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Research Report

Indicators for Comparing Performance of Irrigated Agricultural Systems

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and Wim H. Kloezen

International Water Management Institute

Research Reports

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Contents

Summary

A set of comparative performance indicators is defined, which relates outputs from irrigated agriculture to the major inputs of water, land, and finance. Nine indicators are presented with the objective of providing a means of comparing performance across irrigation systems. These indicators require a limited amount of data that are generally available and readily analyzed. Results of application of the indicators at 18 irrigation systems are presented and large differences in performance among systems are shown. In spite of uncertainties in estimation of indicators, the large differences discerned by the indicators justify the approach taken.

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Introduction

With increasing population and demand for food, sustainable production increases from irrigated agriculture must be achieved. With limited freshwater and land resources, and increasing competition for these resources, irrigated agriculture worldwide must improve its utilization of these resources. Few would disagree with these statements, yet we do not have a way of determining the present state of affairs with respect to irrigated agriculture. The question—how is irrigated agriculture performing with limited water and land resources?—has not been satisfactorily answered. This is because we have not been able to compare irrigated land and water use to learn how irrigation systems are performing relative to each other and what the appropriate targets for achievement are.

With the many variables that influence performance of irrigated agriculture, including infrastructure design, management, climatic conditions, price and availability of inputs, and socioeconomic settings, the task of comparing performance across systems is formidable. However, if we focus on commonalties of irrigated agriculture—water, land, finances, and crop production—it should be possible to see, in a gross sense, how irrigated agriculture is performing within various settings.

This report presents IWMI's "comparative" indicators and experience with their use, based on application across several irrigation systems. At this stage, it is hypothesized that through the use of these indicators, we are able to document and compare key performance attributes of irrigation systems. If so, then it should be possible to compare performance across irrigation systems in a number of settings to understand where we presently stand with respect to productive utilization of land and water, to compare relative performance of systems, and to identify where performance can be improved.

Performance Indicators for Comparison

It is useful to consider an irrigation system in the context of nested systems to describe different types and uses of performance indicators (Small and Svendsen 1992). An irrigation system is nested within an irrigated agricultural system, which in turn can be considered part of an agricultural economic system. For each of the systems, process, output, and impact measures can be considered. Process measures refer to the processes internal to the system that lead to the ultimate output, whereas output measures describe the quality and quantity of the outputs where they become available to the next higher system.

Performance is assessed for a variety of reasons: to improve system operations, to assess progress against strategic goals, as an integral part of performance-oriented management, to assess the general health of a system, to assess impacts of interventions, to diagnose constraints, to better understand determinants of performance, and to compare the performance of a system with others or with the same system over time. The type of performance measures chosen depends on the purpose of the performance assessment activity.

Many authors have proposed indicators to measure irrigation system performance as summarized by Rao (1993) and have given examples of their use at particular irrigation systems (Bos and Nugteren 1974; Levine 1982; Abernethy 1986; Seckler, Sampath, and Raheja 1988; Mao Zhi 1989; Molden and Gates 1990; Sakthivadivel, Merrey, and Fernando 1993; Bos et al. 1994). But, there are very few examples of cross-system comparisons or analyses (Bos and Nugteren 1974; Murray Rust and Snellen 1993; Merrey, Valera, and Dassenaike 1994) Recent studies have attempted to standardize these indicators to allow for better comparison across systems (Bos et al. 1994). We are presently at a state in the development of performance assessment of irrigation where we have a limited number of case studies with intensive measurements of performance, and few examples of studies of performance across irrigation systems.

Much of the work to date in irrigation performance assessment has been focused on internal processes of irrigation systems. Many internal process indicators relate performance to management targets such as timing, duration, and flow rate of water; area irrigated; and cropping patterns. A major purpose of this type of assessment is to assist irrigation managers to improve water delivery service to users. Targets are set relative to objectives of system management, and performance measures tell how well the system is performing relative to these targets. When the performance is not adequate, either the process must be changed to reach the target, or the target itself must be changed. These "internal" indicators aid irrigation system managers to answer the question "Am I doing things right?" (Murray-Rust and Snellen 1993).

We could conclude, although it would be premature, that these internal indicators do not lend themselves well to cross-system comparison. This is due to several reasons. First, internal processes of irrigation systems vary widely from system to system, so that performance indicators are tailored to meet system-specific needs. Second, indicators related to irrigation processes tend to be data-intensive and it is often difficult, time-consuming, and expensive to obtain complete data sets. Third, assumptions about relations between internal processes and outputs may not be valid. It is often assumed that meeting a target will improve output in terms of agricultural production or net benefit to farmers.

An approach to cross-system comparison is to compare outputs and impacts of irrigated agriculture. "External" indicators are used to relate outputs from a system derived from the inputs into that system. They provide little or no detail on internal processes that lead to the output. For example, the critical output of an irrigation system is the supply of water to crops. This output in turn is an input to a broader irrigated agricultural system where water combined with other inputs, leads to agricultural production. As irrigated agriculture always deals with water and agricultural production it should be possible to develop a set of external indicators for cross-system comparison.

The purpose of this study is to present and apply a set of external and other comparative performance indicators that will allow for comparative analysis of irrigation performance across irrigation systems. The indicators reveal general notions about the relative health of the irrigation system, yet they are not too data-intensive to discourage widespread and regular application. Data requirements to calculate the minimum set of indicators are given in annex 1. Such a set of indicators potentially has several purposes. The indicators will allow for comparison between countries and regions, between different infrastructure and management types, and between different environments, and for assessment over time of the trend in performance of a specific project. They will allow an initial screening of systems that perform well in different environments, and those that do not. They will allow for both assessing impact of interventions and managers to assess performance against strategic, long-term objectives.

Features of the Selected Indicators

IWMI's minimum set of external indicators was originally presented by Perry (1996). The indicators have been widely field-tested and slightly amended, resulting in this present list. The intent of presenting this set of indicators is to allow for cross-system performance. Some of the features of the indicators are:

- The indicators are based on a relative comparison of absolute values, rather than being referenced to standards or targets.
- The indicators relate to phenomena that are common to irrigation and irrigated agricultural systems.
- The set of indicators is small, yet reveals sufficient information about the output of the system.
- Data collection procedures are not too complicated or expensive.
- The indicators relate to outputs and are bulk measures of irrigation and irrigated agricultural systems, and thus provide limited information about internal processes.

This set of indicators is designed to show gross relationships and trends and should be useful in indicating where more detailed study should take place, for example where a project has done extremely well, or where dramatic changes have taken place. This approach differs from that of using ratios of actual to target in that the interpretation of these ratios relative to performance is not always clear (e.g., if the target value is 1, is 0.9 better than 1.1?) . A relative comparison of values at least allows us to examine how well one system is performing in relation to others. And, if we have enough samples, this approach may ultimately allow us to develop standards and targets. The main audience for these external indicators comprises policy makers and managers making long-term and strategic decisions, and researchers who are searching for relative differences between irrigation systems while the main audience for internal indicators comprises irrigation system managers interested in day-to-day operations where ratios of actual to target values may be quite meaningful.

As water becomes a limiting resource, an important question that arises is:

What is the value of irrigated agricultural production per unit of water consumed from the hydrological cycle?

Answering this question requires an indicator that measures the contribution of the irrigation activity to the economy in relation to consumption of the increasingly scarce resource, water. Answering this question also requires better understanding than we often have of cropping activities—the output component of the basic indicator, and water balances which indicate the input. The basic indicators here are the output of irrigated agriculture per unit land and per unit water.

The Indicators

Nine indicators are developed related to the irrigation and irrigated agricultural system. The main output considered is crop production, while the major inputs are water, land, and finances.

Indicators of Irrigated Agricultural Output

The four basic comparative performance indicators (see box) relate output to unit land and water. These "external" indicators provide the basis for comparison of irrigated agriculture performance. Where water is a constraining resource, output per unit water may be more important, whereas if land is a constraint relative to water, output per unit land may be more important.

1. $$\text{Output per cropped area}\left(\frac{\$}{ha}\right) = \frac{\text{Production}}{\text{Irrigated cropped area } (A_{cropped})}$$

2. $$\text{Output per unit command}\left(\frac{\$}{ha}\right) = \frac{\text{Production}}{\text{Command area } (V_{div})}$$

3. $$\text{Output per unit irrigation supply}\left(\frac{\$}{m^3}\right) = \frac{\text{Production}}{\text{Diverted irrigation supply } (V_{div})}$$

4. $$\text{Output per unit water consumed}\left(\frac{\$}{m^3}\right) = \frac{\text{Production}}{\text{Volume of water consumed by ET } (V_{consumed})}$$

where,

Production is the output of the irrigated area in terms of gross or net value of production measured at local or world prices (see below),

Irrigated cropped area is the sum of the areas under crops during the time period of analysis,

Command area is the nominal or design area to be irrigated,[1]

Diverted irrigation supply is the volume of surface irrigation water diverted to the command area, plus net removals from groundwater, and

Volume of water consumed by ET is the actual evapotranspiration of crops.

