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Indicators for Comparing Performance of Irrigated Agricultural Systems

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Abstract
A minimum set of performance indicators are defined which relate outputs from irrigated agriculture to the major inputs of water, land, and finance. These indicators are presented with the objective of providing a means of comparing performance across irrigation systems. 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 justifies the approach taken.

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 know 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 socio-economic 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 of how irrigated agriculture is performing within various settings.

This paper presents IIMI'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.

Peformance 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 (Bos et al, 1993).

Performance assessment is done for a variety of reasons including: improving system operations, assessing progress against strategic goals, as an integral part of performance-oriented management, assessing the general health of a system, assessing impacts of interventions, to diagnose constraints, to better understand determinants of performance, and to compare the performance of a system to others or to 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 on their use at particular irrigation systems (as examples: Bos and Nugteren, 1974, Levine 1982, Abernethy, 1986, Seckler and Sampath, 1988, Mao Zhi, 1989, Molden and Gates, 1990, Sakthivadivel et al, 1993, Bos et al, 1994). But, there are very few examples of cross-system comparisons or analysis (Bos and Nugteren, 1974, Murray Rust and Snellen, 1992, Merrey et al, 1994) Recent efforts have attempted to standardize these internal 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 that 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, 1992).

We could conclude, although it would be premature, that these internal, process 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 often 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 agricultue. "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 each and every irrigation system deals with water and agricultural production it should be possible to develop a set of external indicators for comparison across systems.

The purpose of this study is to present and apply a minimum 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. They will allow an initial screening of systems that perform well in different environments, and those that do not. They will allow for assessing impact of interventions and allow for managers to assess performance against strategic, long-term objectives.

Features of the Selected Indicators

IIMI's minimum set of external indicators were originally presented by Perry (1996). They 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 are 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 (i.e. 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

internal indicators are irrigation system managers interested in day-to-day operations where ratios of actual to target may be quite meaningful. The main audience for these external indicators are policy-makers and managers making long-term, strategic decisions, and researchers who are searching for relative differences between irrigation systems.

As water becomes a limiting resource, an important question becomes:

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

To answer 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. Even answering this question 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 relate output to unit land and water. These "external" indicators provide the basis for comparison of irrigated agricultural 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. Output per cropped area $(\frac{\$}{ha}) = \frac{\text{Production}}{\text{Irrigated Cropped Area } (A_{cropped})}$

2. Output per unit command $(\frac{\$}{ha}) = \frac{\text{Production}}{\text{Command area } (A_{net})}$

3. Output per unit Irrigation Supply $(\frac{\$}{m^3}) = \frac{\text{Production}}{\text{Diverted Irrigation Supply } (V_{div})}$

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

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 Crops is the evapotranspiration of crops.

Output per unit of irrigation water supplied and 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 sinks (saline groundwater and seas), and through pollution (Keller and Keller, 1995, Seckler, 1996).

We are interested in a 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 tomatoes, as 1 kg of tomatoes 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 of gross value of production using local values.

The Standardized Gross Value of Production (SGVP) was developed to compare across irrigation systems 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 average World Bank prices for the period 1985 to 1995 (see annex 2 for the list). This should not be adjusted for FOB/CIF and internal transport since we are interested in the productivity of irrigation, rather than the efficiency of markets, transport system, and project location.

Thus if the local price of tomatoes is three times the local price of wheat, we consider the production yield of 10 ton/ha of tomatoes to be equivalent to 30 ton/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.

[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.

$$SGVP = \left(\sum_{crops} AiYi \frac{Pi}{Pb} \right) Pworld ,$$

where,

SGVP is the standardized gross value of production,
Yi is the yield of crop i,
Pi is the local price of crop i, and
Pworld is the value of the base crop traded at world prices.
Ai is the area cropped with crop i
Pb is the local price of the base crop

Other Comparative Indicators

An additional 5 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. Relative Water Supply $= \dfrac{\text{Total Irrigation Supply}}{\text{Crop Demand}}$

6. Relative Irrigation Supply $= \dfrac{\text{Irrigation Supply}}{\text{Irrigation Demand}}$

Relative irrigation supply is the inverse of the irrigation efficiency presented in 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.

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

where

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.
Total Water Supply = Surface diversions plus net groundwater water draft plus rainfall
Irrigation Supply = only the surface diversions and net groundwater draft for irrigation
Irrigation Demand = the crop ET less effective rainfall.
Capacity to deliver water at the system head = the present discharge capacity of the canal at the system head, and
Peak Consumptive Demand is the peak crop irrigation requirements for a monthly period expressed as a flow rate at the head of the irrigation system.

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 in order to maximize returns on water.

The water delivery 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 are used:

8. $$\text{Gross Return on Investment (\%)} = \frac{\text{SGVP}}{\text{Cost of Irrigation Infrastructure}}$$

9. $$\text{Financial Self Sufficiency} = \frac{\text{Revenue from Irrigation}}{\text{Total O\&M Expenditures}}$$

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,

Total O&M Expenditures is 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 is 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 canals 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 non-irrigation 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 are 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 O&M expenditures, financial self-sufficiency would be high. Financial self sufficiency does not tell us the O&M requirement, only the expenditures, so it does not tell us whether the expenditures on O&M are meeting the requirements. A high value of financial self-sufficiency not automatically indicates 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 IIMI was tested in eighteen systems, or parts of irrigation systems located in eleven countries: Burkina Faso, Colombia, Egypt, Malaysia, Mexico, Morocco, Niger, India, Pakistan, Sri Lanka and Turkey. The sites are those at which IIMI is involved either through their field offices, or in 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.

Three types of data were collected: water supply, agricultural, revenue and irrigation costs. Most of the data used for analysis are survey data; derived from official statistics and measurements; or collected and compiled by IIMI and collaborating scientists working in different countries. Although much of the data used come from the secondary sources such as Irrigation Departments, Agricultural Departments, Revenue Departments and State Statistical Departments, IIMI 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 procedure adopted in different countries are documented in IIMI's country reports. Table 2 gives the results of the performance indicators computations for all schemes.

1. SGVP per Unit Command

The gross value of output per unit command varies between $679 and $2888 per ha with a variation ratio of 1 to 4.25 (Fig. 1). The systems at the low end of the spectrum (less than $1500/ha) are those which mostly grow paddy with low cropping intensity. Middle range values of SGVP per ha ($1,500 to 2,000) are produced by those which grow paddy with high cropping intensity of the order of 200%. Those at the high end ($2000/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.

2. SGVP per Unit Cropped Land

The gross value of output 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 $1000 and below while systems producing other non-rice crops including industrial and orchard crops have their gross value of production/unit crop land between $2000 to $3500. This parameter between these two types of systems varies between a ratio of 1:2 to 3.5. In other words, other non-rice producing irrigation systems can be more productive than the rice producing irrigation system by 100% to 200%.

3. SGVP per Unit Irrigation Supply

The gross value of output per unit irrigation supply in Figure 3 varies between 1 to 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 $0.04 to $0.10. Irrigation systems which grow rice during rainy seasons and other field crops during a dry season give a gross value of output per unit irrigation water varying between $0.10 to $0.29. Systems which grown orchards, industrial crops and vegetables yield an SGVP per cubic meter of irrigation water higher than $0.20. The SGVP per cubic meter of irrigation tend to be higher in humid regions where irrigation need are generally lower. Obviously, this also depend on the ability of farmers and system managers to use rainfall effectively.

4. SGVP per Unit Water Consumed

Consumed water is the actual evapotranspiration by irrigated crops (ET). The gross value of output per unit water consumed in Figure 4 shows variation 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 $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 6.

5. Relative Water Supply (RWS)

Values for RWS vary between 0.80 and 4.0 (Figure 5). Half of the systems have RWS values greater than two showing an adequate supply relative to demand.

6. 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 that there is a wide variation in the RIS values among the systems studied (0.41 to 4.81). In situations where water not consumed is lost, say to a sea, and there is a scarce water supply in the river basin, it is better to have a relative irrigation supply near one 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 paddy 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 is lost 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 water supply.

7. Water Delivery Capacity Ratio
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 one indicate that there capacity is not a constraint to meeting crop water demands. Values close to one indicate that there may be difficulties meeting short term peak demands. Often times, additional capacity is designed (at additional cost) to allow for more flexible water deliveries, or to ease management.

8. Financial Self-sufficiency
Table 2 presents percent of self-sufficiency attained by different systems studied. The figures indicate that in systems where management has been turned over from government to locally management entities, a higher percentage of O&M expenditures 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 government to local management.

9. 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 provides the highest rate of return on investment (75%).

Temporal and Spatial Variation of Indicators Within a Project
If the minimum set of external indicators are desegregated 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 show 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 changed from mainly subsistence to commercial farming. Agro-inputs and improved irrigation facilities are now widely used and this resulted in increasing yields.

Until 1991, the financial self-sufficiency averaged 35% indicating that 65% was subsidized by the government. In 1992 this situation altered dramatically when the government decided to turnover 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%, the financial self-sufficiency increased to around 100%.

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

Limitations of the Indicators

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 secondly uncertainties in the estimates. Much of the data comes from secondary sources, not directly measured by the researchers. There is a wide variety in the quality of data obtained from these sources. Secondly, means of estimating lead to errors. For example, there are large uncertainties in estimates of actual crop evapotranspiration and effective precipitation related to the methodology of estimating these terms.

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.

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.

Uncertainty is introduced using SGVP. Variations in local prices is one source of error. Fluctuations in local prices relative to world prices causes distortions. Switching of base crops can change results. In order to minimize errors, IIMI uses standardized world prices based on inflation adjusted averages between 1985 and 1995. It is recommended that a 10 year inflation adjusted local price be used so that performance will not vary greatly with adjustments of local prices. We are more concerned with the productivity of irrigation rather catching effects of local market prices. As an example, figure 9 gives the differences between the SGVP calculated with real prices and computed with average prices. The graphs clearly shows that although the general picture remains the same, seasonal and yearly fluctuations of SGVP tend to be less pronounced if average (or constant) prices are used.
In spite of these difficulties, SGVP is one means that appears sufficiently robust to use to compare between countries.

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% difference, 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%, 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.

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 output 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 indicates a situation of a more constrained water supply and values of productivity per unit of water is 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 external 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, justify the approach taken and the aggregate nature of the analysis made. We are confident that ratios of indicators of 2:1 and greater represents 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 socio-economic setting. 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 external 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 external 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?". They can be used to identify long-term trends in performance and to set and verify long-term strategic objectives.

The next steps is to proceed with gathering these indictors for a greater variety 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.

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Annex 1:
Data requirements to calculate performance indicators

Climate

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

Crops

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

Irrigation

- total amount of irrigation water derived, scheme level, per season or per year (m^3)
- total amount of irrigation applied at field level, per season or per year (m^3)
- actual capacity of main canal and secondary canals (m^3/s)

Financial

- expenditures for Operation, Maintenance and Administration i.e. all cost to run the system (in local currency, per year)
- total income from water fees, farmers' contributions, outstanding debt payments etc. excluding all governement subsidies (local currency, per year)
- investment cost of irrigation infrastructure (local currency per hectare)

Calculation example performance indicators
Samaca Irrigation Project, Colombia

A. Gross value of output

A1. In local currency

For each season the 6 main tradable crops and irrigated pasture were taken into account. These crops cover more than 95 % of the cultivated area.
For example in 1995 the following data were collected:

	season A (Jan - Jun)					season B (Jul - Dec)				
crop	area (ha)	yield (ton/ha)	price (pesos / kg)	average price	GVO (million pesos)	area (ha)	yield (ton/ha)	price (pesos / kg)	average price	GVO (million pesos)
potato	498	25.0	265	221	***3299***	475	18.0	171	200	***1462***
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***
peas	349	4.0	1259	978	***1758***	270	4.0	762	889	***823***
onion	357	25.0	488	444	***4355***	455	25.0	502	467	***5710***
wheat	33	5.0	200	275	***33***	43	5.2	200	284	***45***
pasture	655	332*		332	***217***	655	332*		332	***217***
total	2132				***10,239***	2194				***9,135***

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

Base year is 1995, inflation factor for colombian pesos is 1.0 Total command area is 3,000 hectares. Total amount of water derived (scheme level):
yearly : 11,867 * 10^3 m^3

GVO per unit cultivated area
1000 * (10,239+9,135)/(2132+2194) = ***4,478*** thousand pesos per ha.
GVO per unit command area
1000* (10,239+9,135) / 3000= ***6,458*** thousand pesos per ha.
GVO per unit irrigation delivered
1000 * (10,239+9,135) / 11,867 = ***1,633*** pesos per m^3.

A2. in US dollar : Standardized Gross Value of Production (SGVP)

$$SGVP = \{(yield_{crop\,1}) * (price_{crop\,1} / price_{base\,crop}) * (area_{crop\,1}) + (yield_{crop\,2}) * (price_{crop\,2} / price_{base\,crop}) * (area_{crop\,2}) + (yield_{crop\,3}) * (price_{crop\,3} / price_{base\,crop}) * (area_{crop\,3}) \text{ etc. }\} * (\text{world market price})_{base\,crop}$$

Base crop is the main tradable crop cultivated in the command area. For Samaca potato is taken. To eliminate distortions due to price fluctuations, for local as well as for international prices averages are used: firstly 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 149.4 dollar / ton.

For 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 * (332000 / 221)} * 149 =
6,171,168 US dollar

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

GVO per unit cultivated area: (12,071,078) / (2132+2194) = ***2,790*** US dollar per ha.

GVO per unit command area: 12,071,078 / 3000 = ***4,024*** US dollar per ha.

GVO per unit irrigation delivered: 12,071,078 / 11,867,000 = ***1.02*** US dollar per 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 (option1 in main menu), seperately 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 (%)	wind-speed (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 grow 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	2132			2194		

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 / 2132) + 463.5 * (95 / 2132) + 351.1 * (145 / 2132) + 298.5 * (349 / 2132) + 278.6 * (357 / 2132) + 326.3 * (33 / 2132) + 523.8 * (655 / 2132) =
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 - Jun)	***387.7***	***158.0***
B (Jul - Dec)	***383.2***	***143.4***
Total	***770.9***	***301.4***

The ***<u>GVO per unit consumed</u>*** could be approximated[1] by
GVO / net CWR
in pesos: 19,374 * 10^6 / (2132 * 387.7 + 2194 * 383.2)*10 = ***1162*** pesos per m^3
in dollar: 12,071,078/ (2132 * 387.7 + 2194 * 383.2)*10 = ***0.72*** dollar per m^3
Amount of water derived:

scheme level	season A:	280.1 mm	field level	season A :	193.5 mm
	season B:	268.7 mm		season B :	198.0 mm
	yearly :	548.8 mm		yearly :	391.5 mm

<u>Relative water supply</u>
= (irrigation derived + total precipitation) / crop water requirements[2]

[1] not taken into account losses to sinks and non-beneficial ET due to lack of data
[2] net crop water requirement excluding efficiency losses

scheme level: (548.8 + 699.2) / (387.7 + 383.2) = ***1.62***
field level : (391.5 + 699.2) / (387.7 + 383.2) = ***1.41***

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

scheme level
548.8 / 301.4 = ***1.82***

field level
391.5 / 301.4 = ***1.30***

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 are:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	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 tequirements occur in September, 0.20 l/s/ha
Peak demand is 0.20 * cropped area = 0.20 * 2194 = 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 include all income derived from water fees, water users' association's fees, outstanding debt and interest on anterior debts payments but exclude all kind of government subsidies or payments. For 1995 this was : 92,032,056 colombian pesos. Exchange rate for 1995 is 913 pesos/dollar. Revenue = 100,802 US dollar.
O&M expenditures include all expenditures to run and maintain the system. For Samaca they include operation, maintenance and administration cost, total 86,296,340 pesos = 94,519 US dollar.
Financial self-sufficiency = (100,802 / 94,519) * 100% = ***107 %.***

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 7000 US$ per hectare for 1996 (figures for 1995 not available). The GVO was 2976 US dollar per year per hectare of the command area.
Gross return on investment: 3096 / 7000 = ***42 %.***

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[3] net irrigation requirements excluding conveyance and application losses
[4] net peak demand excluding conveyance and application losses

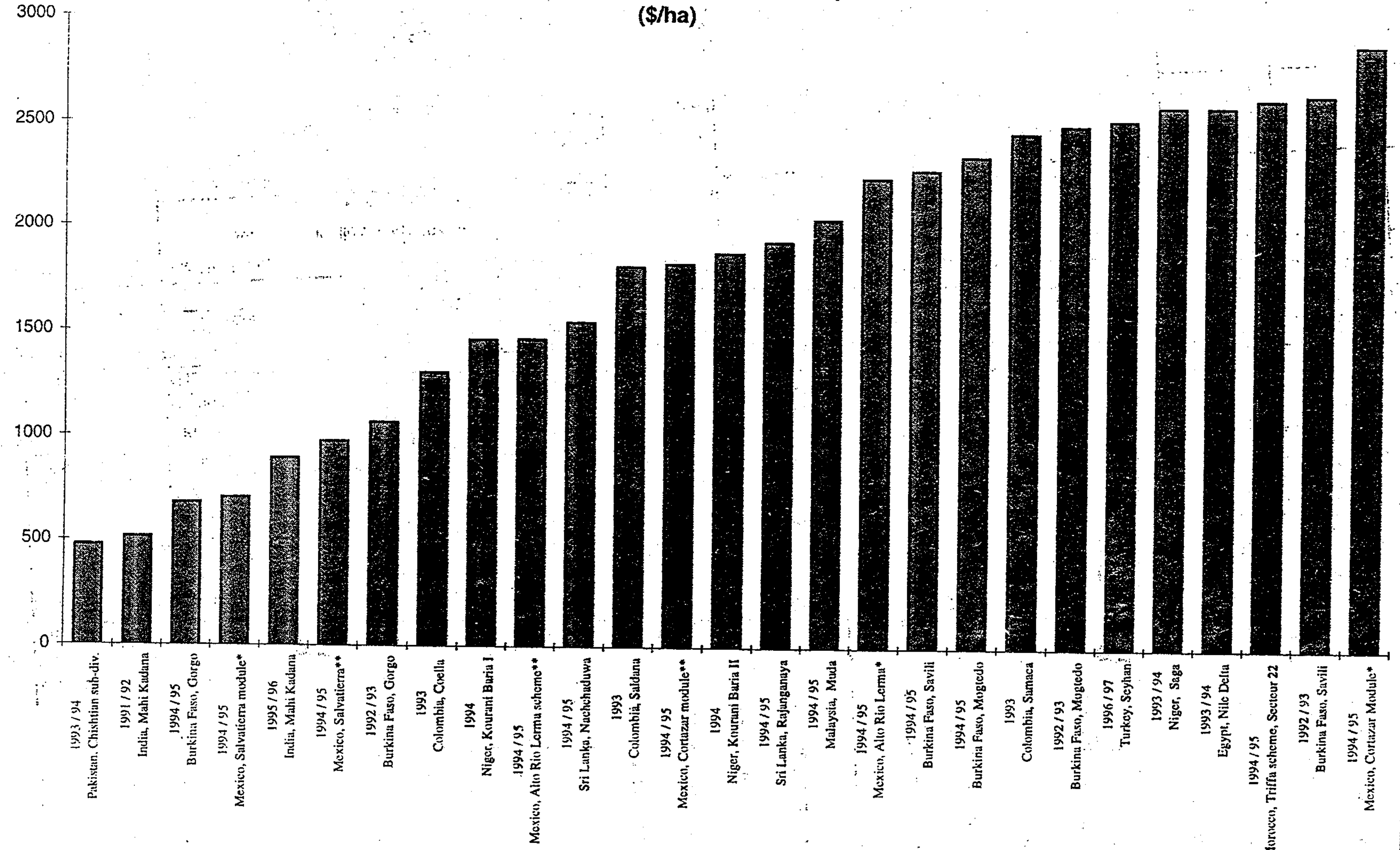
Table 1 - Salient features of the studied irrigation schemes

no.	Country	System name	Type of system	Command Area (ha)	Cropping pattern	Climate	Cropping intensity (%)	Annual rainfall (mm)	Annual evaporation (mm)	Type of management	Water availability
1	Burkina Faso	Gorgo	Tank storage	50 ha	Rice, Potato,	Sudano	93%	400 to	2600 mm	Village	Water short
2		Mogtedo	Village Irrig. scheme	93 ha	Tomato, Beans	Sahelian	200%	1200 mm		co-operatives	systems
3		Savili	Pumping scheme	42 ha		Agroclimatic zone	94%				
4	Colombia	Coella	Diversion	25,600 ha	Rice, Maize, Sorghum	temporate &	101%	1000 to	1800 mm	Transferred to	Water short
5		Saldana	Diversion	13,975 ha	Fruit & vegetables	tropical	161%	1500 mm		WUAs	water abundant
6		Samaca	Storage	3,000 ha	Onion and Potato		160%	700 mm	1100 mm		sufficient water
7	Egypt	Nile Delta	Storage	3.1 mha	Wheat, Maize, Rice, Sorghum, Egyptian cloves, Cotton	Arid	200%	10 to 500mm	-	Agency managed	Sufficient surface surface, ground & drainage water
8	India	Mahi-Kadana	Storage cum groundwater (conjunctive use)	2,12,000 ha	Rice, Wheat, Tobacco Banana, vegetables	Semi-arid	120%	823 mm	1700 mm	Agency managed	Abundant
9	Malaysia	Muda	Storage	96,000 ha	Rice-Rice	Humid	200%	2000 mm	1800 mm		
10	Mexico	Alto Rio Lerma	Storage system	107,541 ha	Wheat, Sorghum, Maize	Moderate	66%	700 mm	-	Transferred to	Surface
		Cortazar Module	1714 deep wells	18,848 ha	& beans. Under ground	sub humid	70%			WUA	water short
		Salavatierra Module	(conjunctive use)	15,897 ha	water used for Wheat, vegetables, alfalfa		46%				project
11	Morocco	Triffa Scheme	Storage and Pumping	36,060 ha	Orchards, Sugarbeets, Potato, Wheat	Semi-arid meditarian	100%	Average 300 150-450 mm	-	Agency managed	Water short
12	Niger	Saga	Pumping from river	407 ha	Rice	Arid	185%	300 to 550 mm		Agency	Water sufficient
13		Kourani Baria I	Pumping from river	425 ha	Rice		176%			managed	
14		Kourani Baria II	Pumping from river	268 ha	Rice		169%				
15	Pakistan	Chishtian sub-div.	Storage cum groundwater	70,656 ha	Wheat, sugarcane, cotton , rice	Arid	120%	200 mm		Agency managed	Water short
16	Sri Lanka	Nachchaduwa	Storage	2539 ha	Rice, Chilies, Soybean Vegetables, Onions	Semi-arid	200%	981 mm	2000 mm	Joint Mgmt	Water short
17		Rajanganaya	Storage	5909 ha	Rice		200%	500 to 1800 mm Ave 750 mm	2000 mm	Joint Mgmt	Water abundant
18	Turkey	Seyhan	Storage	120,200	Maize, cotton, oranges & many others	meditarian	86%	620 mm		Transferred	Water abundant

Table 2 - Performance indicators computed for 18 systems throughout the world

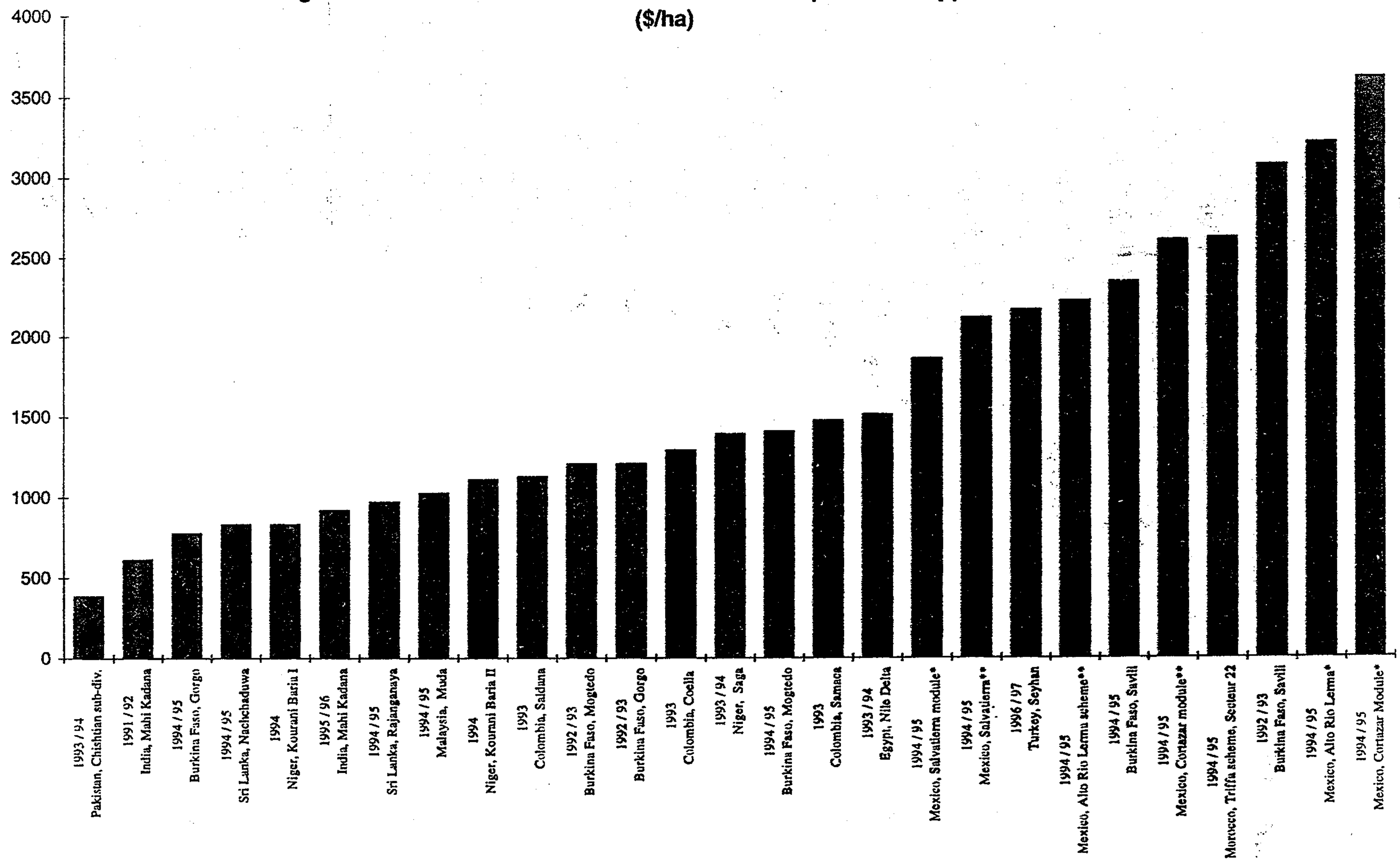
Country	System	Year	Output / unit cropped land ($/ha)	Output / unit command ($/ha)	Output / unit irrigation supply ($/m3)	Output / unit water consumed ($/m3)	Gross Return on Investment %	Financial Self-sufficiency %	Relative water supply Ratio	Relative irrigation supply Ratio	Water delivery capacity 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-div.	1993/94									
Sri Lanka	Nachchaduwa	1994/95	826	1,544	0.04	0.08	34	-	2.0	2.2	-
	Rajanganaya	1994/95	967	1,934	0.06	0.11	43	-	-	-	3.3
Turkey	Seyhan	1996/97									

Figure 1 - Standardized Gross Value of Production per Unit Command ($/ha)



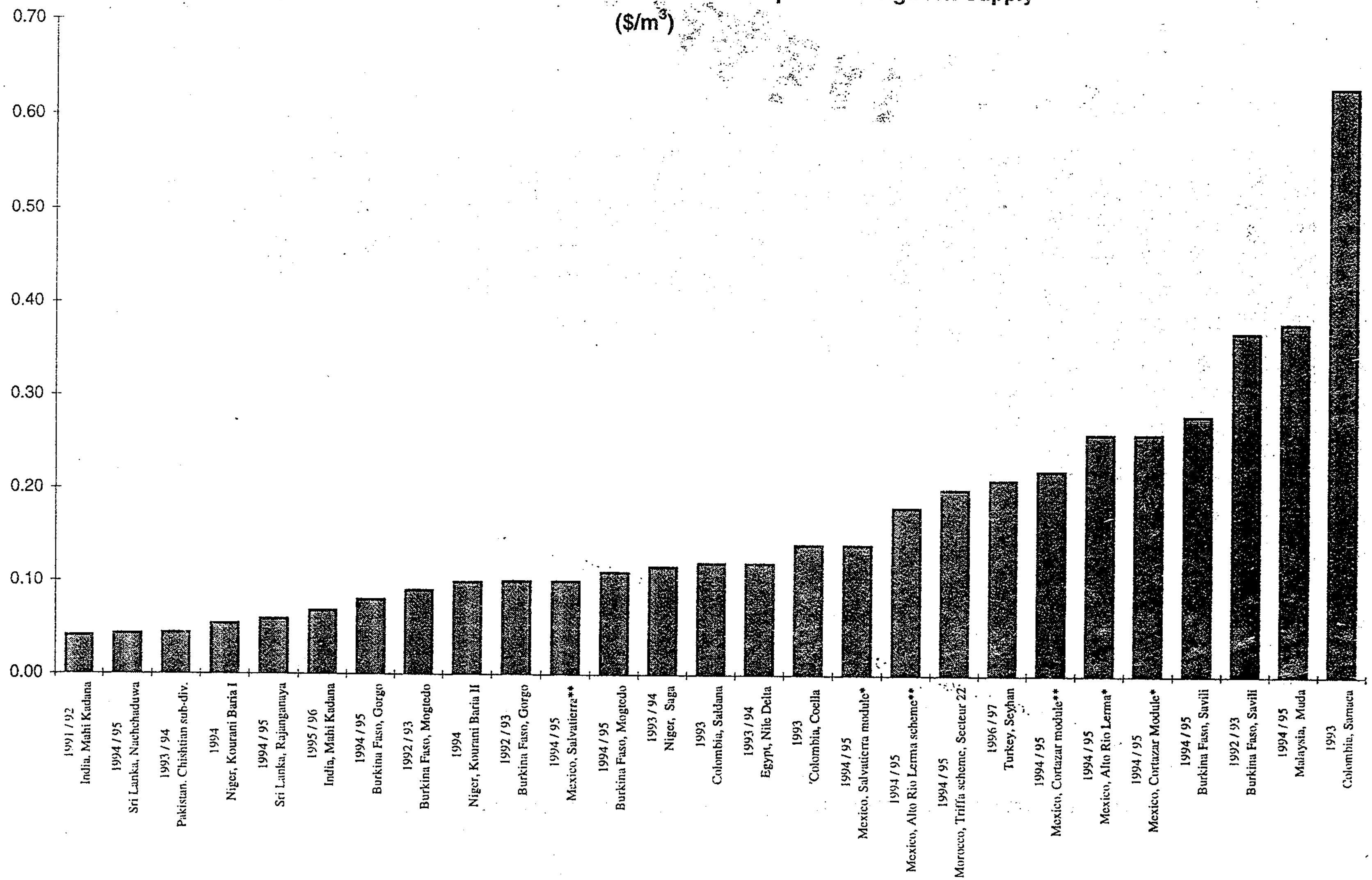
* private wells ** surface and public wells

Figure 2 - Standardized Gross Value of Production per Unit Cropped Land ($/ha)



* private wells ** surface and public wells

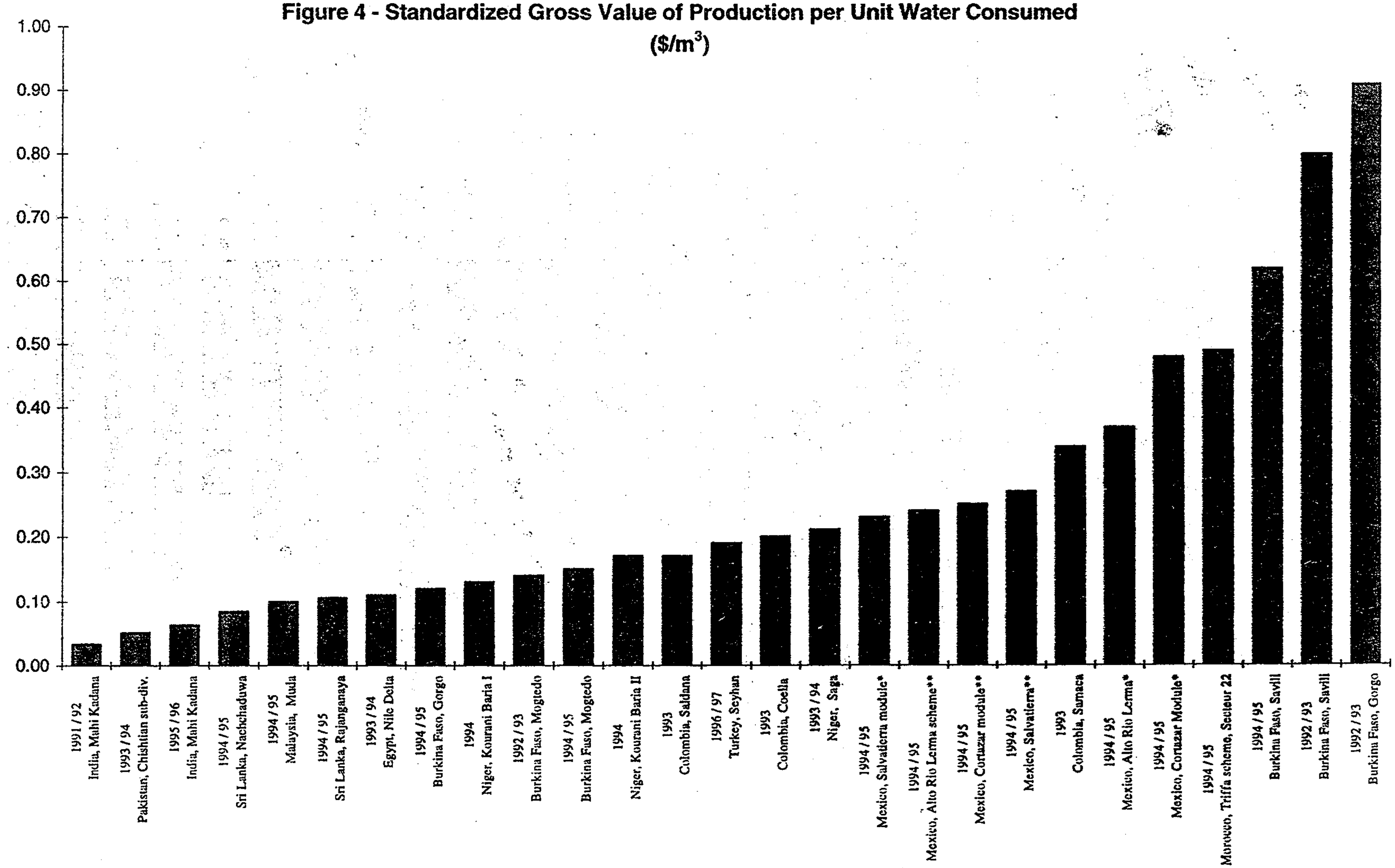
Figure 3 - Standardized Gross Value of Production per Unit Irrigation Supply ($\$/m^3$)



