimension in some systems.

Indicators of the three characteristics — adequacy, timeliness, equity — should enable us to answer, in respect of any given irrigation system, three questions framed on the following lines (Abernethy 1989):

* To what extent does the quantity of water provided suffice for the growth needs of the crops that are planted?

* Does the timing of the water deliveries match the growth needs of the crops and the expectations of the farmers?

* Is the water distributed fairly among the multiple users of the system?

Adequacy

Irrigation efficiencies as described by Bos and Nugteren (1990) are widely used to assess the efficiency of water supply to meet the crop water requirements. In the study of rice systems, Relative Water Supply (RWS) has also been extensively used and its role as an explanatory variable for studying the implications for system management deserves careful attention. In principle, irrigation efficiency and RWS are the reciprocals of each other.

In actual application of these concepts and methodologies, there are different interpretations and practices. For example, the definition of crop water requirement in the Gezira which includes all field losses below the field outlet pipe differs from the normal definition used in other countries (Plusquellec 1990: 26). This implies a field application efficiency, e_a, of 100 percent. However, the field efficiency defined more traditionally, is estimated at about 75 percent (Plusquellec 1990: 7).

There are questions regarding how to standardize effective rainfall, seepage and percolation losses and salt-leaching requirements. Plusquellec† reports these types of difficulties in assessing the efficiency in the ten projects selected for the study by the World Bank.

There is an urgent need for a consistent definition and approach and a standard practice for adoption. It would be desirable to follow the definitions and practices as suggested and illustrated by the authors of those concepts. Otherwise it becomes difficult to interpret and compare the results of various studies.

Timeliness

There are two quite distinct dimensions included in the question of timing of water deliveries. We can distinguish these by the terms "timeliness" and "reliability." Timeliness means correspondence of water deliveries to crop needs. It can be considered on the basis of the accuracy of fit between two time history curves, one of which represents the evapotranspiration needs of the crop throughout its season, and the other the actual deliveries of water.

Reliability, on the other hand, means the degree to which the irrigation system and its water deliveries conform to the prior expectations of its users. Can the farmer feel certain that he knows whether water will come to his field channel on a given day, and in what rate and quantity it will flow? Reliability is very important, affecting the efficiency of various field activities. It includes the concept of predictability of flows as indicated by a water delivery schedule or operational plan without which the concept of reliability does not make sense.

In projects where the water is delivered on prearranged demand such as in some large-scale projects in Latin America and North America, with water orders placed one to seven days in advance, it is relatively easy to quantify the reliability of water deliveries as shown by Palmer (1990) and Palmer et al. (1991) and illustrated in Figures 15 and 16.

Where the water allocation, distribution, and delivery are supply-based and are controlled and regulated by an irrigation agency, the most important question is whether the agency prepares

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† Comment made at the IFPRI-IIMI Workshop on Irrigation System Performance held at Pangbourne, U.K., in February, 1990.

an operational plan and water delivery schedules to guide its operations of regulation and control, monitors the operations, revises the plans and schedules as needed in a systematic manner, and communicates the revisions to the farmers. If the water delivery schedules exist and are implemented, there should be no difficulty in computing the reliability of supply with respect to time, if not with respect to the quantity of supply. However, if no measurements are made and no records kept, there is no way of knowing if the operation is according to the schedules which exist on paper. In many projects, there is no information on volumes of water delivered at various levels (tertiary, secondary, etc.); and even where it exists, it is often unreliable.

Where the schedules are predetermined or established prior to the start of the season, and consist of time of flow and/or fixed outlets as in the original warabandi systems of Northwest India, a higher reliability with respect to time of delivery exists and can be computed. The system is basically an *administered* one and a proportional sharing of the water resource is implicit. These systems have rigidly fixed schedules which are not changed in response to variations in field conditions. Where there are more abundant water supplies and the operating schedule is varied in response to information from the field, the system is a *managed* one (Levine and Coward 1989).

Questions of operational plans and timeliness are much more complex, given the dynamic nature of the states of the water resource and the irrigation systems. Operational plans depend on the strategies selected and resource allocation and priorities. Even in systems backed by reservoir storage, it is only at the beginning of the "dry" season, when the storage volume is known definitely, that allocation decisions and decisions on extent of cropped area to be irrigated can be made with certainty. In the "wet" season, as the reservoir fills with the progress of the season, allocation and crop planning decisions cannot be made without taking some risk. Even the decision on when the season starts and when it ends — an important dimension of timeliness at a macro level — is not easy to make. Farmers also make their decisions on crop choices and planting dates in the face of uncertainty of occurrence of rainfall and the building-up of storage in the reservoir.