Output per unit of irrigation water supplied and output per unit of water consumed are derived from a general water accounting framework (Molden 1997). The water consumed in equation 4 is the volume of process consumption, in this case evapotranspiration. It is important to distinguish this from another important water accounting indicator—output per unit total consumption, where total consumption includes water depletion from the hydrologic cycle through process consumption (ET), other evaporative losses (from fallow land, free water surfaces, weeds, trees), flows to

[1]For example, consider an irrigated area that nominally is to serve 1,000 ha. During the rainy season, 800 ha are irrigated, and during the dry season, 400 ha are irrigated. In this case, the irrigated cropped area is 1,200 ha. The command area is 1,000 ha.

sinks (saline groundwater and seas), and through pollution (Keller and Keller 1995; Seckler 1996).

We are interested in the measurement of production from irrigated agriculture that can be used to compare across systems. If only one crop is considered, production could be compared in terms of mass. The difficulty arises when comparing different crops, say wheat and tomato, as 1 kg of tomato is not readily comparable to 1 kg of wheat. When only one irrigation system is considered, or irrigation systems in a region where prices are similar, production can be measured as net value of production and gross value of production using local values.

The Standardized Gross Value of Production (SGVP) was developed for cross-system comparison as obviously there are differences in local prices at different locations throughout the world. To obtain SGVP, equivalent yield is calculated based on local prices of the crops grown, compared to the local price of the predominant, locally grown, internationally traded base crop. The second step is to value this equivalent production at world prices. To do this we are presently using World Bank prices for 1995 (see annex 2 for the list). This should not be adjusted for free on board/cost insurance freight and internal transport since we are interested in the productivity of irrigation, rather than the efficiency of markets, transport system, and project location.

For example, if the local price of tomato is three times the local price of wheat, we consider the production yield of 10 tons/ha of tomato to be equivalent to 30 tons/ha of wheat. Total production of all crops is then aggregated on the basis of 'wheat equivalent' and the gross value of output is calculated as this quantity of wheat multiplied by the world market price of wheat. The point of this is to capture local preferences—for example, specialized varieties that may have a low international price, but are locally highly valued—and also to capture the value of non-traded crops.

$$SGVP = \left(\sum_{crops} A_i Y_i \frac{P_i}{P_b} \right) P_{world}$$

where,

$SGVP$ is the standardized gross value of production,

Y_i is the yield of crop i,

P_i is the local price of crop i,

P_{world} is the value of the base crop traded at world prices,

A_i is the area cropped with crop i, and

P_b is the local price of the base crop.

It could be argued that the indicator should be net value added rather than gross. There are two reasons to work with the gross figure. First, it is far easier to measure—many of the deductions that must be made to get from gross to net value added are susceptible to distortions (subsidies and taxes on inputs, credit, and irrigation services, for example) or otherwise very difficult to measure (appropriate prices for family labor, and the opportunity cost of land and water). Second, we note that the most common indicator of agricultural performance (yield per unit land, or more commonly just 'yield') is itself a gross indicator, unqualified by indications of input levels, soil type, or even variety. Despite this simplicity, yield serves many agriculturists as a fundamental indicator of performance.

Other Comparative Indicators

Five additional indicators were identified in this minimum set for comparative purposes. These are meant to characterize the individual system with respect to water supply and finances.

Relative water supply as presented by Levine (1982) and relative irrigation supply as developed for this indicator set (Perry 1996) are used as the basic water supply indicators:

5. $$\text{Relative water supply} = \frac{\text{Total water supply}}{\text{Crop demand}}$$

6. $$\text{Relative irrigation supply} = \frac{\text{Irrigation supply}}{\text{Irrigation demand}}$$

where,

Total water supply = Surface diversions plus net groundwater draft plus rainfall.

Crop demand = Potential crop ET, or the ET under well-watered conditions. When rice is considered, deep percolation and seepage losses are added to crop demand.

Irrigation supply = Only the surface diversions and net groundwater draft for irrigation.

Irrigation demand = The crop ET less effective rainfall.

Relative irrigation supply is the inverse of the irrigation efficiency presented by Bos (1974). The term *relative irrigation supply* was presented to be consistent with the term relative water supply, and to avoid any confusing value judgements inherent in the word *efficiency*.

Both RWS and RIS relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how tightly supply and demand are matched. Care must be taken in the interpretation of results: an irrigated area upstream in a river basin may divert much water to give adequate supply and ease management, with the excess water providing a source for downstream users. In such circumstances, a higher RWS in the upstream project may indicate appropriate use of available water, and a lower RWS would actually be less desirable. Likewise, a value of 0.8 may not represent a problem, rather it may provide an indication that farmers are practicing deficit irrigation with a short water supply to maximize returns on water.

The water delivery capacity (WDC) is given below:

7. $$\text{Water delivery capacity (\%)} = \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}}$$

where,

Capacity to deliver water at the system head = The present discharge capacity of the canal at the system head, and

Peak consumptive demand = The peak crop irrigation requirements for a monthly period expressed as a flow rate at the head of the irrigation system.

Water dilivery capacity is meant to give an indication of the degree to which irrigation infrastructure is constraining cropping intensities by comparing the canal conveyance capacity to peak consumptive demands. Again, a lower or higher value may not be better, but needs to be interpreted in the context of the irrigation system, and in conjunction with the other indicators.

Financial Indicators

Two financial indicators that are used are given below:

8. $$\text{Gross return on investment (\%)} = \frac{\text{SGVP}}{\text{Cost of irrigation infrastructure}}$$

9. $$\text{Financial self-sufficiency} = \frac{\text{Revenue from irrigation}}{\text{Total O\&M expenditure}}$$

where,

Cost of irrigation infrastructure considers the cost of the irrigation water delivery system referenced to the same year as the SGVP,

Revenue from irrigation, is the revenue generated, either from fees, or other locally generated income, and

Total O&M expenditures are the amount expended locally through O&M plus outside subsidies from the government.

Policy makers are keenly interested in the returns to investments made. Similarly, researchers would like to be able to recommend systems that yield acceptable returns within a given environment. Large irrigation investments are made in irrigation infrastructure, thus returns compared to investment in infrastructure are presented here. We focus on water delivery infrastructure to be able to analyze differences between various types of delivery systems such as structured, automated, lined, and unlined canal sections. Infrastructure related to river diversions, storage, and drainage is not included here, because of the desire to be able to compare different methods of water delivery. Also, diversion and storage works often serve other nonirrigation purposes so their costs cannot be entirely allocated to irrigation. The cost of the distribution system can either be estimated from original costs, or estimated by using present costs of similar types of infrastructure development.

Financial self-sufficiency tells us what percent of expenditures on O&M is generated locally. If government subsidizes O&M heavily, financial self-sufficiency would be low, whereas if local farmers through their fees pay for most of the O&M expenditures, financial self-sufficiency would be high. Financial self-sufficiency does not tell us the O&M requirement, only the expenditures. A high value of financial self-sufficiency does not automatically indicate a sustainable system as the O&M expenditures might be too low to meet the actual maintenance needs.

Application

The minimum set of external indicators proposed by IWMI was tested in 18 systems, or parts of irrigation systems located in 11 countries: Burkina Faso, Colombia, Egypt, India, Malaysia, Mexico, Morocco, Niger, Pakistan, Sri Lanka, and Turkey. The sites are those at which IWMI is involved through either their field offices or collaborative efforts with research partners. The major features of the systems used for computing the indicators are indicated in table 1. These features suggest that the data used for computation come from a wide range of agro-climatic regions and systems having different characteristics, crops and cropping patterns, water distribution patterns, water resource availability, and management style.

Data on water supply, agriculture, revenue, and irrigation costs were collected. Most of the data used for analysis are survey data derived from official statistics and measurements or collected and compiled by IWMI and collaborating scientists working in different countries. Although much of the data used comes from secondary sources such as irrigation departments, agricultural departments, revenue departments, and state statistical departments, IWMI has put in much effort by way of initiating survey and field observations to acquire reliable data and to check the secondary data for their consistency. The actual data collection procedures adopted in different countries are documented in IWMI's country reports. Table 2 gives the results of the performance indicators computed for 18 schemes throughout the world.

SGVP Per Unit Command

The SGVP per unit command varies between US$679 and $2,888 per ha with a variation ratio of 1 to 4.25 (figure 1). The systems at the low end of the spectrum (less than US$1,500/ha) are those which mostly grow rice with low cropping intensity. Middle range values of SGVP per ha (US$1,500 to $2,000) are produced by those which grow rice with high cropping intensity of the order of 200 percent. Those at the high end (US$2,000/ha and above) include orchards, industrial crops, and some cereals. These initial results indicate that the two important factors contributing to higher gross value of output per unit command are the cropping intensity of rice and the type of crop grown, especially those of orchards and industrial crops.

SGVP Per Unit Cropped Land

The SGVP per unit cropped land, in figure 2, presents two broad classes of irrigation systems. Rice producing irrigation systems have their gross value of output per unit cropped land roughly equal to US$1,000 and below while systems producing non-rice crops including industrial and orchard crops have their gross value of production per unit crop land between $2,000 and $3,500. This parameter between these two types of systems varies between a ratio of 1:2 and 1:3.5. In other words, non-rice producing irrigation systems can be more productive than the rice producing irrigation system by 100 to 200 percent.