* private wells

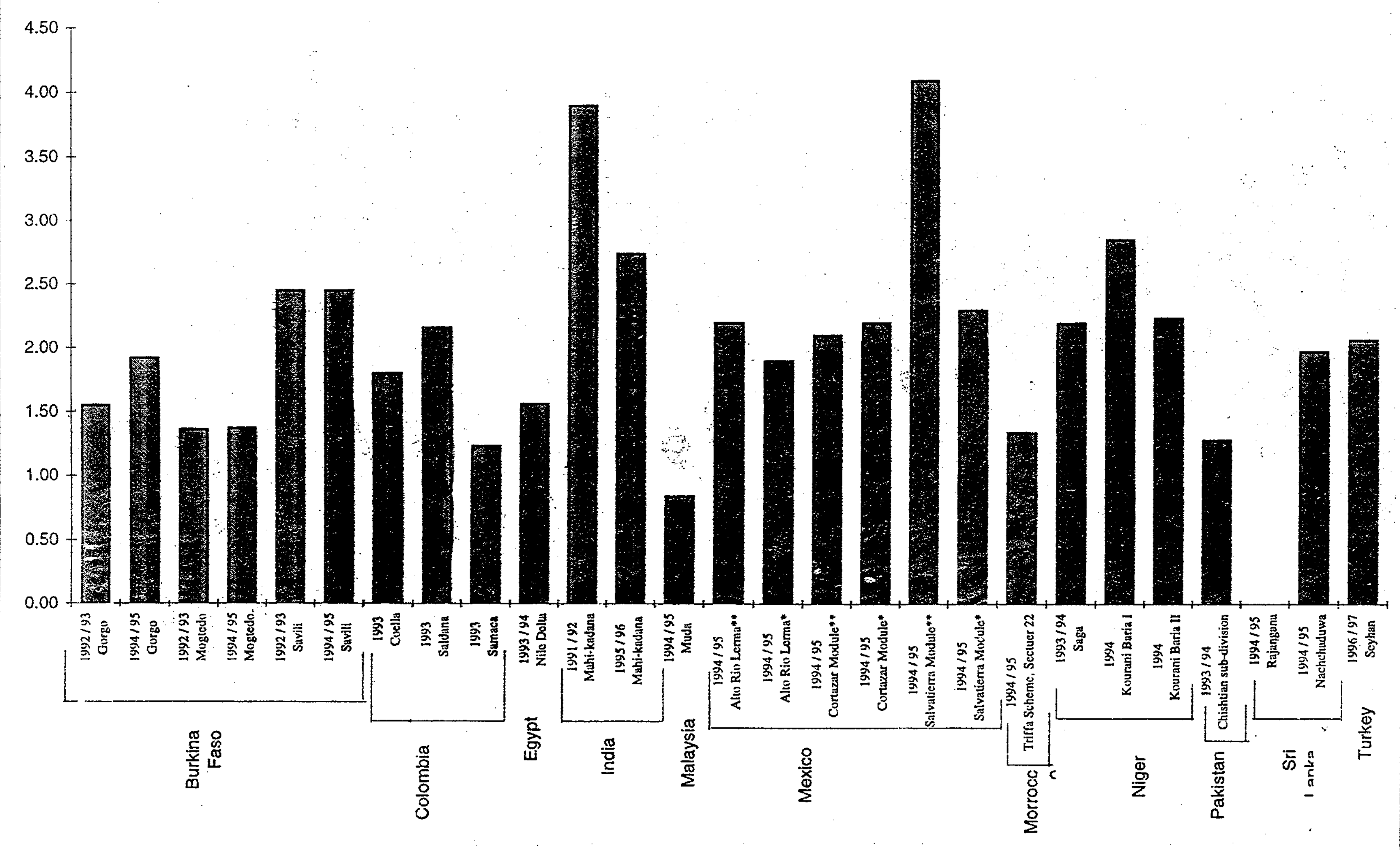
** surface and public wells

Figure 4 - Standardized Gross Value of Production per Unit Water Consumed ($\$/m^3$)



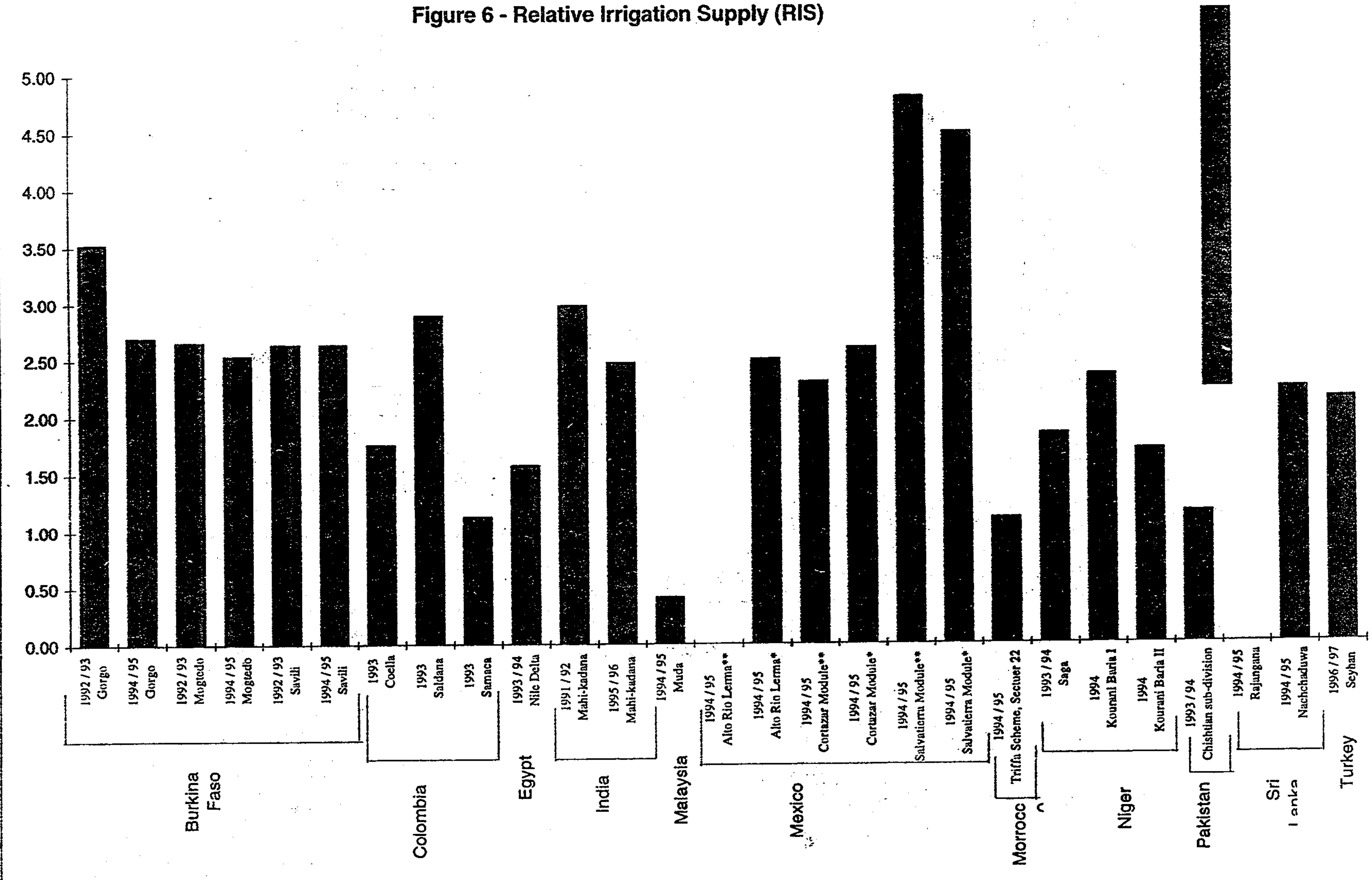
* private wells ** surface and public wells

Figure 5 – Relative Water Supply (RWS)



* private wells ** surface and public wells

Figure 6 - Relative Irrigation Supply (RIS)



* private wells ** surface and public wells

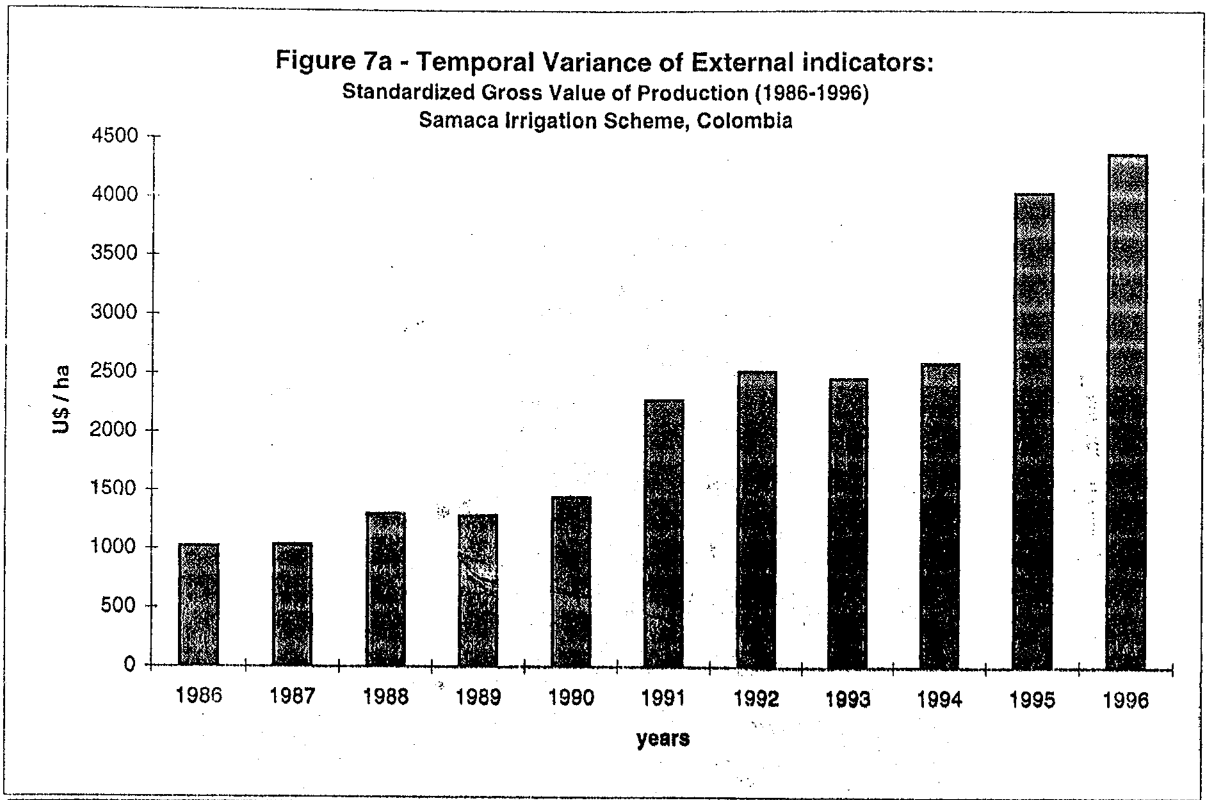


Figure 7a - Temporal Variance of External indicators:
Standardized Gross Value of Production (1986-1996)
Samaca Irrigation Scheme, Colombia
4500
4000
3500
3000
2500
2000
1500
1000
500
0
U$ / ha
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
years

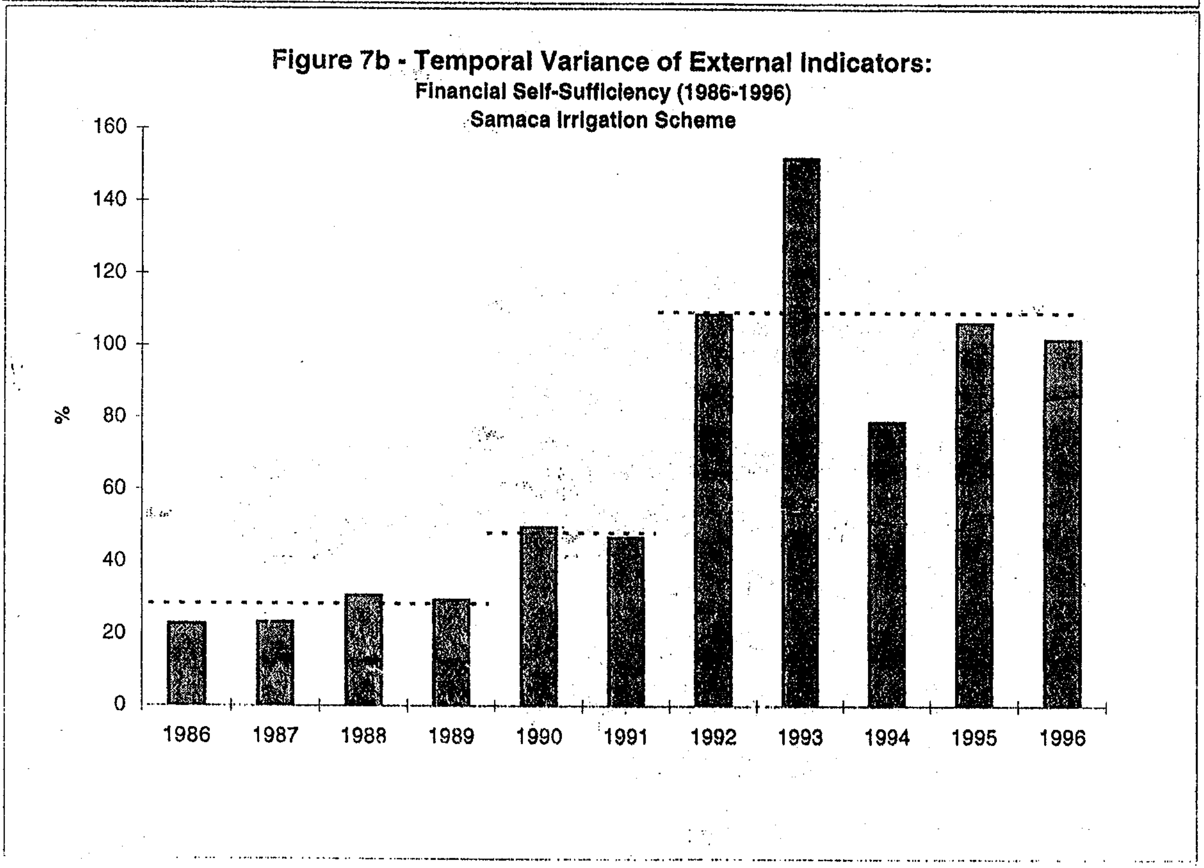


Figure 7b - Temporal Variance of External Indicators:
Financial Self-Sufficiency (1986-1996)
Samaca Irrigation Scheme
160
140
120
100
80
60
40
20
0
%
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996

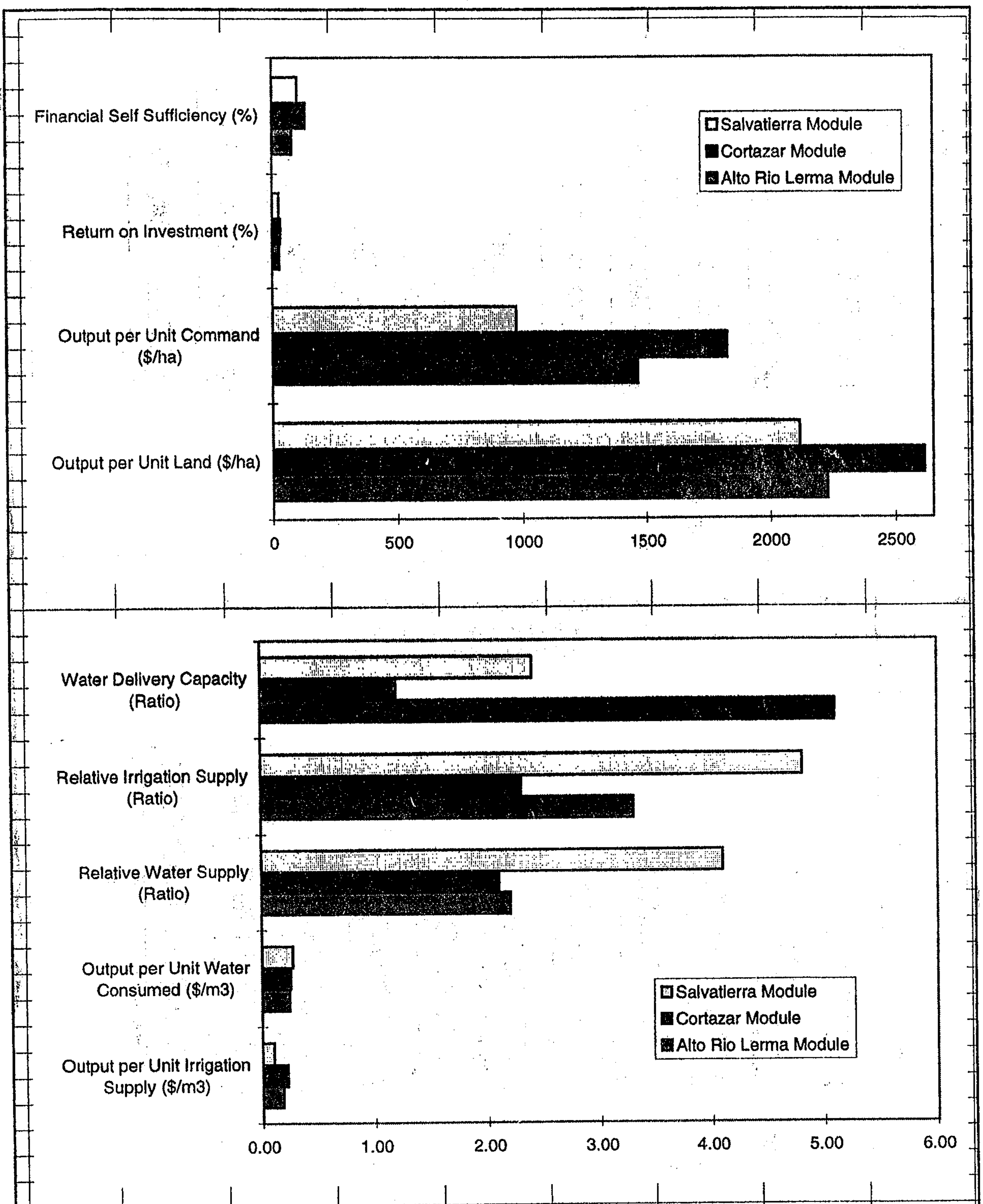


Figure 8 Spatial Variations of External Indicators - Mexico

Figure 9a - Standardized Gross Value of Production per cropped area
calculated with actual local and international prices
Samaca IrrigationScheme

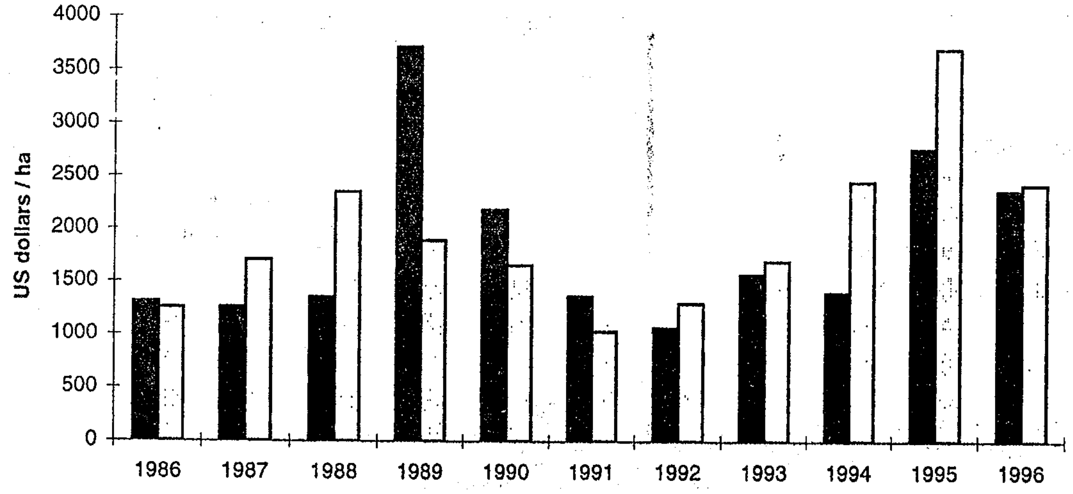
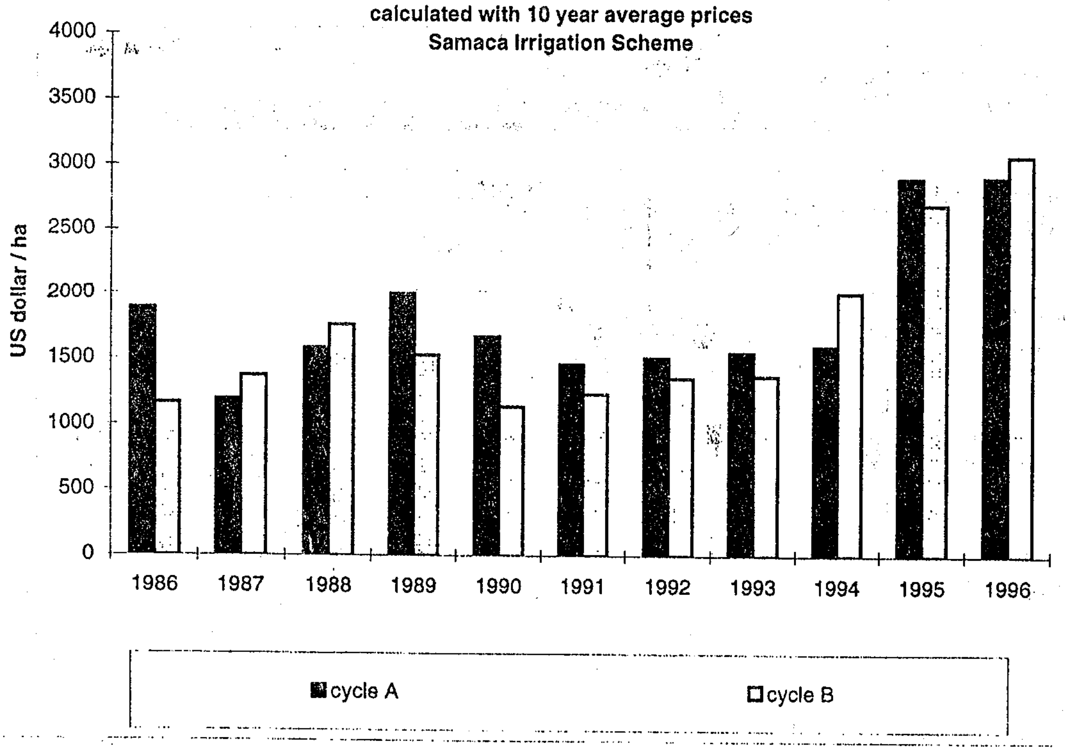
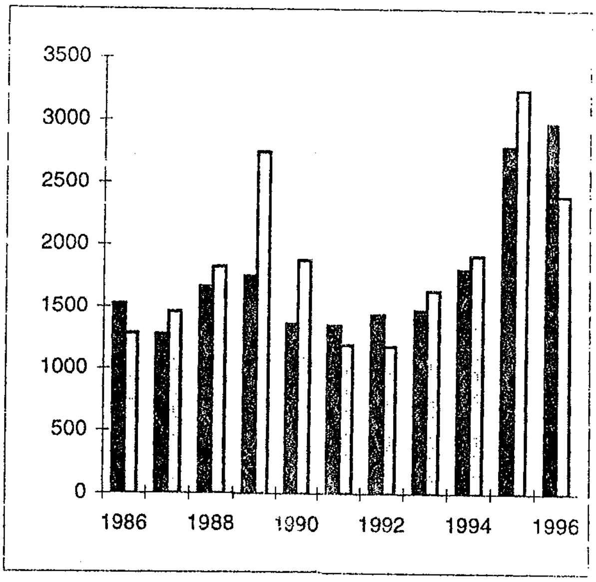


Figure 9b - Standardized Gross Value of Production per cropped area
calculated with 10 year average prices
Samaca Irrigation Scheme



	per cultivated area averaged	per cultivated area real prices
	Equivalant Gross Value of Output, US dollar	Equivalant Gross Value of Output, US dollar
1986	1521	1281
1987	1272	1458
1988	1665	1823
1989	1745	2742
1990	1358	1873
1991	1344	1189
1992	1436	1177
1993	1471	1630
1994	1799	1912
1995	2788	3241
1996	2976	2395



Assessing trends and changes in irrigation performance
The case of Samaca Irrigation Scheme, Colombia

Charlotte de Fraiture, Carlos Garces-Restrepo

Paper presented to the IIMI, ILRI, IHE and INCYTH-CRA
International Workshop on Irrigation Performance
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ABSTRACT

A distinction can be made between internal and external performance indicators. System managers might use internal indicators (like adequacy, timeliness and reliability) to evaluate actual results with targets in order to improve services to water users. Researchers and policy makers might be interested in a rapid, data extensive, performance evaluation in order to assess which types of systems in certain environments function well and which less. For the latter purpose external indicators which focus primarily on main outputs and inputs like water and land, were developed. IIMI identified a minimum set of nine external performance indicators, covering agricultural, water related and financial issues. This set of indicators supplemented by 4 additional indicators was applied to Samaca Irrigation Scheme in Colombia over a time span of 11 years.
The study shows that the set of external indicators lends itself not only for cross system comparison but also for analyzing developments in performance over time within one system. The application of the set provides a sound overview using simple calculation methods and basic information on irrigation, agriculture, climate and financial management. However, for establishing in-depth cause and effect relationships between observed performance and internal management features, additional background information is essential.

[1] The authors acknowledge the excellent work done by Luis Alberto Mora who did the major part of the data collection.

1. INTRODUCTION

1.1 Background

Performance evaluation can be executed for several purposes and by distinct groups of professionals. Depending on the objectives of the performance appraisal either internal or external indicators, or a combination of both, can be adequate. Farmers and system managers can measure performance by comparing actual results to planned targets in order to improve irrigation services to water users, making use of internal indicators. These indicators mainly deal with the irrigation delivery system in terms of adequacy, reliability of flow rates, timeliness, dependability and equity of distribution (Murray-Rust and Snellen 1993 and Rao 1993).

Researchers and policy makers might want to use indicators to compare the performance of different types of systems in various settings. Internal indicators do not lend themselves well to cross system comparison (Molden et al., 1997). Due the site specific character of management practices and targets, results often are hard to compare with other systems and other countries. Furthermore, the measurement of the internal indicators tend to be data intensive. To overcome these problems IIMI identified a minimum set of external performance indicators (Perry, 1996). External indicators focus on outputs and main inputs of the system like land and water. They give little insight in the internal management processes leading to the observed outputs but will identify which types of systems in which setting function well and which less, using a minimum of data. The consistent application of the minimum set of indicators in the different parts of the world will allow for comparisons between different schemes within and across countries and regions. In this way relative performance standards can be developed per type of irrigation scheme to facilitate evaluation of individual systems. The indicators might also prove useful to relate performance to water management practices.
IIMI's minimum set of indicators covering agricultural, financial and water related issues are currently being applied in several countries like Mexico, Colombia, Egypt, Morocco, Sri Lanka and India. Kloezen & Garces (1996) used the indicators to evaluate spatial variation in the performance in different sectors within one scheme in Mexico, while Molden et al.(1997) made a comparison between several schemes throughout the world. In this study the minimum set of indicators was applied to the Samaca Irrigation Scheme in Colombia over a time span of 11 years (1986 - 1996). A temporal analysis of performance using the indicators was accomplished and values of the indicators were compared with those for a range of schemes throughout the world, as described by Molden et al. (1997).

1.2 Methodology

The study was centered around the questions:
What are the trends in performance of irrigated agriculture in Samaca Irrigation Scheme ?
Is the minimum set of indicators as identified by IIMI a suitable tool to describe and analyze temporal variation in performance in Samaca Irrigation Scheme ?

To answer these questions the major changes and trends in agriculture and irrigation management in the Samaca Irrigation Scheme over the last decade were identified (chapter 2). Next the indicators of the minimum set were calculated for each year and their temporal variation was analyzed or: how are the changes reflected by the indicators ? (chapter 3). The set of indicators was supplemented by 4 indicators which could be computed with the available data and which provided additional insight in performance issues.

The indicators, divided in three groups (agricultural, financial and water related) are listed below. The indicators printed in italic are not included in IIMI's minimum set.

Agricultural:

1. *Irrigation intensity*
2. Gross value of output per hectare of the command area
3. Gross value of output per hectare of the irrigated area
4. Gross value of output per unit of irrigation applied
5. Gross value of output per unit of water consumed

Water-related:

6. Relative water supply
7. Relative irrigation supply
8. Water delivery capacity

Financial:

9. Fee collection rate
10. Financial self-sufficiency
11. Gross return on investment
12. O&M expenditures per unit of land
13. O&M expenditures per unit of water

A detailed description of each indicator and calculation method is given in annex 1.

1.3 *Data collection*

Mainly historical data from secondary sources like government offices, commercial centers and research institutes were used. As stated by Small and Svendsen (1992) the use of indirect or secondary data may distort performance assessment if it is believed that the results will affect job performance ratings. Agricultural yields might be estimated on the high side by agricultural engineers working in the area due to their professional bias towards successful commercial farmers rather than small subsistence farmers in the hills. Ditch keepers might report volumes of water delivered closer to the desired or planned than to the actual values. However, obtaining reliable data on direct measures is often difficult and costly. It is necessary to balance the increased value of the more accurate and reliable information provided by the direct measures of performance with the additional cost of obtaining that information. Moreover, IIMI's involvement in Samaca only dated from 1995 onwards while the performance analysis was executed over a time span of 11 years. To overcome above mentioned problems data were carefully double checked with information from other sources and compared with values reported for other similar systems nearby. The obtained data are considered reasonable reliable for this analysis.

The Colombian Irrigation Agency at regional as well as at national level (INAT[2]) could provide data on cropping patterns and water use. Data on financial issues like budgets, expenditures, water fee collection, outstanding debts and personal management were available with the Water Users' Association in Samaca. Crop yields and local prices were collected at a nearby agricultural commercial center (CORPORABASTOS) where the majority of the crops are traded. The International Potato Center (CIP, Peru) provided data on potato prices at world market level. Financial data like inflation and exchange rates were subtracted from the IMF publications International Financial Statistics Yearbook for each year. Crop water demands and net irrigation requirements for individual crops and for the scheme as a whole were calculated with CROPWAT (FAO 1992 and 1993)[3]. For the estimation of the effective rainfall the formula developed by the USBR/USDA-Soil Conservation Service[4] was used. The Colombian Ministry of Environment, responsible for the climate station situated in the command area, had a complete and up-to-date data base on temperature, precipitation, wind speed, solar radiation and relative air humidity for each year. Actual canal capacities and the amount of irrigation water applied in the last semester were measured in the field.

All data were processed with Excel 5.0. To define if the differences in mean values before and after an incident are statistically significant, the simple paired t-test was used. Correlation coefficients and trend lines were calculated with Excel in-built statistical Tool-pack. Data utilized to compute the indicators are summarized in annex 2.

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[2] INAT: Instituto Nacional de Adecuacion de Tierra

[3] Latest version downloaded from website ftp://ftp.fao.org/FAO/AGL/AGWL/CROPWAT/

[4] Refer FAO 1992: $P_{eff} = P_{tot}(125 - 0.2\, P_{tot})/125$ for monthly $P_{tot} < 250$ mm
$P_{eff} = 125 + 0.1\, P_{tot}$ for monthly $P_{tot} > 250$ mm

1.4 General description of the scheme

The Samaca Irrigation Scheme is situated in Eastern part of the Department Boyaca in central Colombia (refer to figure 1 for map). Altitudes in the command area vary from 2600 to 3000 m. The command area covers approximately 3000 hectares of which 54 % consist of flat land while 46 % is hill area.

The mean daily temperatures vary little over the year and average 13.8 °C. The rain fall pattern is extremely irregular within the year as well as over the years. The mean yearly rainfall over the studied period (1986 - 1996) is 690 mm with two pronounced wet periods in October - November and April - May. Occasional hail storms occur in the dryer periods. The potential evapotranspiration[5] which hardly shows any variation throughout the year, amounts to 1020 mm on year basis. Figure 1 shows that November is the only month in which the mean effective rainfall exceeds the evapotranspiration. In the other months irrigation will be required to meet crop water needs. However, due to the enormous fluctuation in precipitation the irrigation needs vary widely between the years. Table 1 summarizes details on climate data for the study period.

The main crops grown in the area are potato, onion and green peas. On a smaller scale vegetables (red beat, cabbage and carrots), wheat, maize, beans and barley are grown. At present some 2000 farmers are benefiting from the scheme. The average land holding 3.5 hectares in the plain and 0.9 hectares in the hill area.

In the valley the agriculture has a commercial character while in the hill part subsistence farming dominates. About 30 % of the total command area is currently used for (irrigated) pasture, mainly situated in the hill area.

The system receives irrigation water from 2 serial reservoirs with capacities of 4.7 and 1.5 Mm^3 .The reservoirs receive water from precipitation falling on the catchment area. Two lined secondary canals with a capacity of 250 and 400 l/s convey water along the contour line to the hillside areas. The valley receives water from the river that originates from the reservoirs. This river is used as main canal and drain at the same time.

Farmers in the valley receive the water on demand. If they need water they submit a written request to the ditch keeper. Based on the demands the management makes a weekly schedule of delivery detailing time and duration. It should be noted that most farmers in the valley are fairly independent of the management concerning exact amount and timing because most of them constructed ponds on their plots to store the water temporarily. The water is extracted with motor pumps connected with sprinklers.
The hillside area is divided in irrigation units each having their own storage tank. These tanks are small (12 to 36 m^3) and mainly used for domestic purposes. In theory there is a continuous water supply to the units. However, because of technical problems (design errors) nearly half of the units are forced to rotate the water.

[5] ET o according to Penman-Monteith, calculated with CROPWAT

Water fees are fixed on the basis of land area, independent of the volume actually used. There are two different fees: one for the plain area (45 US$ per ha, 1996) and a lower one for the hill area (25 US$ per ha, 1996). Farmers in the valley pay more because generally the commercial farming in the valley requires more water than the subsistence type of farming in the hills. Everyone with land in the command area is obliged to pay water fees regardless the fact whether the land is actually irrigated or not.

2. TRENDS AND CHANGES

2.1 *History of the scheme*

The biggest and oldest of the 2 reservoirs was built in the middle of the last century by a textile company who used the water to generate electricity. After the retention wall broke down farmers in the region decided to ask the government for credit to rebuild the wall and construct canals which would allow the use of water for irrigation. The construction of the reservoir and the main 2 canals finished in 1941. The system was initially administrated by the Water Department and later by Water and Electricity Institute.
In 1966 the Colombian Institute for Agricultural Reform took over the system and initiated some technical improvement in the canal and drainage system. Ten years later the Colombian Institute for Hydrology and Land Improvement was created and took over responsibility for the operation, management, maintenance and administration of the system. During this period the second reservoir was built and many improvements in the infrastructure were realized. These investments were paid by the government agency. In late 1992 the government agency transferred the system's management to the users. The entire system including reservoir and main canals was transferred.

2.2 *Trends and changes during the last decade*

A continuing trend in agriculture in Colombia is the shift from subsistence to commercial farming. Over the last decade Colombia's economy has been liberalized: importation taxes and exportation subsidies were reduced substantially while subsidies in agriculture were cut or reduced. Due to this opening-up of the market local farmers had to compete with imported products. On the other hand, agro-inputs became more widely available at lower prices. This resulted in a change in attitude towards farming: farmers started producing for the market rather than only for subsistence and increasing the use of agro-chemicals. Consequently, crop yields over the last decade show a rising trend.
The first two changes as described below which influenced management and agricultural practices in Samaca Irrigation System could be seen as specific events in this general process of economic liberalization.

A. Changes in cropping pattern

figure 2

Until the late 80s barley was a profitable crop in Samaca because the nearby beer factory was offering a good and steady price. However, with the opening of Colombia's economy the beer factory started to import cheaper barley from outside Colombia. This caused a dramatic reduction in price and area cropped with barley. At present it is mainly cultivated for own consumption.

In the second cycle of 1989 onion was introduced as a cash crop in the system. The deep loamy soils and the moderate climate appeared to be suitable for this crop. Good access roads and nearby markets made it easy to commercialize. Potato and onion are now the most important crops grown in the area. Onion prices fluctuate considerably from one month to another and growing this crop involve risks: one season the farmer may make high profits while the next season (s)he will lose money. Another problem is the frequent occurrence crop diseases mainly caused by monoculture.

B. Irrigation Management Transfer

In October 1992 the management and administration of the Samaca Irrigation System was transferred to the Water Users' Association. This was done as part of a national program to reduce government subsidies and expenditures in the irrigation sector and to transfer responsibilities from government to the direct beneficiaries. The Irrigation Management Transfer in Colombia started in the 70s when 2 systems (Saldana and Coello) were transferred to the users on their own request. Farmers claimed that they were able to manage the systems more efficiently and at lower costs than the government agency (Vermillion and Garces 1996). During the 80s no irrigation systems were transferred. Around 1990 the government launched a nation wide program to transfer irrigation systems. Samaca Irrigation System was the sixth scheme transferred under this government initiated program. The IMT process in Samaca started in 1991 when the water fees paid by the beneficiaries were raised with 170 % in order to increase financial self-sufficiency and to reduce government expenditures. In the same year the negotiations between the Water Users Association and the government agency started about the conditions of transfer. The negotiation process took one year. The IMT document was signed in October 1992 but it was only in January 1993 that the WUA really assumed the full management responsibilities.

C. Abolishment of the volumetric fee

Until 1990 the scheme used a volumetric water fee per cubic meter of irrigation water on top of the fixed fee per hectare. The fee amounted to approximately 2 to 3 dollars for 1000 m^3 (1995 constant prices). Around 15 % of the total income from water fees was derived from the volumetric fee. The volumetric fee was abolished by the irrigation management because of practical reasons: firstly, because of the high administration costs. Secondly, because reported water volumes could easily be manipulated by ditch keepers, as accurate measuring devices were not available.