Assumptions made regarding land preparation times and staggering of land preparation by different sections of farmers often prove erroneous and the operational plans and water delivery schedules prepared on the basis of such assumptions do not hold good and must be revised on the basis of information obtained from the field. This emphasizes the need for feedback, communication, and interaction between the farmers and the agency, the ability and the willingness on the part of the agency to be responsive and flexible within a certain range of predetermined parameters, and a physical infrastructure that enables controlled regulation and implementation of the operational decisions made. There should also be a clear policy and understandings on how to cope with shortages in the storage volumes of water if they occur towards the later part of the season. The decision making can become even more complex in diversified cropping systems and in systems involving conflicting water rights.

The burden of the argument is that the timeliness dimension is intricately connected with allocation and distribution issues, which naturally imply issues of adequacy and equity and need to be treated in a more holistic manner than in a disaggregated fashion. However, an operational strategy and water delivery schedule are primary prerequisites to any determination of reliability in supply-based systems. Their existence comprises one of the important *process* indicators of performance.

The contributions of Clemmens (1990) and Molden and Gates (1990) are significant in this regard. The state variables defined and the performance indicators formulated by Molden and Gates serve to locate the causes of underperformance by seeking answers to the following questions:

* How accurate is the preparation of the water delivery schedule with respect to the needs and demands downstream of a particular location (outlet, head of distributary, etc.)?

* Is the physical system capable of delivering the scheduled quantity of water?

* Is the agency capable of operating the system to deliver the water as per the schedule?

The performance indicators given in Table 6 deserve to be applied and tested in a large number of systems for which the necessary data are available. Some well-managed systems in Taiwan and Korea which have regular monitoring systems may provide a source of data for such testing. Another source is field research data of IIMI and others from various country projects, such as the data used by Molden and Gates (1990).

Equity

Levine and Coward (1989) point out that a system that is considered fair by most farmers is more likely to be productive and efficient than one that the state has designed on the basis of productivity and efficiency but which is considered unfair by the farmers. The dynamic nature of the context within which irrigation occurs frequently necessitates changes in physical infrastructure and organizational arrangements, including those which determine system operation and maintenance. Rules and operating procedures are implemented by the use of the physical works as well as by the actions of the controlling agency and the farmers. Thus decisions about the physical structures and procedures of the operating agency and the roles of water users must be made with explicit consideration of their interacting nature.

Equity in water allocation and distribution has different dimensions. In situations where the stored volume of water in the reservoir is not adequate to meet the demands of the full command area over the entire season, the command area may be divided into a number of zones and available water allocated to a few of the zones in such a way that supply and demand are matched. Then, equity in allocations to various zones is sought to be achieved by appropriate rules that govern allocations over a number of seasons or years. This requires good recordkeeping and formal institutional mechanisms involving agency personnel and farmer representatives from various zones.

Seasonal equity of water deliveries in a system can be evaluated by various indicators: Water Delivery Performance (WDP) (Lenton 1984); Modified Interquartile Ratio, IQR (Abernethy 1986); and Theil's Information Measure of Inequality (Sampath 1988). Abernethy's IQR is easy to communicate to agency personnel and is highly recommended. However, it is desirable to test the various measures of inequity in a sample of systems and researchers should examine them in their comparative research to verify their comparative advantages and disadvantages under various field conditions.

Joint Effects

Joint effects of *adequacy* and *timeliness* can be evaluated by indices such as the Water Delivery Performance (WDP) defined by Lenton (1984) or Abernethy's (1986) potential productivity (Figure 19). Both measures can show the joint impact of any shortcomings in adequacy and timeliness in terms of crop loss. Doorenbos and Kassim (1979) have brought together much information on the effects of water deficits at different growth stages for a large number of economic crops. It is not clear, though, how to assess the effects of excess water application and inadequate drainage, especially for a diversified cropping system with many non-rice crops at different stages of growth.

For rice systems, the effects of water shortages and water stress and consequent reductions in yield have been studied by Small et al. (1981), who propose a water shortage index; Wijayaratna (1986) who uses a Water Availability Index (WAI); and Ng (1988) who develops reliability, resiliency, and vulnerability criteria. They are of different degrees of sophistication, and researchers working on the subject should pay close and careful attention to them. Their utility for evaluation at the system level in a cost-effective manner is yet to be established.

IRRIGATED AGRICULTURE SYSTEM

Agricultural Productivity

Agricultural production performance indicators include cropping intensity, ratio of area planted and area harvested, annual yield, productivity of land, and productivity of water. The importance of particular indicators depends on the relative scarcity of land and water, and the cropping patterns and sequences — monocrop or mixed cropping. The units of measurement also vary. For a monoculture of rice, tons/ha and kg/m^3 are useful. For mixed crops, productivity needs to be expressed in monetary terms, i.e., dollars/ha or $dollars/m^3$ of water. These indicators are easier to compute from generally available data than the indicators of water delivery performance.