SGVP Per Unit Irrigation Supply

The SGVP per unit irrigation supply in figure 3 varies between a ratio of 1 and 15 and can be grouped into three classes. Purely rice-based systems give a gross value of output per unit volume of irrigation water varying between US$0.04 and $0.10. Irrigation systems which grow rice during rainy

TABLE 1.
Salient features of the studied irrigation schemes.

No.	Country	System name	Type of system	Command area (ha)	Cropping pattern	Climate	Cropping intensity	Annual rainfall (mm)	Annual evaporation (mm)	Type of manage-ment	Water availability
1	Burkina Faso	Gorgo	Tank storage	50	Rice, potato, Tomato, bean	Sudano	0.93	400 to 1,200	2,600	Village cooperatives	Water-short systems
2		Mogtedo	Village irrigation scheme	93		Sahelian	2.00				
3		Savili	Pumping scheme	42		Agroclimatic zone	0.94				
4	Colombia	Coella	Diversion	25,600	Rice, maize, sorghum	Temporate and tropical	1.01	1,000 to 1,500	1,800	Transferred to WUAs	Water-short
5		Saldana	Diversion	13,975	Fruit and vegetables		1.61				Water-abundant
6		Samaca	Storage	3,000	Onion and potato		1.60	700	1,100		Sufficient water
7	Egypt	Nile Delta	Storage	3,100,000	Wheat, maize, Rice, sorghum, Egyptian cloves, Cotton	Arid	2.00	10 to 500	–	Agency-managed	Sufficient surface water, groundwater, drainage water
8	India	Mahi Kadana	Storage-cum-groundwater (conjunctive use)	212,000	Rice, wheat, Tobacco, banana, Vegetables	Semiarid	1.20	823	1,700	Agency-managed	Abundant
9	Malaysia	Muda	Storage	96,000	Rice-rice	Humid	2.00	2,000	1,800	Agency-managed	High rainfall but insufficient stored surface water
10	Mexico	Alto Rio Lerma	Storage system	107,541	Wheat, sorghum, maize and bean. Underground water used for wheat, vegetables, alfalfa	Moderate Subhumid	0.66	700	–	Transferred to WUA	Surface Water-short project
		Cortazar Module	1,714 deep wells	18,848			0.70				
		Salavatierra Module	(conjunctive use)	15,897			0.46				
11	Morocco	Triffa Scheme	Storage and pumping	36,060	Orchards, sugarbeet, Potato, wheat	Semiarid Mediterranean	1.00 150–450	Average 300	–	Agency-managed	Water-short
12	Niger	Saga	Pumping from river	407	Rice	Arid	1.85	300 to 550		Agency-managed	Water-sufficient
13		Kourani Baria I	Pumping from river	425	Rice		1.76				
14		Kourani Baria II	Pumping from river	268	Rice		1.69				
15	Pakistan	Chishtian sub-division	Storage-cum-groundwater	70,656	Cotton, rice	Arid	1.20	200 mm	Agency-	Water-short managed	
16	Sri Lanka	Nachchaduwa	Storage	2,539	Rice, chili, soybean, Vegetables, onion,	Semiarid	2.00	981	2,000	Joint management	Water-short
17		Rajangana	Storage	5,909	Rice		2.00	500 to 1,800 Average 750	2,000	– do –	Water-abundant
18	Turkey	Seyhan	Storage	120,200	Maize, cotton, oranges, and many others	Mediterranean	0.86	620		Transferred	Water-abundant

TABLE 2.
Performance indicators computed for 18 systems throughout the world.

Country	System	Year	Output / unit cropped land ($/ha)	Output / unit command ($/ha)	Output / unit irrigation supply ($/m^3)	Output / unit water consumed ($/m^3)	Gross return on investment %	Financial self-sufficiency %	Relative water supply Ratio	Relative irrigation supply Ratio	Water-delivery capacity Ratio
Burkina Faso	Gorgo	1992/93	1,205	1,065	0.10	0.91	9	42	1.6	3.5	3.5
	Mogtedo	1992/93	1,204	2,499	0.09	0.14	21	79	1.4	2.7	2.1
	Savili	1992/93	3,085	2,652	0.37	0.80	33	–	2.5	2.6	2.9
	Gorgo	1994/95	771	679	0.08	0.12	6	35	1.9	2.7	3.5
	Mogtedo	1994/95	1,403	2,384	0.11	0.15	20	78	1.4	2.5	2.1
	Savili	1994/95	2,348	2,281	0.28	0.62	29	28	2.5	2.6	2.9
Colombia	Coella	1993	1,290	1,303	0.14	0.20	24	114	1.8	1.8	2.2
	Saldana	1993	1,125	1,811	0.12	0.17	33	127	2.2	2.9	3.2
	Samaca	1993	1,472	2,462	0.63	0.34	36	109	1.2	1.1	1.7
Egypt	Nile Delta	1993/94	1,510	2,594	0.12	0.11	26	–	1.6	1.6	1.3
India	Mahi Kadana	1991/92	605	515	0.04	0.03	30	–	3.9	3.0	2.9
	Mahi Kadana	1995/96	916	893	0.07	0.06	52	53	2.7	2.5	2.6
Malaysia	Muda	1994/95	1,021	2,041	0.38	0.10	59	–	0.8	0.4	–
Mexico	Alto Rio Lerma										
	Surface + Public wells	1994/95	2,227	1,464	0.18	0.24	28	80	2.2	3.3	5.1
	Private wells	1994/95	3,220	2,242	0.26	0.37	64	–	1.9	2.5	–
	Cortazar Module										
	Surface + Public wells	1994/95	2,615	1,827	0.22	0.25	33	133	2.1	2.3	1.2
	Private wells	1994/95	3,626	2,888	0.26	0.48	66	–	2.2	2.6	–
	Salvatierra Module										
	Surface + Public wells	1994/95	2,117	974	0.10	0.27	27	101	4.1	4.8	2.4
	Private wells	1994/95	1,863	703	0.14	0.23	75	–	2.3	4.5	–
Morocco	Triffa Scheme, Sec. 22	1994/95	1,087	1,358	0.27	0.34	–	47	1.3	1.1	–
Niger	Saga	1993/94	1,389	2,592	0.12	0.13	–	139	2.2	1.8	–
	Kourani Baria I	1994	827	1,460	0.05	0.17	–	–	2.9	2.4	–
	Kourani Baria II	1994	1,107	1,879	0.06	0.11	43	–	2.2	1.7	–
Pakistan	Chishtian sub-division	1993/94	384	477	0.04	0.05	–	40	1.3	1.2	0.8
Sri Lanka	Nachchaduwa	1994/95	826	1,544	0.04	0.08	34	–	2.0	2.2	–
	Rajangana	1994/95	967	1,934	0.06	0.11	43	–	–	–	3.3
Turkey	Seyhan	1996/97	2,167	2,526	0.21	0.19	108	88	2.07	2.15	2.62

FIGURE 1.
Standardized gross value of production per unit command.

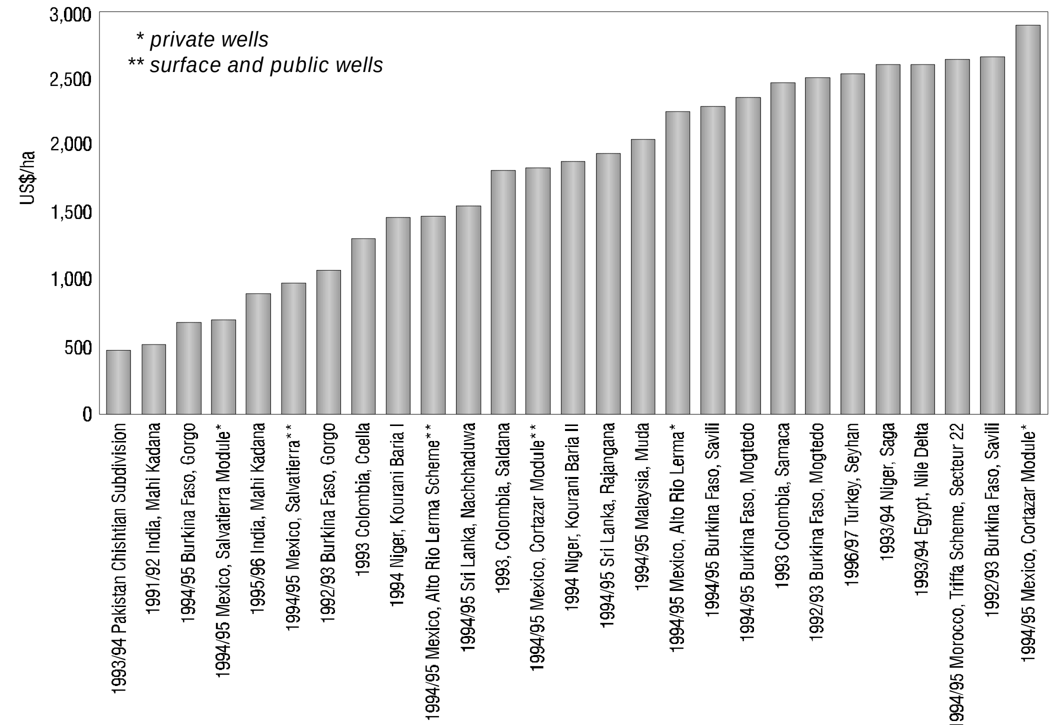


FIGURE 2.
Standardized gross value of production per unit cropped land.