The abolishment of the volumetric fee coincides with a jump in area covered with irrigated pasture. Apparently many farmers decided to use their fallow land for a water consuming but low value crop like pasture as soon as the water charge became independent of the actual volume utilized. Over the last three years the area covered with irrigated pasture is decreasing while potato and onion are gaining importance.

In the following chapter a description will be given of how the above mentioned developments are reflected in the performance indicators.

3. PERFORMANCE INDICATORS

The minimum set of consists of nine indicators covering agricultural, financial and water related issues (Perry 1996). For this analysis the set was complemented by 3 indicators describing the financial performance in more detail. Annex 1 gives the definitions of the indicators used in this study. Annex 2 provides an example of how the indicators were computed while annex 3 summarizes the data required for the calculation.
The values of the computed indicators are used to compare performance of the Samaca Irrigation Scheme with 18 irrigation systems located in 11 countries around the world (for details on this cross country comparative performance study refer to Molden et. al., 1997).

3.1 Agricultural indicators

A. Irrigation intensity

figure 3

The average irrigation intensity defined as the irrigated area divided by the command area, fluctuated around 0.85 during the late 80s. Between 1990 and 1991 the irrigated area increases rapidly bringing the irrigation intensity to an average of 1.65. The sudden rise

coincides with the abolishment of the volumetric fee and the introduction of onion as a new cash crop. The abolishment of the volumetric fee lead to a dramatic increase in irrigated pasture while the introduction of a new cash crop (onion) resulted in an increase of area cultivated. The irrigation management transfer had no visible impacts on irrigation intensity. The jump occurred before the transfer.

B. Standardized gross value of production per unit of land

figure 4

The general trend in the standardized gross value of production (SGVP) per cultivated area is a rising line, mainly attributed to a general increase in yields of the two main crops, potato and onion. This can be explained by the changing attitude in farming (from subsistence to commercial) and improved agricultural inputs. The outputs in US dollars rise from around 1,500 US$ per hectare during the second half of the 80s to 2,500 US$ per hectare[6] in the last few years. In 1991 the SGVP dropped because farmers increased the area with irrigated pasture (low value crop) as a result of the abolishment of the volumetric fee. After 1992 the SGVP is picked up again as high value crops like potato and onion gain importance at the expense of pasture.

During 1986 to 1989 the SGVP per unit command area is slightly lower than the SGVP per unit cultivated area since the irrigation intensity is smaller than 1. After the abolishment of the volumetric fee and the introduction of onion the irrigation intensity rises substantially and consequently the SGVP per unit command area shows a jump. In 1995 the SGVP leaps up again, mainly by sustained yield improvements of potato and onion (the two main crops grown in the area). The SGVP per unit command area rises from less than 1000 dollar per hectare in 1986 to well over 4000 dollar per hectare in 1996 (constant dollars).

Comparing the values of SGVP per unit of land with those of other schemes throughout the world, Samaca ranks within the upper 25 % of the systems studied (Molden et al. 1997). It should be noted that the SGVP is a measure of productivity of the scheme and as such indicate little about individual farmers' income which may in fact rank much lower because onion requires high fertilizer and pesticide inputs and involves a lot of risks.

There were no visible impacts of Irrigation Management Transfer on the SGVP. Agricultural production depend on many factors like climate, inputs, diseases and price policies. Irrigation management is only one of the many factors having an impact on the system's agricultural output. Furthermore, there is little evidence that farmers changed agricultural practices because of the transfer. This was illustrated by the results of a recently held questionnaire in which farmers were asked about the transfer: 68 % of the

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[6] constant dollars, base year 1995.

respondents claimed that they did not know what transfer meant, or could not remember (Giraldo 1997).

C. Standardized gross value of production per unit of water

figure 5 and 6

The values for the SGVP per unit of irrigation water show rising line, following the general trend of increasing agricultural production over the last decade . Despite the rising trend, there is a lot of variation between the years, the lowest value being 0.31 US$ per cubic meter irrigation supplied and the highest 1.24 US$ per m^3. A closer analysis based on seasonal instead of annual values, reveals a rather high correlation[7] between SGVP per unit of irrigation and precipitation (refer figure 6). If the precipitation is high, less irrigation will be needed (and hence applied). Therefore, in wet years the indicator gives high values, in dry years low values. The strong correlation between precipitation and the amount of irrigation supplied reflects a very efficient use of rain in the Samaca Irrigation Scheme. The command area is small and compact and if it rains the valve operator at the main reservoir will close the gate. Farmers who still need water can use water from their individual storage tanks at their field.

Compared with other schemes throughout the world Samaca Irrigation Scheme has one of the highest SGVP per unit of irrigation water applied. This is due to the combination of a reasonable amount of rainfall spread over the year, the relative low values of evapotranspiration due to climatic factors and the ability of farmers to use rain effectively for their crops.

Water consumption by crop ET is used in the calculation of SGVP per unit of water consumed (Molden et al. 1997). Potential ET is used to approximate actual ET due to lack of information on crop water stress. Water can also be consumed by flow to sinks and other non-crop ET (Seckler 1996). In the case of Samaca crop ET will be the dominating factor in overall water consumption. as there is little flow to deep sinks due to the hilly nature of the area. Free water surface evaporation losses from both reservoirs will be limited due to low temperatures at the altitude of 3500 m. Water that is not consumed locally is available for use for down stream users. In fact, drainage water leaving the command area is used for a small irrigation scheme further down stream. The SGVP per unit of water consumed varying from 0.31 US$ to 0.77 US$ per m^3 is considerably lower than the SGVP per unit of irrigation applied (0.31 - 1.24 US$ per m^3). An important part (average of 45 % over 11 year) of the crop water requirements is met by precipitation. The increase of irrigated pasture (low value and water consuming) causes a drop in 1991 but soon after the values increase again due to the growing importance of high value crops like onion and potato.

[7] correlation coefficient amounts to 0.76

3.2 *Water related indicators.*

A. Relative Water Supply and Relative Irrigation Supply

figure 7

The relative water supply was originally developed by Levine (1982) as a measure of water availability. It indicates how much water (in the form of rain and irrigation) is available in relation to the total water needs. Values lower than 1.5 suggest a 'tight' water availability in which strict management is required to meet needs in a satisfactory way[8]. It lends itself to improved understanding for the major participants in the irrigation process i.e. irrigation managers and farmers. In Samaca the values vary from 1.23 for the driest year to 2.04 for the wettest year. The low values in the drier years suggest a tight water availability. The farmers reacted on this situation by constructing small earthen reservoirs in their plot to allow them to be more flexible and independent of the system's water supply in moments of water scarcity. At present there are some 567 of such reservoirs, with an average capacity of some 3000 m^3 and the number is still growing.

The relative irrigation supply gives the fraction of the amount of irrigation actually supplied in relation with the net irrigation needs. It was calculated at both field and scheme level. For field level calculations the volumes at field inlets reported by ditch keepers are used. At field level the values are generally low, with an average of 0.88. In the dry year 1991 the computed value of 0.49 would imply that only half of the (net) irrigation requirements were met. The calculated values are probably under-estimating the actual values for RIS. An explanation could be that ditch keepers tend to under-estimate the quantity of water supplied to match reported figures with the planned quantities. Moreover, in 1990 the volumetric fee was abolished so that it became less important to measure water quantities accurately. This observation is supported by the fact that crop yields hardly suffered during this period.

The RIS at scheme level is higher due to conveyance and operational losses in the main canals. An average at scheme level of 1.61 compared to field level values reflects an conveyance and operational efficiency of around 55 %.

Roughly, the RWS and the RIS are following the same pattern. In years of water abundance the irrigation supply is relatively high while in water short years the RIS only is around 1.0. The figures show that the Samaca Irrigation Scheme is able to use the water efficiently. The high irrigation amounts in water abundant years does not mean that the water is wasted or lost because downstream the system's drainage water is reused by another irrigation scheme.

[8] Levine (1982) suggest this critical value of 1.5 for rice systems in Asia. Most probably for non-rice systems like Samaca this value will be higher because of lower field application efficiencies.

The changes in irrigation management are not clearly reflected in RWS and RIS. Total precipitation appeared to be a far more predominant factor determining values of these indicators than agricultural and water management practices.

B. Water Delivery Capacity

figure 8

The water delivery capacity indicates the degree in which the actual canal capacity is sufficient to convey the peak demand of the overall system. At the same time it gives an indication of the degree in which the system is utilized in comparison with its actual full capacity. Until 1989 the values fluctuated around 4, indicating a degree of under-utilization of the infrastructure's full capacity by a factor 4. Then it suddenly drops down to 1.0 in 1992 while in the last four years it stabilized around 1.7. This sudden change can be attributed to the changes in cropping pattern as described in chapter 2. The introduction of onion as cash crop causes an increase in water requirements because onion demands more water than crops previously prevailing in the system (like barley). The augmentation of area under irrigated pasture further increases crop water requirements, mainly because of the length of the growing season. The low values of the water delivery capacity in 1992 are caused by the low precipitation (and hence high irrigation demands) combined with a sudden increase in area irrigated pasture.

From the temporal variation in the water related indicators an impact of Irrigation Management Transfer on water management could not be deduced. Most probably there were no major changes in water management after transfer because the WUA continued following the same procedures for water distribution as the government agency was applying before transfer. Furthermore there were no significant changes in infrastructure after 1993.

3.3 Financial indicators

A. Financial self-sufficiency and fee collection rate

figure 9

From 1986 to 1990 the financial self-sufficiency of the scheme was average 35 %, indicating that only 35 % of the total operation and maintenance expenditures were paid out of the collection of water fees and 65 % was subsidized by the government. With the Irrigation Management Transfer this situation altered dramatically. Although the actual transfer took place at the end of 1992, the government already started the process in late

1991 by increasing the water fees. The water fees were raised with a 170 % from approximately 19 to 42 US$ per hectare[9] (refer table 4) and financial self-sufficiency rose from 50 % in 1991 to 109 % in the next year, indicating that by that time the government subsidies were reduced to zero and all cost to run and maintain the system were covered by the users themselves. Since IMT the system has not received any government subsidies except for some financial support for maintenance of local dirt roads.

However, a closer look at the financial situation of the scheme reveals a less optimistic picture and three issues might negatively influence the financial self-sufficiency in the near future. Firstly, although the system has been able to pay its operation & maintenance expenditures out of the water fee payments, it has no provision for an emergency and/or revolving fund. This situation is common in the transferred systems in Colombia (Quintero, 1997) and provokes the question who will pay for rehabilitation if this becomes necessary in the near future.

Secondly, for 1997 the WUA requested the government support to rehabilitate the main canal. The government approved rehabilitation works for some 140,000 US dollar to be spent in the first trimester. The execution and the payment of the works will be done under direct management of the government agency. This expenditure will not be visible in the administration of the scheme. Therefore, the financial self-sufficiency will remain roughly at the same level on paper, while in reality the government started subsidizing the system's rehabilitation.

A third concern is the decline in fee collection rate over the last few years. The fee collection rate was at its highest (85 %) just before transfer, probably because the irrigation agency at that time paid extra attention to fee collection in order to reduce subsidies. The last 4 years the collection rates are slowly declining to 70 % in 1996. The outstanding debt rose from US$ 34,000 at the time of transfer to US$ 118,000 in 1996, of which about 35 % was formed by accumulated interest. The Board of the WUA recently decided to involve lawyers to get people to pay their outstanding debts. As the water is allocated per irrigation unit it is hard to cut off water from individual farmers, although the statutes of the WUA mention this sanction in case of non-payment.

B. O&M expenditures per unit of land

graph 11

The total O&M expenditures (corrected for inflation, base year 1995) tend to increase only slightly over the years (refer table 4), although the cultivated area increased considerably over the years. The total O&M expenditures appeared to be independent from the area cultivated. This situation is inherent at the way the water fees and the O&M budgets are fixed: since the management transfer the fees are raised each year according

[9] this is the highest water fee category valid for valley. In the hills the fee is 55 % lower

to the inflation. The O&M budgets are then determined according to amount of money they are expecting to collect from the water fees. So, the water fees and O&M budgets are not based on the maintenance needs but on anticipated water fee collection. According to the order of priority works are executed as far as the money lasts. Emergencies like machines breaking down lead to the postponement of other works. Apparently the WUA is not able to convince farmers that a raise in water fee in real terms might be needed to do all necessary maintenance. The way in which the maintenance is planned -- based on the amount of water fees farmers are prepared to pay rather than on real needs -- may cause a deterioration of the infrastructure and equipment in the long run, although from the indicators there is little evidence that this is already the case.

The O&M costs per hectare of the command area remain more or less on the same level, fluctuating around 35 US dollar per hectare. Due to the increased irrigation intensity expenditures per cultivated area steadily come down from 185 US dollar per hectare in 1986 to 75 US dollar in 1996. The sudden peak in 1994 is caused by the exceptional high expenses that year due to some emergencies like machine break down.

The irrigation management transfer did not have visible impacts on the total O&M expenditures. However, a closer analysis of the financial data reveals a shift in money spent: after transfer the WUA started to cut down on costs of personnel involved in operation. This results in less ditch keepers and a higher personnel turnover. This might endanger the smooth operation of the system in the long run although from the indicators there is little evidence that this is already the case.

C. O&M expenditures per unit of water

O&M expenditures in Samaca Irrigation System are independent of the total amount of water applied. Consequently, the O&M expenditures fluctuates with the amount of irrigation water applied which, as mentioned earlier, highly correlates with the amount of rainfall. The average O&M expenditures per unit of irrigation applied over the last decade amounts to US$ 0.011 per m^3. So, only 2 to 3 % of the SGVP per cubic meter of irrigation applied is spent on O&M.

There were no data available to compare these figures with other schemes.

D. Gross return on investment

The construction of the Samaca Irrigation Scheme started in 1941 when the biggest of the two reservoirs was built. Since then the system was many times adapted and improved. The last big improvement was the construction of the second reservoir in 1992. Because of the large time lapse in which the system evolved to its actual form, it is hardly possible to give an estimate of the total construction costs. Therefore, the mean investment cost per hectare of a nearby system currently under construction is taken as basis for the

calculation of the gross return on investment. This investment amount to about 7000 US$ per hectare, bringing the return on investment on 22 %. The investment cost of 7000 US$ per hectare is probably an over-estimation for the Samaca Irrigation Scheme because the nearby scheme uses a more expensive irrigation technology.

Data to establish a temporal analysis over the last decade were not available.

4. Summary and concluding remarks

This case study showed that the minimum set of indicators, when applied over a range of years provides a very suitable tool to describe trends and changes in the Samaca Irrigation System. With basic data on climate, cropping pattern, yields, prices, irrigation and O&M expenditures a temporal analysis of performance could be made. Furthermore, a comparative performance evaluation in Samaca in relation to other schemes around the world could be established. In view of the simple calculation method and basic data requirements the minimum set of indicators could be very well applied to other schemes to study developments in performance over time.

Trends and changes reflected by the performance indicators

The abolishment of the volumetric fee in 1990 led to a sharp increase in irrigated pasture at former fallow land areas. Apparently farmers decided the convert fallow land in a low labor intensive, low value but water consuming culture like irrigated pasture when the water charges became independent of the volume of water used. As a result the irrigation intensity and the overall productivity per unit of the command area augmented while the productivity per unit of water consumed showed a decline. Later the area cultivated with cash crops like onion and potato gained importance at the cost of irrigated pasture and standardized gross value of production per unit of both land and water increased. At the same time the water delivery capacity came down indicating a growing intensive use of the system's physical infrastructure. Remarkably, this increased intensive use does not seem to have impacts on the total O&M expenditures which only increases slightly over the years. The O&M expenditures per hectare of the command area decline because an increasing part of the command area is being cultivated.

The correlation between precipitation and output per unit of irrigation reveals an efficient use of rain. This is due to the compact character of the command area and the numerous little reservoirs constructed by individual farmers to be more flexible and independent of the system's water distribution. This fact is also reflected in the relation between relative water supply and relative irrigation supply which broadly follow the same patterns.

The impacts of Irrigation Management Transfer are mainly found in the financial management of the scheme. The financial self-sufficiency -- still around 35 % in the late 80s -- is more than 100 % during the last few years, indicating that the beneficiaries bear

the full O&M costs of the system by paying water fees. Although farmers are able to operate the system with the collected water fees, they do not have an emergency or revolving fund. The question remains who will pay for emergencies or rehabilitation when this becomes necessary in future. For this year (1997) the WUA requested the government for assistance for rehabilitation works in two canals.

There is no indication that after management transfer the WUA is able to run the system at lower costs than the government agency. The total O&M expenditures before and after IMT remained more or less on the same level. This is mainly due to the way in which budgets are fixed. The water fees are based on previous fees adapted for inflation. Maintenance works are based on the amount of money the WUA is expecting to collect rather than real needs. The actual (low) spending on maintenance might result in a deterioration of the infrastructure on the long run although from the indicators there is no evidence that this is already the case.

To obtain a better judgment of the impacts of irrigation management transfer a more detailed analysis is essential since these are mainly found in the financial and personnel management of the system, rather than on outputs of the system. In this study the indicators O&M expenditures per unit of land and water and fee collection rate were added to achieve a better understanding of the IMT process..

Performance evaluation relative to other schemes

Compared to 18 schemes where the set of performance indicators was applied the Samaca Irrigation Scheme ranks among the highest 25 % in production per unit of land and unit of water. The SGVP per unit of land is high because of the high value cash crops grown in the command area (onion and potato) while the major part of the other schemes paddy is grown. The high SGVP per unit of irrigation applied is due to the reasonable amount of rainfall relative to the reference ET and the farmers' ability to utilize this rain effectively. Comparing the values of the Relative Water Supply among the range of systems, Samaca has an average amount of water available in relation to its water requirement while the Relative Irrigation Supply ranks among the lower 25 % indicating an efficient use of irrigation water.

Limitations of the minimum set of indicators

Application of the minimum set of indicators provides a good overview on how the scheme as a whole performs relative to other schemes or compared with foregoing years, making use of basic information which often is available on scheme level. However, the applied indicators do not lend themselves to a thorough in-depth cause and effect analysis of the observed performance variation. In this study in order to clarify certain performance features additional indicators, like fee collection rate and O&M expenditures were introduced and at a few occasions seasonal instead of annual analysis was necessary for better understanding. To evaluate and fully comprehend the impacts of the irrigation management transfer additional indicators focused on internal management processes

(and hence extra information) will be essential. In this case study the entire scheme was taken as unit of analysis without paying attention to aspects like equity of distribution, timeliness and reliability of flow rates. By leaving out these internal processes at local level, the analysis might be more interesting for researchers and policy makers than for farmers and system managers. For example the indicators express agricultural outputs in gross values while for farmers the net values or profitability are of principal concern.

The quality of the indicators is as good as the data utilized to compute them. In this study historical data derived from secondary sources are used. Despite careful cross checking some distortion could not be avoided. Irrigation water quantities at field level might be underestimated by ditch keepers while agricultural yields are likely to be appraised at the high side by agricultural extension workers. These uncertainties are inherent to data from secondary sources.

The amount of water consumed by crops, water lost by non-beneficial evaporation and irrigation needs cannot be measured directly in the field but must be approximated using existing formulas and/or the researchers' assessments. The consistent use of adequate methods to estimate effective rainfall, crop water requirements and irrigation needs is a prerequisite for cross system comparison.

The minimum set does not include indicators concerning environmental issues or sustainability. A wide range of indicators is available for example the percentage of the command area abandoned due to environmental problems (salinity, water logging, erosion) or quality of water entering the system related to the quality of water leaving the command area. For example in Samaca it would have been interesting to evaluate the effects of the augmentation of the area cropped with onion on water quality since a large amount of agro-chemicals are used for this crop[10]. This would have given a more balanced view of the system's sustainability than only looking to productivity. The main obstacle is the availability of information due to the bias of data collectors towards agricultural information and water quantities rather than environmental data like water quality.

[10] In fact, in Samaca an environmental study was conducted in 1996 (Gonima and Gomez, 1996). The study concluded that there were no water quality problems in the system. As samples were only taken during a short period of time no longer term conclusions about sustainability issues could be drawn.

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Table 1: Climate data
Samaca Irrigation Scheme

Yearly values

Year	total precipi-tation (mm)	ETo (Penman) mm *	av. daily temp. (°C)
1986	781.3	976	13.7
1987	565.6	1033	14.2
1988	891.1	965	14.3
1989	610.1	976	13.4
1990	691.0	1011	14.0
1991	553.3	1026	14.3
1992	647.6	1033	14.4
1993	573.6	1030	14.3
1994	803.7	976	14.1
1995	699.2	1051	14.3
1996	758.7	972	13.7
Averag	688.7	1004.5	14.1
St Dev	110.6	31.6	0.3

Mean monthly values

Month	Total precipi-tation (mm)	Effective rain USDA (mm)	ET_o Penman Monteith (mm)	ET_o - Eff. Rain (mm)	Standard deviation total prec.	Standard deviation ET_o
Jan	26.0	23.7	5.2	18.4	23.2	5.2
Feb	53.6	46.2	7.8	38.4	30.1	7.8
Mar	83.2	65.1	6.1	59.0	48.6	6.1
Apr	69.5	58.4	6.0	52.5	28.0	6.0
May	66.0	55.9	3.7	52.2	27.6	3.7
Jun	38.4	34.7	3.8	31.0	19.7	3.8
Jul	35.1	32.4	4.5	27.9	11.7	4.5
Aug	27.6	25.9	5.5	20.4	9.9	5.5
Sep	49.0	42.1	6.7	35.4	31.7	6.7
Oct	94.4	69.7	7.1	62.5	61.5	7.1
Nov	109.2	79.9	4.3	75.6	54.8	4.3
Dec	36.8	32.5	6.4	26.1	29.2	6.4
Annual	688.6	566.4	67.0	499.5	27.3	1.3

* calculated with CROPWAT using the modified Penman Monteith formula

Table 2: Agricultural Indicators Samaca Irrigation Scheme

Year	Irrigation intensity ratio	SGVP per unit command area (US dollar per ha)	SGVP per unit cultivated area (US dollar per ha)	SGVP per unit irrigation supplied (US dollar per m^3)	SGVP per unit of water consumed (US dollar per m^3)
1986	0.82	889	1328	0.31	0.33
1987	0.80	1027	1272	0.39	0.33
1988	0.72	1304	1665	0.59	0.47
1989	0.65	1287	1745	0.36	0.45
1990	1.00	1450	1358	0.42	0.32
1991	1.63	2276	1344	0.44	0.31
1992	1.62	2521	1436	0.65	0.32
1993	1.64	2462	1471	0.63	0.34
1994	1.45	2592	1799	1.05	0.44
1995	1.49	4042	2788	1.02	0.71
1996	1.51	4373	2976	1.24	0.77

0.44

all prices mentioned are corrected for inflation with base year 1995

Table 3: Water Related Indicators Samaca Irrigation Scheme

Year	Relative Water Supply (ratio)	Relative Irrigation Supply scheme (ratio)	Relative Irrigation Supply field * (ratio)	Water Delivery Capacity (ratio)
1986	1.52	1.47	0.89	4.35
1987	1.55	1.62	0.90	2.97
1988	2.03	2.14	0.92	3.44
1989	2.04	2.63	1.19	4.52
1990	1.60	1.90	0.98	1.73
1991	1.36	1.30	0.49	1.23
1992	1.25	0.98	0.57	1.01
1993	1.23	1.13	0.60	1.67
1994	1.40	1.19	0.96	1.83
1995	1.60	1.82	1.30	1.71
1996	1.61	1.55	0.88	1.71
Average	1.56	1.61	0.88	2.38
StDev	0.27	0.49	0.25	1.24

* based on volumes at field inlets reported by ditch keepers

Table 4: Financial Data
Samaca Irrigation Project

Year	Fee collection rate (%)	Financial Self-sufficiency (%)	Fixed water fee (valley) (US dollar per ha)	Total O & M expenditures (US dollar)	O & M expenditures per unit command (US dollar per ha)	O & M expenditures per unit irrigation (US dollar per m^3)
1986	74	23	9	82,916	38	0.013
1987	78	23	9	83,427	37	0.014
1988	55	31	9	94,909	40	0.019
1989	48	29	9	94,563	36	0.010
1990	83	50	18	97,976	35	0.010
1991	85	47	19	104,053	36	0.007
1992	76	109	42	82,052	28	0.007
1993	81	152	37	64,213	22	0.006
1994	77	79	41	119,609	41	0.017
1995	71	107	45	94,520	32	0.008
1996	70	102	45	94,556	32	0.009
						0.011

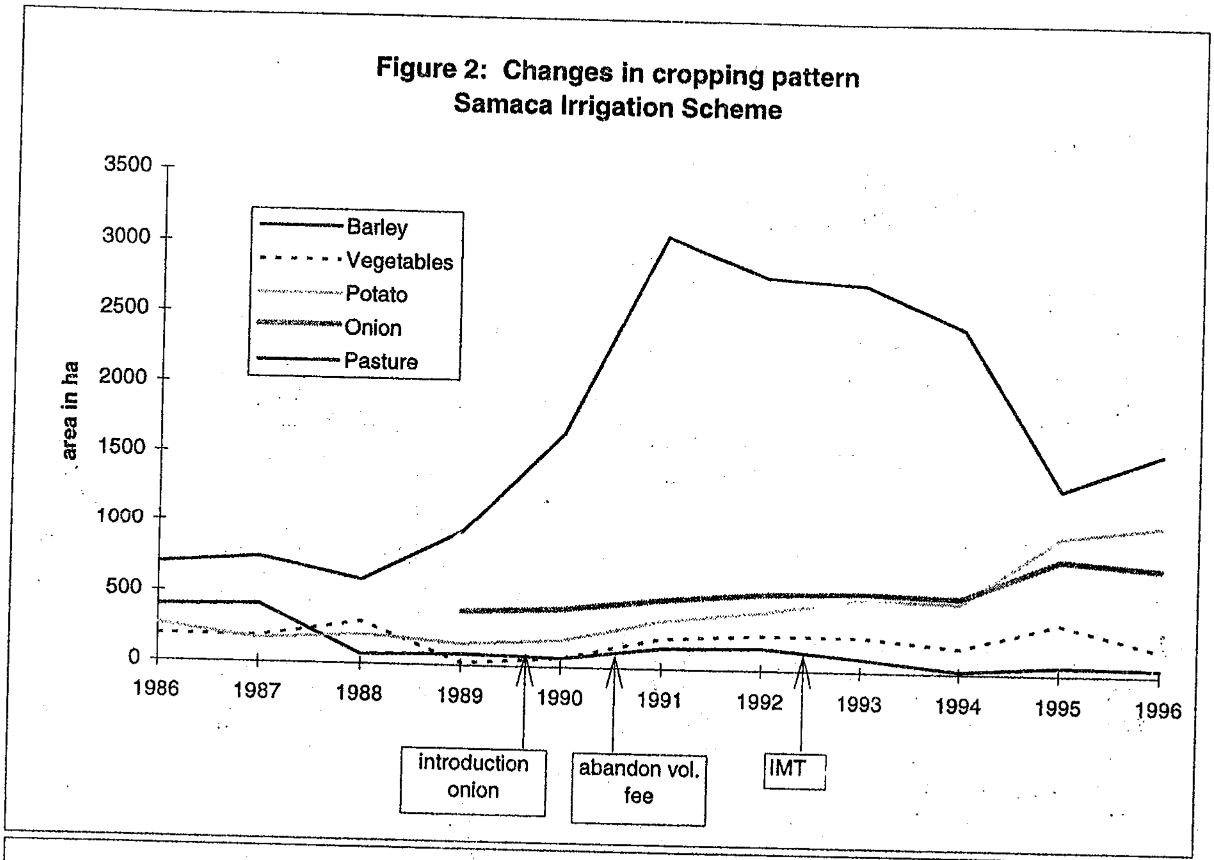


Figure 2: Changes in cropping pattern
Samaca Irrigation Scheme
3500
3000
2500
2000
1500
1000
500
0
area in ha
Barley
Vegetables
Potato
Onion
Pasture
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
introduction onion
abandon vol. fee
IMT

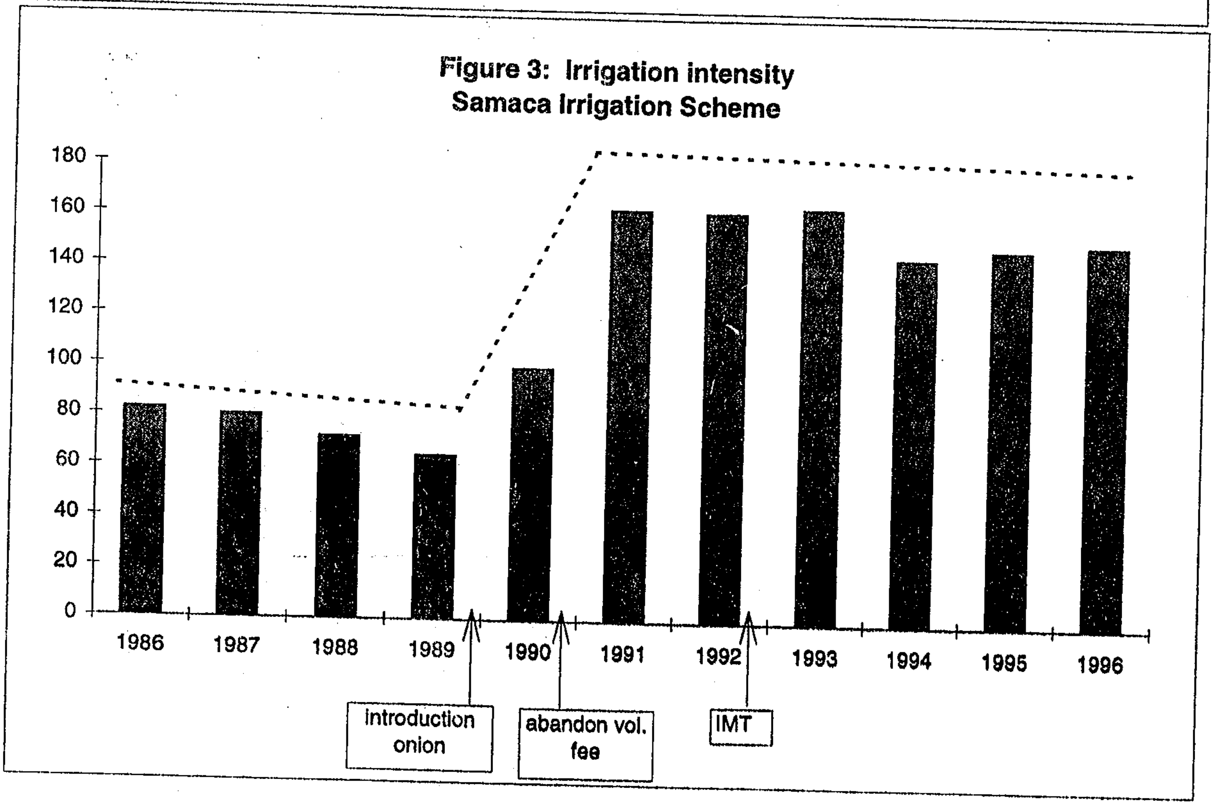


Figure 3: Irrigation intensity
Samaca Irrigation Scheme
180
160
140
120
100
80
60
40
20
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
introduction onion
abandon vol. fee
IMT

Figure 4: Standard Gross Value of Production per unit of land Samaca Irrigation Scheme

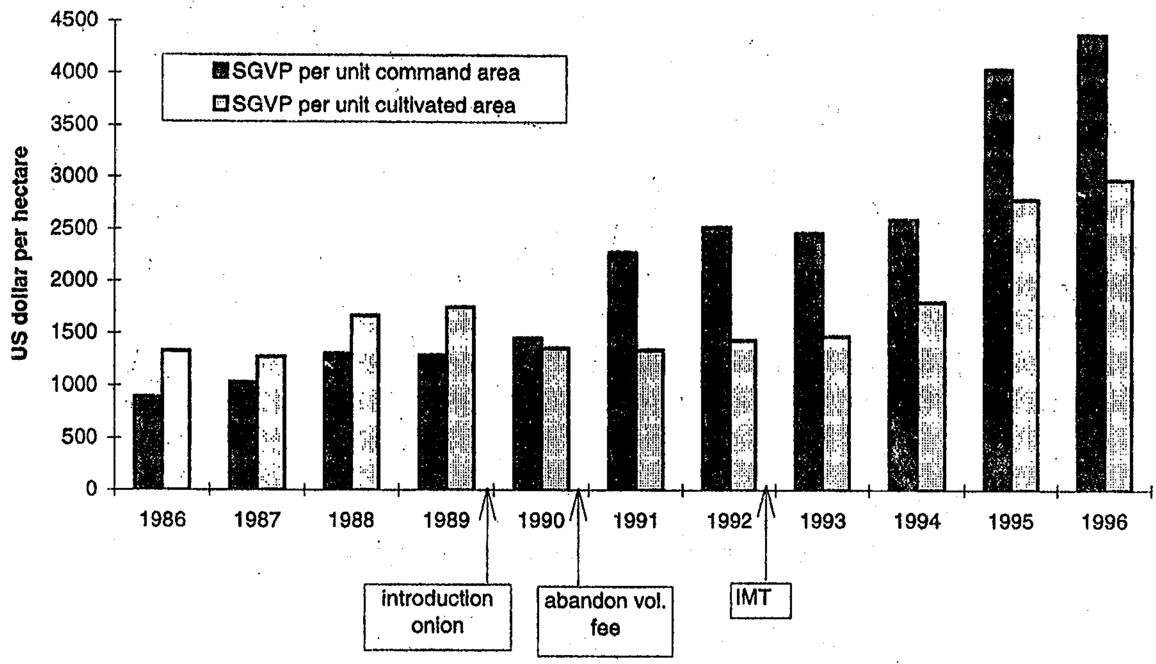


Figure 5: Standard Gross Value of Production per unit of water Samaca Irrigation Scheme

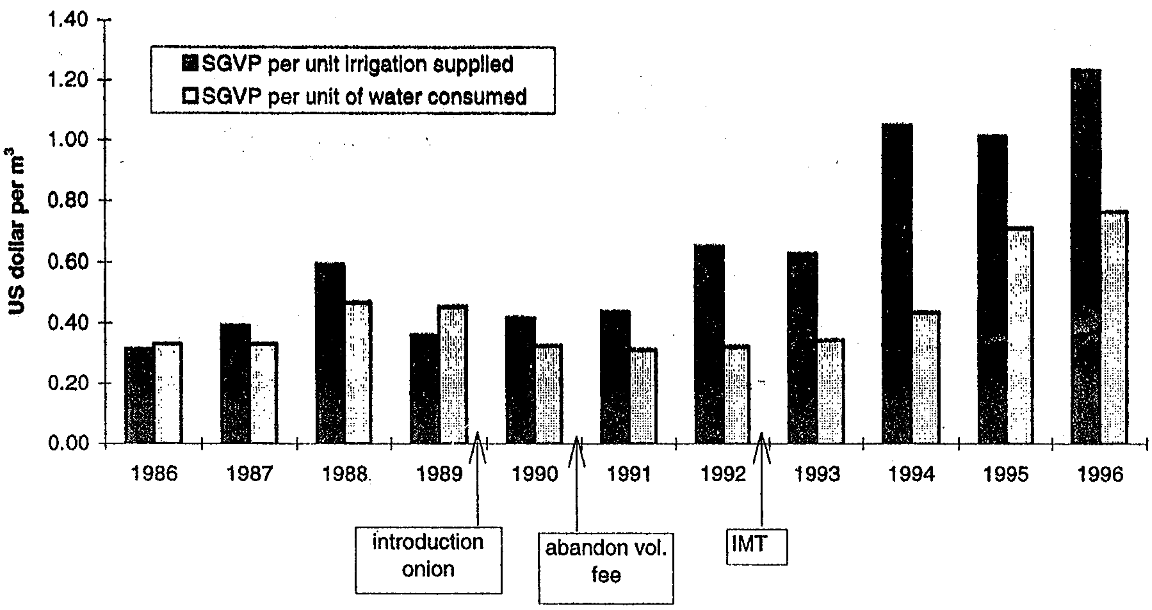


Figure 6: Correlation between SGVP per unit of irrigation and precipitation Samaca Irrigation Scheme