Cropping intensity is not a very clear parameter of the level of utilization of the installed irrigation capacity in the context of a movement towards more complex and diversified crop systems where perennial and long-duration crops may be mixed with short-term crops (Abernethy 1990). One suggestion made at the IFPRI-IIMI seminar in Washington in March 1991 related to devising a more suitable indicator than cropping intensity. The alternative indicator suggested was "percent of time in a potential growing season that a field has a crop (or crops) on it."

Focusing on systems in which water is the scarce resource, annual yield per hectare and the productivity per unit of water delivered at the head of the system give a good picture of the performance with respect to production. As Levine (1990) points out, agricultural production information, particularly if it can be obtained with reasonable distribution over the command area of the system, can provide an index of the 'health' of the system, if not its 'illness.' For example, if the production information indicates that production is high by comparison to similar nonirrigated areas, and the distribution is reasonably uniform, i.e., a high mean and low standard deviation, and productivity with respect to water is similarly high, one might conclude that not too much could be wrong with the irrigation component of the combined irrigation/agriculture system, and further investment to improve the irrigation system is unlikely to have a high payoff. Agricultural production information can thus be used as a powerful screening device, as well as for long-term performance monitoring.

AGRICULTURAL ECONOMIC SYSTEM

Economic indicators of the profitability of agricultural operations to the farmer as well as to the general economy of the country can be obtained from:

i. Gross revenue from crop production,

ii. Gross value added,

iii. Net income for the farmer, and

iv. Average labor productivity.

Net income for the farmer depends on whether he is an owner-operator working on his own land (and maybe, with his own tractor) or a tenant, and on the contribution of his family labor to the total labor component. These are, of course, very much compounded and affected by government policies on prices and subsidies for both inputs and outputs, and terms of trade between agricultural and nonagricultural sectors of the economy. International comparisons are also affected by currency exchange rates and their fluctuations and necessary corrections need to be incorporated. Therefore, performance at this level may not be closely related to the performance of the irrigation system.

The *financial* viability of the organization operating and maintaining the irrigation system, whether it is a public agency or otherwise, is indicated by its success in cost recovery, which includes: i) O & M costs; ii) income from irrigation water charges and other revenues, if any; and iii) the consequent degree of self-sufficiency and financial autonomy (Mao Zhi 1989). These are system-level and process indicators of the irrigation system (discussed below).

OTHER INDICATORS

Social Indicators

Social viability and social impact questions are very important but complex, covering all levels of irrigated agriculture. Conceptual understanding, a prerequisite for identifying meaningful performance indicators, is primitive. The irrigation management literature contains only a few contributions in this area.

As noted above, Garces (1983) proposes two qualitative descriptors for an indicator he calls "response" with reference to the "human subsystem" of irrigation:

Response capacity (RC) seeks to measure the preparedness and versatility of project staff to plan, address and resolve day-to-day operation and management of the system.

Farmers' satisfaction (FS) refers to the degree of satisfaction of farmers with the services provided by the irrigation system.

Chambers identifies a set of potential social benefits of irrigation which could be measured by specific indicators (Chambers 1988: 19–46; especially Figure 2.1). Improved irrigation results directly in higher farm output and higher labor demand. These in turn have a set of impacts on the well-being of people directly affected by irrigation which include: less out-migration to towns; better housing; better nutrition; better health (less sickness); better access to goods; and improved ability to purchase basic goods. He cites one study in eastern India that documented how increased employment reduced the need to migrate for jobs, and because of this stability people were sending their daughters to school for the first time — thus linking irrigation with female education!

The relationship between irrigation management and gender relations is an important area on which research is only beginning. What are the differential impacts of irrigation on women and men and how can these be measured? Many social characteristics have no direct relationship to irrigation, or when present they constitute a relationship that is so tenuous and complicated by other intervening systemic variables that they are not very useful for the purpose of assessing *irrigation* performance — as important as they may be for a wider study of irrigated agriculture. The existing case studies show complex and site-specific chains of causation, making it difficult to identify performance indicators that would be of broad or general significance.

† This section was prepared by Douglas J. Merrey; it is similar to a section on this question discussed in a paper currently in preparation at IIMI.

In view of the lack of development in this area, we suggest using a limited number of performance indicators for social viability at this point. We propose two types of indicators, "social capacity," and "social impacts." Some potential indicators for these are as follows:

Social capacity. This refers to the social (as distinguished from physical, biological, or economic) capacity of the people and organizations for managing and sustaining the irrigated-agriculture system. The suggested indicators are closely related to *process* indicators. Possible indicators include:

* Response capacity (Garces),
* Degree of farmer involvement in system management,
* Effectiveness and legitimacy of farmer organizations, and
* Ratio of level of knowledge vis-a-vis what is required given a person's role (i.e., farmers, gate operators, managers).

The data for these indicators can be obtained through careful sample surveys.