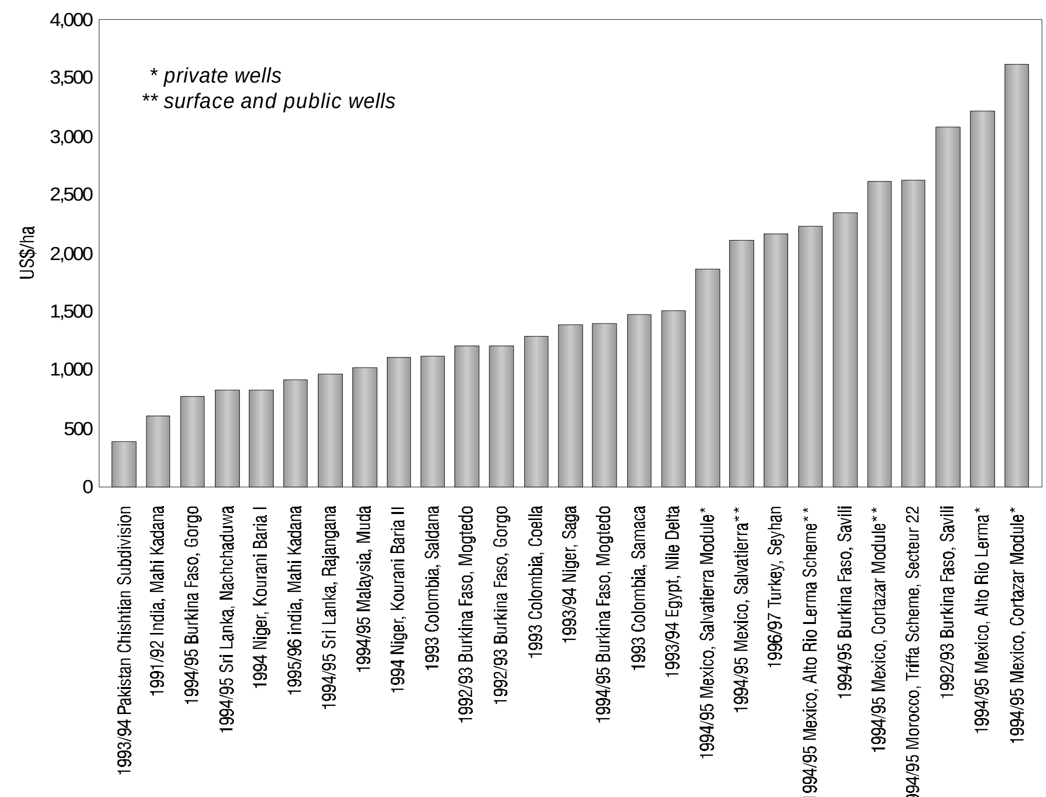


FIGURE 3.
Standardized gross value of production per unit irrigation supply.

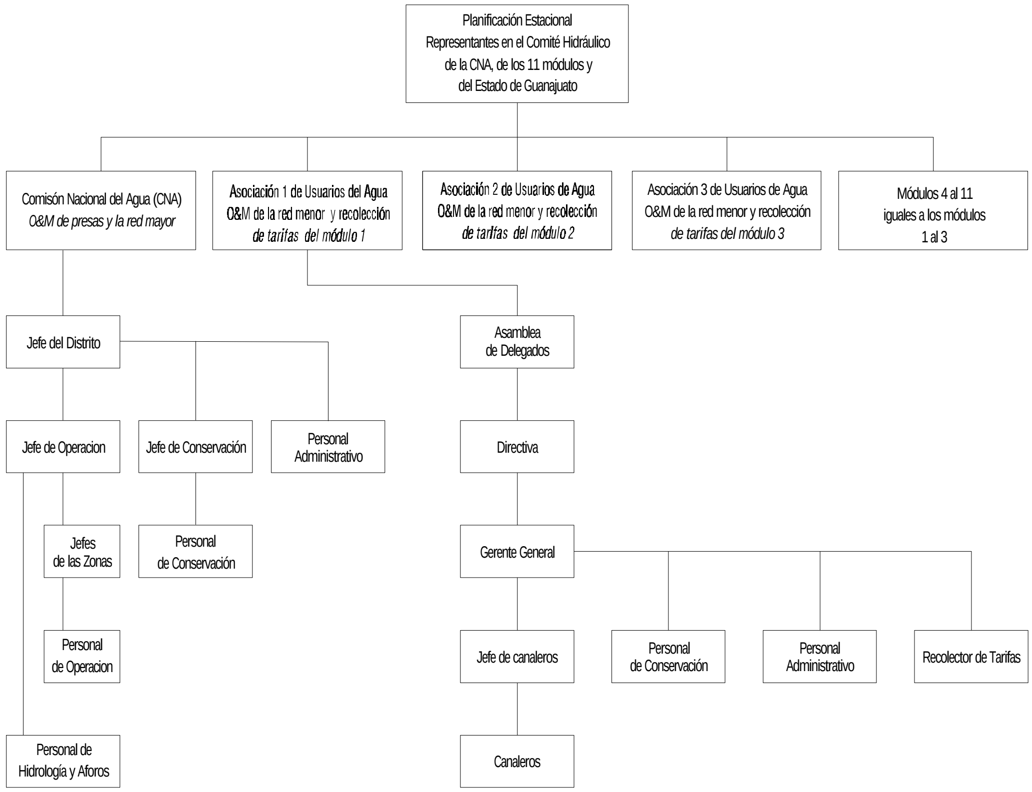


FIGURE 4.
Standardized gross value of production per unit water consumed.

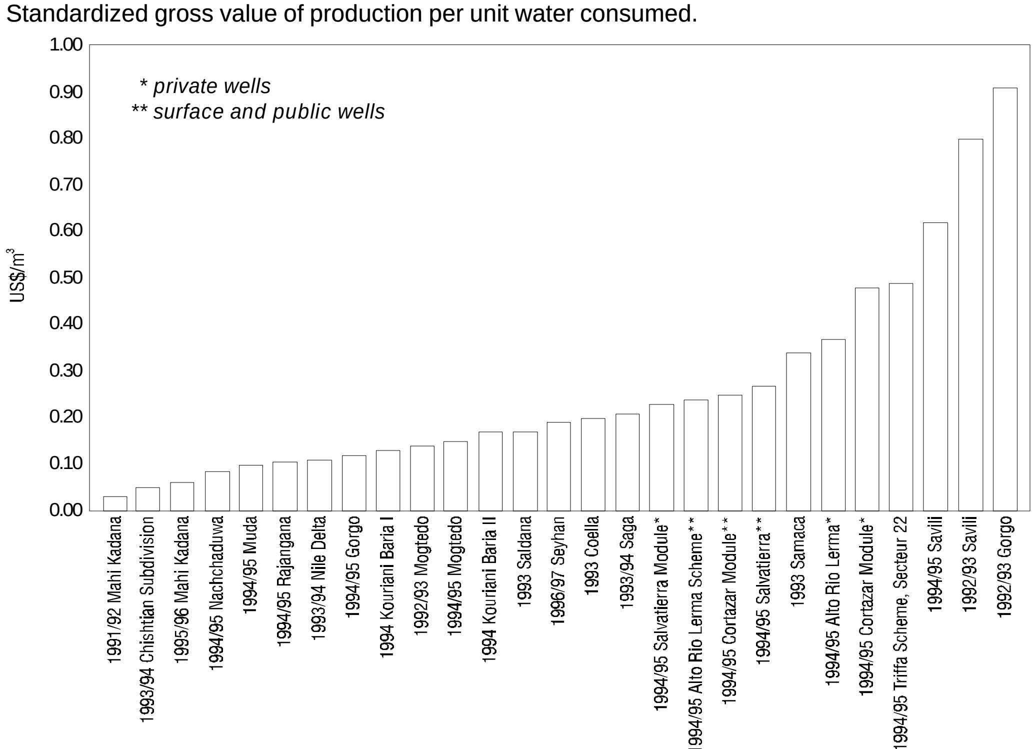
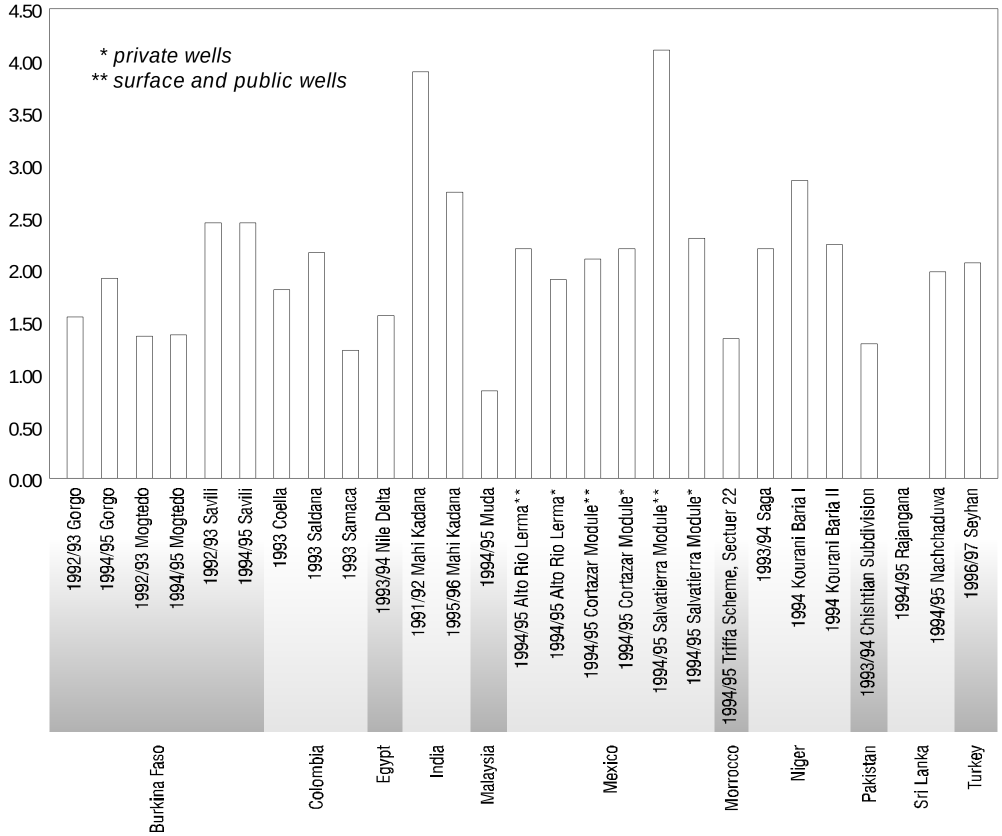