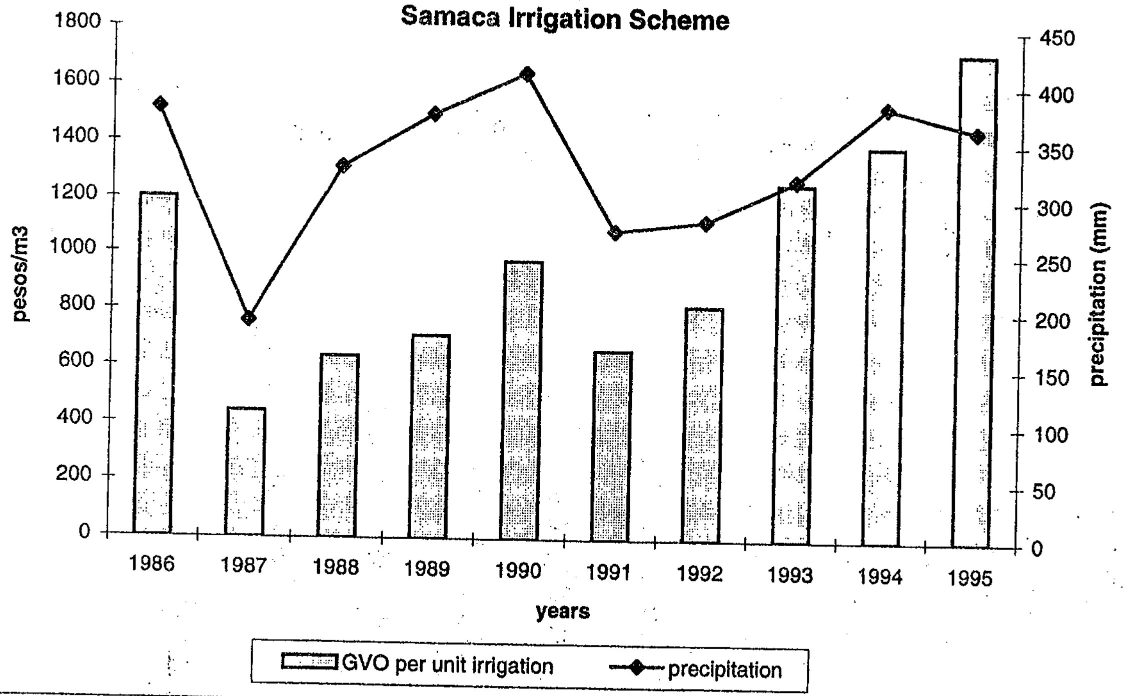
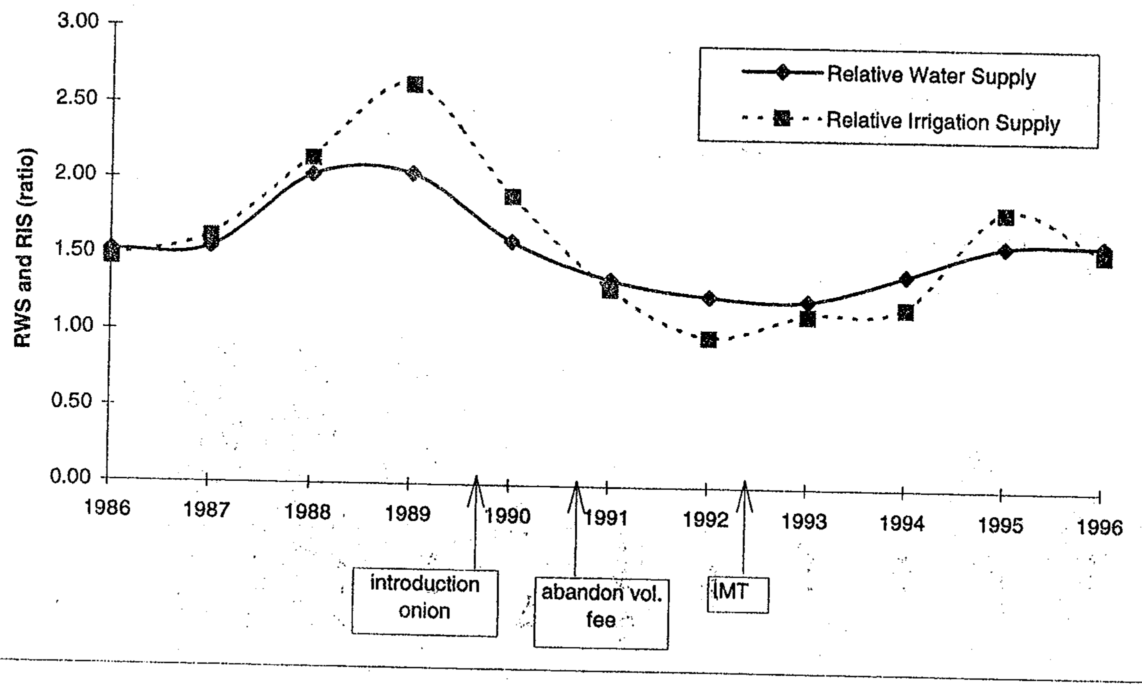


Figure 7: Relative Water Supply and Relative Irrigation Supply Samaca Irrigation Scheme



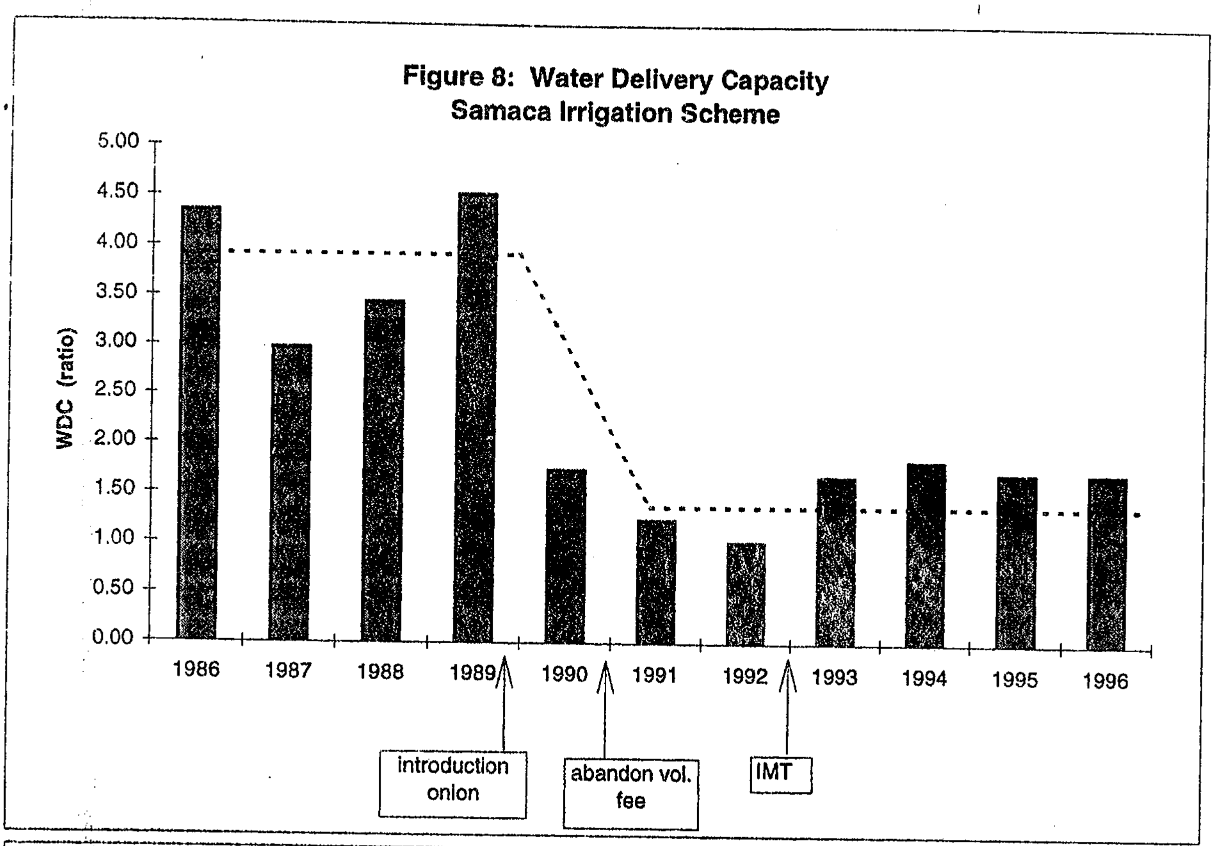


Figure 8: Water Delivery Capacity
Samaca Irrigation Scheme
WDC (ratio)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
introduction onion
abandon vol. fee
IMT

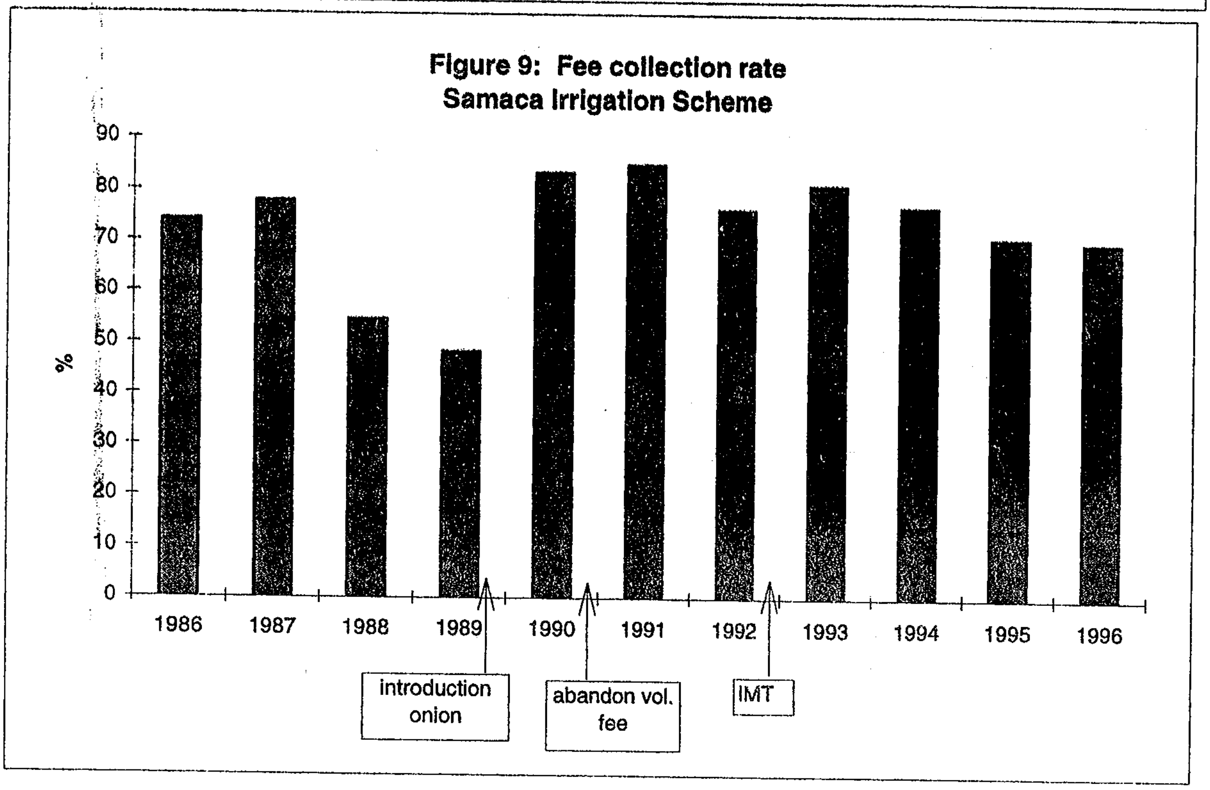


Figure 9: Fee collection rate
Samaca Irrigation Scheme
%
90
80
70
60
50
40
30
20
10
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
introduction onion
abandon vol. fee
IMT

Figure 10: Water Fee and Financial Self-sufficiency Samaca Irrigation Scheme

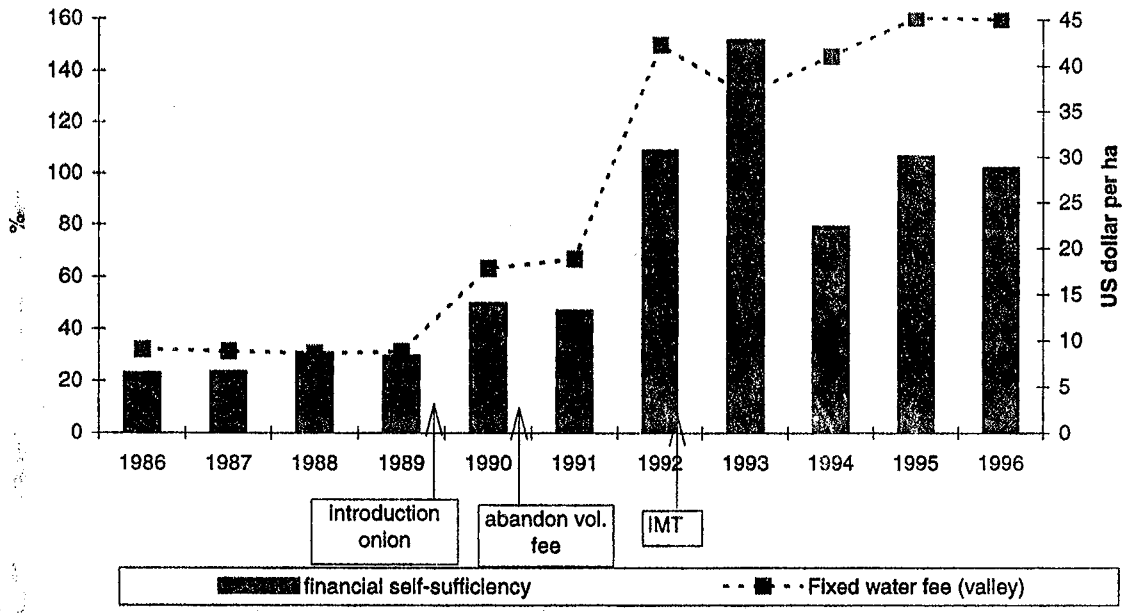
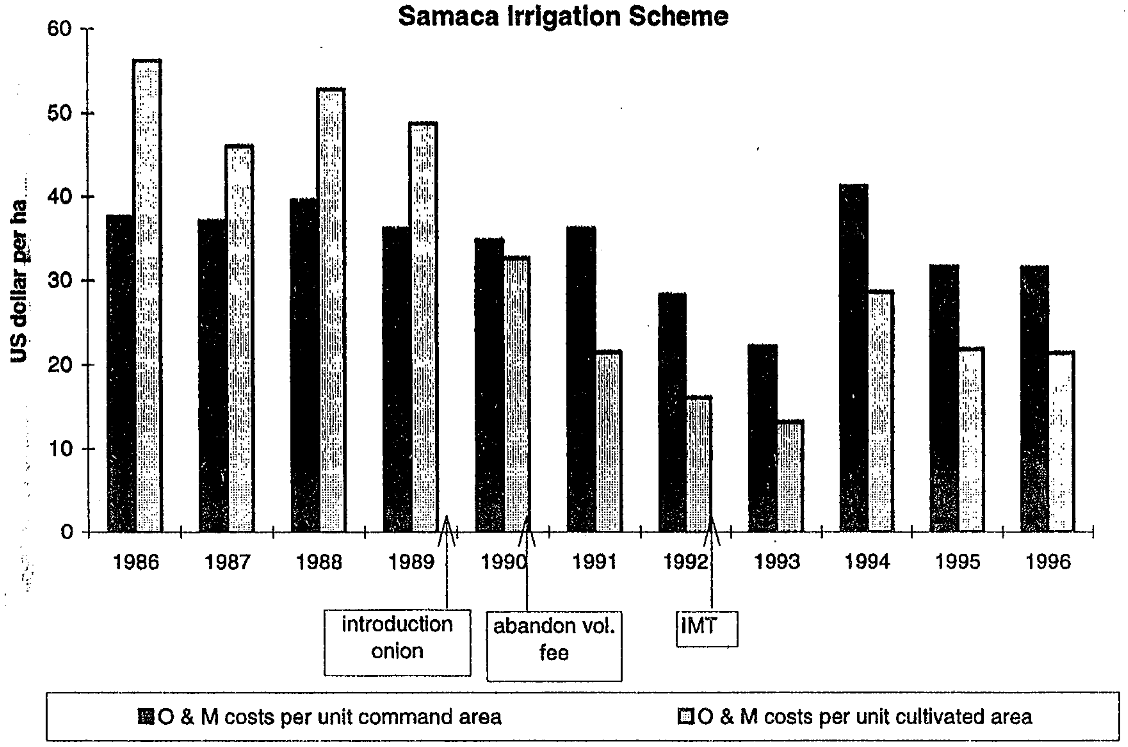


Figure 11: O & M expenditures per unit of land Samaca Irrigation Scheme



ANNEX 1: Definition of Performance Indicators Used

Agricultural Indicators

1. Irrigation Intensity (%) $= \dfrac{\text{Irrigated Cropped Area } (A_{cropped})}{\text{Command area } (A_{net})}$

2. Output per cropped area $(\dfrac{\$}{ha}) = \dfrac{\text{Production}}{\text{Irrigated Cropped Area } (A_{cropped})}$

3. Output per unit command $(\dfrac{\$}{ha}) = \dfrac{\text{Production}}{\text{Command area } (A_{net})}$

4. Output per unit Irrigation Supply $(\dfrac{\$}{m^3}) = \dfrac{\text{Production}}{\text{Diverted Irrigation Supply } (V_{div})}$

5. Output per unit Water Consumed $(\dfrac{\$}{m^3}) = \dfrac{\text{Production}}{\text{Volume of Water Consumed by ET } (V_{consumed})}$

where,

Production is the output of the irrigated area in terms of gross value of production measured at world market 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 Crops is the evapotranspiration of crops.

The production is estimated by using the concept standardized production. (refer to Perry 1996 and Molden 1997 for details) computed as follows:

$$SGVP = \left(\sum_{crops} AiYi \frac{Pi}{Pb} \right) Pworld\ ,$$

[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.

where,

SGVP is the standardized gross value of production,
Yi is the yield of crop i,
Pi is the long term average of the local price of crop i, and
Pworld is the long term average of the value of the base crop traded at world prices.
Ai is the area cropped with crop i
Pb is the long term average of the local price of the base crop

Water related indicators

6. Relative Water Supply $= \dfrac{\text{Total Water Supply}}{\text{Crop Demand}}$

7. Relative Irrigation Supply $= \dfrac{\text{Irrigation Supply}}{\text{Irrigation Demand}}$

8. Water Delivery Capacity (%) $= \dfrac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}}$

where

Crop Demand = Potential crop ET, or the ET under well watered conditions.
Total Water Supply = Surface diversions plus net groundwater water draft plus rainfall
Irrigation Supply = only the surface diversions and net groundwater draft for irrigation
Irrigation Demand = the crop ET less effective rainfall.
Capacity to deliver water at the system head = the present discharge capacity of the canal at the system head, and
Peak Consumptive Demand is the peak crop irrigation requirements for a monthly period expressed as a flow rate at the head of the irrigation system.

Financial Indicators

9. Financial Self Sufficiency (%) $= \dfrac{\text{Revenue from Irrigation}}{\text{Total O\&M Expenditures}}$

10. Fee Collection Rate (%) $= \dfrac{\text{Collected Fees}}{\text{Anticipated Fee collection}}$

11. $$\text{Gross Return on Investment (\%)} = \frac{\text{SGVP}}{\text{Cost of Irrigation Infrastructure}}$$

12. $$\text{O \& M expenditures per unit of land} = \frac{\text{Total O\&M Expenditures}}{\text{Command area } (A_{net})}$$

13. $$\text{O \& M expenditures per unit of water} = \frac{\text{Total O\&M Expenditures}}{\text{Diverted Irrigation Supply } (V_{div})}$$

where:

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

Collected fees, is the annual revenue generated from water and irrigation fees, paid by water users, excluding income from anterior debt payment or interest,

Anticipated Fee Collection, is the expected annual revenue generated from water and irrigation fees, as billed to water users, excluding anterior debts or interest,

Revenue from Irrigation, is the revenue generated, either from fees, or other locally generated income, but excluding revenues from government subsidies,

Total O&M Expenditures is the amount expended locally through O&M plus outside subsidies from the government.

ANNEX 2: Calculation example performance indicators, Samaca Irrigation Scheme, Colombia, 1995

A. Standardized Gross Value of Production

For each season the 6 main tradable crops and irrigated pasture were taken into account. These crops cover more than 95 % of the cultivated area.
For example in 1995 the following data were collected:

crop	season A (Jan - Jun) area (ha)	yield (ton/ha)	price (pesos / kg)	ave-rage price	GVO (million pesos)	season B (Jul - Dec) area (ha)	yield (ton/ha)	price (pesos / kg)	ave-rage price	GVO (million pesos)
potato	498	25.0	265	221	***3299***	475	18.0	171	200	***1462***
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***
peas	349	4.0	1259	978	***1758***	270	4.0	762	889	***823***
onion	357	25.0	488	444	***4355***	455	25.0	502	467	***5710***
wheat	33	5.0	200	275	***33***	43	5.2	200	284	***45***
pasture	655	332*		332	***217***	655	332*		332	***217***
total	2132				***10,239***	2194				***9,135***

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

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) $_{base\ crop}$

Base crop is the main tradable crop cultivated in the command area. For Samaca potato is taken. To eliminate distortions due to price fluctuations, for local as well as for international prices averages are used: firstly 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 149.4 dollar / ton.

For 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 * (332000 / 221)} * 149 = 6,171,168 US dollar
Likewise for second season in 1995 the SGVP is 5,899,910 US dollar
Total yearly value: ***12,071,078*** US dollar
Total command area is 3,000 hectares. Total amount of water derived (scheme level): yearly 11,867 * 10^3 m^3

GVO per unit cultivated area: (12,071,078) / (2132+2194) = ***2,790*** US dollar per ha.
GVO per unit command area: 12,071,078 / 3000 = ***4,024*** US dollar per ha.
GVO per unit irrigation delivered: 12,071,078 / 11,867,000 = ***1.02*** US dollar per 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 (option1 in main menu), seperately 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 grow 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	2132			2194		

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 / 2132) + 463.5 * (95 / 2132) + 351.1 * (145 / 2132) + 298.5 * (349 / 2132) + 278.6 * (357 / 2132) + 326.3 * (33 / 2132) + 523.8 * (655 / 2132) =
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 - Jun)	***387.7***	***158.0***
B (Jul - Dec)	***383.2***	***143.4***
Total	***770.9***	***301.4***

The ***GVO per unit consumed*** could be approximated[1] by
GVO / net CWR
in pesos: 19,374 * 10^6 / (2132 * 387.7 + 2194 * 383.2)*10 = ***1162*** pesos per m^3
in dollar: 12,071,078/ (2132 * 387.7 + 2194 * 383.2)*10 = ***0.72*** dollar per m^3
Amount of water derived:

scheme level	season A:	280.1 mm	field level	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***
field level : (391.5 + 699.2) / (387.7 + 383.2) = ***1.41***

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

scheme level
548.8 / 301.4 = ***1.82***

field level
391.5 / 301.4 = ***1.30***

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.

[1] not taken into account losses to sinks and non-beneficial ET due to lack of data
[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

For 1995 the scheme irrigation requirements are:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	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 tequirements occur in September, 0.20 l/s/ha
Peak demand is 0.20 * cropped area = 0.20 * 2194 = 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 include all income derived from water fees, water users' association's fees, outstanding debt and interest on anterior debts payments but exclude all kind of government subsidies or payments. For 1995 this was : 92,032,056 colombian pesos. Exchange rate for 1995 is 913 pesos/dollar. Revenue = 100,802 US dollar.
O&M expenditures include all expenditures to run and maintain the system. For Samaca they include operation, maintenance and administration cost, total 86,296,340 pesos = 94,519 US dollar.
Financial self-sufficiency = (100,802 / 94,519) * 100% = ***107 %.***

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 7000 US$ per hectare for 1996 (figures for 1995 not available). The GVO was 2976 US dollar per year per hectare of the command area.
Gross return on investment: 3096 / 7000 = ***42 %.***

ANNEX 3: Data requirements to calculate performance indicators

Climate

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

Crops

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

Irrigation

- total amount of irrigation water derived, scheme level, per season or per year (m^3)
- total amount of irrigation applied at field level, per season or per year (m^3)
- actual capacity of main canal and secondary canals (m^3/s)

Financial

- expenditures for Operation, Maintenance and Administration i.e. all cost to run the system (in local currency, per year)
- total income from water fees, farmers' contributions, outstanding debt payments etc. <u>excluding</u> all governement subsidies (local currency, per year)
- investment cost of irrigation infrastructure (local currency per hectare)

COMPARATIVE PERFORMANCE ASSESSMENT OF THE ALTO RIO LERMA IRRIGATION DISTRICT, MEXICO

WIM H. KLOEZEN

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COMPARATIVE PERFORMANCE ASSESSMENT OF THE ALTO RIO LERMA IRRIGATION DISTRICT, MEXICO

Wim H. Kloezen[1]

Introduction

This paper describes and evaluates the application of IIMI's set of external performance indicators to the Alto Rio Lerma Irrigation District (ARLID), located in the Mexican state of Guanajuato. The paper has two objectives[2]:

- First, to test whether within one irrigation system, external indicators allow to distinguish between differences in performance across system levels, over time and between irrigation sources.

- Second, to evaluate the data collection procedure that was used for applying external indicators.

As argued by Molden in his paper for this workshop, the objective of using external indicators is to evaluate outputs and impacts of intervention in individual systems, comparison of performance of a system over time, and also to allow comparison of systems in different areas and at different system levels. This is in contrast to internal indicators, which are generally used to assess actual performance to system specific management targets relative to goals established by irrigation managers (Small and Svendsen 1990 and 1992)[3].

Rao (1993) provides an excellent summary of the literature on internal indicators, and many authors have applied one or more internal indicators at particular irrigation systems (see for instance Jurriens 1996). Beyond doubt, each of these indicators have proved to be useful as they provide important information about internal operational performance processes of the particular systems were the indicators were applied. However, as a set, the indicators mentioned above have shown some limitations to their usefulness and applicability. These limitations include:

- Most authors propose to use different indicators, or use different methodologies and tools to

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[1] Associate Expert in Irrigation Management, IIMI-Mexico National Program. The author wishes to acknowledge the contribution of Alfredo Marmolejo and Jose Jesus Ramirez, IIMI's research field assistants in ARLID. He also thanks the staff of the CNA District Office in Celaya and the Board, technical staff and farmers of the Modules in ARLID. IIMI gratefully acknowledges the financial support of the Mexican Office of the Ford Foundation and the Directoraat Generaal Internationale Samenwerking (DGIS) of the Ministry of Foreign Affairs, Government of the Netherlands.

[2] The objectives of IIMI's research in ARLID went beyond the research objectives for this particular paper and included assessments of internal and external performance, impacts of an irrigation management transfer program and an evaluation of agricultural support services provided by public and private agencies. Results of these studies are discussed in forthcoming papers by Kloezen and Garces and by Kloezen, Garces and Johnson.

[3] Small and Svendsen (1990 and 1992) call this the *goal-oriented model*. This model is different from the *natural system model*, which measures performance more in terms of a system's ability to obtain inputs than in terms of either its outputs or impacts.

measure the same indicator. Although recent efforts have tried to standardize some internal indicators (Bos *et al* 1994), proposals for new internal indicators or other methodologies to measure indicators are still emerging. As a result, comparisons across systems or overtime are hardly possible[4].

- Internal indicators are based on the existence of clearly defined management goals and operational targets. However, in many irrigation systems, these goals and targets either lack or are too widely defined and inconsistent with each other (Brewer, Sakthivadivel and Raju 1997).
- As pointed out by Small and Svendsen (1990), measuring internal indicators following the goal-model approach, implies that subjectivity enters the performance evaluation both in the establishment of the goals and targets themselves, and in the way in which differing goals are weighted. System managers, policy maker, farmers and researchers might all set different goals and targets, especially in systems where goals and targets are not yet (or poorly) defined, or where goals have changed as result of dramatic changes in for instance cropping patterns, water availability or the political economic system.
- Generally, these internal indicators address how the input (water) is used, but does not provide information on to what wider hydrological, agricultural, economic, social and environmental impacts the inputs has led.
- Most of the performance assessment exercises described in literature were done in the context of intensive research programs, often in order to test new indicators that were introduced by researchers, rather than proposed by system managers. As a consequence, little is known on how system managers perceive the usefulness of these indicators for daily system operation and on how easy it is to apply these indicators for day to day monitoring purposes.
- Measurement of most internal indicators require complicated data collection procedures. Monitoring systems, if any, are normally not set up to collect these required data. As a consequence, applying the indicators requires additional staff, skills and equipment, which are generally not available within irrigation systems, or difficult to obtain.

Without pretending to be able to overcome all the limitations mentioned above, it is hoped that by developing a standardized set of external indicators, at least some of these problems will be dealt with. In the next section a description of the irrigation district is given. Then, the research methodology is presented, followed by 4 sections in which examples of the application of external indicators are given. A subsequent section provides a comparison between the external and internal indicators. The paper concludes with an evaluation of the data collection procedures used and draws some lessons on the usefulness and applicability of external indicators.

The Irrigation District

ARLID was constructed in the 1930s and has a gross command area of 112,772 hectares. It is located in the State of Guanajuato, central Mexico. The district is located in the upper reach of the 48,215 km^2 Lerma-Chapala water basin, which crosses five states and serves nine irrigation districts as well

[4] See for example Oad and Sampath (1995), who introduce an indicator to measure predictability, or Meintzen-Dick (1995), who revisits the indicator to measure timeliness.

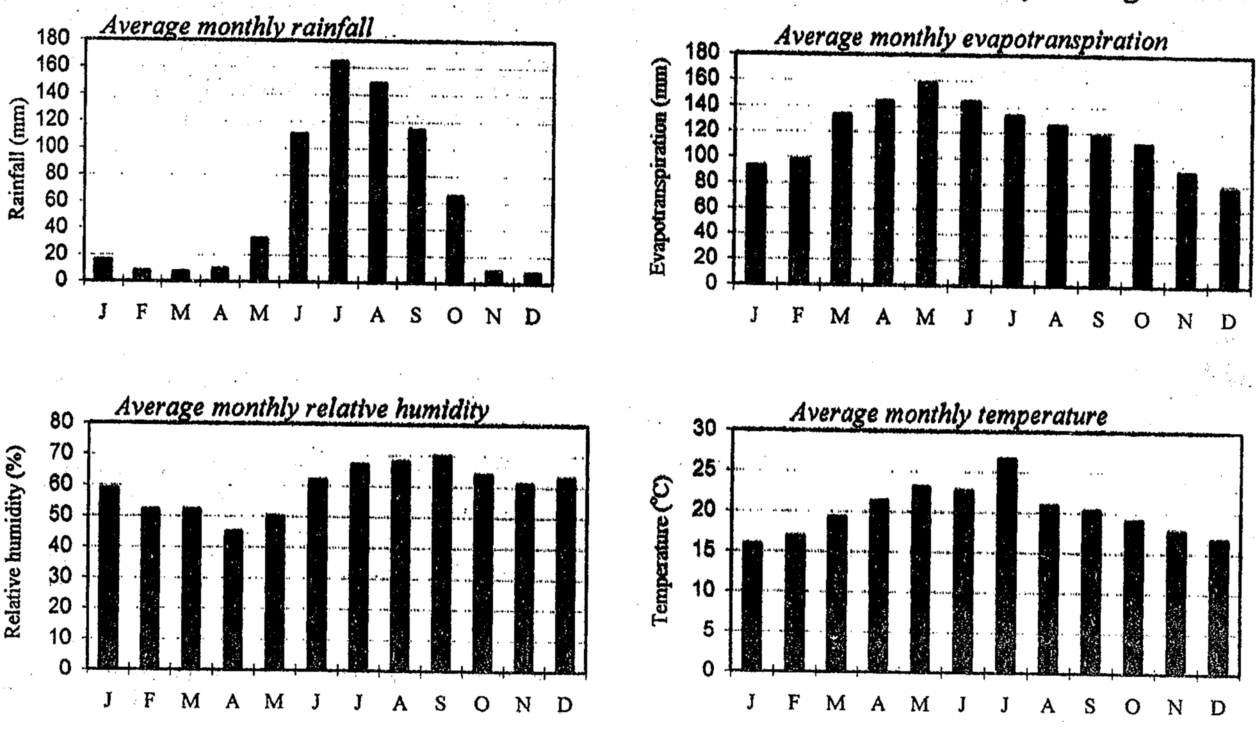
as the huge lake Chapala near Guadalajara. The total catchment run-off of this basin is approximately 4,740 million cubic meters (MCM), of which on an average 43 percent (or 2,020 MCM) is made available for the irrigation districts, 30 percent to small scale irrigation systems and the remaining to Lake Chapala, domestic and industrial uses. Of the 9 irrigation districts, ARLID is the largest, taking approximately 44 percent (or 880 MCM) of all the water stored for use within the districts (CNA 1992).

Surface water for the district is provided by four earthen dams with a combined storage capacity of 2,140 MCM, serving 77,697 hectares. In addition, there are a total of 1,714 deep wells serving 35,075 hectares. The irrigation network comprises 475 km of main canals and 1,658 km of secondary and tertiary canals. Likewise, there is a network of approximately 1,031 km of drainage canals. Wheat and barley are normally grown during the dry winter season while sorghum, maize and beans are the main crops grown in the wetter summer season. Farmers with access to groundwater tend to grow more vegetables.

The State of Guanajuato has a high concentration of wells: approximately 20 percent of all the wells in Mexico are found in this State. The State has 18 different aquifers, 3 of which are exploited by the farmers of ARLID. The total area underlaid by these three aquifers is 330,600 hectares, with an average annual recharge of 500 MCM.

The climate is moderately sub-humid and with an average yearly precipitation of 730 mm and an average temperature of 19 ^{0}C. Yearly evapotranspiration is approximately 1,900 mm and relative humidity is about 60 %. The dry winter season, which receives approximately 80 mm of rainfall, starts in November and ends in April. The summer season lasts from May until November and has an average of 670 mm of rainfall (Figure 1).

Figure 1. Climatic data for the Alto Rio Lerma Irrigation District, monthly averages 1963-96.



There are roughly 24,000 water users in the irrigation district, with 55 percent classified as *ejidatarios*[5]; and 45 percent classified as small private growers[6]. The average land holding in the irrigation district is 5 hectares.

The irrigation district is divided into eleven modules, each managed by an individual WUA and ranging in size from 1,513 hectares to 18,694 hectares. Annex 1 shows the high diversity in the social (number of private growers versus *ejidatarios*) and physical (infrastructure and irrigation source) characteristics of these modules. The irrigation district and the location of its eleven modules are shown in Map 1.

Irrigation Management in ARLID

Institutional

In the late 1980s the Government of Mexico (GOM) decided to restructure and modernize its agricultural sector. One component of the strategy adopted was an irrigation management transfer (IMT) program aimed at transferring management authority of the public irrigation systems from CNA to water users associations. As a result of this program, responsibility for O&M of the irrigation systems went from being exclusively that of federal government organizations to being shared with the newly created WUAs. Officially CNA's role is now restricted to management of the nation's reservoirs, headworks and main canals. Also in 1992, hydraulic committees were formed at district level to make an annual irrigation plan and to control whether this plan is effectively implemented. These committees, where CNA, WUAs and local state officials meet, provide a venue for participatory management, negotiation and decision making.

Users began sharing responsibility for management with CNA in November 1992[7]. As a result of IMT, the WUAs of the modules became responsible for O&M below the secondary canal off-takes on the main canal to the field level. WUAs have recruited professional and technical staff for operation of the irrigation system, managed by general managers appointed by the boards of the associations. The boards are elected by a free vote of the users and comprise a president, secretary and treasurer, with elected substitutes for each position. Figures 2 shows the institutional set-up of the district and the modules after transfer. The board, plus delegates from each *ejido* and two delegates per municipality representing the small growers, constitute a general assembly which generally meets each month. Prior to management transfer CNA employed 273 staff (1992), while in 1996 only 116 staff remained.