Social impacts. This refers to the effects on people, their well-being, social organization, and livelihoods of irrigation. They are therefore a type of *impact* indicators. Measurements can include comparisons of irrigated and adjacent nonirrigated areas, variation over time and space within the irrigated area, and variations among socioeconomic classes. Possible indicators include:

* Farmer satisfaction (as measured by surveys, distributions and volume of complaints against the agency, disputes among farmers, etc. [Garces]),†
* Employment generation (comparison of number of days per ha, relative wages, farmers' incomes),
* Quality of housing, ownership of basic consumer items,
* Nutritional and health status, with emphasis on water-borne diseases,
* Migration patterns,
* Gender relations (work loads, access to resources, independent incomes), and
* Access to resources (land tenure, availability of alternative employment).

The data for these indicators can be obtained relatively easily from existing sources, or through sample surveys.

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† Uphoff et al. (1990) describe a useful indicator called "Water Problem Index (WPI)" that is more sophisticated than Garces' measure, while still simple to use (Douglas J. Merrey, personal communications).

Sustainability Indicators

Ascertaining the likely sustainability of a system over time requires determining the variation with respect to time (seasons, years, etc.) of key indicators, tracing the secular trends and understanding the processes causing these trends. Assessment of time-dependent variation of adverse effects like waterlogging or salinity is important for monitoring a system's physical sustainability. Smedema (1990) describes the process by which irrigation development may induce waterlogging and salinization of land and how these are to be taken into account in an irrigation performance assessment. Suitable waterlogging and salinity indicators, to be used as performance assessment standards, are generally available for assessing common agricultural damage: water-table depth, soil salinity concentration in the root zone, and abandoned area.

Waterlogging and salinity damage can, to a large extent, be controlled by adequate drainage. Much of the waterlogging and salinization of irrigated land is due to the fact that such drainage measures were not provided at the project development stage, or were not provided when the problems started to emerge, or when provided, are not adequately designed or maintained. Therefore, coverage of waterlogging and salinity trends in an irrigation performance assessment requires that both the irrigation and drainage facilities be assessed.

Sustainability has many dimensions including effective institutions and we are yet to identify the most appropriate indicators. They will probably be more country-specific and project-specific.

Systemic Descriptors and Process Indicators

Systemic descriptors and process indicators are useful to evaluate the management and its functioning within the socioeconomic environment and governmental policies. Some of these indicators can be seen in Mao Zhi (1989), and the World Bank reports on performance (Plusquellec 1989). These descriptors and indicators are important in any effort to explain the causes of a system's output and impact; they are, however, measures of neither.

The process indicators of financial viability of the agency operating the system are among the most important and have been referred to in an earlier section. Many more process indicators governing a system's structure, its systems and procedures, degree of professional skills of the staff, and the style of functioning of the agency, can conceivably be formulated, and should form an important area for future research.

In addition to process indicators, other useful descriptors of the system concern the number of persons employed in an agency at the management level and in the operations and maintenance for, say, 1,000 ha of command area, or 1,000 farm units, or 1,000 farmers. It is important to look at these figures in relation to the complexity of controls in the system and the density of structures and facilities, like distribution and field channels, drainage channels and service roads. The sizes of the farm units are also important factors in interpreting these figures.

CHAPTER 4

Conclusion: Proposed Minimum Set of Indicators for Screening Problem Systems

A PRINCIPAL OBJECTIVE of the current studies on performance assessment is to facilitate the development of a consensus on a limited set of performance indicators that irrigation agencies concerned with irrigation management in developing countries could incorporate in their monitoring and evaluation and also in their research and development efforts to improve irrigation performance.

If irrigation management agencies use Small and Svendsen's conceptual framework for assessment of irrigation performance and develop goals for the evaluation process, delineate the boundaries of the systems, set targets for achievement, and monitor the performance, it should be possible to select a minimum set of indicators for assessing performance. Such a minimum set would serve a *screening purpose* to indicate broadly whether the system is performing very well, or moderately well, or below acceptable levels. In case it is believed that the system is not performing well, more detailed investigations would be necessary to diagnose the problems affecting the system and to identify measures and interventions that would improve the performance of the system. This would need a different set of indicators more appropriately determined for the purpose of diagnostic analysis and presumably for the following phase of action research.

This means that we need one common and limited set of performance measures for screening purposes, which might also serve the purpose of broad comparative studies, and separate sets of more detailed measures specific to the system for diagnosis and improvement.

The minimum or limited sets of indicators should be such that they are determined routinely in the monitoring and evaluation function of the system's planning and operation. Such minimum sets have, in fact, been suggested and discussed by Abernethy (1989, 1991) and FAO (1991).

Two considerations govern the choice of a minimum set. First, the set should provide adequate information to assess over seasons and years the performance of the water delivery system, agricultural production, and returns to farmers and the broader economy without excessive demands on data collection and hence cost of obtaining the information. Second, the set should contain as few indicators as possible. There is an obvious tradeoff involved in the choice of the set. After some years of experience in the use of the proposed minimum set of indicators in assessing performance of irrigation systems of different types in a variety of situations, researchers and managers might consider revisions to the proposed minimum set necessary and desirable.