FIGURE 5.
Relative Water Supply (RWS).



seasons and other field crops during a dry season give a gross value of output per unit irrigation water varying between US$0.10 and $0.29. Systems which grow orchards, industrial crops, and vegetables yield an SGVP per cubic meter of irrigation water higher than US$0.20. The SGVP per cubic meter of irrigation tends to be higher in humid regions where irrigation needs are generally lower. Obviously, this also depends on the ability of farmers and system managers to use rainfall effectively.

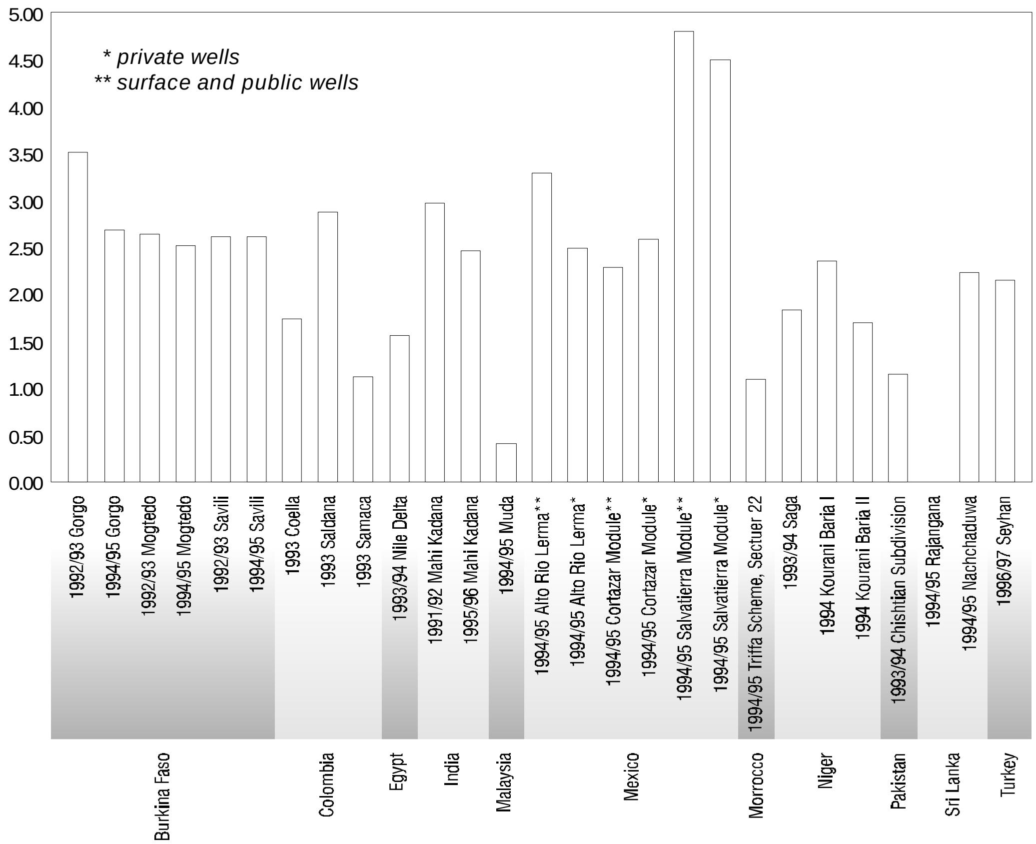
SGVP Per Unit Water Consumed

Consumed water is the actual evapotranspiration from irrigated crops (ET). The gross value of output per unit water consumed in figure 4 shows variations of 1 to 6. It is seen that purely rice-based systems with abundant water supply and rice-based system with cropping intensity less than 100 percent give a gross value of output per unit water consumed of about US$0.10 whereas water-short systems with orchard and industrial crops and those systems with private-well pumping give a gross value of output per unit water consumed between $0.20 to $0.60. This parameter among these two types of systems varies over a range of 1:2 to 1:6.

Relative Water Supply (RWS)

Values for RWS vary between 0.80 and 4.0 (figure 5). Half of the systems have RWS

FIGURE 6.
Relative Irrigation Supply (RIS).



values greater than 2 showing an adequate supply relative to demand.

Relative Irrigation Supply (RIS)

Relative irrigation supply (RIS) focuses on supply of irrigation water alone, in contrast to RWS which also includes rainfall. When irrigation tightly fills the gap of water requirements after they are met by rain, RIS is near unity. The RIS values plotted in figure 6 indicate there is a wide variation in the RIS values among the systems studied (0.41 to 4.81). In situations where return flows go to a sea or a sink, and there is a scarce water supply in the river basin, it is better to have a relative irrigation supply near 1 than a higher value.

It is instructive to note that the Muda System in Malaysia which uses a real-time monitoring of water-depth in rice fields is able to use rainfall effectively and has the lowest RIS value. This is particularly impressive as the storage is about 200 km upstream from the diversion point. Water not consumed by ET in the Muda System flows to the sea, so it is important for this area to closely match supply with demand. At Muda, RIS and RWS values are minimized by using a real-time monitoring rainfall and adjusting the irrigation release from storage/diversion structures to effectively use the rainfall component of the water supply.

Water Delivery Capacity Ratio

The water delivery capacity ratio indicates whether the system design is in anyway a constraint to meet the maximum crop water requirement. Values much greater than 1 indicate that their capacity is not a constraint to meeting crop water demands. Values close to 1 indicate that there may be difficulties meeting short-term peak demands. Oftentimes, additional capacity is designed (at additional cost) to allow for more flexible water deliveries, or to ease management.

Financial Self-Sufficiency

Table 2 presents percent of self-sufficiency attained by different systems studied. The values indicate that in systems where management has been turned over from government to locally managed entities, a higher percentage of O&M expenditure is generated locally than in government-managed systems. While the locally managed systems achieve a self-sufficiency of nearly 100 percent, agency-managed systems have a financial self-sufficiency of 30 to 50 percent. This result has to be interpreted cautiously as we have taken into account only two systems which have been turned over from the government to local management.

Gross Return on Investment

In computing the gross return on investment, computations of investment cost of distribution systems posed a problem. In many cases, we used a current estimated cost of construction per hectare prevailing in those countries where we could not get reliable construction cost of project under consideration. The values of gross return on investment presented in table 2 show a wide variation between 6 and 75 percent. Rice-based irrigation systems with less-abundant water give a low return on investment (6 to 30%) while private pump irrigation systems provide the highest rate of return on investment (75%).

Temporal and Spatial Variation of Indicators within a Project

If the minimum set of external indicators is disaggregated in time and space, they serve as tools for internal management of irrigation systems and for evaluating impacts of interventions. These concepts are demonstrated by applying indicators to two systems: Samaca in Colombia for impact assessment, and Alto Rio Lerma in Mexico for operational management.

In Colombia, for the Samaca Irrigation Project, the indicators were computed for a period of 11 years (1986 to 1996). Two of the indicators, output per unit command and the financial self-sufficiency, are displayed in figure 7.