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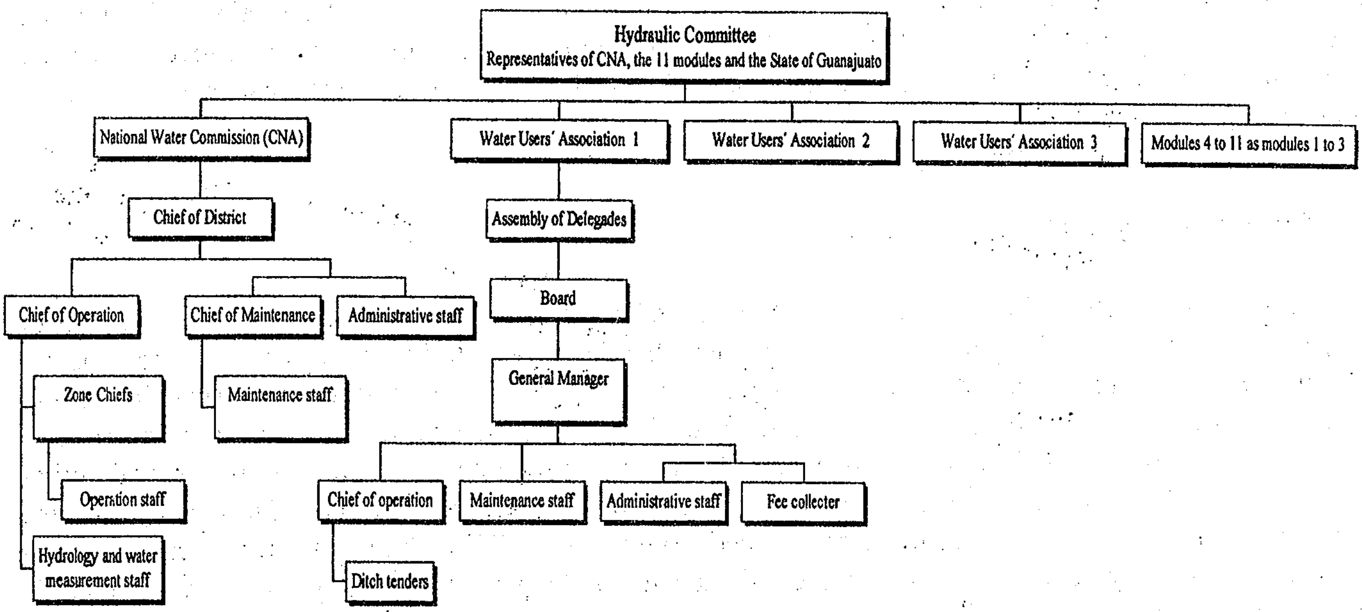
[5] Members of the land reform communities that were created during the Mexican revolution in the early part of the 20th century. Until the revision of Article 27 of the Constitution in 1992, *ejido* land belonged to the Mexican State.

[6] The concept "small private grower" (*pequeño propietario*) is a misnomer because in Mexico such user category could allow ownership up to a hundred hectares for an individual owner. In practice, this area becomes larger when a user divides the area among relatives.

[7] See Kloezen, Garces and Johnson (forthcoming) for a detailed discussion of the IMT program in ARLID and its impact on, amongst others, water use, O&M financing, maintenance and agricultural and economic productivity.

Figure 2. Institutional set-up of the Alto Rio Lerma Irrigation District and its eleven modules, after transfer.



Water Rights

The IMT program was accompanied by the promulgation of the new National Water Act in 1992. This Act clarifies water rights and enables trading of water. Regulations that support the Act were passed in 1994. Under the Act, each WUA within an irrigation district is granted a concession, which entitles them to a share of the water available for each season. These shares or concessions are proportional to areas with surface water rights in each module. Although concessions are granted for periods of up to 20 years, CNA retains broad discretionary power over the concessionaires right to use water and over all water transactions (sales or rental)

Under the 1992 water act, concessions may be granted to individual water users, however there appears to be a strong preference on the part of the CNA to make concessions to WUAs (Rosegrant and Schleyer 1996). The idea is that WUAs develop internal rules and regulations to equally grant subsidiary water rights to their members. Yet, in the case of ARLID none of the WUAs have established these rules and regulations. Water sales and rental arrangements among farmers was and is common practice, with or without CNA approval.

Under the new act water can be traded, for instance between two WUAs. Water sales need the approval of the CNA, as well as of the majority of the general assembly of the WUAs involved.

Financial

Prior to transfer of management responsibility, farmers paid water fees directly to CNA. However,

due largely to deteriorating infrastructure and maintenance services, the proportion of fees collected fell from 85 percent in the early 1960 to only about 15 percent by the late 1980s (Palacios 1994a; Whiteford and Bernal 1996). Following transfer, fees are set and collected directly by the WUAs. Generally, farmers pay their fees prior to receiving their irrigations. In 1995 and 1996 irrigation service fees at ARLID were approximately US$7.5 per hectare per irrigation[8]. With 5 irrigations per year fees total US$37.50 per hectare, or 2.5US$ /1,000 m^3 with an approximate total irrigation depth of 1,500 mm. By 1997, these fees have increased to US$13.5 per hectare per irrigation.

As a result of IMT, a negotiated proportion of the fees collected by the WUAs is paid to CNA for provision of O&M services at the headworks and in the main canals. Percentage paid to CNA range from 11 percent to 28 percent of the fees collected, depending on the complexity and level of service CNA provides to each module. The annual water fee paid by farmers and established by the WUA must be approved by CNA.

Water allocation and distribution rules

Allocation. Water allocation rules at ARLID are based on three principles. First, at the beginning of each agricultural year (November) CNA determines the water availability in the reservoirs serving the district. Each module is concessioned a percentage of the available volume in the reservoirs. These concessions are in proportion to areas with surface water rights in each module, and are irrespective of the actual area irrigated or the crops grown. Based on these concessions and the water availability at the start of the agricultural year, the hydraulic committee makes a annual plan of how much volume will be allocated to each module. These planned volumes can differ slightly from the concessioned percentage as every year these volumes are adjusted for under or over usage of water by the module in the previous year.

Second, normally the full command area of each module can be irrigated. However, in times of water scarcity the total area to be irrigated is determined in negotiation between CNA and the modules in the hydraulic committee. This can vary from module to module and is basically determined by physical characteristics of the module, experiences with past cropping patterns and farmers preferences.

Third, the hydraulic committee also decides on the number of irrigations that can be delivered to each module, the start and the end of each irrigation period, and whether irrigation will be provided during both winter and summer seasons. Generally, this decision counts for all modules. CNA is reluctant to open the dams to deliver water to only a few modules as this would mean considerable conveyance losses in the main system

Distribution. Water distribution rules are based on four principles. First, a farmer cannot receive more irrigations than the maximum number of irrigations allocated to the module. Exceptions are made for farmers who grow crops that require more frequent irrigations, like beans, but only if this extra irrigation falls within an irrigation period determined by the third allocation rule mentioned above. Second, each farmer can grow any crop he wants to grow. Third, farmers cannot request water for more than the area registered in his or her name. In case the hydraulic committee decides

[8] The average exchange rate for the years 1995-97 was US$1.00 = N$7.50.

that less than the full command of the module can be irrigated, the module decides on the maximum area that can be irrigated by a farmer. Forth, the maximum volume of water a farmer can receive is determined by the module, based on a theoretical or planned water depth per irrigation. Generally, the module does not distinguish between water requirements of different crops, but uses a flat depth across its farmers, irrespective of the crop he or she grows.

Scheduling. Based on the total number of irrigations requested for farmers and the planned water depth, the module calculates the weekly total volume requested for by farmers. The weekly requests are communicated to CNA for scheduling deliveries to the modules. Daily CNA and module staff check at the module intake whether requested volumes are actually delivered. Water distribution between the secondary canals or laterals within a module is based on the same arranged scheduling. For each canal the total volume requested is calculated and gates are set accordingly. Unlike what is common practice at the head of the module, volumes that enter the secondary canals are not measured, but are estimated by ditchtender based on their experiences.

Operational targets and monitoring

Explicit management targets do not exist for ARLID, but interviews with system managers and two years of observations of daily management practices reveal that CNA and the modules are concerned about meeting the following six targets:

- Modules get the seasonal volume of water they have been assigned to at the start of the agricultural year.
- Modules and farmers do not irrigate an area that exceeds the planned area.
- Modules receive the weekly scheduled volume of water they have requested for at the start of each week.
- Farmers get the number of irrigations they are entitled to and have requested and paid for.
- Farmers get sufficient water to irrigate the area they are entitled to to irrigate.
- O&M costs should be fully recovered from the farmers.

CNA and the modules use several techniques to monitor whether these targets are met. Monitoring is done at three system levels.

At the field level, ditchtenders report daily to the module how many farmers have received water, for how much area and for which crop. At the end of each day ditchtenders meet at the module office to check whether their reports correspond with the weekly schedule. An estimate of the volumes delivered to each farmer is also reported. Weekly these reports are aggregated for the entire module and are sent to the CNA district office.

At the module level, daily measurements are taken at the head of the main canal, as well as at a

small number of other hydrological control points. Daily reports mention both planned or scheduled and actual volumes. In theory, these volumes are checked by CNA and the module. Reports should carry signatures of both. A weekly report that totals daily volumes is sent to the CNA district office.

At the district level, CNA aggregates the reported volumes, irrigated areas and crops and produces monthly reports which are presented and discussed in the hydraulic committee meeting. Finally, as farmers have to pay their water prior to each irrigation they receive, modules are able to keep good track on the total amount of fees paid by farmers. At the end of each season, the modules report their total fee collection to CNA. As the seasonal plan defines the total area to be irrigated as well as the number of irrigations to be delivered, it is easy to calculate the total planned fee collection (planned irrigated area * # of irrigations * fee) and to monitor whether actual collection follows planned collection.

Although the described activities should be sufficient to monitor daily, weekly, monthly and seasonal performance relative to the 6 targets mentioned above, a few practices limit this. First, the ditchtenders' reports form the basis for most of the data reported to both the modules and the CNA district office. As will be demonstrated below, their estimates are often very inaccurate and unreliable. Second, monitoring of daily and weekly water distribution is based on aggregated field reports, rather than on real measurements at the canal level (except for the head of the main canal). Even so, all modules use computers, aggregation of field level data takes a lot of time. As a consequence, the production of weekly reports takes more than a week, production of monthly reports sometimes several months, and seasonal reports are normally not published before the start of the next season. As a result, these reports hardly serve as tools to take immediate management decisions when needed.

Data Collection Methodology

Performance indicators were applied for winter and summer cropping seasons from 1982 to 1997 to the district as a whole and to the 11 irrigation sub-units (or modules).

IIMI's study of ARLID was started in October 1995, with the establishment of a project offices in Cortazar and Salvatierra modules. Data collected include primary sources in the two modules and secondary sources with respect to the files kept by the respective WUA and CNA at regional, state and central levels.

The study combines data from a number of different sources, at different system levels. Time series data for the cropping seasons 1982-97 stem from records kept by CNA at irrigation district, regional and central level, as well as from the 11 WUAs at the module level. These data included cropping patterns, crop yields, farm gate prices, climate data from seven selected stations within and near the district, monthly and seasonal canal flows at different system levels, dam storage and releases, cost and volumes of maintenance work done, irrigation fees collected and planned and actual O&M budgets. Where possible, daily or weekly records were used and aggregated by IIMI, rather than using seasonal or annual summary reports published by the agency and the modules.

CNA as well as most WUAs use computers to enter, monitor and process their data. IIMI always had full and unconditionally access to these as well as other files, which provided excellent transparency of the data used for this study. Several tools were applied to check the quality of the data. Aggregation of module level data provided a cross-check for data collected at the district level. Secondary data was further cross-checked by data collected from other sources like rural development

banks. Although not presented in this paper, primary hydrologic data collected for an ongoing performance study (Kloezen and Garces, forthcoming) provided a tool to cross-check the quality of officially reported canal flows at different hydrologic control points in the system during a period of four irrigation seasons.

The FAO CROPWAT and its complement CLIMWAT software packages were used to calculate crop water requirements (FAO 1996). The program is based on the calculation of a reference evapotranspiration (ETo) through the modified Penman-Montieth equation and provides three methods for the calculation of effective rainfall. Data on humidity, windspeed and hours of sunshine were taken from two nearby stations given in CLIMWAT. Rainfall and maximum and minimum temperature data were collected from 5 stations within or near the district and the two selected modules.

Outputs per unit of land and water were calculated following the standardized procedure described in Molden (1997). This procedure converts cropping patterns that comprise multiple crops into 'equivalent' yields and Standardized Gross Value of Production. The equivalent crops used is this study are wheat for the winter season and sorghum for the summer season.

To make comparisons across countries and time possible, IIMI converts local units and currencies to international standard units and constant US dollar prices. Especially the latter proved to be a difficult task for the evaluation of the Mexican IMT program. By December 1994 Mexico faced an economic crisis, which was followed by a devaluation of the peso against the dollar (from 3.5 pesos per dollar in July 1994 to an average of 7.5 pesos per dollar during the period 1995-97), as well as an inflation rate of approximately 50% in 1995. The start of the crisis fell exactly in the middle of the 4 post-transfer years. In this paper, as far as possible, all prices are converted into constant July 1994 dollars for the time series.

This paper present results that are mainly based on the collection of these secondary data for the use of external indicators. However, in order to evaluate this data collection procedure, comparison with primary field data collection procedures is useful. The following primary data were collected

- Daily field observations of water management related practices by leaders of WUAs, CNA staff, ditchtenders and farmers during a period of two years (Kloezen and Garces forthcoming).

- Measurements of water flows in selected canals, laterals and fields during four irrigation seasons; volumes pumped and energy consumption of selected wells (*ibid.*).

- A household survey in order to establish the cost of production and the cost of water to farmers, during a period of one year (*ibid.*)

- Users' perceptions of the impact of the IMT program were captured by both semi-structured open-ended interviews and a farm survey. For the farmer survey the system was divided into four zones which aggregated modules with similar physical, hydraulic, agronomic and socio-economic conditions. A total of 125 randomly selected farmers within the four zones were interviewed through a carefully designed and pre-tested questionnaire (Kloezen, Garces and Johnson forthcoming).

- Open and informal interviews with key informants, as well as attendance at CNA, module and hydraulic committee meetings and workshops during a period of two years helped to better interpret secondary data and the impact of the IMT program on the position of farmers and irrigation staff (*ibid.*).

The data collection procedures described above are evaluated later in this paper, after the discussion of the result.

External Performance: One Year, One District

The basic idea behind external indicators is that they provide a tool to compare irrigation performance of a specific district to other irrigation systems world wide and to other years. Yet, it would be interesting to see what kind of information on irrigation management performance and its agricultural output can be obtained by only looking at external performance in one year.

Data for the 1995-96 were used for this purpose and are presented in Table 1. Production values are already given in 'equivalent' yields in order to follow the standardized procedure. Corresponding farm gate and world market prices of base crops are given to calculate the agricultural-based indicators. The indicators are explained in the paper that Molden prepared for this workshop.

The 1995-96 agricultural years was average in terms of rainfall and water availability. In November 1995, the start of the 1995-96 agricultural year, the gross storage in the four reservoirs supplying the district was 1,118 MCM, of which approximately 742 MCM was assigned to irrigation. This gross storage is the sixth lowest level in a series of 14 years reported in Kloezen, Garces and Johnson (forthcoming), while the volume assigned to irrigation is about 140 MCM less than the annual average of 880 MCM available for the district. The hydraulic committee decided that this volume was sufficient for a total of five irrigations: four for irrigation of winter wheat, and a single irrigation for summer sorghum. As is shown in Table 1, the actual total supply for both season was 807 MCM, of which 773 MCM was released from the dams and the remainder from public wells. This means that dam release was five percent higher than planned by the hydraulic committee.

Table 2 summarizes the external indicators for the irrigation district, which are discussed below.

Relative Water Supply (RWS). The indicator is the ratio of total water supply to the total demand at field level, and can be used both as a measurement of adequacy (Levine 1982) and seasonal timeliness (Meintzen-Dick 1995). According to IIMI's definition, the total crop demand at field level includes consumptive use, non-beneficial ET, losses to drains and net flow to groundwater. Given the lack of reliable data and the complexity of the surface-groundwater interface, non-beneficial ET, losses to drains and flows to groundwater could not be measured, but are estimated to be 5 percent of total demand.

Table 2 shows that the RWS values are high, generally above 2.0 at the level of the intakes to the modules. Previous worldwide experience with the RWS indicator would suggest that the district did not face a constraining water availability situation during the observed year and that water distribution is not tightly related to crop water demand (Levine 1982, Murray-Rust 1983 and Garces 1983). Water supply has adequately met the crop water requirements.

Table 1. Basic data set used to calculate external indicators of the Alto Rio Lerma Irrigation District, agricultural year 1995-96.

	Winter 1995	Summer 1996
Gross Command Area (ha)		
Surface irrigation	77,697	77,697
Public wells	7,421	7,421
Surface irrigation plus public wells	85,118	85,118
Private wells	27,654	27,654
Cropping Intensity (%)		
Surface and public wells	70	60
Private wells	75	90
Main Crop (% of total cropped)		
Surface and public wells	Wheat (92%)	Sorghum (81%)
Private Wells	Wheat (62%)	Sorghum (82%)
Equivalent Production (ton/ha)		
Surface and public wells	6.7	9.8
Private Wells	8.9	9.6
Gross Irrigation Supply (x 1,000 m^3)		
Surface and public wells	667,440	139,236
Private wells	191,370	111,002
Rainfall (mm)		
Total	54	683
Effective	44	510
Evaporation (mm)	929	1,098
CROPWAT Water Requirement (mm)		
Surface and public wells	500	497
Private Wells	467	507
Sales Prices (US$ /ton)		
Farm Gate Price	247 (wheat)	120 (sorghum)
World Market Price	262 (wheat)	105 (sorghum)

Relative Irrigation Supply (RIS). This indicator is the ratio of irrigation supply over irrigation demand (total demand less effective rainfall). Effective rainfall is assumed to be 80 percent of total rainfall. This 80 percent method is one of the three methods suggested by CROPWAT, and is supposed to be suitable for areas with relatively low storms. Storms in ARLID never exceed 20 mm/day. By definition, effective rainfall can never exceed the crop water requirements. In cases where effective rainfall equals crop water requirements, the RIS value is zero.

The winter season value of 2.5 suggests abundant irrigation supply relative to the irrigation requirement. For the rainy summer season the value of zero means that effective rainfall equaled crop water requirement or was higher, which means that no irrigation would have to be supplied.

Table 2. External indicators for the Alto Rio Lerma Irrigation District, 1995-96.

Indicator	Unit	Winter 1995-96	Summer 1996	Entire Year
Relative Water Supply	(ratio)	2.4	1.9	
Relative Irrigation Supply	(ratio)	2.5	0.0	
Water Delivery Capacity	(ratio)	4.6	5.6	
GVO / unit of land cropped	US$ / ha	1,752	1,028	2,780
GVO / unit of command	US$ / ha	1,228	612	1,840
GVO / unit irrigation supply	US$ / m^3	0.16	0.37	
GVO / unit water consumed	US$ / m^3	0.35	0.21	
Gross return on investment	%			23
Financial Self-sufficiency				
Actual collection over O&M cost	%			109
Actual over Planned collection	%			123
Loss to waterlogging and siltation	%			negligible
Fall of static water table	meter/year			2 to 5

Water Delivery Capacity (WDC): This non-dimensional indicator addresses the question of whether the system has been designed and constructed in such a way as to be able to meet the peak water demand in a particular period. The high values for the system as a whole can be explained because it is the river itself that carries the discharges supplied by the dams to the various main canals. Hence, in order to obtain the WDC it is better to look at each of the main canals. Two examples are given here. The Coria main canal that serves in Cortazar, Irapuato and Abasolo modules has RWS values of 1.1 and 1.3 for the winter and summer seasons, respectively. WDC values for Gugorrones main canal in Salvatierra module are 2.2 and 2.6, respectively. These examples show that the modules have sufficient capacity at their intakes and therefore allow for the high RWS values presented above.

Yields. Table 1 shows that the average winter wheat equivalent production in ARLID was 6.7 ton/ha The equivalent sorghum production of summer sorghum is 9.8 ton/ha. These equivalent production values for wheat and sorghum are high compared to actual production levels for these crops: between 5.5 ton/ha and 7.0 ton/ha for wheat, and between 7.0 ton/ha and 8.5 ton/ha for sorghum. The higher equivalent values is explained by the fact that farmers also grow beans and vegetables, which produce high wheat and sorghum equivalents. Both normal and equivalent yield levels are high compared to other irrigation district in Mexico (Palacios-Vélez 1994b) and nearby small scale irrigation systems in the State of Guanajuato (Dayton-Johnson 1997).

GVO per unit of land cropped (US$/ton). The winter season value is close to US$1,800. The corresponding summer season value is much lower as a result of depressed world market prices of the main crop: US$262/ton for winter wheat against US$105/ton for summer sorghum.

The annual GVO is approximately US$2,800 per hectare cropped. Here, a problem with this external indicators expresses itself. One need to have a reference to be able to interpret the value. In comparison to 15 other systems studied by IIMI (Molden, Sakthivadivel and Perry forthcoming), the output per unit of cropped land of ARLID are among the highest.

GVO per unit of command area (US$/ton). The annual cropping intensity of 130% explains why

the total annual GVO of US$1,840 per hectare is lower than the value obtained from the previous indicator. .

GVO per unit of irrigation supply (US$/m³). The winter season value of US$0.16/m³ is slightly higher than those reported for the Coello (US$0.12/m³) and Saldaña (US$0.11/m³) systems in Colombia, which are also arranged scheduled systems but under different climatic and economic conditions (Vermillion and Garces 1996). Comparison with other systems reveals that -irrespective of the relatively high RWS values found- the ARLID output per unit of irrigation supplied values are in the range from medium to higher values (Molden 1997).

Although the market price for the main summer crop is much lower than for the winter season crop (Table 1), the values of output per unit of surface irrigation supplied are nonetheless higher since much less irrigation is needed due to the higher rainfall.

GVO per unit of water consumed (US$/m³). In general, for the winter season, these values are higher than in the previous indicator because it excludes system losses and considers only that resource that was actually evapotranspirated by the crop, the non-beneficial ET, losses to sinks and thus is no longer available to be used elsewhere.

Gross return on investment. The construction cost of a water distribution system of the same characteristics of the ARLID can be obtained from current construction work by CNA. This cost is estimated at US$8,000 per hectare (CNA 1996). Utilizing the annual GVO per unit of command for the entire year on the district, the gross return on investment is 23 percent. This value compares favorably with those reported by Vermillion and Garces (1996) for Coello and Saldaña and RUT (Alvarez 1997) in central Colombia, but are much lower than the values obtained in Samaca (Mora Peña 1997).

Financial self-sufficiency. This indicator can be expressed in both actual fee collection over actual O&M expenses and actual fee collection over planned fee collection. Planned fee collection is obtained from the product of the fee per hectare, times the number of irrigations entitled to, times the area to be cropped. From Table 2 it is apparent that the level of self-sufficiency is above 100% for this particular year. This suggests that expenses are kept under control and that there is good planning in establishing fee levels required to operate the system smoothly.

Environmental impacts. No significant evidence was found pertaining to negative environmental effects as a consequence of either water logging or salinity conditions.

Groundwater table fluctuations have been monitored and point towards a worrisome situation. In 1995, and following a trend over the last five years, static water tables are falling at an average annual rate of 2 to 5 meters, reaching an average depth of more than 100 meters. The high concentration of wells in the State of Guanajuato has resulted in an alarming annual over-exploitation of groundwater of 829 MCM for the entire State and 117 MCM for the three aquifers that serve the irrigation district. These volumes correspond to an over-exploitation of the aquifers by factors of 1.4 and 1.2 for the State and the district respectively.

Summarizing this section, the values in Table 2 suggests that ARLID is a system without any constraints in water availability and water delivery capacity. The high RWS and RIS may point to the need of further research on how exactly the water is used and what happens to excess water. The system produces high outputs, both per unit of land and unit of water. Furthermore, farmers adequately cover O&M costs. The alarming level of fall in the static water table definitely asks for further studies on how the aquifer is management.

Comparison of Performance Across Modules

As is demonstrated in the previous section, the application of external indicators for one district for one year provides a snap shot of the type and quality of performance. This is particularly the case if performance can be compared to other systems or if reference values are available for each of the indicators. This section of the paper shows that application of external indicators to sub-units allows to distinguish important differences in performance within the system. Although, the indicators do not explain these differences, they help to signal out irrigation management gaps within the system. Three examples are used to support this argument.

The first example shows the difference in RWS values for the winter irrigation season across the 11 modules. Figure 3 shows RWS for three successive winter seasons, plus the average of these values. A number of observations can be made from this graph.

First, there is a clear difference between the modules. The three year average of the 11 modules is 2.6. Yet, as can be observed from the graph, especially Acambaro and Salvatierra modules have much higher averages (3.5 and 4.6, respectively), whereas Valle has only 1.7. The rest of the modules have values that range from 1.9 to 2.9. The high value of Acambaro can be explained by the fact that this module is located right under the Solis dam and hence has easy access to water. Furthermore, owing to its climate conditions, it needs less irrigations and therefor can use its concession to apply higher water depths per irrigation. As explained in detail by Kloezen, Ramirez and Melgarejo (1996) and Kloezen and Garces (forthcoming), the extremely high values in Salvatierra are explained by the fact that this module has a high percentage of crops with lower water requirements, like beans and vegetables. Yet, the module plans and schedules its irrigation deliveries as if all farmers grew wheat. Also, the module suffers from severe disrepair of its infrastructure as it uses some of the most ancient irrigation canals in the Latin American continent.

Second, with exception of two head-end modules of Acambaro and Salvatierra, there does not seem to be a clear head to tail bias of water allocation between the modules. This suggests that the district management seems to succeed in allocating irrigation following the proportional concession of each module.

Third, seven of the 11 modules succeeded in reducing its RWS values in the three successive years demonstrated in Figure 3. As will be discussed below, this reflects the effort of most modules to reduce its water use after the responsibility of irrigation management had been transferred to them in 1992.

Figure 3. RWS values for the modules of the Alto Rio Lerma Irrigation District, winter seasons 1994 to 1997.

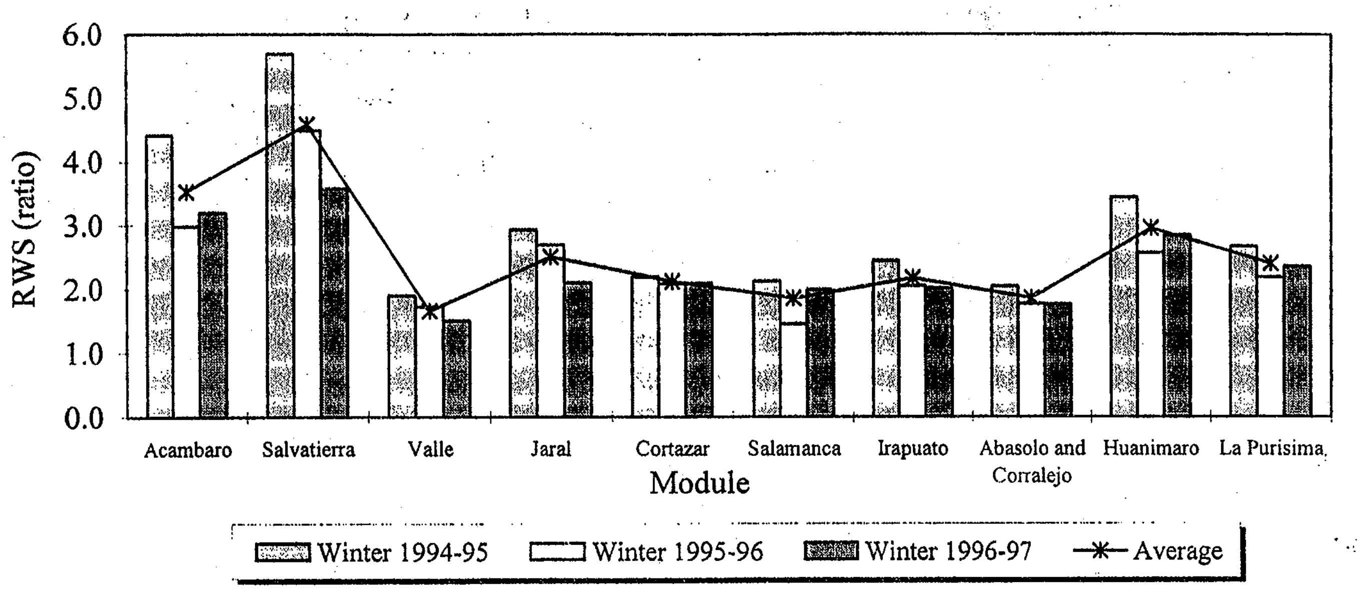
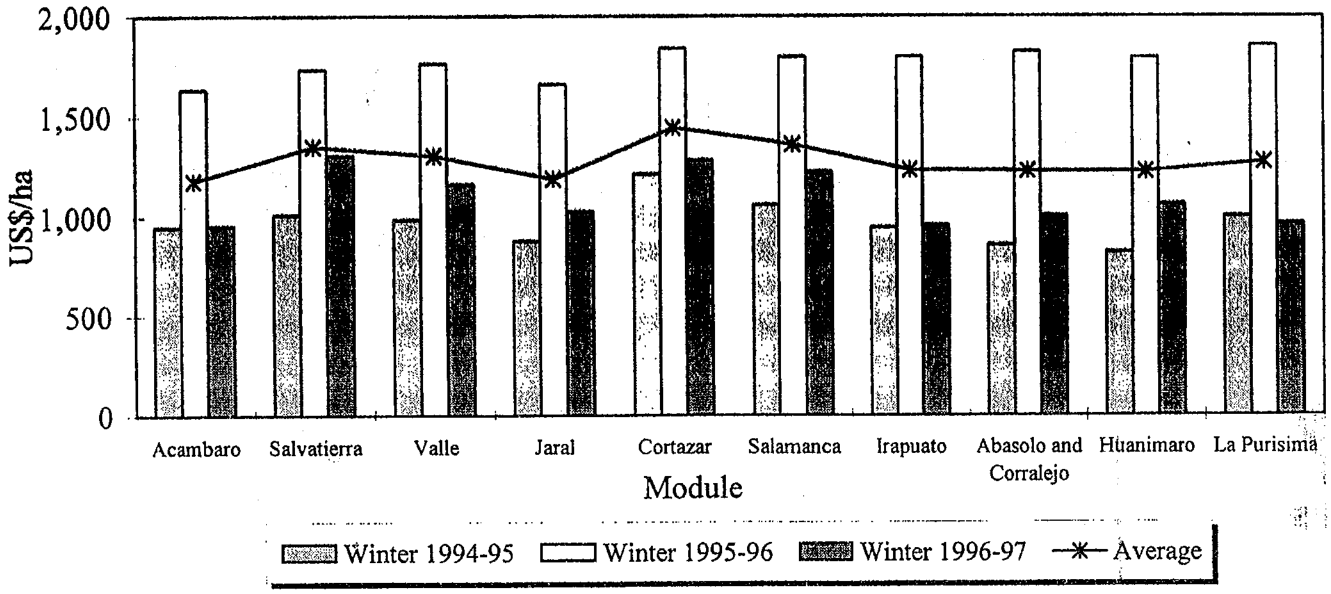


Figure 4 shows the second example of how external indicators can be used to distinguish between differences in performance across modules.

Figure 4. Standardized gross value of production (GVO) per hectare for the modules of the Alto Rio Lerma Irrigation District, winter seasons 1994 to 1997 (adjusted for World Market Price).

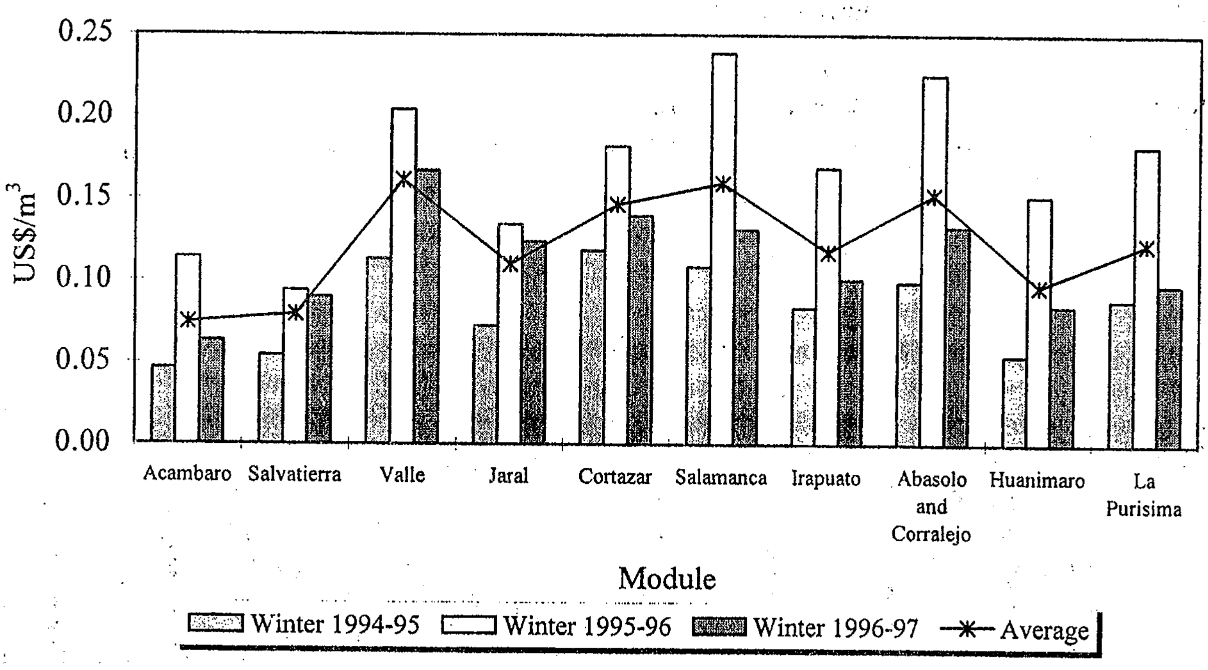


Although, 'normal' wheat yields ranged from 5.5 to 7.0 ton/ha in the three years reported in Figure 4, equivalent yields ranged from 5.2 ton/ha in Huanimaro (1994-95) to 7.6 ton/ha in Salvatierra (1996-97). This high equivalent yield in Salvatierra is explained by the fact that during the 1996-97 winter season 21% or the irrigated area was cropped with beans. Yet, Figure 4 shows surprisingly little difference in standardized GVO/ha. The average value is US$ 1,279 per hectare, while the standard deviation is only US$81/ha (or 6.3 %). This suggests that the modules are able to guarantee productivity, irrespective of their level of water availability. There is no correlation between the RWS values and the productivity of the modules. The correlation coefficients between these values are -0.13, -0.50 and -0.11 for 1994-95, 1995-96 and 1996-97 respectively[9].

A second important observation from Figure 4 is the high difference in values between three years that are reported. The average values for these years are US$973/ha, US$1,769/ha and US$1,095/ha. These difference are entirely attributed to the change in world market price for wheat in those years: US$159/ton, US$262/ton and US$ 173/ton, respectively.

Finally, Figure 5 shows the output per unit of irrigation water supplied. It could be regarded as a combination of both previous graphs and summarizes the conclusion of this section. The graph shows the high range in values, with no clear bias to the location of the module. The average value is US$0.12/m^3, while the standard deviation of the average values is US$0.03/m^3 (or 25%). Comparision of the three graphs suggests that farmers in ARLID pursue yield per unit of land as an objective, rather than optimizing their output per unit of water.

Figure 5. Standardized gross value of production (GVO) per m^3 for the modules of the Alto Rio Lerma Irrigation District, winter seasons 1994 to 1997 (adjusted for World Market Price).