Based on the review of literature, the following indicative minimum set of performance indicators is proposed:

Performance of the water delivery system (quality of irrigation services)

* Delivery performance ratio,

* Relative water supply (especially for rice) or irrigation efficiencies for conveyance and distribution,

* Modified interquartile ratio,

* Reliability of water delivery as predicted by a delivery schedule, and

* Fluctuations in groundwater levels.

Performance of the irrigated agriculture system

* Yield per unit land compared to nearby rain-fed land (average and standard deviation),

* Yield per unit water, and

* Percent of time in a potential growing season that a field has a crop (or crops) on it.

In the case of diversified cropping systems, the productivity values will need to be expressed in monetary terms; for monocrop systems, the values should be in both kilograms and monetary terms.

Performance of the irrigated agricultural economic system

* Profitability to farmers — net (income) return per unit land, and

* Profitability of the system — net return on investment in the irrigation system.

It is possible to start with a small sample of observations and data collection and increase the sample size in case of high variability. Even small samples can give very useful information. Most Third World irrigation systems lack adequate data on water deliveries, as illustrated in the World Bank studies on performance. It would be impossible to measure the performance of the quality of irrigation service without measurements of water flows.

It would be ideal if generalizable standards of performance could be suggested. However, there is such a wide range of variations among systems and the conditions under which they operate that the only practical approach is to set standards for specific systems. Small and Svendesen (1992) provide a useful discussion of types of performance standards.

This suggests that we urgently need to develop a process of working with system managers to help them articulate the objectives and criteria relevant to assessing the performance of specific systems, and demonstrate the utility of the minimum set of indicators to assess performance. Preparation of such performance assessment case studies in close collaboration with irrigation agencies should receive high priority in both national and international research on irrigation performance.

References

Abernethy, C.L. 1986. Performance measurement in canal water management. ODI-IIMI Irrigation Management Network Paper 86/2d.

Abernethy, C.L. 1989. Indicators of the performance of irrigation water distribution systems. Symposium on the Performance Evaluation of Irrigation Systems. 23 November 1989. Colombo: IIMI.

Abernethy, C.L. 1991. Indicators and criteria of the performance of irrigation systems. In FAO, Improved Irrigation System Performance for Sustainable Agriculture. Proceedings of the Regional Workshop organized by FAO in Bangkok, Thailand. 22–26 October 1990. Rome: FAO.

Abernethy, C.L. 1993. Measurement of reliability in irrigation water delivery systems. Lecture presented at the 3rd annual workshop of the Network on Irrigation Management for Crop Diversification in Rice-Based Systems, Dhaka, Bangladesh, 8 February 1993. Colombo: IIMI.

Bird, J. D. 1991. Introducing monitoring and evaluation into main system management — A low investment approach. Irrigation and Drainage Systems 5:43–60.

Bos, M.G. and J. Nugteren. 1990. On irrigation efficiencies. 4th edition [1st edition 1974]. Wageningen: International Institute for Land Reclamation and Improvement/ILRI Publication 19.

Bos, M. G.; W. Wolters; A. Drovandi and J. A. Morabito. 1991. The Viejo Retamo Secondary Canal — Performance evaluation case study: Mendoza, Argentina. Irrigation and Drainage Systems 5:77–88.

Chambers, R. 1988. Managing canal irrigation: Practical analysis from South Asia. Oxford and IBH Publishing Co., New Delhi.

Clemmens, A.J. 1990. Understanding delivery performance before rehabilitation, irrigation, and drainage. In Proceedings of the 1990 National Conference; Steven C. Harris (ed.). American Society of Civil Engineers.

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

Doorenbos J. and A.H. Kassam. 1979. Yield response to water. FAO Irrigation and Drainage Paper 33.

FAO 1991. Improved irrigation system performance for sustainable agriculture. Proceedings of the Regional Workshop held in Bangkok in 22–26 October, 1990. Rome: FAO.

Garces, C. 1983. A methodology to evaluate the performance of irrigation systems: Application to Philippine national systems. Unpublished Ph.D. thesis, Cornell University, Ithaca, New York, U.S.A.

Goldsmith, H. and I. W. Makin 1991. A comparison of two methodologies for assessment of irrigation performance under the warabandi system. Irrigation and Drainage Systems 5:19–29

Heermann, D. F.; W. W. Wallender and M. G. Bos. 1990. Irrigation efficiency and uniformity. In Management of Farm Irrigation Systems; G. J. Hoffman, J. A. Howell and K. H. Solomon (eds.). American Society of Agricultural Engineers. Pages 125–149.

Holmes, D.W. 1983. Irrigated rice land, a program to compute water requirements. Report O D 53. Wallingford, England: Hydraulics Research.