Despite yearly fluctuations, SGVP per unit command shows a clear rising trend. This increase in SGVP is mainly attributed to a general increase in yield of the 2 main crops (potato and onion) grown in the area. Over the last decade, Colombia's economy has been liberalized with subsidies in agriculture cut or reduced substantially. Attitudes in farming have changed from mainly subsistence to commercial farming. Agro-inputs and improved irrigation facilities are now widely used resulting in increased yields.

Until 1991, the financial self-sufficiency averaged 35 percent indicating that 65 percent was subsidized by the government. In 1992, this situation altered dramatically when the government decided to turn over the system operation and management to the users' association. From then onwards farmers had to bear the full costs to run the system. Water fees were raised by 170 percent and the financial self-sufficiency increased to around 100 percent.

For Mexico, the entire district of Alto Rio Lerma and its two transferred subsystems Cortazar Module and Salvatierra Module were selected for comparison of indicators on a spatial basis. Figure 8 displays the computed indicators for these subsystems irrigated with surface and public well systems. The results indicate that the Cortazar Module outperforms in all indicators compared to Salvatierra Module as well as the entire district of Alto Rio Lerma, while Salvatierra Module's performance is less impressive. This gives some indication of differences in results of the turnover program.

FIGURE 7A.
Temporal variance of external indicators: Standardized gross value of production (1986–1996) per command area, Samaca Irrigation Scheme, Colombia.

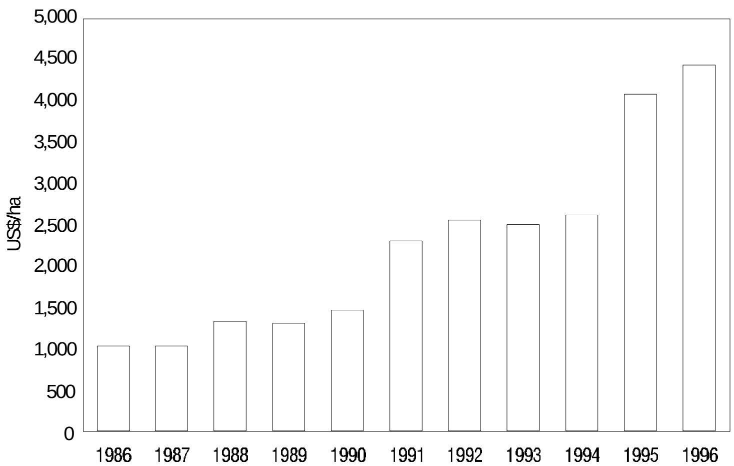
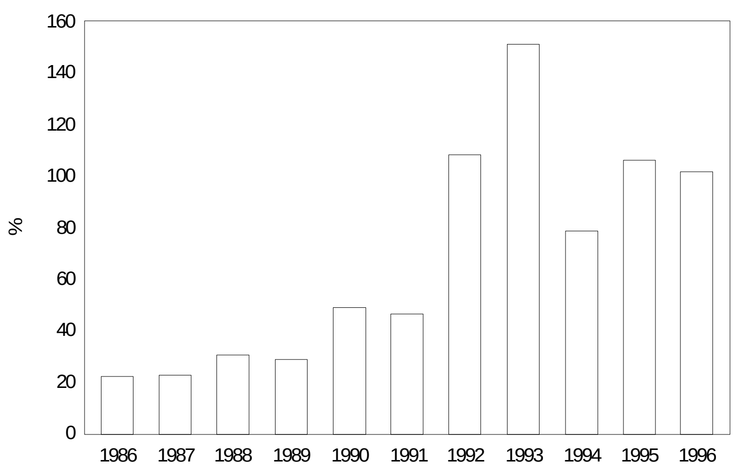


FIGURE 7B.
Temporal variance of external indicators: Financial self-sufficiency (1986–1996), Samaca Irrigation Scheme.

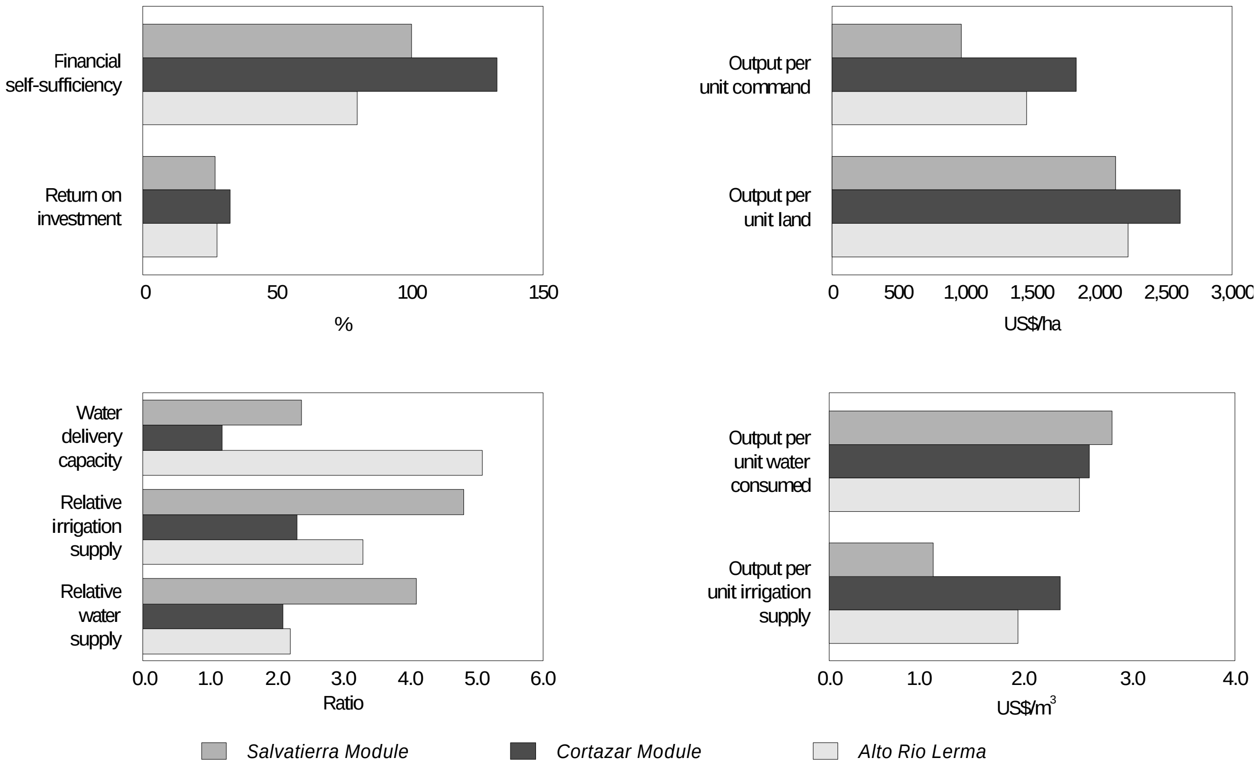


Limitations of the Indicators

First, the major difficulty of using the indicators is the uncertainty involved in many of the estimates. Two major types of uncertainties exist: uncertainties in the source of data and uncertainties in the estimates. Many of the data come from secondary sources, not directly measured by the researchers. There is a wide variety in the quality of data obtained from these sources. Second, means of estimating leads to errors. For example, there are large uncertainties in estimates of actual crop evapotranspiration and effective precipitation related to the methodology of estimating these values.

The largest degree of uncertainty exists in the estimation of effective precipitation. Several methods exist to estimate effective precipitation (Dastane 1974), and the results vary depending on the method chosen. We also know that differences in physical and management characteristics of irrigated areas play a large role in determining how much rainfall is effective. For example, a flat area with low rainfall using bunds where farmers practice deficit irrigation will capture rainfall much more effectively than a sloping irrigation system in a hilly area, with a plentiful surface supply. At present, there are inadequate methods to estimate effective rainfall under the variety of situations that exist. For this study, we relied on the best judgment of the researcher to estimate effective precipitation.

FIGURE 8.
Spatial variations of external indicators, Mexico.