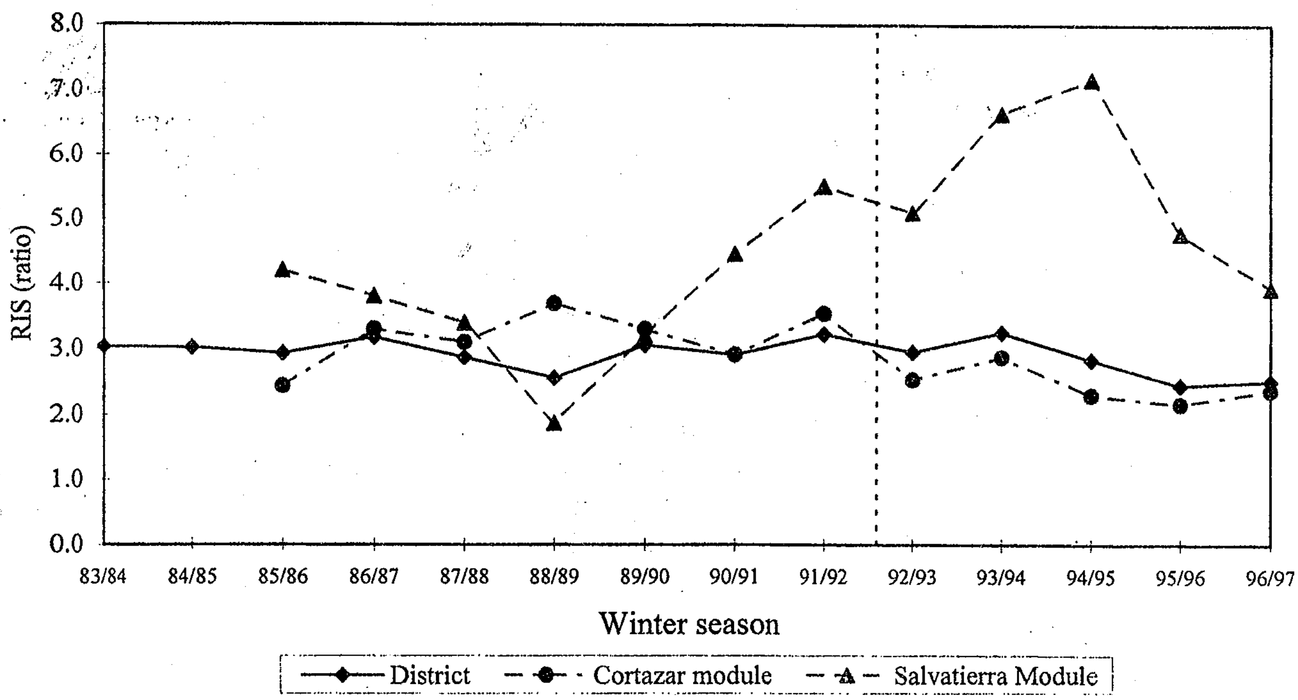


[9] Also Garces (1983) demonstrates in his thesis that, especially for RWS values higher than 1.5, there is no correlation between RWS and productivity.

Comparison of Performance over Time

IIMI's first mandate to do research in ARLID was to assess the impact of the IMT program on irrigation management, O&M financing, cost of water to farmers as well as to evaluate agricultural and economic effects of this program. The set of external indicators proved to be an excellent way to start comparing the quality of performance over time. For this purpose 1983 to 1997 time series were used, which comprise 10 pre-transfer and 5 post-transfer years. It was hypothesized that these time series would help to indicate major changes in performance as a result of an management intervention program like IMT. These time series were applied at the district level, as well as for two selected modules: Cortazar and Salvatierra. During the course of the study the need to add other and more detailed external and internal indicators emerged, particular in the fields of reservoir management, seasonal water allocation between modules, maintenance and O&M financing. The minimum set of indicators proved to limited in assessing changes in system maintenance, which appeared to be one of the most remarkable impacts of IMT in ARLID. In this section only a few examples of the use of external indicators for assessing impacts of intervention are given. Kloezen, Garces and Johnson (forthcoming) provide a detailed analyses of the IMT program in ARLID.

Figure 6. Relative Irrigation Supply (RIS) values, Alto Rio Lerma Irrigation District and Cortazar and Salvatierra modules, winter season 1983-1997



The minimum set of external indicators provide two indicators that evaluate water use: Relative Water Supply and Relative Irrigation Supply. For the purpose of illustration, the RIS indicators is used in this section[10]. Figure 6 shows the historical change in this value for the winter irrigation

[10] The example given here only concerns the winter season, which is the main irrigation season. As seasonal total and effective rainfall

season and for the district and the two modules.

The first observation follows the one made on Figure 3: there is a considerable difference in values between the three examples presented. Particularly, Salvatierra module deviates from the average district values. Some of the reasons for this have been explained above and include, low cropping intensities, high diversity in crops grown, planning and scheduling as if all the crops require the same irrigation as wheat, and an infrastructure in condition of severe disrepair (Kloezen, Ramirez and Malgarejo 1996).

As for the impact of IMT on water use: the average district values continue to be high (around 3.0), which means ample irrigation supply over irrigation requirement, with little difference before and after IMT (average values of 3.0 and 2.8 for the pre and post-transfer periods, respectively). Although, there seems to be a slightly downward trend after IMT, the averages suggests that, at the district level, IMT has not had a discernible impact on the use of irrigation water. This is supported by other observations made during the period of research. Generally, IMT has not brought major changes to the way seasonal planning is done. At the district level, the hydraulic committee adopted the same planning method as was used by CNA. Also, modules continue to follow the methodologies established by CNA before transfer.

The example of Cortazar shows noteworthy differences in pre and post-transfer averages: 3.2 and 2.4, respectively. After its start in 1992, the module has put in a major effort to use its irrigation concession more optimal by training and closely supervising ditchtenders, restricting areas to be irrigated and rehabilitating some laterals and structures. This explains the clear downward trend in RIS values after 1992.

It is apparent that Salvatierra, in its initial years after IMT, could not stop the trend toward higher RIS values that was started under CNA management. Although values are still high in 1996 and 1997, the module unmistakably has made an effort to change its management policies and tries to optimize the use of its irrigation water.

One of the objectives of the Mexican IMT program was to aim at higher O&M cost recovery and financial self-sufficiency. The set of external indicators provide to look at this issue. One of the main reasons why farmers agreed to assume O&M responsibilities was that this would give them direct control over the fees collected from water users. In order to prepare farmers to paying fees that better reflect the actual O&M cost, two year before transfer CNA increased the charge by approximately 400 percent. After transfer the modules did not succeed in keeping up with inflation rates, which explains the fall from approximately US$ 17 per ha-irrigation in 1993 to about US$ 7.5 in 1996[11] and US$13.5 in 1997.

Figure 7 shows a decline in fees paid by farmers after correction for inflation. The fee dropped in terms of total cost per hectare per season, as well as the fee as a percentage of gross value of output (GVO). The figure indicates that the cost of irrigation to farmers has declined from almost 6 percent of the GVO in the year of transfer to two percent in 1996 and has come back to 5 percent in 1997.

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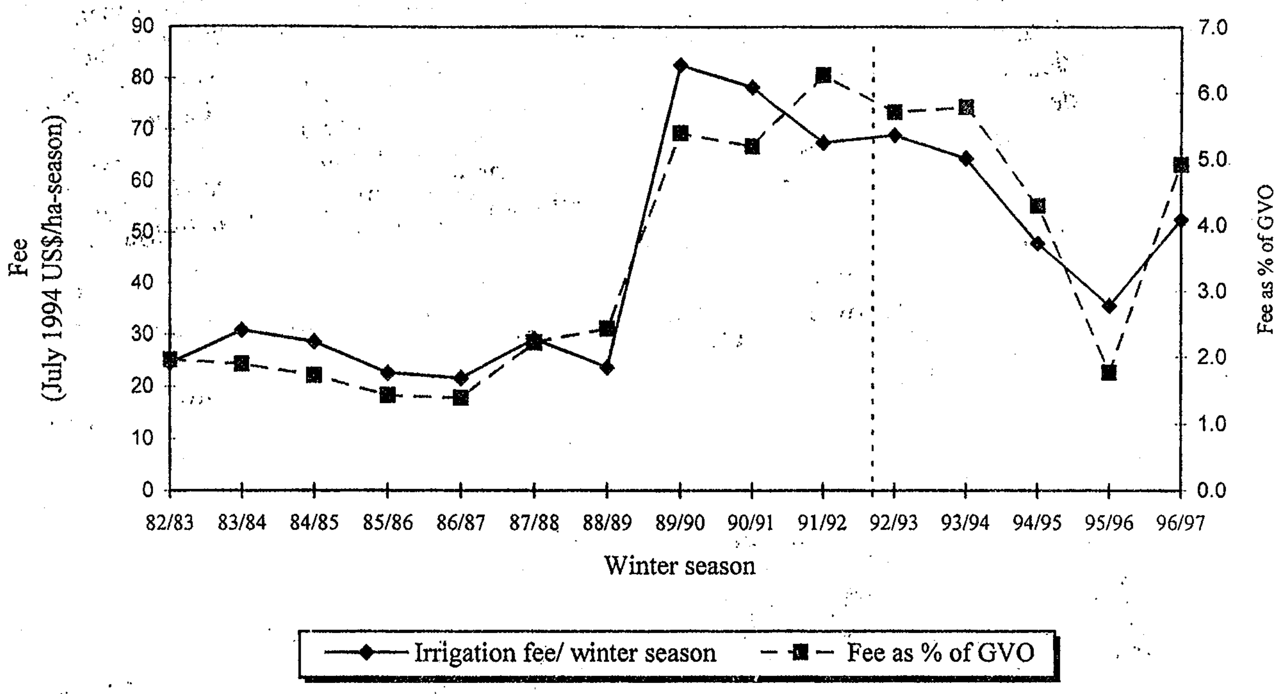
are low, RIS values follow the same trend as the RWS values and are generally a bit higher. Also, for the same reason, the method used to calculate effective rainfall has little effect on the RIS value.

[11] In actual peso terms the fee has remained the same.

Figure 7. Seasonal irrigation fee per hectare and as percentage of GVO, Alto Rio Lerma Irrigation District, winter seasons 1982-1997.



Irrespective of the recent erosion of the per hectare-irrigation fee, the modules succeeded in dramatically increasing the overall collection rate, as is shown in Table 3.

Table 3. Change in self-sufficiency and fee collection rate, Alto Rio Lerma Irrigation District (constant July 1994 dollars).

	1	2	3	4	5	6		
	Actual O&M cost		Planned collection		Actual collection		Self-sufficiency	Collection rate
	US$	US$/ha	US$	US$/ha	US$	US$/ha	% (5/2)	% (5/3)
1989	4,074,928	44	na	-	2,030,577	22	50	-
1990	4,144,268	44	na	-	1,742,121	19	42	-
1991	4,993,439	55	na	-	2,933,486	32	59	-
1992	4,796,412	55	na	-	na	-	-	-
1993	3,861,661	44	4,017,071	46	4,963,686	57	129	124
1994	4,233,114	49	4,636,448	53	5,275,288	61	125	114
1995	3,376,913	35	2,991,052	31	3,678,126	38	109	123
1996	2,495,467	26	2,608,077	28	3,180,179	34	127	122

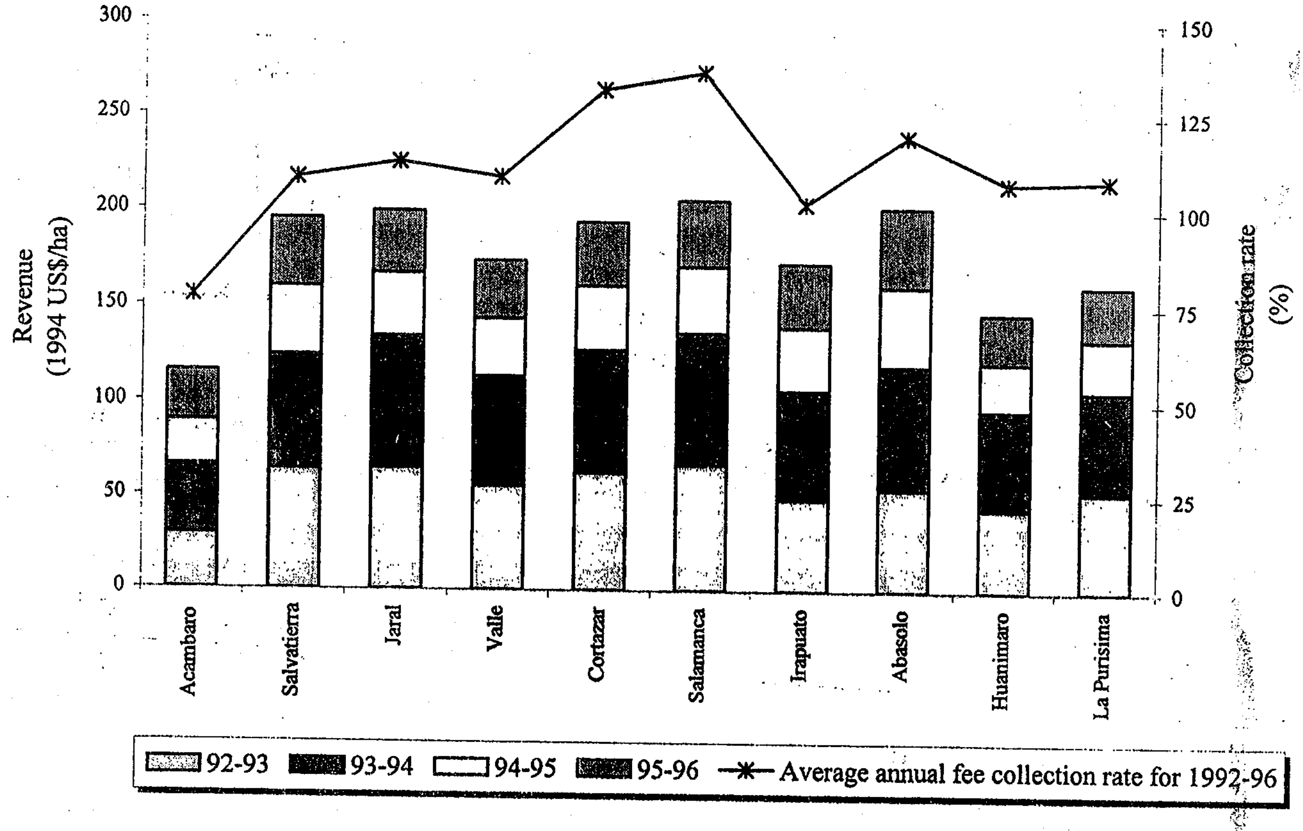
na: not available

The table shows the development of both the self-sufficiency (actual collection over actual

expenditure[12]) and the fee collection rate (actual collection over planned collection). Clearly, one of the major impacts of transfer in ARLID is the enormous improvement in self-sufficiency: from about 50% in the three years preceding transfer to over 120% in the post-transfer years.

Figure 8 combines time series and comparison across modules and shows the difference between modules in revenue mobilized per hectare from irrigation fees. These revenues range from US$ 116 to US$ 205 per hectare for four years, with an average of US$ 182 per hectare (1994 dollars). Acambaro module, which because of its higher elevation and cooler climate get by with one less irrigation and consequently collects less revenue from the fee. The figure also shows the historical decline in fee revenue as a consequence of the economic crisis that followed the December 1994 devaluation of the peso. Finally, the figure shows that most modules succeeded in maintaining a fee collection rate above 100%[13].

Figure 8. Fee revenue (US$/ha) and average collection rate (%), modules of the Alto Rio Lerma Irrigation District, 1992-96.



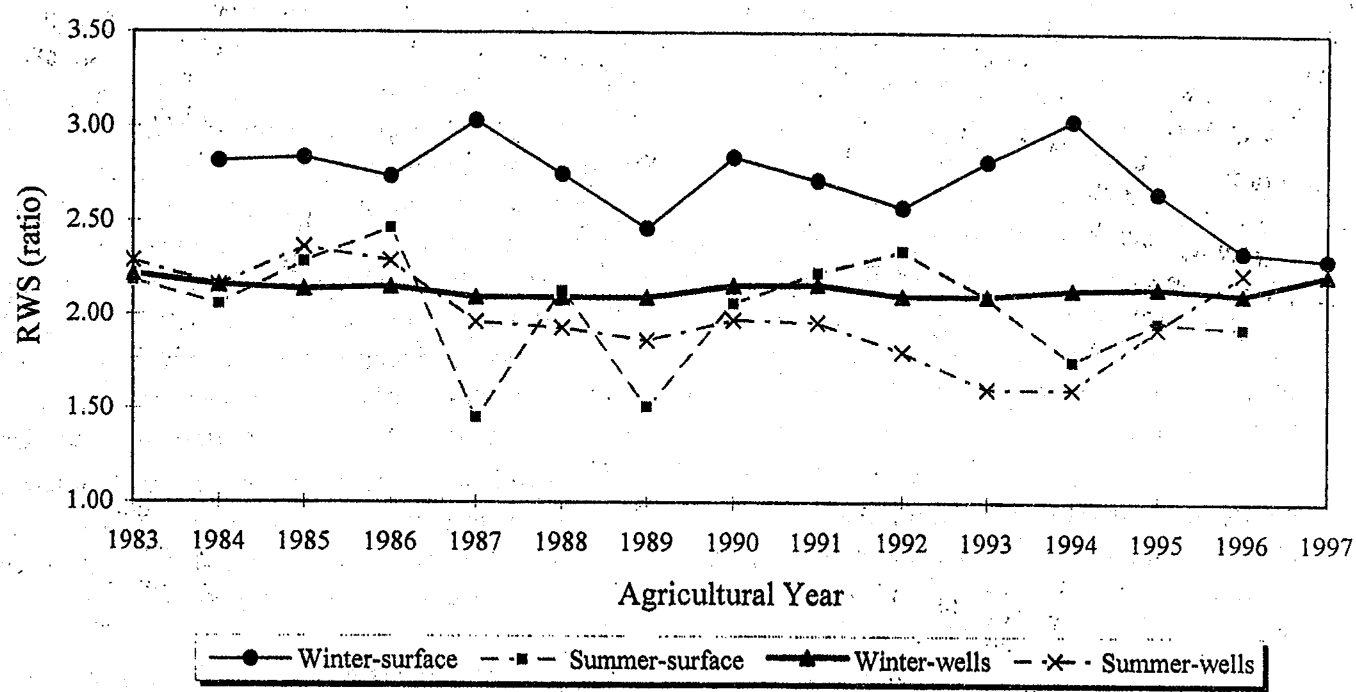
[12] The actual O&M expenditures after 1992 do not include the cost of the staff still employed by CNA as these are all paid out of federal funds rather than out of the fees collected from farmers.

[13] This was possible because modules often could deliver more irrigations over and above the amount upon which the planned collection target was based.

Comparison of Performance between Surface and Well Irrigation

External indicators were also used to compare performance of irrigation with different sources. RWS values for surface and well irrigation are compared in Figure 9. For the winter season, RWS values for wells are generally lower than those for canal water (averages of 2.1 and 2.7, respectively), but equally high for the summer season (average 2.0). However, given that the RWS values for canals are calculated at the intake point of the modules, while those for the wells represent on-farm level water supply, it is concluded that the farmers who use wells apply more water to their fields. Two reasons explain this. First, especially during the summer season, private well owners generally do not wait for the rains to come and start irrigating as soon as they can. As a result, often well users have already applied one or two irrigations when the rainy season sets on. Second, owing to subsidized energy tariffs the per hectare cost of pumping water during the winter season equals that for the irrigation fee paid for surface irrigation (Kloezen and Garces forthcoming).

Figure 9. Difference in RWS values between surface irrigation and well irrigation, Alto Rio Lerma Irrigation District, agricultural years 1983-97.



It is expected that some of the excess pumped water percolates to the aquifers and hence can be re-used. However, in places within the district the aquifers are located 150 meters below field level, which makes measuring recharge from excess irrigation very complicated. As a result, reliable CNA data on this type of recharge do not exist. But even if some of the excessive surface and pumped water recharges the aquifer, the fall of the static aquifer level with 2 to 5 meters per year and the annual over exploitation rate of 1.4 show that the lack of aquifer management policies and strategies.

The total volume pumped increased between 1983 and 1988 as a result of the relatively dry years of the early 1980s and the granting of concessions to new wells. Pumped volumes have dropped since

1989, basically because of the dramatic fall of the water table (*ibid.*). Although new concessions are not granted anymore, a program to upgrade existing pumps and wells was started in 1995 with the aim so use energy and water more efficiently. The first results of this program indicate to lower energy consumption, but it is not yet clear whether farmers pump less water.

The annual standardized GVO per hectare is approximately US$2,900 US$/ha for surface irrigation, and ranges from US$2,900/ha to US$4,000/ha for wells. The higher values for wells reflects the higher value crops usually grown under this technology.

Comparison with Internal Performance Indicators: an Example

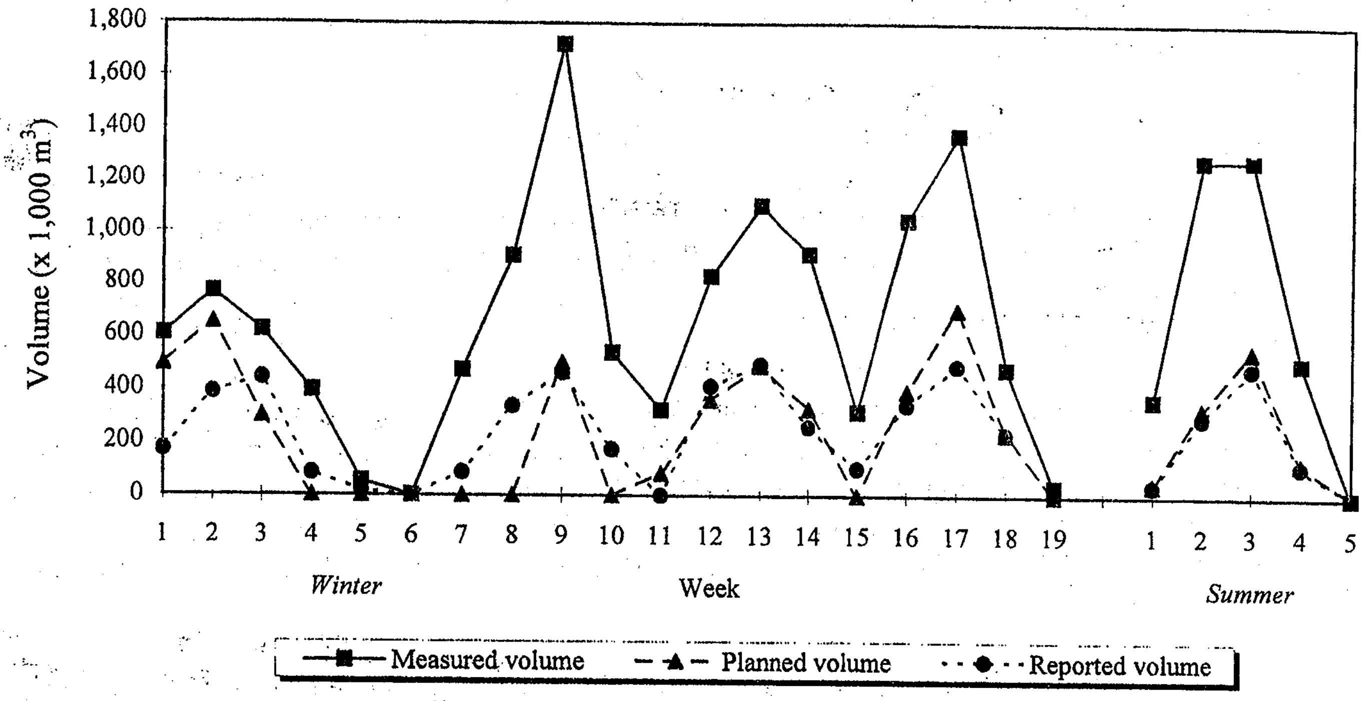
As mentioned in footnote 2, IIMI's research of ARLID also included performance assessments of a range of internal indicators (Kloezen and Garces forthcoming), which measured performance from field to district level and assessed actual performance over planned targets and reported values. In order to compare the type of information that can obtained from internal indicators with the information presented in the previous sections of this paper, one example of an internal indicator is discussed below: the actual supply over planned and reported supplies.

The actual supply was obtained through field measurements by IIMI (for the selected fields and canals) and by CNA for the intakes to the modules. Planned irrigation supplies are obtained from daily and weekly schedules of the modules and CNA and are the result of the monitoring activity by these agencies as discussed above. Similarly, reported volumes were obtained and aggregated from the daily field reports of the ditchtenders.

Figure 10 shows an example of weekly irrigation supplies to a selected lateral in Cortazar, which serves 650 hectares. The first observation is that planned and reported values show a very high correlation; on the average reported supplies are 97 percent of planned supplies. The reason for this is that at the level of the laterals and fields ditchtenders estimate but do not measure volumes. Although each delivery should provide a uniform planned irrigation depth to each farmer who requested an irrigation, the time allocated to irrigate one hectare is fixed by the ditchtender. The duration of supply is determined by the ditchtenders experience and the relationship with the individual water users. As a result, actual supplies can deviate considerably from planned deliveries. Yet, generally ditchtenders only report roughly the time farmers receive water. The ditchtender's main concern is to report the area a farmer had requested and paid an irrigation for, rather than the actual volume supplied. Using the planned water depth, he then calculates back the theoretical discharge (m^3/s), which is what they record in their daily irrigation reports to the modules. Measurements in 20 selected fields along this canal during a period of two irrigation seasons confirm this practice: during the winter season measured volumes were on the average 30% higher than reported, while for the summer season this was 33% (Kloezen and Garces forthcoming).

The second observation from the graph is the almost consistently higher measured values compared to planned values: on the average they are 194 percent higher. This can be explained through a combination of poor control at the intakes of the selected canal, lack of a measuring device and failure to adjust gate settings after conditions of the infrastructure had changed as a result of intra-season maintenance, as was the case in week 7.

Figure 10. Measured, planned and reported weekly volumes for a selected canal in Cortazar module, winter 1995-96 and summer 1996.



This example learns that application of an internal indicator provides information that would not have been obtained when only external indicators had been applied. For instance, only by applying the indicator for two years, IIMI could make observations on the way supplies are monitored and reported. These observations proved to be of crucial importance to be able to understand the source, the quality and the reliability of the data collected and reported by the modules and CNA, which in theory could form the basis of some the external indicators. The way irrigation deliveries are reported by ditchtenders blurs the actual adequacy of irrigation supplies in official CNA and module reports. As these reported volumes are the basis of the monitoring done by CNA and the modules, from the field upto the district level, this practice has also considerable consequences for the quality of the performance monitoring.

Also, after applying the internal indicators, IIMI has a better understanding of the priorities CNA and the modules have in their irrigation management practices. For instance, although in theory water distribution within the module is arranged by volumetric demands, the modules are more concerned about meeting the committed area to be irrigated. The priority of area over flows is consistently found at different system levels: from the level of module management (responsible for weekly planning) to the ditchtender at the field level (responsible for daily records), and is conducive to high levels of adequacy, not only to the module, but also within fields.

Finally, the example points strongly to two limitations of internal indicators. First, the example is very site (and in this case, canal) specific and does not provide information on actual performance in other canals or modules. Although, IIMI has done similar exercises in other canals and other

modules, it is very reluctant to make far reaching conclusions on the management of entire modules or the district.

Second, measuring actual over planned supply at any given system level is one of the most simple exercises of assessing internal performance. Yet, what is the use of it, if system managers themselves have not included this activity it in their daily monitoring program? As mentioned above, the only supply actually monitored is at the intake of the module. Like the example of reporting deliveries shows, monitoring is more geared towards meeting administrative accountability than to managerial accountability.

Evaluation of Data Collection Procedures

This section evaluates the data collection procedures that were used to obtain the performance results presented and discussed above. It provides a comparison between the time and resources needed for calculating IIMI's external indicators to the effort needed to measure the limited set of selected internal indicators.

External indicators. The external indicators rely heavily on the availability of secondary data. Once contacts and good working relationships with CNA and the modules were established, IIMI was provided full and unconditional access to the requested data. As CNA and most modules use computers to enter and process their data, often computerized data files could be copied and used. Yet, data collections took more time than the one month anticipated. There are several reasons that explain this.

- In theory, most of the data could have been obtained at the district level (collected and aggregated by CNA). This would have required considerable less time input. However, it was felt that for the purpose of cross-checking and quality control, data should be collected as much as possible at the primary source. This has improved the reliability of the data presented in this study. However, logistically this meant that many time consuming visits had to be made to the modules. Furthermore, it takes CNA and the modules months to process their seasonal data.

- Often, different modules use different formats to enter their data. This makes comparison of module data and aggregation of module data to district level data difficult.

- Rather than using reported and aggregated volumes from the ditchtenders' reports, total volumes supplied to the modules had to be calculated by adding daily water measurements taken at a large number of control points. This is a time consuming process.

- Yields and farm gate prices vary from module to module and needed to be cross-checked with data from other sources.

- Converting yields and prices of more than 30 crops to a base equivalent crop at several system levels, for two seasons over a period of 15 years and for both surface irrigation and wells, required the development and management of large data bases.

- Given the differences in climate within the system, climate data from several stations had to be collected. Visits to more than 10 stations were made to check the quality of the collection procedure used by the stations. Because of the poor quality of the equipment used or awkward location of the station, several weather stations were rejected. Also, the remaining stations appeared to have considerable data gaps.

- Sometimes historical data were difficult to find, mainly as a result of the three administrative changes that the Ministry of Agriculture and CNA faced over the last 10 years. As a result, archives and files were lost or data formats had changed frequently. This complicated historical comparisons.

- Collection of financial data proved to be time consuming because it takes time to understand, interpret and cross-check the different line items and monetary flows presented in the books. In addition, financial years and agricultural years do not always correspond.

Development and modification of the spread sheets to enter and process the data took approximately two weeks. Data collection and checking took about four months. A secretary was hired and trained to enter the data, on which approximately one month was spent.

Internal indicators. In comparison to the external indicators, data collection procedures for applying internal indicators are more complex and time and resources consuming. Distinction must be made between data required for applying internal indicators at the module and district levels, and applying indicators at the level of selected canals and fields.

For the former purpose, in addition to the data required for the external indicators, secondary data on amongst others dam storage, dam releases and volumetric concessions, as well as planned and reported values data were collected, which took approximately one additional month.

Three engineers worked full time for more than a year to collect primary data and make measurement at the level of selected canals and fields. In addition, a M.Sc student and a part time assistant-engineer were hired to take the twice daily staff gauge readings and to provide assistance with the calibration of the staff gauges. Calibration of the staff gauges installed by IIMI proved to be the most time consuming activity. In addition, much time was spent on visiting the selected fields and taking several flow measurements per field, per irrigation. Calibrating selected wells, measuring flows from wells, taking energy consumption readings, as well as applying the farmer survey to obtain crop budgets, production costs and cost of water, appeared to be a relatively easy activity. An additional five months were spent on entering, cleaning and processing primary data.

Conclusions

The first objective of this paper was to test the usefulness of external indicators. The examples presented above clearly point out that internal and external indicators are fully complementary rather than competing and that they serve different research and monitoring purposes.

Application of external indicators at the district provides some idea of the 'health' of the system by looking in general terms to water use, agricultural and economic outputs, level of financial self-

sufficiency and environmental impacts. However, this only proved to be possible because of the author's access to information about other system that could be referred to. The use of external indicators provides good information on the differences in quality of water management performance between the modules and water sources and hence on general performance of the entire district as well. Furthermore, it proves to be a powerful tool to assess the impact of intervention programs like IMT not only on system management, but on the agricultural and economic outputs if the management strategy as well. Finally, information obtained from applying external indicators help to point potential gaps in irrigation management policies, such as the way planned irrigation depths are calculate and the management of aquifers that serve the district.

The most important drawback of the external indicators is that they do not provide sufficient information on the reasons behind and the mechanisms of different types and quality of performance. Nor do they provide information on the logic behind management priorities and the nature of gaps in irrigation management policies. But they were not meant to do that.

In addition to measuring what they are supposed to measure (actual over planned performance), internal indicators fill in some of those analytical gaps and help to raise new questions that with the help of other research techniques, such as attending module and hydraulic committee meetings, observations of module-farmer relationships and interviews, can be answered. Yet, as the one example presented above shows, the most important problem with internal indicators is that they are very site specific and do not allow comparison with other systems, or even other sub-units within the same system. Furthermore, they are often used to assess actual performance relative to management targets that were set by researchers rather than system managers themselves.

Having worked with both external and internal indicators learns that both sets support and strengthen each other. Daily measurements and observations of irrigation management practices at lower system levels appeared to be necessary to understand the logic behind and the quality of the secondary data obtained from module, district and more central levels. For instance, it clearly pointed out the poor quality of the reported data, and consequently the low reliability of CNA's and the module's own monitoring data. These observations made IIMI to decide to take the extra effort explained above to cross-check the secondary data required for the external indicators. We strongly believe that this has considerably helped to improve the data used for the external indicators.

The second objective was to evaluate the applicability of external indicators. Several observations can be made in this respect.

- Compared to applying internal indicators (which generally requires daily measurements at different system levels), the application of external indicators is less time and resources consuming. Yet, given the large size of the system, the several system levels, the high diversity in cropping patterns, the several irrigation technologies and the overlap in irrigation seasons of most Mexican irrigation system, collecting, verifying and processing the basic data needed to calculate the external indicators proved to be more complex and time consuming than anticipated.

- The water-based external indicators rely on a water balance approach, as it aims to consider non-beneficial ET, flows to groundwater and so on. However, in many systems reliable secondary data on these components are not available. If comparisons are made across systems or countries it is necessary to know if the excess water in a particular place can be used elsewhere or not. A value

of 2.0 is not necessarily better than 2.5 if in the latter case there is no opportunity to utilize the extra resource somewhere else. Compared to other systems, ARLID has good data. Yet, even with a relatively large research team and a good group of collaborators, IIMI-Mexico did not have the expertise, equipment and budget to better understand the hydraulic position of ARLID within the huge Lerma-Chapala water basin, nor to better understand the interaction between surface irrigation and recharge of the aquifers.

- In systems like ARLID cropping patterns as well as yields and prices vary from module to module. For this study we were fortunate that both CNA and all modules keep very good seasonal records on these agricultural data. For similar systems, but in different settings or countries with less well maintained secondary data and trained irrigation staff, applying even the minimum set of external indicators will be a difficult task.

- Using external indicators for time series proves to be difficult in cases like Mexico, which suffered from two economic crisis in the years recorded for this study. Devaluation of the national currency against the dollar as well as high annual inflation rates that generally follow these crisis, make it difficult to convert standardized GVOs to constant dollar prices.

- Using international world market prices in stead of local farm gate prices to calculate standardized GVOs only is useful when across country comparisons are made. For across system comparisons within one country and for comparisons over time it is better to convert local prices to a standard year using a local price index as it avoids that variations in world market prices distort actual local prices and outputs.

- Using standardized GVO to make over time comparisons of outputs and cost of irrigation to farmers is only possible if the correlation between GVO and NVO is constant over time as well. However, it is not clear whether this holds for countries like Mexico, which under went several economic reforms that affected the cost of production to farmers. The relation between GVO and NVO requires further study and the methodology to collect data on cost of production needs to be standardized.

- Although Molden, Sakthivadivel and Perry (forthcoming) combine different seasons to yearly values, in this case study it was necessary to apply the indicators to individual cropping seasons since the climate conditions for the winter and summer season are very different in terms of irrigation needs. Aggregation of seasonal information to yearly values does not provide useful information on system performance and potential gaps in irrigation management practices and policies. Likewise, as canal water and ground water are essentially managed separately it was also necessary to calculate individual indicators per water source. This meant a substantial increase in time needed to collect and process the data.

- An important parameter of the RIS is the effective rainfall. However, there exist several methods to calculate this. The results of each method might differ considerably and hence affect the RIS value. The main irrigation season in ARLID is the winter season, with very little rainfall.

Therefore, the method used to calculate effective rainfall hardly affects the RIS value. However, in seasons with more heavy storms and in hilly areas, the method to be chosen becomes very important and has to be standardized across systems.

The objectives of this paper were to evaluate the usefulness and applicability of external indicators relative to internal indicators. A next step in the research process would be to correlate types and quality of internal performance to external performance. This would require a much larger sample of years, modules, fields, and possibly systems and countries. From a methodological point of view, this enforces the need to standardize external indicators, which is currently attempted by IIMI. Moreover, it would require standardization of the enormous set of existing internal indicators and methodologies to calculate them.