Jensen, M.E. (ed.). 1974. Consumptive use of water and irrigation water requirements. Report of Technical Committee on Irrigation Water Requirements. American Society of Civil Engineers. Irrigation and Drainage Division.

Jensen, M.E. (ed.). 1983. Water requirements. Chapter 6 in Design and operation of farm irrigation systems. ASAE Monograph No. 3. American Society of Agricultural Engineers.

Lenton, R.L. 1984. A note on monitoring productivity and equity in irrigation systems. In Productivity and equity in irrigation systems; Niranjan Pant (ed.). Ashish Publishing House.

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

Levine, G. 1990. Some reflections on irrigation performance evaluation. A note presented at the IFPRI-IIMI Workshop on Irrigation System Performance at Pangbourne, U.K. in February 1990.

Levine, G. and E. Walter Coward, Jr. 1989. Equity considerations in the modernization of irrigation systems. ODI-IIMI Irrigation Management Network Paper 89/2b.

Makin, I. W.; H. Goldsmith and J. C. Skutsch. 1991. Ongoing performance assessment — A case study of Kraseio Project, Thailand. Irrigation and Drainage Systems 5:31–42.

Malhotra, S.P.; S.K. Raheja and David Seckler. 1984. A methodology for monitoring the performance of large-scale irrigation systems: A case study of the warabandi system of northwest India. Agricultural Administration 17:231–259.

Mao Zhi. 1989. Identification of causes of poor performance of a typical large-sized irrigation scheme in south China. Asian Regional Symposium on the Modernization and Rehabilitation of Irrigation and Drainage Schemes. Published by Hydraulics Research. Wallingford, England; Asian Development Bank, and National Irrigation Administration of the Philippines.

Merriam, J.L.; M.N. Shearer and C.M. Burt. 1983. Evaluating irrigation systems and practices. In Design and operation of farm irrigation systems; M. E. Jensen (ed.). ASAE Monograph No. 3. American Society of Agricultural Engineers.

Molden, David J. and Timothy K. Gates. 1990. Performance measures for evaluation of irrigation water delivery systems. Journal of Irrigation and Drainage Engineering, ASCE 116 (6):804–823.

Ng, Poh-kok. 1988. Irrigation systems performance monitoring and evaluation: Reliability, resiliency and vulnerability criteria for assessing the impact of water shortage on rice yield. IIMI Review 2(1):12–16.

Palmer, Joel D. 1990. Delivering appropriate quantities of water to the farm. In Irrigation and Drainage, Proceedings of the 1990 National Conference; Steven C. Harris (ed.). American Society of Civil Engineers.

Palmer, J. D.; A. J. Clemmens; A. R. Dedrick; J. A. Replogle and W. Clyma. 1991. Delivery system performance case study: Wellton — Mohawak irrigation and drainage district, U.S.A. Irrigation and Drainage Systems 5:89–109.

Plusquellec, Hervé L.; 1989. Two irrigation systems in Colombia: Their performance and transfer of management to users' associations. WPS 264. Agriculture and Rural Development Department. The World Bank, Washington, D.C., U.S.A.

Plusquellec, Hervé L. 1990. The Gezira Irrigation Scheme in Sudan: Objectives, design and performance. Technical Paper No. 120. The World Bank, Washington, D.C., U.S.A.

Plusquellec, Hervé L.; Kathryn Mc Phail and Christian Polti. 1990. Review of irrigation system performance with respect to initial objectives. Irrigation and Drainage Systems 4:313–327.

Sampath, Rajan K. 1988. Equity measures for irrigation system performance evaluation. Water International 13:25–32.

Seckler, David; R.K. Sampath and S.K. Raheja. 1988. An index for measuring the performance of irrigation management systems with an application. Water Resources Bulletin 24(4):855–860.

Small, L.E.; C. Capule and M. Oallares. 1981. An index to evaluate the effects of water shortage on the yield of wetland rice. IRRI Research Paper no. 70.

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

Small, L.E. and Mark Svendsen. 1992. A framework for assessing irrigation performance. Working Paper on Irrigation Performance 1. Washington, D.C. International Food Policy Research Institute.

Smedema, L. K. 1990. Irrigation performance and waterlogging and salinity. Irrigation and Drainage Systems 4:367–374.

Smith, Laurence E. D. 1990. An economist's perspective on irrigation performance assessment: With examples from large-scale irrigation in Morocco. Irrigation and Drainage Systems 4:329–343.

Svendsen, Mark and L.E. Small. 1989. A framework for assessing irrigation system performance. Symposium on the Performance Evaluation of Irrigation Systems. 23 November 1989. Colombo: IIMI.

Uphoff, Norman; M. L. Wickremasinghe and C. M. Wijayaratna. 1990. "Optimum" participation in irrigation management: Issues and evidence from Sri Lanka. Human Organization 49 (1):26–40.