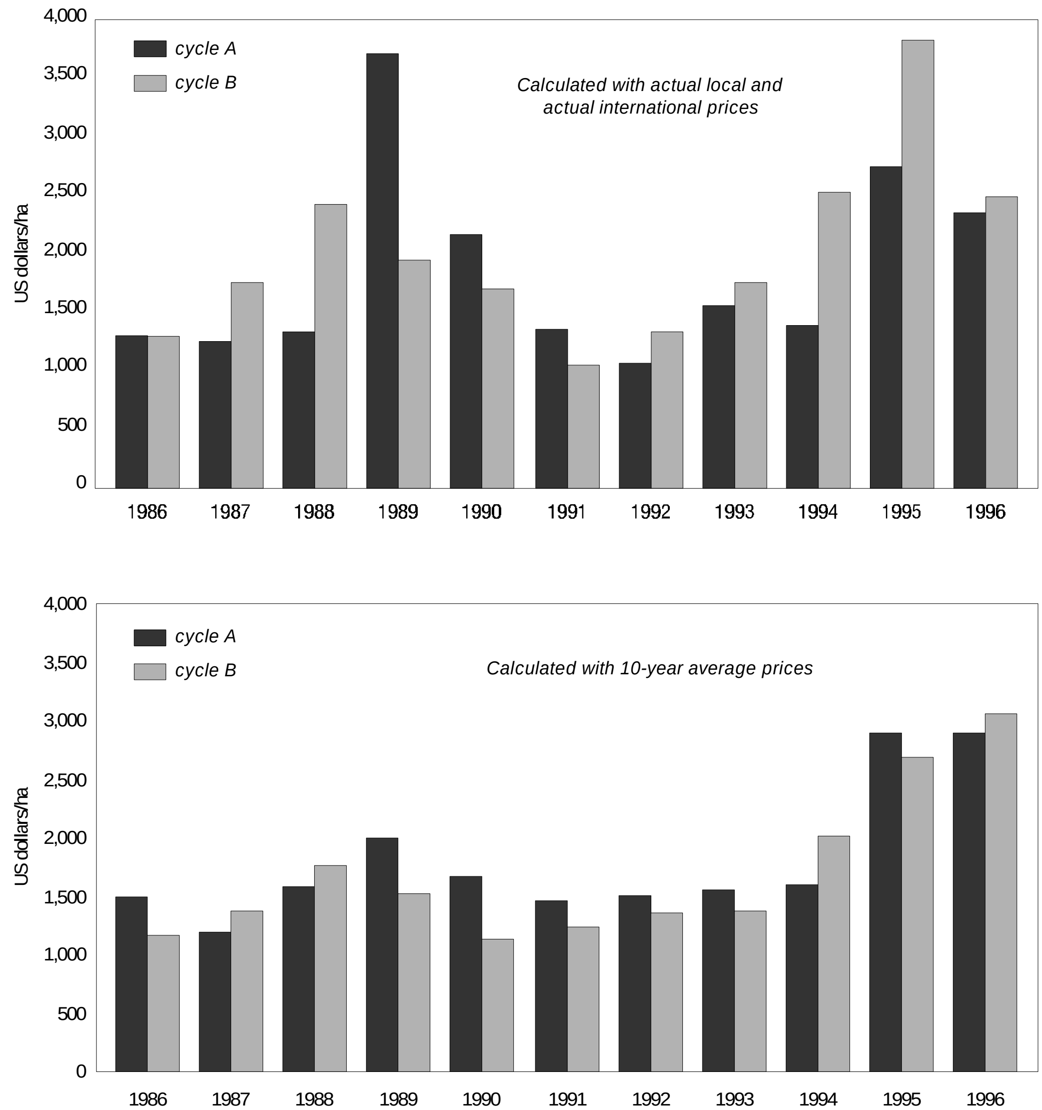


Similar to effective precipitation, but to a lesser extent, estimates of actual crop evapotranspiration are subject to uncertainties in their quantification. On a regional scale with varying soils, water deliveries, and farmer practices, it is quite difficult to obtain a regional estimate. It is even more difficult to get a good estimate when deficit irrigation is practiced or crops are stressed.

Clearly, the variability in prices (which directly affects SGVP) is a threat to the stability of SGVP as an indicator. Figure 9 shows SGVP calculated with actual annual prices (inflation adjusted) and with the 10-year average price. Although it is clear that results are more stable with the average price, it is important to note that the overall trends (an initial rise, a fall, then a recovery to the best overall productivity) are reflected in both graphs. This gives confidence in the approach, and suggests only that caution should be exercised in selecting the appropriate price sets depending on the purpose of the analysis.

Given that there are large uncertainties, can the indicators be used to show differences in irrigation performance? Where the magnitude of difference is large, say greater than 50 percent, we are confident we are discerning differences. And there are many cases where the magnitude is quite large. If the difference noted is small, say less than 20 percent, then we cannot confidently say there is a difference in performance between systems. As further research, sensitivity to uncertainties in parameter estimation to results is required.

FIGURE 9.
Standardized gross value of production per cropped area, Samaca Irrigation Scheme.



Interpretation of Results

With nine indicators per system, how do we interpret results? How do we say that system A is better than system B? The basic comparative indicators (indicators 1 through 4) represent the basic performance indicators. Where land is limiting relative to water, output per unit land may be more important. Where water is a limiting factor to production, output per unit water may be more important.

The water supply indicators (RWS, RIS, and WDC) are better suited to place the irrigation system in its physical and management context. Higher values of RWS, RIS, and WDC indicate a more generous supply of water. In this case, productivity to land may be more important. Where the water supply indicators show a lower value it indicates a situation of a more constrained water supply and values of productivity per unit of water are more important.

If performance in terms of output per unit land or water was high, what was the cost? The Gross Return on Investment indicator can give an idea of the costs involved to give such a return. With more data on external indicators we can ask such questions as "in similar environments, can we achieve the same performance at cheaper costs?" Or, "what additional infrastructure costs are required to achieve better performance?"

The comparative indicators can be used in irrigation management to assist in setting strategic objectives and measuring progress against those objectives. In this case, SGVP is not an appropriate term for output. Rather, gross or net returns from production should be used. The main purpose of SGVP is to allow comparison between systems.

Discussion

The indicators are able to discern large differences in performance relative to land, water, and production. The magnitude of these differences, in our view, justifies the approach taken and the aggregate nature of the analysis made. We are confident that ratios of indicators of 2:1 and greater represent clear differences in levels of performance.

With a larger sample, it may be possible to relate performance to key features of irrigation systems: infrastructure (fixed, flexible), management (agency, joint, farmers), allocation and distribution procedures (demand versus supply), climate (wet, dry), and socioeconomic setting (large and small holdings). The performance study will allow comparison of how well one system is performing relative to others in similar settings. This is an important tool for policy makers who want to know how and how much to invest in irrigation. The comparative assessment will give gross indications of where improvements can be made—in types of management, infrastructure, or water allocation.

The comparative indicators should allow us to set up a screening process for selecting systems that perform relatively well, and those that do not. Based on the initial experience from the external indicators, we can probe further into determinants of system performance using more refined techniques.

These indicators are not meant to replace day-to-day monitoring techniques that allow for performance-based management. They are useful in answering the question "am I doing the right thing?" (Murray-Rust and Snellen 1993). They can be used to identify long-term trends in performance and to set and verify long-term strategic objectives.

The next step is to proceed with gathering these indictors for a greater variety and number of irrigation systems. A typology will be developed for irrigation systems. The typology will allow comparison of irrigation systems with similar settings. Additionally, it will allow us to identify different aspects that lead to better performance. The comparative study will allow a screening of irrigation systems to highlight key issues relative to performance, and allow targeting of research to better understand key determinants of performance.

Data Requirements to Calculate Performance Indicators

Climate

To calculate evapotranspiration

- monthly precipitation (mm)
- mean daily maximum and minimum temperatures, per month (^{o}C)
- mean monthly windspeed (m/s)
- mean monthly relative humidity (%)
- mean daily hours of sunshine, per month (hours/day)

Crops

- total command area (ha)
- cropping pattern of irrigated crops (planting dates, growth length in days)
- area per crop, per season, or per year (ha)
- yields, per season or per year (tons/ha)
- local prices, per season, or per year (local currency/ton)
- world market prices for main crop (US dollars/ton)

Irrigation

- total amount of irrigation water diverted, scheme level, per season, or per year (m^3)
- net groundwater supply to system calculated by pumpage minus recharge or change in groundwater level times specific yield
- actual capacity of main canal and secondary canals (m^3/s)

Finance

- expenditures for operation, maintenance, and administration, i.e., all costs to run the system (in local currency/year)
- total income from water fees, farmers' contributions, outstanding debt payments, etc., *excluding* all government subsidies (local currency/year)
- investment cost of irrigation infrastructure (local currency/ha)

Calculation Example of Performance Indicators, Samaca Irrigation Project, Colombia

A. *Standardized Gross Value of Production (SGVP)*

A1. In local currency

For each season the six main tradable crops and irrigated pasture were taken into account. These crops cover more than 95 percent of the cultivated area. For example in 1995, the following data were collected:

Crop	Season A (Jan. – June)					Season B (July – Dec.)				
	Area (ha)	Yield (tons/ ha)	Price (pesos/ kg)	Average price	SGVP (million pesos)	Area (ha)	Yield (tons/ ha)	Price (pesos/ kg)	Average price	SGVP (million pesos)
Potato	498	25.0	265	221	3,299	475	18.0	171	200	1,462
Maize	95	1.3	502	380	62	80	2.0	250	346	40
Vegetable	145	20.0	189	255	548	216	20.0	194	239	838
Pea	349	4.0	1,259	978	1,758	270	4.0	762	889	823
Onion	357	25.0	488	444	4,355	455	25.0	502	467	5,710
Wheat	33	5.0	200	275	33	43	5.2	200	284	45
Pasture	655	332*		332	217	655	332*		332	217
Total	2,132				10,239	2,194				9,135

* 332,000 pesos per season per ha, four cuttings per season.