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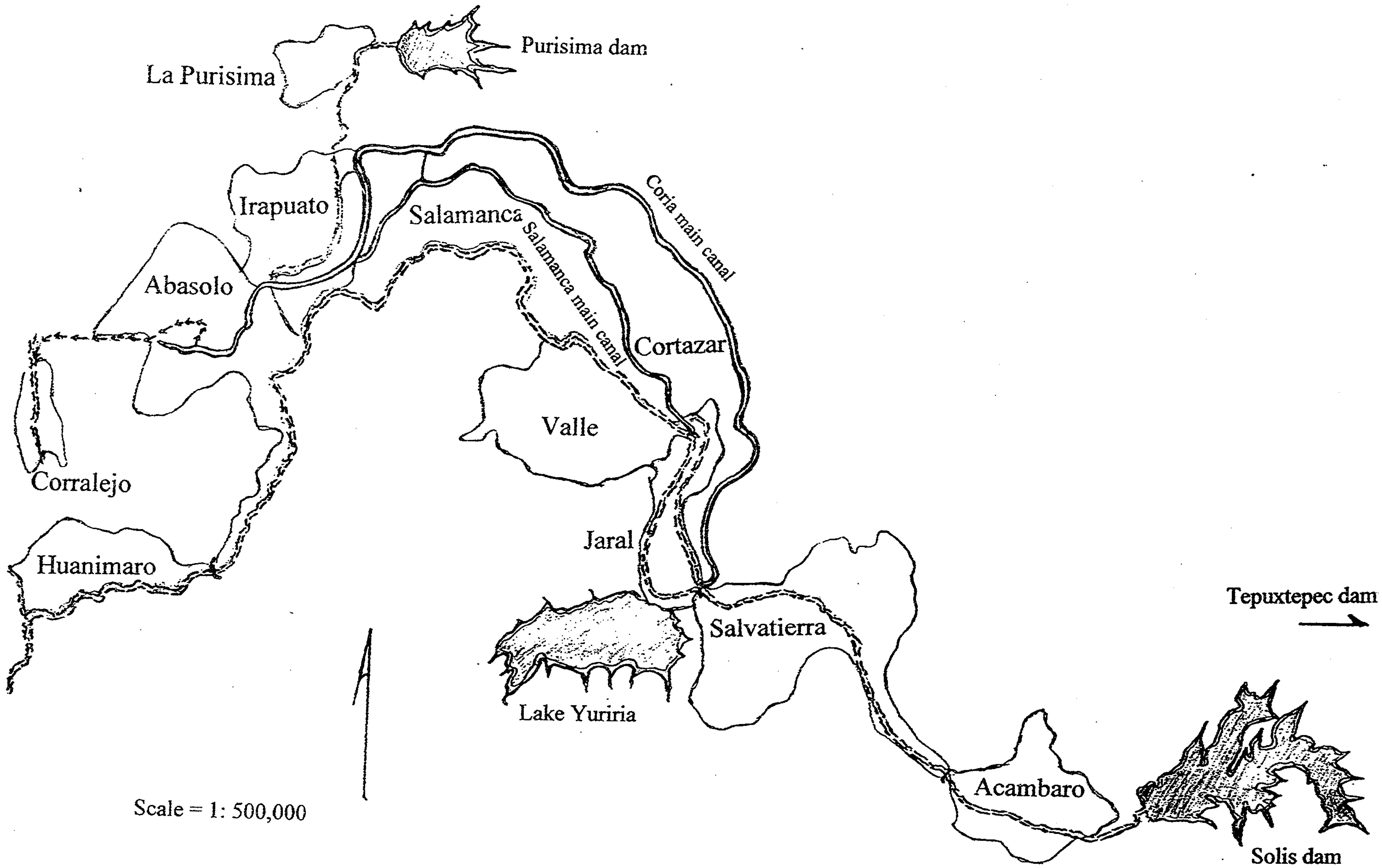
Purisima dam
La Purisima
Irapuato
Salamanca
Coria main canal
Salamanca main canal
Abasolo
Cortazar
Valle
Corralejo
Jaral
Huanimaro
Tepuxtepec dam
Salvatierra
Lake Yuriria
Acambaro
Solis dam
Scale = 1: 500,000

\nnex 1.

ïalient features of the 11 modules in the Alto Rio Lerma Irrigation District

	Area (ha)			Number	Number of users			Area by irrigation source (ha)				Irrigation network (km)			Drainage network (km)		
fodule	Ejido sector	Private growers	Total	of ejidos	Ejido sector	Private growers	Total	Surface	Public wells	Private wells	Total	Main canals	Second. canals	Total	Main drains	Second. drains	Total
.cambaro	6,545	2,304	8,849	23	1,622	308	1,930	6,727	257	1,724	8,708	43	101	144	28	96	123
alvatierra	13,561	2,336	15,897	44	5,082	972	6,054	12,775	565	2,753	16,093	116	120	236	42	176	218
ıral	3,236	3,453	6,689	16	1,062	401	1,463	4,381	371	1,992	6,744	60	73	134	12	80	92
alle	7,359	6,319	13,678	31	1,773	536	2,309	7,990	778	3,955	12,723	31	162	193	52	83	135
ortazar	9,781	8,668	18,448	35	2,169	993	3,162	10,934	1,964	5,796	18,694	75	238	312	23	85	108
ılamanca	5,165	8,992	14,157	37	1,178	1,534	2,712	12,109	573	3,426	16,108	61	174	235	10	91	101
apuato	4,078	4,312	8,391	19	984	285	1,269	4,810	688	3,090	8,588	18	102	120	18	43	61
basolo	5,229	11,136	16,365	38	1,164	1,259	2,423	10,911	1,152	3,390	15,453	28	141	169	33	39	72
uanimaro	2,261	1,470	3,731	18	611	229	840	2,802	430	491	3,723	20	20	40	15	41	56
orralejo	1,219	297	1,516	5	264	11	275	653	643	217	1,513	12	0	12	0	1	1
ı Purisim:	3,437	982	4,419	15	936	118	1,054	3,605	0	820	4,425	11	52	63	27	27	54
otal	**61,871**	**50,269**	**112,140**	**281**	**16,845**	**6,646**	**23,491**	**77,697**	**7,421**	**27,654**	**112,772**	**475**	**1,183**	**1,658**	**260**	**761**	**1,021**

RESEARCH PROGRAM ON

IRRIGATION PERFORMANCE

(RPIP)

RIO TUNUYAN MEDIO IRRIGATION SYSTEM

MENDOZA , ARGENTINA

THE LEGAL AND ADMINISTRATIVE SETTING FOR THE USE OF WATER RESOURCES IN MENDOZA, ARGENTINA

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ABSTRACT

The legal-administrative setting for the use of water resources in Mendoza Province is founded on different legal rules. This includes the National Constitution, the Argentine Civil Code, National Laws, the Constitution of the Provincial State, the General Water Law, (legal) administrative regulations of the General Department of Irrigation.

The current water law is based on the roman law, on the Arab irrigation water rights which were brought to Argentina by the Spaniards and on the practices of the original American pre-Colombian 'intermediate law'. The latter is marked by a strong regional sense. As such, the water law is strongly influenced by the region's elements of nature and attempts to offer solutions to problems.

The legal rules are discussed from a behavioral and organizational perspective. Examples from the Lower Tunuyan System are given to illustrate the day-to-day effects on irrigation water management.

Key words: water law, irrigation, management, Argentina

1 Introduction

Between 1880 and 1914 Argentina in general, and Mendoza Province in particular, went through a period of spectacular macro-economic growth. During this "golden age" of Argentina, exports from the country ranked first in Latin America, while the per capita income ranked tenth in the world. Mendoza Province developed in a similar fashion and became the fourth important center of agro-industrial development in the country.

During this period the provincial government renewed the legal and administrative system. This was needed to create instruments to cope with the economic development because of immigration, the related inflow of capital and technology, and the opening of domestic and world markets.

With an average rainfall of 180 m per year water is one of the scarce natural resources that received legal attention. The water law of 1884 for Mendoza Province is based on the roman law, on Arab water rights traditions which were brought to Argentina by the Spaniards and on the original water

use practices of the pre-Colombian 'intermediate law'. This intermediate law was used between the emancipation of 1810 and the enactment of the General Water Law of Mendoza Province in November 1884. The most important concept of the intermediate law was that it always compromised between the agricultural and economic requirements of the different irrigated areas by enacting special provisions for each area. As such, the water law is strongly influenced by the region's natural setting and by attempts to offer solutions to problems encountered by the population.

2 The Legal System

The legal system of Argentina is based on the concept that the provinces retain all the power that has not been delegated to the Federal Government by the Constitution (art.121). Thus, the power of the Federal Government is limited. However, certain powers can be simultaneously exercised by the Federal and the Provincial Governments (arts. 75, paragraph 18 and 1260) (López 199#). The Water Law is such a field where laws and related regulations are issued by federal, provincial and municipal agencies. A short description is given below.

2.1 Federal Laws on Water

According to article 75, paragraph 12 of the (Federal) National Constitution, the National Congress is in charge of issuing the basic laws. The Civil Code, being one of these basic laws, lists in article 2340 which natural resources are public property. With respect to water public property includes:

- bays, ports, anchorage's and seas up to the distance from the shore as determined by special laws.
- sea beaches
- rivers, their beds and water flowing through their natural beds,
- all other water bodies that are suitable for general uses,
- groundwater,
- navigable lakes and their beds; islands in the seas or in any class of river or navigable lake.
- surface water that has its source in one province and discharges into another province (arts. 2350 and 2637 of the Civil Code) and rain water that falls on public places (art. 2635 of the Civil Code).

The legal ownership of non-navigable lakes is under discussion; this because the Civil Code does not state anything about it. However, the right to use these lakes is granted to riparian states (art. 2359 of the Civil Code).

The Constitution (art. 2339 of the Civil Code) says that the above public ownership of water either is with the federal state or with the provinces. The provinces have granted the Federal Government the jurisdiction over navigation (arts. 12, 26 and 75, paragraph 10) and inter-provincial transfer of water (article 75, paragraph 13).

2.2 The Provincial Constitution

The 1916 Constitution of Mendoza Province devotes one full Chapter to water legislation and management. This Chapter deals with water rights and with the administration of water resources. This is justified by the fact that water is a scarce publicly owned natural resource for use in the general interest. Hence, the administration of water is public, not private. This does not mean that it is administered only by the state. The Provincial Constitution sets forth that water users can, and in fact they do, participate in the administration of water resources.

With respect to water management the Provincial Water Law decentralized the administrative system

into three staggered layers:

- The provincial executive power is with an independent agency, the General Department of Irrigation (DGI) which, in accordance with the provincial Water Law, is in charge of water management in Mendoza Province. Users participation is through the Honorary Appeal Council having one member for each of the five major river basins.
- The (five) Subdelegado's (of DGI) are the autonomous water management authorities for each of the river basins. Users participation is through the Honorable Users Board with a representative for each of the Users Associations.
- Water users (within an irrigation command area) have the legal right to associate and to elect the authorities in charge of managing the related irrigation system.

The above institutions are public and exercise executive, technical, financial, budgetary, taxation and jurisdictional functions. The General Department of Irrigation, and its Subdelegado's, pertains to the Provincial Government, the Users Associations, however, are not. All organizations are financed entirely through water charges.

2.3 Amendments to the General Water Law

The above legal system looks rather static. However, because it regulates the broad outline of water management only, many changing needs of society could be handled through a changing administrative interpretation of the law. Nevertheless, since the General Water Law has been in force (1884) it has been amended several times. These amendments were needed to:

- grant and revoke irrigation water rights,
- update the concessions register by DGI,
- regulate the generation of hydroelectric power,
- operate a fund for minor works,
- regulate groundwater use and administration
- establish a state society for the generation and supply of hydro-electric power.

Since 1990 some environmental laws were passed such as the Environmental Preservation, Conservation, Protection and Improvement Law, the Hazardous Wastes Law and the Regulative Framework of the Drinking Water Supply and Sanitation Service.

3 The General Department of Irrigation

The organizational structure of the Directorate General is laid down in the provincial legal system as shown in Figure 1. The full-line-box parts of DGI are situated in the DGI headquarters in Mendoza town. The five Subdelegado's hold office in the irrigated area in each of the five major river basins.

The Honorary Appeal Council and Administrative Tribunal play a significant role in the management of water resources. The Appeal Council was established through the Provincial Constitution and is regulated by Law N° 322 of 1905. The Council has five members, each of them representing the water users in one of the five major river basins. The Council is the second-line court for matters pertaining to public water distribution and use. It handles appeals on rulings by the Inspector of the UA's. If its rulings are not considered acceptable, an appeal can be filed before the Supreme Court of Justice of Mendoza Province which is the only and last legal resort in this matter.

The Honorable Administrative Tribunal was founded through Law N° 322 (article 26) and is entrusted with the following responsibilities: appoint and remove all employees of the General Department of Irrigation; approve the annual budget of the General Department of Irrigation; set the level of water charges; approve the elections of authorities managing the Users Organizations and, if

needed, appoint an "auditor" to approve the annual budget of Users Associations, grant groundwater use concessions and draft the Department's internal by-laws and other by-laws imposing rights and obligations on water users.

The General Irrigation Superintendent is the highest executive and technical authority of the General Department of Irrigation. He is appointed by the Provincial Government for a 5-year term. To relieve DGI from political pressure, this term in office differs on purpose from the 4-year term of the Government. The superintendent is responsible for the management of natural rivers and streams and controls the administration of man-made (irrigation and drainage) canal systems. All requests for public water use concessions have to be submitted to him. He is also a water judge. In this function he chairs the Honorary Appeal Council.

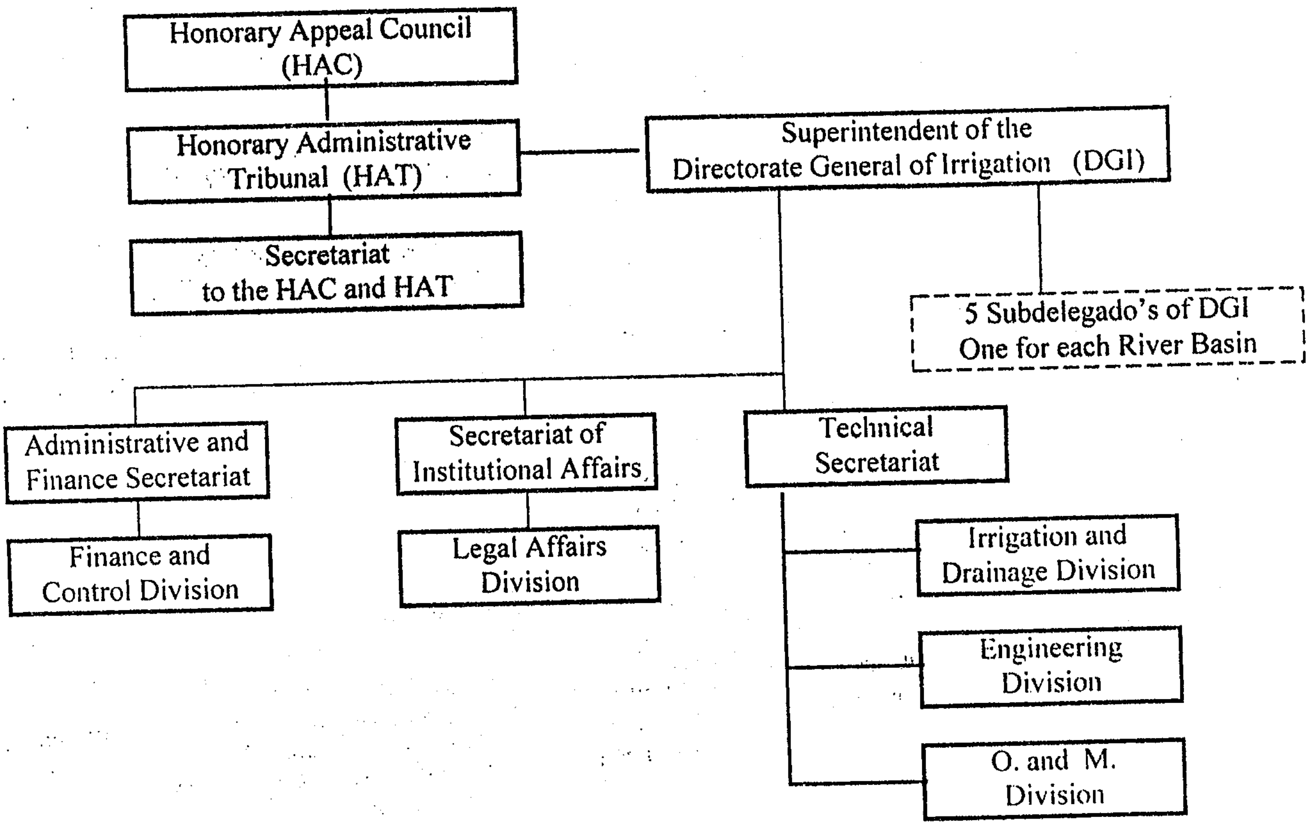

Figure 1 Orgamization Structure of the Directorate General of Irrigation

The legal duties of DGI further include:

- The coordination of major works. Such works either can be planned by the Provincial Government or by the General Department of Irrigation All major works must be authorized by a special law
- The planning and design of the expansion of existing irrigated areas and the construction of new irrigation projects also calls for legislative authorization.
- All hydraulic works, either planned by Users Associations or by individuals, should be approved by the General Department of Irrigation. DGI also has to approve the plans of operation of irrigation systems in the Province.
- If the flow rate in a river is insufficient to meet all simultaneous water rights in the related basin efficiently, the Superintendent of DGI may decide to switch from continuous to a rotational delivery of water to users. This rotational system again delivers water to users in proportion to their water rights.

- DGI regulates the protection of the environment against harmful effects of water use and includes some rules related to pollution control.

As mentioned above, the General Department of Irrigation is authorized to draw up and approve its annual Expense Budget and Resource Calculation. This regulation gives DGI complete financial self-sufficiency from the Provincial Government. The financial resources of DGI come from various categories of water users as illustrated in Figure 2.

The Subdelegado of DGI in the Lower Tunuyan irrigated area is responsible for the management, operation and maintenance of the structures in the Tunuyan River and the conveyance canal system including the structure where water is supplied to the 13 Users Associations. Water is supplied continuously and in proportion to the water rights as registered in the Concessions Register of Public and Private Water Rights. According to the Water Law, this register is administered by DGI. The organizational structure of the Subdelegado is shown in Figure 3.

As shown, water users participate through the Honorary Users Board. The Subdelegado's and the Users Associations may request assistance from the three specialized divisions of DGI on administrative and technical matters; e.g. office automation, budgeting, feasibility studies, detailed design of canals and related structures, earth moving equipment, etc. Hence, there are regular contacts between the Users Associations and DGI and vice versa.

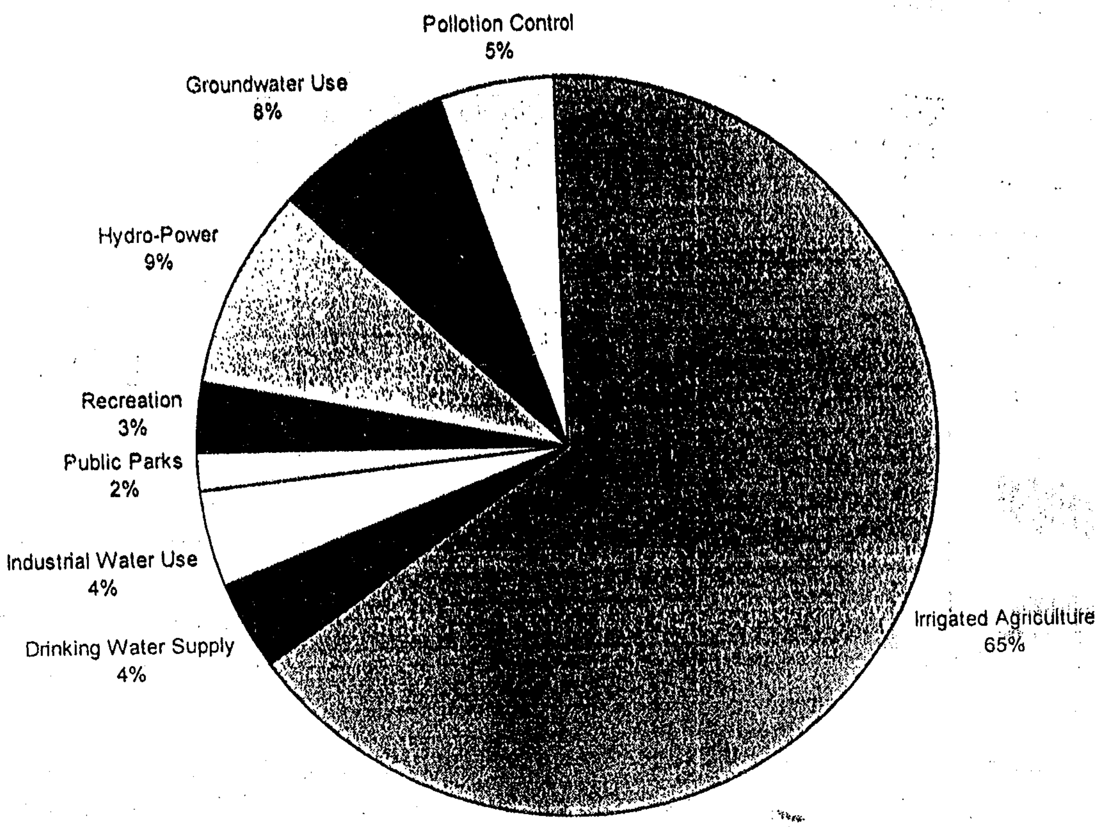

Figure 2 Distribution of financial resources of DGI from various categories of water users (DGI 1996)

Based on the forecast during the spring (October) of the available snow in the Andes Mountains, and on the available storage in Carrizal reservoir, DGI estimates the intended irrigation water supply for the next irrigation season. The monthly supply of water is based on:

- the average monthly crop irrigation water requirements of the entire irrigated area
- water to be stored in the root zone for use by winter crops immediately before the canal closure period (extra delivery in May)
- water delivered to enable farmers to till their land following the canal closure period (extra delivery in August)

Water supply from Carrizal Dam is intended to be interrupted during:

- the public holidays; Christmas, New Year and Easter.
- the winter canal closure months June and July.

In addition, the DGI intends to interrupt water delivery:

- if any one rain shower exceeds approximately the cumulative evapotranspiration for the following 5 days. This rather flexible rule results to canal closure if rain on the command area exceed 20 to 50 mm per event.
- if damage occurs on a canal or a related structure. The Subdelegado of DGI then closes the canal.

The intended irrigation water supply from Carrizal Dam by DGI to the 13 WUA's is published each year in October.

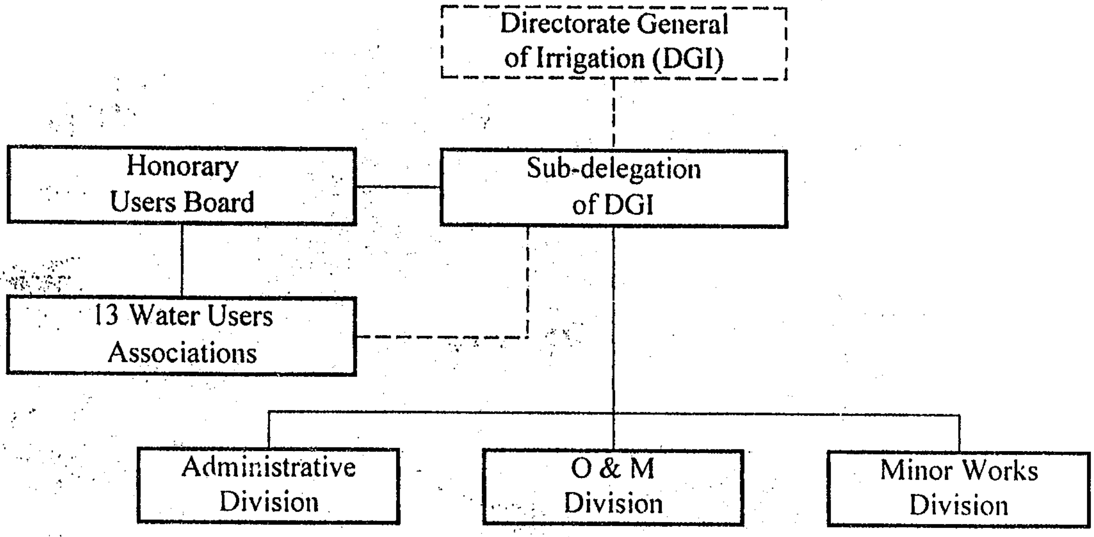

Figure 3 Orginazational Structure of the Sub-Delegade of DGI in the Lower Tunuyan Area

The above organizational structure of DGI and its five Sub-Delegate offices are self-financed by the water users through the related charges. Obviously, the water users benefit from an organization that effectively delivers the set level of service to the water users. In this context users are involved in the water delivery policy of DGI at three levels (Section 2.2). In this context they focus on:

- the degree to which the services of DGI and the Subdelegado's respond to the needs of the water users, and
- the efficiency with which DGI uses the financial resources at its disposal.

As a result, DGI became an effective organization, managing 350 000 ha with 530 staff at an average cost of 23 US$ per hectare (Marre et al 1997).

4 Users Associations

According to the Provincial Constitution water users have the right to associate and to elect the authorities in charge of managing the related irrigation canals, structures and drainage facilities and to manage the revenues collected for their management, operation and maintenance. Since the reorganization of 1984 (Chambouleyron 1984) many of the smaller Users Associations have merged. Currently there are 157 associations in the Province. The Lower Tunuyan System is divided into 13 Users Associations, each managing one secondary canal command varying between 425 and 13334 ha.

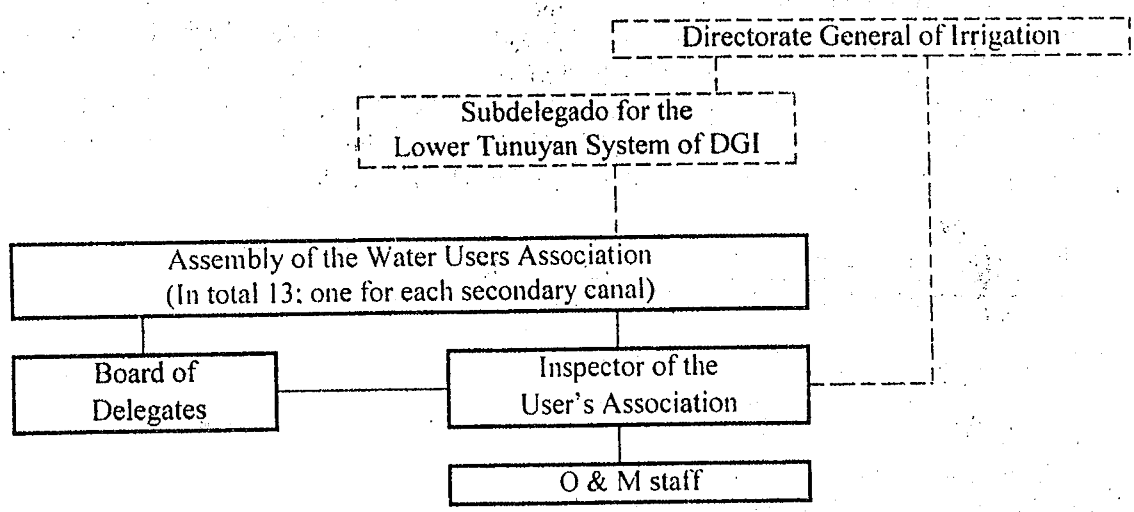

Figure 4 Organization Structure of water users organizations in the Lower Tunuyan Irrigation System

The Inspector of the Users Association and the Board of Delegates were regulated by Law N° 1676 (1946) which subsequently was amended by laws 2012 (1951), 2260 (1953), 2503 (1958) and 5302 of 1988. The elections are organized by the out-going Inspector under the supervision of the Honorable Administrative Tribunal of DGI. Persons can be elected for a period of 4 years and can be reelected provided they receive 2/3 of the votes. Otherwise the election is nullified and a new election is organized. To be eligible, or to have the right to vote, a person must hold water rights in the related command area and must have paid all water charges.

The Inspector manages the Users Association. As such he manages operation and maintenance of the canal system, controls the water delivery to water users and he handles the funds that users pay for water charges. He also is a first-line judge for all water distribution conflicts that may arise among users within his association (Bustos et al 1997). His rulings can be appealed before the Sub-delegate of DGI in the irrigated area or, when there is no Sub-delegate, the Superintendent of DGI.

The Board of Delegates is responsible for determining the water charge users should pay for operation, maintenance, etc. of canals and related structures, for authorizing and budgeting minor works to be constructed during the related year, for examining the Inspector's account and for

accusing the Inspector before the Superintendent of DGI when administrative irregularities are detected. The November meeting of the Assembly approves the Annual Expense Budget and the Resource Calculation for the Users Association and to approve the certified account over last years spending.

The Inspector and the Board of Delegates serve without pay. However, the law authorizes the Honorable Administrative Tribunal to approve that Inspectors be paid a monthly per diem when they have to carry out very complex tasks.

The water users are obliged to clean and repair canals and related structures at least once per year. The water user either can fulfill this obligation in kind (e.g. by their own labor or by their workers) or by subcontracting. If the user is in neglect, the Users Association will arrange for the maintenance to be done. The user is due to pay the Association to cover the cost made to maintain the related canals. In both cases, each user's contribution to canal maintenance is proportional to the area of the land with water rights.

As mentioned above, all Users Associations are public entities which according to the provincial water law exercise executive, technical, financial, budgetary, taxation and jurisdictional functions. The water charges levied by the Association makes them financially self-sufficient. The part water charge covering the budget of the Users Association decreases from 28 US $/ha for small (<1000 ha) to 10 US $/ha for large (>12000 ha) command areas (Marre et al 1997). The day-to-day activities of Users Associations can best be illustrated with the percentage distribution of their expenditures. On the average, the UA's in the Lower Tunuyan spend 69 % of their budget on operation and maintenance. A further break-down of the O&M fraction is shown in Table 1.

Table 1 Average weight of items in the UAs' budgets (Marre et al 1997)

Budget Item	*Average percentage of total Budget*
Salaries of O&M personnel	15
Canal cleaning and maintenance	21
Minor works	17
Per Diem and Transport	13
Administrative cost of O&M	3
Average O&M fraction of budget	--- +
Total:	69 %

As mentioned above, the Water Law regulates the right of water users to associate and to elect the authorities in charge of managing the related irrigation canals, structures and drainage facilities and to manage the revenues collected for their management, operation and maintenance. The Board of Delegates of the UA sends one member to the Honorary Users Board of the Irrigation District (Subdelegado of DGI). This board, in turn, sends one member to the Honorary Appeal Council of DGI. Hence, users participation is organized from the UA up to the DGI. The entire management structure works rather effective. This can be illustrated by the fact that the entire administration is self-financed through water charges paid by the users and by the fact that water is delivered according to the agreed schedule.

5 Water Rights

The water law regulates all 'permanent' rights to use surface water and groundwater in accordance with actual use at the time the law was accepted in 1884. It further regulates the subsequent 'eventual' rights on the use of surface water and groundwater. This, although groundwater was

considered to be a privately owned resource until the Civil Code was amended through Law 17.711 (19##). As mentioned, the law classifies concessions as "permanent" and "eventual". The permanent rights should be provided at any time; the eventual rights are honored once permanent water rights have been honored. Water rights are given in perpetuity.

AS mentioned before, the Superintendent of DGI may decide to switch from continuous to a rotational delivery of water to users if the flow rate in a river is insufficient to meet all simultaneous water rights in the related basin efficiently. This rotational system again intends to deliver water to users in proportion to their water rights.

In granting new water rights, the law establishes the following rigorous system of priorities amongst water user groups:

1 domestic use
2 railways
3 irrigation
4 factories and other manufacturing plants
5 ponds for fish hatcheries.

Within each user group priorities are sub-divided according to:

1 uses of higher social importance
2 seniority of the request.

In the Tunuyan System the origin of the water rights go back to 1884 when rights were given to the original 'share holders' of the canal system; e.g. a sort of a canal company. According to the 'Ley General de Aguas', all land that was irrigated at that moment received a permanent right to irrigation (surface) water in proportion to the area of the irrigated land. All land that became irrigable after this year received 'eventual rights to water'. Hence, if the river discharge exceeded the needs of the land with permanent rights, the excess water was delivered to the land with 'eventual' water rights. Since the construction of Carrizal Storage Dam (1972), more reliable surface water became available. Since then land with 'eventual water rights' receive irrigation water for 80% of the irrigable area.

Commonly, a command area (also at farm level) contains both; an area with permanent water rights, $A_{permanent}$ and an area with eventual water rights, $A_{eventual}$. The reduced area,

$$A_{reduced} = A_{permanent} + 0.8\ A_{eventual}$$

$A_{reduced}$, equals

The reduced area is used to divide water proportionally between command areas. Since 1884 also non-agricultural users received water rights. These rights are converted into 'equivalent rights per hectare'. The Subdelegado of DGI has the legal obligation to supply water in proportion to the water rigths $A_{reduced}$ in the command areas of the UA's (Table 2).

Table 2 Equivalent Surface Water Rights in the Tunuyan System

Type of Users	*Equivalent in ha*
Irrigated Agriculture	78198
Industries	36
Recreation	522
Drinking Water Supply	nil (groundwater)
Public Parks	935
Hydro-Power	nil (use only)

All water rights are registered by the General Department of Irrigation in the Concessions Register of Public and Private Water Rights. The water law charges DGI with the updating of this register and has to provide this information to the related Subdelegodo and Users association. The Register is the basis for the water delivery schedule and for setting water charges.

As mentioned above, the legal ownership of water remains with the Province, while the right to use water is attached to the purpose for which the right was granted. As a result, water rights are fixed to the (irrigated) land and cannot be sold separately. If a water right not consumed during 5 years for the purpose to which it is attached, it is lost.

Conclusions

Water management in Mendoda Province is well founded (since 1884) in the Constitution and in the provincial Water Law. The water Law is partly based on the 'traditional' intermediate water law that was in force before 1884. As a result, the Water Law always compromises between the agricultural and economic requirements of the different irrigated areas by enacting special provisions for each area. As such, the water law is strongly influenced by the region's natural setting and by attempts to offer solutions to problems of the population (water users).

The irrigation water administration of Mendoza Province is organized through three public institutions; the central office of DGI, the five Sub-delegates of DGI and 157 Users Associations.

The Board of Delegates of easch UA sends one member to the Honorary Users Board of the Irrigation District (Subdelegado of DGI). This board, in turn, sends one member to the Honorary Appeal Council of DGI. Hence, users participation is organized from the UA up to the DGI. The entire management structure works rather effective. This can be illustrated by the fact that the entire administration is self-financed through water charges paid by the users and by the fact that water is delivered according to the agreed schedule.

The above three types of water management organizations are managed as business enterprise. In this context continuous attention is given to:
- the degree to which the services of DGI and the Subdelegado's respond to the needs of the water users, and
- the efficiency with which DGI uses the financial resources at its disposal.

As a result, DGI became an effective organization, managing 350 000 ha with 530 persons.

Since the early 80-ties the Water Users Associations have merged into larger units. There now are only 157 associations in 350 000 ha ranging in size between about 350 to 13000 ha. Because of the level of skill of the management of the UA's communication with DGI and the Sudelgado's improved.

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THE IRRIGATION WATER RATE IN MENDOZA'S DECENTRALIZED AND PARTICIPATORY IRRIGATION ADMINISTRATION AN ANALYSIS

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1. INTRODUCTION

Ever since the General Water Law was passed in 1884, water administration in the Province of Mendoza (Argentina) has been decentralized and participatory. Regulated by Law No. 322 in 1905, it sets forth both the organization and the autonomy of the General Irrigation Department (DGI). On the basis of the water policy principles upheld in the Provincial Constitution (text corresponding to the third one, year 1894, section 9 on 'Water Regulation'), there developed in the province a true participatory management of water which, with slight changes, continues to this day.

Decentralization is based on the existence of a central administrative agency absolutely independent from the provincial Executive Power. In fact, the DGI prepares its own budget which, once pproved by the Administrative Tribunal, is collected through the irrigation water rate. This brings in genuine revenue which permits financial self-sufficiency and renders independent water management possible.

Users' participation takes place at different administrative levels --hence, the system's definition as participatory. At the first level, a users' representative of each of the oases in the province sits on the Administrative Tribunal, which assists the Superintendent in the administration of water resources by participating in the design of the sector's policy. The second level deals with river management. Here, for every river, an Honorary Users' Board, with representatives of the upper, mid and lower areas of the oasis, assists the Subdelegate. The third and probably the most important level corresponds to the autonomous and autarchic Water Users' Associations (WUAs), which elect their own authorities by direct vote, prepare and administer their own budgets, and collect irrigation water rates in their respective command areas. Their administrative structure is made up of an Inspector --or water judge of first instance--, three delegates, who assist the Inspector in all matters pertaining to water management, and gatekeepers, who are responsible for the actual delivery of water to the users.

During its first hundred years of operation, the above administrative scheme has experienced several changes. In its first stage, society was mostly agricultural and the irrigation system supplied all water uses, agriculture being the most important. At that time, there was a WUA for each canal, totalling almost 800 in the whole province. As society became more complex and water uses diversified, water management concentrated in larger organizations. In order to obtain economies of scale, a consolidation process of small associations into larger ones began in 1985 and ended in 1994. At present there are 157 WUAs.

This reorganization brought about greater management efficiency, profitable economies of scale, and the possibility of making investments in the irrigation system (Chambouleyron et al., 1995).

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The unification process of WUAs was followed by a federative process, i.e. the concentration of second-degree WUAs into what is known as Federation of WUAs. According to a project formulated by the DGI, this process, which began in 1992, would allow for better coordination and greater efficiency as regards water management.

This paper sets out to revise the mechanism for the calculation of the irrigation water rate in a specific number of WUAs in the oases irrigated by the Mendoza and Tunuyán rivers. The objective is to determine whether there is a relationship between the size of the WUAs, their budgets, and expense efficiency in order to formulate fair water rate payment policies.