Vander Velde, Edward J. 1991. Performance assessment in a large irrigation system in Pakistan: Opportunities for improvement at the distributary level. Improved Irrigation System Performance for Sustainable Agriculture. Proceedings of the Regional Workshop organized by FAO, 22–26 October 1990, Bangkok. Rome: FAO.

Weller, James A.; Edilberto B. Payawal and Salvador Salandanan. 1989. Performance assessment of the Porac River Irrigation System. Asian Regional Symposium on the Modernization and Rehabilitation of Irrigation and Drainage Schemes. Hydraulics Research Ltd., Wallingford, England; Asian Development Bank and National Irrigation Administration of the Philippines.

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

Wijayaratna, C.M. 1986. Assessing irrigation system performance: A methodological study with application to Gal Oya Scheme, Sri Lanka. Ph.D. thesis, Cornell University, Ithaca, New York, U.S.A.

Appendix 1

Case Studies of Two Irrigation Systems in Colombia:
Their Performance and Transfer of Management to Users' Associations

Chief Characteristics of Coello and RUT Irrigation Districts.

	COELLO	RUT
A. GENERAL		
Climate		
– Classification	Humid tropic	Humid tropic
– Average annual rainfall	1,350mm	1,123mm
– Average annual temperature	27.6° C	28.5° C
Water supply		
– Source	Rio Coello	Cauca River
– Flow	Unregulated	Unregulated
– Average annual flow	452 Mm^3	10,110 Mm^3
– Groundwater quality	C2S1-C3S1	C3S1
Registered irrigation area	27,187 ha	9,742 ha
Irrigated soils	Colluvial	Alluvial
Main crops	Rice, cotton, sorghum	Cotton, soya, sorghum, pasture
Land tenure		
– Number of farms	1,681	1,857
– Average farm size	16.2 ha	5.7 ha
– Total area of farms smaller than 5 ha (as % of total)	5%	19%,
– Total area of farms smaller than 20 ha (as % of total)	29%	50%
– Areas affected by agrarian reform (as % of total)	5%	1%
No. of water users' associations		
District management	USOCOELLO	HIMAT

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	COELLO	RUT
B. SYSTEM DESCRIPTION		
Type diversion structure	Gravity Side-intake	Pumping station 4 x 1.7m^3/sec
Irrigation system		
Main canals	91.3 km	75.5 km
Secondary canals	78.8 km	51.3 km
Tertiary canals	80.0 km	–
Total	250 km	126.8 km
No. of measuring devices	81	16
Transit capacity of main system	25.0 m^3/sec	13.8 m^3/sec
Farm outlets	990	350
Capacity of drainage system		
Main drains	21.5 km	26. km
Secondary drains	–	76.7 km
Tertiary drains	–	41.6 km
Total	21.5 km	144.3 km
Pumping station	–	2
Access roads	177 km	350 km
Present condition of components		
Diversion structure	Fair	–
Pumping stations	–	Medium
Main canals	Fair	Fair to poor
Distribution system	Fair	Fair to poor
Drainage system	Fair	Medium
Access roads	Good	Good
Hydromechanical equipment	Good	Fair

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C. ACTUAL PROJECT PERFORMANCE		
– System of water allocation and distribution	Prearranged demand	Prearranged demand
– Advance notice needed for water delivery	1 day	2 to 3 days
– Conveyance and distribution efficiency	65.1%	67.6%
– Field application efficiency	(45%)[a]	(65%)
– Overall efficiency	(30%)[a]	(42%)
– Average annual water diverted	15,900m^3	3,830m^3
– Average annual water delivered	10,360m^3	2,600m^3
– Water delivered for rice per season	14,000m^3	–
– Flexibility of water distribution	Satisfactory	Satisfactory
– Reliability of water distribution	Satisfactory	Questionable
– Method of water measurement	(Visual estimate	(Visual estimate)
– Environmental impact		
. Waterlogging	No	500 ha affected
. Salinization	No	500 ha affected
. Silt	Medium[b]	

Notes: [a] High silt content but effective desilting devices.
[b] Author's estimate.

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	COELLO	RUT
D. OPERATION AND MAINTENANCE		
Number of district employees		
– Operations	19	20
– Maintenance	60	54
– Administration	18	10
Total	97	84
Net registered area per O & M employee	280 ha	115 ha
Number of ditchriders	6	6
Net irrigated area per ditchrider	4,531 ha	1,623 ha
No. of farms per ditchrider	280	309
Farm turnouts per ditchrider	165	58
Operations activities	Good	Satisfactory
Maintenance activities	Good	Medium
O & M estimated cost (1987)		
(Col$ thousands)	211,107	132,840
(US$ thousands)	844.4	531.4
Actual costs of water distribution (Col$/ha)	7,764	13,635
(US$/ha)	31.05	54.5
Average cost of water delivered at farm turnouts (US$1,000/$m^3$)	3	21
Water charges (1988)		
• fixed rate (Col$/ha)	2300 - 2500	10,000
(US$/ha)	7.7 - 8.3	33.3
• volumetric rate		0.52
(Col$/$m^3$)	0.52	1.68
(US$1,000/$m^3$)	1.73	5.6
Collection rate for water fees	100% (1987)	106% (1986)
Cost recovery (1987)	86.9%[c]	76.5%

Notes: [c] The 13.1 difference is covered by other district revenues.
Source: Plusquellec, 1990.