The base year is 1995, inflation factor for Colombian pesos is 1.0, and total command area is 3,000 hectares. The total amount of water diverted yearly (scheme level) is 11,867 * 10^3 m^3.

SGVP per unit cultivated area
10^6 (10,239+9,135)/(2132+2194) = 4,478,000 pesos per ha.

SGVP per unit command area
10^6 (10,239+9,135) / 3000 = 6,458,000 pesos per ha.

SGVP per unit irrigation delivered
10^3 (10,239+9,135) / 11,867 = 1,633 pesos per m^3.

A2. In US dollars : Standardized gross value of production (SGVP)

SGVP = {(yield $_{crop\ 1}$) * (price $_{crop\ 1}$ / price $_{base\ crop}$) * (area $_{crop\ 1}$) +
+ (yield $_{crop\ 2}$) * (price $_{crop\ 2}$ / price $_{base\ crop}$) * (area $_{crop\ 2}$)
+ (yield $_{crop\ 3}$) * (price $_{crop\ 3}$ / price $_{base\ crop}$) * (area $_{crop\ 3}$) etc. } * (world market price) $_{base\ crop}$

The base crop is the main tradable crop cultivated in the command area, which is taken as potato for Samaca. To eliminate distortions due to price fluctuations, for local as well as for international prices, averages are used: first, local prices per crop and per year are corrected for inflation (base year 1995), then the 10-year average over 1986-1995 is taken. The average world market price for wheat is US$149.4/ton.

For the first season in 1995, the total SGVP is:

{25 * 498 + 1.3 * (380 / 221) * 95 + 20 * (255 / 221)
* 145 + 4 * (978 / 221) * 349 + 25 * (444 / 221)
* 357 + 5 * (275 / 221) * 33 + 655 * (332,000 / 221)} * 149 = US$6,171,168

Likewise, for the second season in 1995 the SGVP is US$5,899,910
Total yearly value: US$12,071,078

SGVP per unit cultivated area: (12,071,078) / (2,132+2,194) = 2,790 US$/ha.

SGVP per unit command area: 12,071,078 / 3,000 = 4,024 US$/ha.

SGVP per unit irrigation delivered: 12,071,078 / 11,867,000 = 1.02 US$/$m^3$.

B. *Crop Water Demand*

For each crop, the seasonal water demand is calculated with CROPWAT. The reference evapotranspiration (ET_o) according to Penman-Monteith and the effective rainfall are calculated with CROPWAT (FAO 1992) (option 1 in main menu), separately for each year. In this case, the USBR-formula for effective rainfall is chosen (input: daily temperature, relative humidity, windspeed, sunshine hours, total rainfall).

For example, for 1995

Month	Average daily temp. (°C)	Humidity (%)	Windspeed (km/day)	Daily sunshine (hrs/day)	ET_o Penman-Monteith (mm/day)	Total precipitation (mm/ month)	Effective rainfall (USBR) mm/month
January	13.8	76	171	7.0	3.0	1.3	1.3
February	14.3	77	180	10.2	3.7	65.1	56.6
March	14.8	78	169	6.1	3.2	142.8	102.0
April	14.7	77	155	4.2	2.8	37.6	34.8
May	14.2	79	142	4.9	2.8	64.1	55.9
June	14.2	76	193	4.1	2.7	51.5	46.2
July	13.5	80	174	5.1	2.7	26.5	25.1
August	14.1	73	175	5.3	3.0	52.8	47.2
September	13.5	78	149	5.4	2.9	27.8	26.3
October	14.6	78	118	3.2	2.5	60.3	53.0
November	14.3	74	145	5.2	2.8	86.5	71.5
December	14.3	80	139	3.3	2.3	82.9	69.2
Total					1043	699.2	589.1

Then, the net crop water requirement (CWR) and the net irrigation requirement (IR) are computed for each irrigated crop and for each growing season (option 2 in CROPWAT main menu). The crop coefficients provided with CROPWAT program are used (input: planting dates and growth length in days). For Samaca 1995, the outcomes were:

Crop	Area (ha)	Net crop water requirement: Season A (mm/season)	Net irrigation requirement: Season A (mm/season)	Area (ha)	Net crop water requirement: Season B (mm/season)	Net irrigation requirement: Season B (mm/season)
Potato	498	394.6	136.7	475	381.0	118.3
Maize	95	463.5	166.9	80	444.3	166.0
Vegetables	145	351.1	116.2	216	336.7	138.9
Peas	349	298.5	106.7	270	283.9	144.8
Onion	357	278.6	94.7	455	270.6	50.1
Wheat	33	326.3	137.4	43	329.8	131.3
Pasture	655	523.8	245.2	655	511.8	225.5
Total	2,132			2,194		

The total net crop demand for season A is:

$CWR_{potato} * (area_{potato} / area_{total}) + CWR_{maize} * (area_{maize} / area_{total}) + etc. =$

394.6 * (498 / 2,132) + 463.5 * (95 / 2,132) + 351.1 * (145 / 2,132) + 298.5 * (349 / 2,132) + 278.6 * (357 / 2,132) + 326.3 * (33 / 2132) + 523.8 * (655 / 2,132) = *387.7* mm / season.

In the same way, the total net irrigation requirements are computed.

Results:

Season	Net crop water requirement	Net irrigation demand
A (Jan - June)	387.7	158.0
B (July - Dec)	383.2	143.4
Total	770.9	301.4

The SGVP per unit consumed could be approximated by SGVP / net CWR

in pesos: $19{,}374 * 10^6 / (2{,}132 * 387.7 + 2{,}194 * 383.2)*10$ = *1,162* pesos/m^3
in dollars: 12,071,078/ (2,132 * 387.7 + 2,194 * 383.2)*10 = *0.72* dollar/m^3

Amount of water diverted:

Scheme level		Field level	
	season A: 280.1 mm		season A : 193.5 mm
	season B: 268.7 mm		season B : 198.0 mm
	yearly : 548.8 mm		yearly : 391.5 mm

Relative water supply = (Irrigation derived + total precipitation) / crop water requirements[2]

Scheme level: (548.8 + 699.2) / (387.7 + 383.2) = *1.62*

Relative irrigation supply = Irrigation applied / irrigation requirements[3]

Scheme level: 548.8 / 301.4 = *1.82*

Water delivery capacity = Actual canal capacity/scheme peak demand[4]

Actual canal capacity was measured at the main reservoir outlet. The capacity is 750 /s.

The scheme irrigation requirement was calculated with CROPWAT (option 4 in main menu) using the climate data, cropping pattern, planting dates, and area as mentioned above.

For 1995, the scheme irrigation requirements were:

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
IR in l/s/ha	0.13	0.08	0.01	0.17	0.11	0.11	0.08	0.08	0.20	0.09	0.05	0.04

Peak irrigation requirements occur in September, 0.20 l/s/ha.
Peak demand is 0.20 * cropped area for that month = 0.20 * 2,194 = 439 l/s.
Water delivery capacity: 750 / 439 = 1.71.

C. *Financial Data*

Financial self-sufficiency = Revenue from irrigation / O&M expenditures

The revenue from irrigation includes all income derived from water fees, water user association's fees, outstanding debt and interest on debt payments but excludes all kind of government subsidies or payments. For 1995, this was : 92,032,056 Colombian pesos. The exchange rate for 1995 was 913 pesos/dollar so the revenue from irrigation was US$100,802.

O&M expenditures include all expenditures to operate and maintain the system. For Samaca, they include operation, maintenance, and administration costs, totaling 86,296,340 pesos or US$94,519.

Financial self-sufficiency = (100,802 / 94,519) * 100% = 107 %.

In this case, income generated was more than the expenditure.

Gross return on investment = Gross value of output / Cost of distribution system

The cost of the distribution system is not known for the Samaca Project as the system was built over a time span of several decades. As an approximation, the investment cost of a similar system nearby (currently under construction) is taken. This amounted to US$7,000 per hectare for 1996 (figures for 1995 not available). The SGVP was US$2,976 per year per hectare of the command area.

Gross return on investment is 3,096/7,000 = 42 %.

[2]Net crop water requirement excluding efficiency losses.

[3]Net irrigation requirements excluding conveyance and application losses.

[4]Net peak demand excluding conveyance and application losses.

ANNEX 3

World Market Prices of Agricultural Products in Constant 1995 Dollars

Crop	Unit	1980	1985	1990	1993	1994	1995	1996
Rice (Thai 5%)	$ / mt	680.1	342.1	322.9	263.9	289.4	321.0	353.7
Maize	$ / mt	207.4	195.0	130.3	114.4	116.3	123.5	173.1
Sorghum	$ / mt	213.4	179.0	123.9	111.0	112.4	119.0	156.7
Wheat	$ / mt	286.1	236.0	161.5	157.2	162.0	177.0	216.7
Soybean	$ / mt	490.6	390.0	294.2	286.0	272.4	259.3	318.2
Coffee, robusta	c / kg	537.3	460.2	140.9	129.8	283.4	277.1	188.5
Cotton	c / kg	341.6	229.0	216.9	143.5	190.7	212.8	185.1

Source: Commodity Price Outlook, World Bank, Development Prospect Group, August 1997.

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