Appendix 2

List of Performance Indicators

Performance indicators used in the publications reviewed in this paper are classified in this section. It is meant to help clarify the types of indicators used for various systems in the framework of Small and Svendsen (1990, 1992), and identify the authors of publications who used them.

1. IRRIGATION WATER DELIVERY SYSTEM	AUTHORS WHO DEVELOPED OR USED INDICATORS (IN THIS REVIEW)
A. *Adequacy*	
(i) Irrigation efficiencies	Mao Zhi, Clemmens, Molden and Gates, Bos and Nugetem, Plusquellec, Weller, Goldsmith and Makin
(ii) Relative water supply for rice system — sometimes modified using effective rainfall in place of total rainfall.	Levine, Garces, Weller
B. *Reliability*	
(i) Reliability of flow rates	Palmer, Makin et al.
(ii) Reliability of volumes	Palmer, Palmer et al.
(iii) Reliability of timeliness or dependability	Molden and Gates, Palmer, Plusquellec
C. *Equity of distribution*	
(i) Interquantile ratio (I_1)	Abernethy, Goldsmith and Makin, Bird, Vander Velde
(ii) Interquantile ratio (modified IQR - I_2)	Abernethy
(iii) Spatial uniformity of depth of water on the field-	Merriam et al., Weller
Christiansen's coefficient or distribution uniformity	Merriam et al., Weller
(iv) Spatial uniformity of ratio of the delivered amount to the required or scheduled amount measured by coefficient of variation (CV)	Molden and Gates
(v) Flow distribution proportional to area	Garces
(vi) Delivery performance ratio (DPR) or its reciprocal and its variation along a canal	Bos et al., Vander Velde
(vii) Theil's measure of inequality	Sampath
D. *Variability of flows at outlets (turnouts) along canals coefficient of variation (CV)*	Bird, Vander Velde
E. *Operational performance - Delivery performance ratio (DPR) or its reciprocal*	Clemmens, Clemmens et al., Molden and Gates, Bos et al., Vander Velde

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F. Delivery schedule performance	Clemmens, Clemmens et al., Molden and Gates, Bos et al.
G. Joint effects of adequacy and timeliness (i) Water delivery performance (ii) Relative yield	 Lenton Abernethy
H. Efficiency of land preparation	Garces, Bird
2. IRRIGATED AGRICULTURE SYSTEM	
A. Cropping intensity, area utilization	Mao Zhi, Garces, Plusquellec
B. Productivity per unit of land (monocropped systems) Yield : Rain-fed-based Yield : Potential-based Yield : Top yielders-based Yield per unit area	 Garces Garces, Abernethy Garces Mao Zhi
C. Productivity per unit of water (monocropped systems)	Mao Zhi, Garces, Weller
D. Equity of production distribution over area	Garces
3. AGRICULTURAL ECONOMIC SYSTEM	
A. Performance indicators for economics of crop production (i) Irrigation benefit per unit area (ii) Irrigation benefit per unit of irrigation water	 Mao Zhi Mao Zhi
B. Cost of water delivery and cost recovery (i) Average cost of water delivered at farm turnouts (ii) Water charges (fixed rate per unit of land or volumetric rate) (iii) Income from irrigation water charges (iv) Percentage of financial self-sufficiency (percentage of O & M costs recovered)	 Plusquellec Plusquellec Mao Zhi, Garces Mao Zhi, Garces, Plusquellec
C. Project economic rate of return	Plusquellec et al.
4. SOCIAL INDICATORS OF PERFORMANCE (i) Response capacity of the agency (ii) Farmer satisfaction	 Garces Garces

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5. ENVIRONMENTAL IMPACTS AND SUSTAINABILITY OF THE SYSTEM	
(i) Waterlogging and monitoring groundwater levels	Garces, Plusquellec, Bos et al., Smedema
(ii) Salinization and soil toxicities	Garces, Plusquellec, Smedema
(iii) Irrigation water quality	Garces
6. SYSTEMIC AND PROCESS INDICATORS	
(i) Area provided with field irrigation and drainage system and efficiency of facilities in good condition	Mao Zhi, Plusquellec Plusquellec
(ii) Number of employees in O & M etc.	Mao Zhi, Garces, Plusquellec
(iii) Financial self-sufficiency and cost recovery	