To this end, a comparative analysis is made of the costs that the farmer has to defray for supporting the irrigation system. As the province has a unified system for the preparation of Expense Budgets and Financial Calculations for every fiscal year, and as budget appropriations are the same for all WUAs, it was possible to subject the different budgetary items to comparative analyses.

2. MATERIALS AND METHODS

The 1994 Expense Budgets and Financial Calculations were analyzed through a stratified sample representing the distribution per area of all WUAs in the Province. The WUAs belonging to the Mendoza and Tunuyán river oases were then selected, as they have the largest irrigated areas and the greatest diversification of water uses.

The sample is made up of 111 Water Users' Associations, of which 71 belong to the Mendoza River and 49 to the Upper and Lower Tunuyán River. Both, then, represent 70.7% of the provincial total (157).

These oases have different characteristics. The Mendoza River, a non-regulated river, supplies water to a densely populated urban and industrial conglomerate which causes water pollution and quality degradation problems along the irrigation system. Water is used for drinking water supply, power generation, industry and recreation, but not for agriculture. The Tunuyán River, on the other hand, is a regulated river. Although there are important urban centers and agricultural industries (food processing plants), water is mainly used for agriculture.

Table 1 - Water Users' Associations distributed according to oasis and size

	Area of the WUA (ha)						
Oasis	>1000	1000 -3000	3001 - 6000	6001- 9000	9001 - 12000	< 12000	TOTAL
Río Mendoza	25	28	12	4	2	-	71
Lower Tunuyán	7	7	6	1	3	3	27
Upper Tunuyán	4	5	2	1	1	-	13
TOTAL	36	40	20	6	6	3	111

Source: The authors, on data supplied by the DGI.

As shown in Table 1, smaller WUAs prevail in the Mendoza River oasis whereas larger ones prevail in the Tunuyán oasis. They all share the same management problems as regards both administrative-accounting and technical aspects.

2.1. Construction of the sample

The sample selected for analysis is made up of 31 WUAs stratified according to area so that they are representative of the associations making up the provincial total.

Stratification according to size responds to the initial hypothesis that this is a variable that determines the various degrees of efficiency in the management of the WUAs and, consequently, has a direct impact on the irrigation water rate.

The WUAs in the sample represent 19.7% of the provincial total. However, if only the oases of the Mendoza and Tunuyán Rivers are taken into account, the percentage rises to 28% .

2.2. Irrigation water costs in the Province of Mendoza

2.2.1. Canal cleaning

Mendoza's Water Law assigns the irrigation system users the responsibility for the regular maintenance of secondary, tertiary and quaternary canals in direct proportion to their registered area. In everyday language this is known as **limpieza de cupo** (cleaning quota).

This task is performed either by the users themselves or else by outsourcing, in which case it is paid directly by the users with no intervention of the WUA. This entails a cost for the users, which is calculated per hectare per year, as shown in Table 4.

2.2.2. Irrigation water rate (fee)

The irrigation water rate consists of two parts:

1) the canal pro rata
2) the DGI's budget

It may be defined as the 'total contribution made by farmers in *pesos*[5] per hectare and per year for irrigation water supply'. In other words, it is the cost of the service rendered by their respective WUA for operating and managing the irrigation system together with the service provided by the DGI for administering water at the oasis level. This means that the user has to pay to the DGI a given sum per hectare per year.

2.2.3. The canal pro rata

The pro rata is calculated by dividing the total expenses estimated for the fiscal year by the number of hectares of the Water Users' Association.

The total expenditures are included in the Expense Budget (Table 2), which is prepared every year by the Inspector and submitted to the Users' Assembly for approval. The Expense Budget is made up of the following items:

- **Personnel:**Amount to be paid to gatekeepers.
- **Canal cleaning and maintenance:** Expenses due to canal cleaning and maintenance during the cut-off period, repairs, quota cleaning by remiss users, machine-hours, and other outlays on the system's maintenance (Resolution No. 300 of the Honorable Administrative Tribunal-DGI).
- **Forestation**
- **Outsourcing:** Payments made to third parties for providing water distribution and other services which the WUA contracts directly, such as the construction and repair of bridges, intakes, flow dividers, gates, etc. This item varies greatly from one WUA to another as there is no uniform criterion for its determination.
- **Per diem and transportation:**Per diem and transportation expenses paid to the Inspector, the delegate, and the gatekeepers.
- **Maintenance and repairs of machines and vehicles:** It comprises those expenses relative to the maintenance of the WUA's vehicles and, to a lesser degree, the outlays on machinery and equipment repairs.
- **Contingencies**
- **Minor works:** Expenses due to canal lining, construction of bridges, flow dividers, gates, etc., and paid for by the WUA.

[5] Rate of exchange: 1 (one) peso = US$ 1.

- **Machinery and tools:** Costs accrued from the purchase of new implements for daily work.
- **Books, stationery and office equipment**
- **Administrative fees:** Accountant fees and administrative personnel salaries (secretary, PC operator, etc.).
- **Banking expenses**
- **Incidental expenses**
- **Debts due from past fiscal years**
- **Debts to the DGI**
- **Publicity**
- **Contribution to the Federation of WUAs:** This is a new item; it is not included in all the Associations' budgets as the process of unification is not yet complete.
- **Hardware, software and communications**
- **Other**

2.2.4. The DGI pro rata (DGI budget)

It is calculated by dividing the DGI's annual budget by the total number of registered hectares.

Its main components are:

a) **maintenance fees**: They are paid by each and every one of the registered users in the province as a contribution to the DGI's operational expenses.

b) **dams maintenance fees**: They are the contribution paid for the maintenance of the dam from which each canal derives irrigation water.

c) **machine operation expenses**: They refer to the payment of the operating expenses of the equipment used in canal cleaning mainly (Herrera, 1992).

3. RESULTS ANALYSES

Table 3 includes the main outlays, areas, estimated collection percentages, and the irrigation water rate of all WUAs in the Mendoza and Tunuyán oases. Included next are other tables that have been prepared grouping the data in strata according to area.

Table 2 - Water Users' Associations. Province of Mendoza, Argentina

Expenses divided by items - 1994

Code	Water Users' Association	Expenditures in the 1994 - Fiscal year																		
		(01)	(02)	(03)	(04)	(05)	(06)	(07)	(08)	(09)	(12)	(11)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	TOTAL
1182	Canal Espino	0	345	0	1055	440	0	0	0		250	50	360	0	0	0	0	0	0	2500
1290	Hijuela Funés	3570	2430	0	150	0	0	0	0		0	0	350	500	0	0	0	600	0	8400
1183	Rama Valle Hermoso	0	3000	0	5850	2100	0	0	2000		660	35	320	0	0	0	0	900	0	14865
2130	Rama Henriquez	0	3500	0	3500	2400	0	0	1000		1800	600	350	1000	0	0	0	0	0	14350
1222	Hijuela Divisadero Centro y Sud	0	500	0	4450	1500	0	0	0		350	20	400	0	0	0	0	0	0	7220
1803	Hijuela Montenegro	5500	2000	0	500	700	0	0	0		350	0	350	0	200	0	0	2214	0	11814
1009	Hijuela Segunda Guiñazú	5000	2000	0	400	4200	0	0	1000		500	100	360	0	0	0	0	3755	0	27615
5014	Canal Rincón	4000	2100	0	1000	1200	0	0	500		500	200	400	600	0	0	0	0	0	19347
5740	Manantiales Tyan. Zona Centr	6000	1500	0	500	3000	0	0	100		300	200	400	100	0	0	0	2300	0	15600
1220	Hijuela Divisadero Norte	0	4000	0	6000	1800	0	0	700		1800	600	350	1000	0	0	0	0	0	16550
1281	Hijuela El Chilcal	0	1600	1000	3900	4800	0	0	1000		600	100	360	0	0	0	100	1400	0	14860
1285	Canal Lunlunta	0	3900	0	7240	6200	0	0	500		550	60	350	0	0	0	50	3400	0	30750
2137	Rama Godoy y Cauces Derivado	4700	5500	0	4600	3220	0	0	1000		1000	50	350	1950	0	0	150	0	0	25020
1070	Tajamar Unificada	0	17060	0	14729	14640	0	0	2000		1055	140	720	0	5000	0	0	7470	1600	65044
1003	Luján Centro Unificada	10000	6500	0	7000	13800	400	0	1000		800	200	500	3000	0	0	0	11370	0	57570
2598	Rama Nueva California	6890	10000	0	7000	4800	0	0	1000		1800	1200	350	1200	0	0	0	1800	0	37740
1231	Rama Marienhoff y Villa Cent	0	2500	0	6000	2000	0	0	500		400	100	500	0	0	0	0	0	0	13500
1242	Canal San Pedro y San Pablo	21500	19000	1000	33400	6500	4000	0	3000		3500	100	500	7200	10000	15000	500	1000	500	137700
2183	Cl.Mz.San Martín e Hij. Deri	13203	51500	5000	20000	15000	10000	0	3000		5000	6000	350	3500	0	0	0	1500	3000	147053
1237	Gustavo André Unificada	18000	12970	0	9530	6000	0	0	0		1800	100	500	500	0	0	500	1000	500	52900
5725	Arroyo Claro Unificado	7000	17000	0	1000	7000	2000	0	200		500	150	400	50	4000	0	0	7478	0	56978
2533	Canal Matriz Santa Rosa	0	5000	1000	10000	4000	0	0	500		2400	1000	350	2000	0	0	0	0	0	26750
1037	Rama Jarillal Unificada	13607	40650	0	10898	32560	9000	0	0		2000	200	360	6000	0	0	900	14025	4000	150000

Water Users' Associations. Province of Mendoza, Argentina

Expenses divided by items - 1994

(continued)

Code	Water Users'Association	Expenditures in the 1994 - Fiscal year																		
		(01)	(02)	(03)	(04)	(05)	(06)	(07)	(08)	(09)	(12)	(11)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	TOTAL
2140	Rama Chimba y Cauc.Der.Unif.	38000	25100	800	10400	19200	2200	0	5000		7200	2200	400	0	13000	7500	200	600	3000	137300
1736	Tulumaya Unificada	34210	10500	1000	43000	10000	3000	0	0		2300	300	500	2460	0	0	0	12730	0	160000
1056	Mathus Hoyos Unificada	58049	41030	0	12080	35000	1800	0	9000		1000	1200	820	0	0	0	0	33225	0	242404
2397	Canales del Tramo Medio y C.	26000	34500	0	34000	9000	2000	0	2000		2400	700	400	5000	0	0	1000	0	4000	130000
2194	Rama Montecaseros y C.Deriv	95420	9000	200	5700	14400	2200	0	4500		2400	1000	300	0	0	0	1000	0	4000	146232
1118	Naciente-Chachingo Unificada	18000	28000	0	53000	28000	1000	0	5000		6000	1000	600	0	0	0	1000	20700	2000	169300
2123	Canal Matriz Independencia	0	56000	1000	1200	2400	600	0	2000		800	50	0	0	0	0	0	0	0	64850
2022	Canal Mz.Reducción y C.Deriv.	56000	28100	2000	16000	3500	9500	1000	8500		1200	150	350	1000	0	0	200	100	200	143800

Source: D.G.I., Mendoza

References:

(01) Personnel
(02) Canal cleaning and maintenance
(03) Forestation
(04) Outsourcing
(05) Per diem and transportation
(06) Maintenance and repairs of machines and vehicles
(07) Well operation and maintenance
(08) Contingencies
(09) Minor works
(10) Machinery and tools

(11) Books, stationery and office equipment
(12) Administrative fees
(13) Banking expenses
(14) Incidental expenses
(15) Debts due from past fiscal years
(16) Debts to the DGI
(17) Publicity
(18) Contribution to the Federation of WUAs
(19) Hardware, software and communications

Table 3 - Water Users' Associations. Province of Mendoza, Argentina

Expenses and resources - 1994

Code	Water Users' Association	Oasis	Area (ha)	Estimated Collection (%)	Total Expenses ($)	Total O&M ($)	O&M (%)	Canal Pro rata ($/ha)	DGI Pro rata ($/ha)	Rate ($/ha)
1182	Canal Espino	Mza	134	53	2500	2090	84	19.81	25.88	45.69
1290	Hijuela Funés	Mza	310	50	8400	6150	73	28.94	25.69	54.63
1183	Rama Valle Hermoso	Mza	439	70	14865	11610	78	17.01	26.12	43.13
2130	Rama Henriquez	T Inf	499	60	14350	11200	78	22.38	19.47	41.85
1222	Hijuela Divisadero Centro y Sud	Mza	555	65	7220	6800	94	12.99	39.55	52.54
1803	Hijuela Montenegro	Mza	557	45	11814	12100	44	29.89	32.75	62.64
1009	Hijuela Segunda Guiñazú	Mza	725	60	27615	8800	45	16.45	25.72	42.17
5014	Canal Rincón	T Sup	823	30	19347	11300	72	1.98	31.29	33.27
5740	Manantiales Tyan. Zona Centr	T Sup	1042	50	15600	13600	82	12.47	18.18	30.65
1220	Hijuela Divisadero Norte	Mza	1081	50	16550	10900	73	16.49	39.55	56.04
1281	Hijuela El Chilcal	Mza	1101	50	14860	9050	77	21.85	31.20	53.05
1285	Canal Lunlunta	Mza	1698	71	30750	17890	58	18.00	23.42	41.42
2137	Rama Godoy y Cauces Derivado	T Inf	1769	61	25020	19020	76	9.09	19.47	28.56
1070	Tajamar Unificada	Mza	2068	48	65044	47484	73	27.12	22.72	49.84
1003	Luján Centro Unificada	Mza	2219	60	57570	38100	66	20.20	25.00	45.20
2598	Rama Nueva California	T Inf	2252	50	37740	30490	81	24.60	19.45	44.05
1231	Rama Marienhoff y Villa Cent	Mza	2542	50	13500	10900	81	5.28	33.21	38.49
1242	Canal San Pedro y San Pablo	Mza	3422	50	137700	83900	61	33.00	26.35	59.35
2183	Canal Mz.San Martín e Hij. Deri	T Inf	3512	50	147053	104703	71	7.00	17.97	24.97
1237	Gustavo André Unificada	Mza	3535		52900	48300	91	17.01	30.91	47.92
5725	Arroyo Claro Unificado	T Sup	3853	38	56978	32500	57	19.40	22.89	42.29
2533	Canal Matriz Santa Rosa	T Inf	3920	60	26750	21400	80	5.51	17.93	23.44
1037	Rama Jarillal Unificada	Mza	4840	55	150000	99715	66	30.01	25.72	55.73

Water Users' Associations. Province of Mendoza, Argentina

Expenses and resources - 1994

Code	Water Users' Association	Oasis	Area (ha)	Estimated Collection (%)	Total Expenses ($)	Total O&M ($)	O&M (%)	Canal Pro rata ($/ha)	DGI Pro rata ($/ha)	Rate ($/ha)
2140	Rama Chimba y Cauc.Der.Unif.	T Inf	5118	80	137300	99900	73	31.37	19.47	50.84
1736	Tulumaya Unificada	Mza	6365	70	160000	100010	62			
1056	Mathus Hoyos Unificada	Mza	6494	50	242404	147159	61	22.71	23.14	45.85
2397	Canales del Tramo Medio y C.	T Inf	7531	65	130000	105900	81	10.98	17.97	28.95
2194	Rama Montecaseros y C.Deriv	T Inf	9596	70	146232	126920	87	22.19	19.48	41.67
1118	Naciente-Chachingo Unificada	Mza	9692	70	169300	133000	79	15.10	26.42	41.52
2123	Canal Matriz Independencia	T Inf	10934	72	64850	60400	93	1.38	17.97	19.35
2022	Canal Mz.Reducción y C.Deriv.	T Inf	14160	60	143800	115600	80	10.01	17.69	27.70

Source: DGI, Mendoza

3.1. Water distribution cost components

3.1.1. Canal cleaning

As shown in Table 4, the smaller the area of the Water Users' Association the higher the canal cleaning cost for the farmers. As users in small WUAs must bear higher costs, they are at a disadvantage with respect to the other users. In fact, users in WUAs having less than 1000 ha incur an average cost of $ 28, whereas those in WUAs with more than 6000 ha pay an average cost of $ 10.

Table 4 - Secondary and tertiary canal cleaning costs defrayed by farmers per workday per hectare (*)(**)

WUA Area (ha)	Secondary and tertiary canal length (*)	Drain length (m/ha) (*)	Maintenance (days/ha)	Maintenance costs per farmer ($/ha)
Less than 1000	33	10	1,86	28
1000 to 3000	24	8	1,4	21
3001 to 6000	15	6	0.85	13
6001 to 9000	13	4	0,69	10
9001 to2000	12	3	0,58	9
Over 12000	12	3	0,68	9

(*) Wages: $ 15 per day.
(**) Chambouleyron et al., 1994.

Table 5 shows the average maintenance costs, as well as the pro rata of the canal and of the DGI, the irrigation water rate, and the total cost of the service. Columns 3 and 4 show a decreasing irrigation water rate due to high bureaucratic costs, which have a stronger impact on smaller WUAs. The same phenomenon is observed when analyzing the DGI's budget, which, once pro rated for all WUAs in the province, is considerably greater for smaller associations.

Table 5 - Average costs of irrigation services

	1	2	3	4	5
	CANAL MAINTENANCE	WUA PRO RATA	DGI BUDGET	IRRIAGTION WATER RATE	TOTAL COST
WUA Area (ha)	Average maintenance costs	Average canal pro rata (WUA's budget)	Average DGI pro rata (DGI budget)	Average rate (2 + 3)	Average total service cost 1+2+3 = 5
Less than 1000	28	28	28	56	84
1000 to 3000	21	16	26	42	63
3001 to 6000	13	25	23	48	61
6001 to 9000	10	26	21	47	57
9001 to 12000	9	13	21	34	43
Over 12000	9	10	18	28	37

N.B.:All values are given in $ per hectare per year, and they are averages weighted according to area.
Source:The authors, on DGI data and the WUAs' budgets.

In spite of the fact that all users are rendered the same service, column 5 shows variations in final service costs for those users belonging to smaller associations.

To reinforce this concept, Figure 1 is a graphic representation which links the items making up the irrigation service cost with the area of the WUAs.

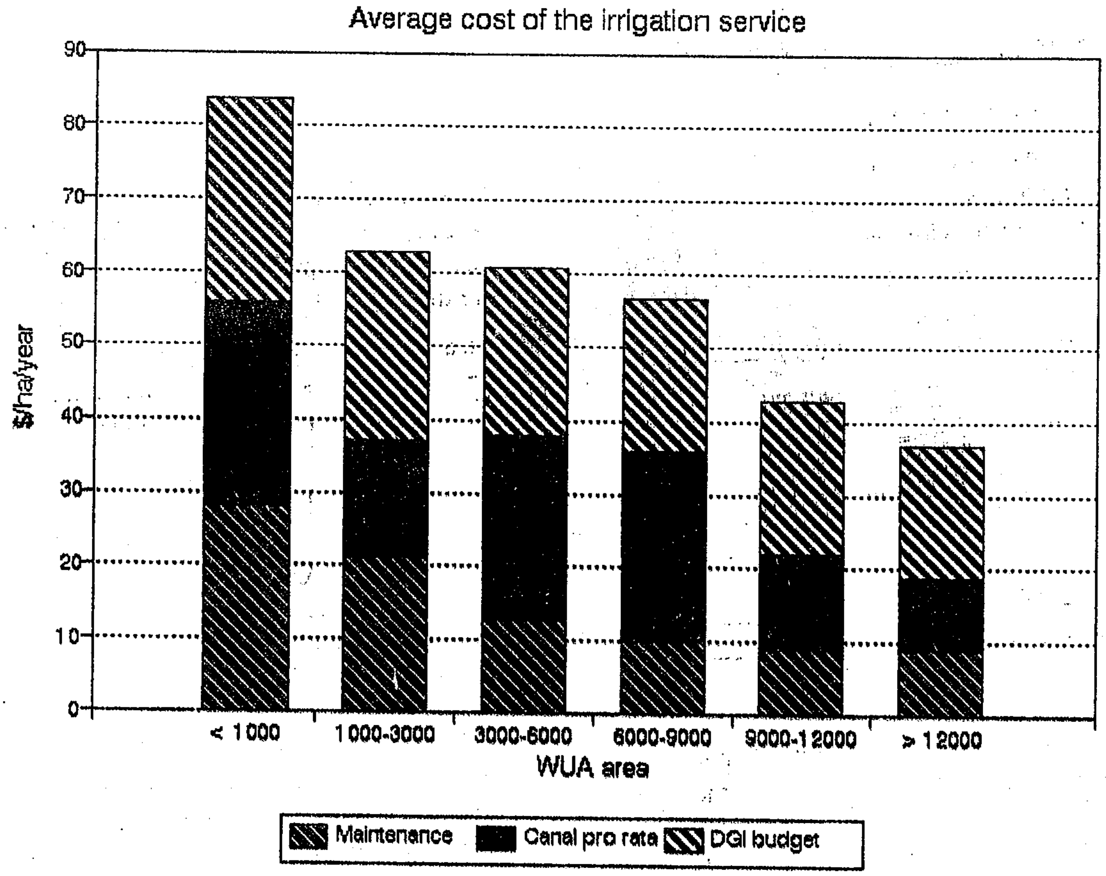

Figure 1

The IRRIGATION WATER RATE results from the total expenditures of both the WUAs and the DGI. Its higher for the smaller WUAs, in which bureaucratic costs have a weight greater than the investments (improvements). This conclusion, anticipated by Chambouleyron in 1992, can be verified by analyzing Table 8.

3.1.2. The DGI pro rata

The rate corresponding to the DGI budget, which in the smaller inspections exceeds $ 28 per hectare and in the larger ones is an average $ 20 ha/year (Table 5, column 3), is not used to improve the system but to defray the central agency's bureaucratic operational costs, which, as already stated, has taken up many of the activities formerly carried out by the WUAs.

Budgetary variations --prorated among all the WUAs-- do not respond to stratification by area. Neither can differences be ascribed to location in one oasis or the other. The question is whether the DGI rate --by definition, the Annual Budget divided by the number of hectares registered for all water uses in the Province-- should be the same for all WUAs, except, of course, for those cases in which works have been built and their cost reflected in the rate.

3.1.3. The canal pro rata

In the case of the canal pro rata (the WUA's budget), the only element apparently responsible for variations is the sum corresponding to the debts due from past fiscal years which the WUA expects to collect. This sum is sometimes 100% higher than the revenue collection estimated for the current fiscal year. As may be inferred from the budgets examined, the expected collection of those debts leads to a lower canal pro rata. Given the difficulties that collection entails (Table 6), calculating a lower pro rata could be interpreted as a political strategy on the part of the Inspectors.

3.2. Revenue collection levels

The calculation of the canal pro rata is always based on an estimate of the annual expenditures incurred by the WUA. There are no variables from which to infer that the determination of expenditures, funds and pro rata is made on a rational basis.

An analysis of the budgets reveals that these WUAs are not financially self-sufficient since they do not collect the revenue they need and suffer recurrent crises (see the low collection levels expected, which on average reach 54% in inspections with over 9000 ha and 65% in the smaller ones; Table 6).

Table 6 - Average collection estimated for the present fiscal year (%)

WUA'S Area (ha)	Collection Percentage
Less than 1000	55
1000 to 3000	62
3001 to 6000	71
6001 to 9000	60
9001 to 12000	54
Over 12000	54

Source: The authors, on data from the WUAs' Financial Calculations.

In view of this situation, Inspectors spend the money collected as overdue debts to cover the estimated expenses. However, they cannot make investments because they do not have enough funds. When they do manage to generate some savings or collect overdue debts, they adopt the policy of lowering the irrigation water rate per hectare instead of constructing works and making investments that would improve or, at least, keep the irrigation system in good conditions.

3.3. Operation and irrigation system management expenses

Canal cleaning (or maintenance) is the users' responsibility, and it is done according to their cleaning quotas. To calculate a farmer's cleaning quota, the canal length is divided by the total number of irrigation rights and multiplied by the area of his farm. The result represents the length of the canal he is to be clean.

Operation (O) includes the following activities: water distribution; distribution control; organizing the irrigation schedule (i.e., the rotation system according to which each owner may irrigate); and, in general, all related activities for which the Inspector --with the assistance of delegates and gatekeepers-- is responsible.

Irrigation system management (M) comprises the construction of works such as intakes, flow dividers, canal gates, and all minor works required for the conservation of the shared infrastructure. The cost of such works is included in the budgets under the item 'Outsourcing'.

The numerous items in the WUAs' budgets were classified in order to determine which are the most important outlays and how they are reflected in the total expenditures estimated for the fiscal year.

3.3.1. Composition of the O&M sector

After the different budget items were classified, it was detected not only that the amounts for the expenditures grouped under 'System Operation and Management' --listed above-- were appropriated to the fulfillment of the WUAs' essential goals but also that they were the most significant in the budgets. In fact, O&M expenditures (Table 7) represent on average 69.3% of the total outlays in the budgets analyzed.

The remaining 30.7% corresponds to minor expenses, usually of an administrative nature, incurred in support functions to the essential O&M. For instance: contingencies, banking expenses, debts to the DGI, publicity, office equipment, contribution to the Federation of WUAs, etc.

Table 7 - Composition of the O&M Costs of Water Users' Associations. Province of Mendoza, Argentina

O&M ITEM	% OF BUDGET
Personnel	15,39
Canal cleaning and maintenance	20.53
Outsourcing	16,52
Per diem and transportation	13,37
Administrative fees	3,45
Total:	69,26

Source: The authors, on data from the WUAs' budgets.

3.3.2. Structure of the O&M sector

This budget sector includes the items described below.

- **Personnel**. It comprises salaries, retirement and social security contributions for the WUA's permanent employees (gatekeepers and administrative staff). It represents 15.39% of the total budget, which is relatively low although this is not the only item under which personnel expenses are included: some inspections record them under 'System Cleaning and Maintenance'.

- **Canal cleaning and maintenance.** It includes the expenditures the WUA incurs to maintain those parts of the system neglected by the users who are responsible for them (quotas). It represents 20.53% of the WUAs' total expenditures. In theory, this percentage is later charged to remiss users (those who fail to perform the tasks indicated by the Inspector). In fact, it is included as expenditure in the budget, thus having an impact on the rate paid by all irrigators.

- **Outsourcing.** It represents the money invested in maintenance, i.e. lining, construction of intakes, flow dividers, and all other activities required to improve the irrigation system. Its relative weight is very low: 16.52% . This not only shows that investments in improving the existing infrastructure are insufficient but also points to its state of deterioration.

- **Per diem and transportation expenses.** This item represents some 13.4% of the WUAs' budget. If compared with the percentage allotted to system maintenance (16.5%), it is very high and points to the fact that the Inspector's position is not completely honorary. It is a considerable portion of the expenses which are reflected in the canal pro rata. Table 8 presents the weight this item has in comparison with the total expenses incurred by the WUAs.

Table 8 - Percentage of 'Per Diem and Transportation Expenses' costs in comparison with total budgets

WUA'S Area ha	Total expenses ($)	Total per diem and transportation	%
Less than 1000	106.111	12.540	12
1000 to 3000	276.634	54.260	20
3001 to 6000	707.981	80.660	9
6001 to 9000	532.404	54.000	10
9001 to 12000	380.382	47.800	13
Over 12000	143.800	3.500	10

Source: The authors, on data from the WUAs' budgets.

3.3.3. O&M and the WUAs' budget

As seen in Table 9, the costs of O&M items, defined above, represent on average about 82% of the budgets of the WUAs of larger relative area --i.e., over 9000 ha. In the smaller ones, 1000 to 3000 ha, O&M totals 68% of the budgeted amounts. The difference, more than 12%, shows that administrative costs have a higher incidence on the smaller WUAs.

Table 9 - Average O&M costs in all WUAs' budgets

WUA'S Area (ha)	Average O&M costs ($)	Average O&M costs (%)
Less than 1000	8.756	66
1000 to 3000	21.937	71
3001 to 6000	70.059	69
6001 to 9000	117.690	66
9001 to 12000	106.773	84
Over12000	115.600	80

Source: The authors, on data from the WUAs' budgets.

An example of what has been stated is shown by item 'Contribution to the Federation of WUAs' (Table 2, column 18). Its weight is greater in smaller inspections: some 19% of the total budget of inspections having between 1000 and 3000 ha. In those of larger relative area it amounts to 11% . In all cases, this item constitutes an additional cost to the users --this being the reason why larger inspections are still reluctant to join the Federation (Chambouleyron et al. 1995).

Item 'Minor Works' has very little incidence on the budgets analyzed (Table 10). It is most significant that 58% of the WUAs in the sample have not even contemplated this type of investments, a fact which further contributes to the physical deterioration of the irrigation system.

Table 10 - Investments in minor works as a percentage of the total WUAs' budgets

Hectares	%
Less than 1000	11,1
1000 to 3000	6,5
3001 to 6000	4,7
6001 to 9000	2,6
9001 to 12000	2,3
Over 12000	10,0

Source: The authors, on data from the WUAs' budgets.

There are no items and/or expenditures from which to infer that investments in minor works are being made.

3.4. Performance parameters in a decentralized and participatory irrigation administration

The irrigation water fee has been defined, and its structure and components analyzed. The collection levels attained by the different WUAs open up, one way or the other, the possibility of an efficient management as they represent the WUAs' means to operate and manage the irrigation network.

The management performance of each association can be assessed by measuring collection levels. To this end, a number of performance parameters has been defined and justified (Bos, M. et al., 1995).

The development and verification of such parameters call for systematic and steady research in different periods of time to ascertain and adjust every one of their values. The idea, at this stage, is to demonstrate the applicability of the so-called 'social viability' indicators, which have been discussed at a theoretical level.

They comprise administrative indicators of the WUAs' financial capacity, administrative management, as well as an assessment of their capacity for self-management.

In a preliminary research, only 5 (five) WUAs were analyzed. Each of them represents one stratum belonging either to the Mendoza or to the Lower Tunuyán oases (Table 11).

Tabla 11 - WUAs under study

WUA	Area (ha)	River
Montenegro	less 1000	Mendoza
Medrano	1000 to 3000	Tunuyán
Norte Alto Verde	3001 to 6000	Tunuyán
Montecaseros	6001 to 9000	Tunuyán
Reducción	over 9000	Tunuyán

3.4.1. The administrative performance parameter (APP)

It is the ratio between the actually collected amount and the theoretically collectable amount as a function of the register in accordance with the legislation in force. It can be described as:

APP = (Current year's water rights + Previous years' water rights/Total WUA's water rights

The denominator, what each WUA expects to collect, is obtained by multiplying the total number of registered hectares times the canal pro rata. The numerator is formed by adding together the amount collected in the current fiscal year at the corresponding fee and the debts due from past fiscal years.

This parameter measures administrative efficiency according to the amount collected as payment for irrigation water services. The APP optimal value should be close to 1. The values calculated for the WUAs in the sample are shown in Table 12.

Table 12 - Administrative performance parameters

WUA	Area (ha)	APP
Montenegro	557	0,36
Medrano	2900	0,95
Alto Verde	5533	0,68
Montecaseros	9596	0,75
Reducción	13000	0,63

This table shows that only the Medrano WUA has an APP close to the optimal value, followed by the Montecaseros and Norte Alto Verde WUAs.

Payment arrears undoubtedly have a strong impact on the parameter, which --in turn-- is a clear indication of the users' economic and financial situation.

Here follow some comments explaining the difficulties arising from the definition and subsequent application of the APP to the current situation:

- Pro rata estimated on the basis of historical data.
- Obsolete Users' Registers.
- In most cases, lack of precise information on the actually irrigated area.
- Inspectors always 'estimate' the collection of debts due from past fiscal years. This points to the incomplete decentralization of the administrative-accounting and financial functions transferred from the DGI to the WUAs.

3.4.2. Financial viability of the irrigation system

Concerning the decentralized WUAs' financial aspects, the following three complementary parameters are proposed:

3.4.2.1. Total financial viability

It is the ratio between the amount actually allocated to cover operation and maintenance expenses and the amount really required for those activities.

Total financial viability = Actual O&M Allocation/Total O&M Requirements

This indicator shows the degree of ease and/or difficulty with which a WUA meets the expenses incurred under its most important item. Table 13 shows the values obtained in the sample of WUAs analyzed.

Table 13 - Total financial viability (FV)

WUA	FV
Montenegro	0,46
Medrano	0,58
Norte Alto Verde	0,61
Montecaseros	0,69
Reducción	1,25

Also in this case the optimal value is 1, which is achieved by those WUAs that self-finance all of their O&M expenditures. The WUA representing the smallest area stratum has the lowest index (0.46). The Reducción WUA's value points to an erroneous calculation.

3.4.2.2. Financial self-sufficiency

This parameter is used to clearly determine a WUA's capacity to cover the expenses derived from the system's operation and water distribution with genuine funds.

The numerator is obtained by multiplying the WUA's number of hectares registered for all water uses times the value of the canal pro rata expressed in pesos per ha ($/ha). The denominator is the total funds required to finance the operation and management costs of the WUA's canal system.

It is expressed as follows:

Financial Self-Sufficiency = Actual Income/Total O&M Requirements

Table 14 shows the values obtained for the WUAs in the sample:

Table14 - Financial Self-Sufficiency

WUA	FSS
Montenegro	0,41
Medrano	0,68
Norte Alto Verde	0,54
Montecaseros	0,78
Reducción	0,67

The optimal value is 1. In practice, however, it is about 0.7, which shows that the income is not sufficient to defray the expenses incurred in water distribution, and much less make investments. In two WUAs, the indicator shows a value close to 0.5, which reinforces the hypothesis that the current conditions, aggravated by low productivity levels, strongly condition the collection levels in the system.

3.4.2.3. Performance of the canal pro rata (fee)

It is expressed as follows:

Performance of Canal Pro Rata = Irrigation Rates Collected/Irrigation Rates Due

This parameter shows the total income paid by the farmers in a given year as canal pro rata (numerator) divided by what the WUA expects to collect at the moment of preparing the budget.

In practice, the WUAs do not have other genuine income and, moreover, they have high percentages of farmers in arrears. The numerator is always smaller, which shows that the amounts collected are low when compared with the theoretical collection level calculated on the basis of the Users' Register used. As can be seen in Table 15, only one WUA, with over 9000 ha, has reached a

value higher than 0.7 and has a relatively high efficiency level --though still quite distant from 1, which would be the optimum in a financially well-ordered WUA.

Table 15 - Fee colelction performance

WUA	FCP
Montenegro	0,41
Medrano	0,62
Norte Alto Verde	0,53
Montecaseros	0,75
Reducción	0,60

3.4.3. Sustainability of the irrigable area

It is a global parameter used in planning and monitoring a WUA's overall management.

It is defined as follows:

Sustainability of Irrigable Area = Current Irrigable Area/Initial Total Irrigable Area

Again, it is worth noting the importance of updating both the registered area and the actually irrigated area.

Table 16 shows the values for this indicator as obtained from the sample.

Table 16 - Environmental sustainability and drainage

WUA	SI
Montenegro	0,48
Medrano	0,90
Norte Alto Verde	0,60
Montecaseros	0,61
Reducción	0,60

The low values obtained are largely due to the fact that most WUAs do not know exactly how many properties have been abandoned, subdivided, or else have changed from agricultural to urban or urban-industrial soil use.

The water effectively distributed for irrigation purposes is reflected in the indicator values. In three of the WUAs under study, it is 0.6. The Medrano WUA shows a high value (0.9) for this parameter --a more efficient water distribution according to availability and users' needs-- as a result of having updated its register and of using real data on agricultural and urban properties.

3.4.4. Summary of results

The differences between the amount really collected and what the WUAs expect to collect show that there is a large number of irrigators in arrears. This is partly due to the fact that their calculations are based on obsolete Users' Registers.

The values of the sustainability indicator, as well as those of financial self-sufficiency and viability, are about 0.7. This means points to a similarity between the number of actually irrigated hectares and the 'active' registered properties with water rights.

The items in the budgets that the WUAs prepare according to DGI directives are excessive and complex. However, in everyday management, they are in fact reduced to what has been identified as 'system operation and maintenance'. The amount collected hardly suffices to cover this set of items; and this only for the actually irrigated properties which pay the irrigation fee rate.

Table 17 - Summary of results

WUA	Area (ha)	Parameters				
		APP	FV	FSS	FCP	SI
Montenegro	557	0,36	0,69	0,41	0,41	0,48
Medrano	2900	0,95	0,58	0,68	0,62	0,90
Norte Alto Verde	5533	0,68	0,61	0,54	0,53	0,60
Montecaseros	9596	0,75	0,69	0,78	0,75	0,61
Reducción	13000	0,63	1,25	0,67	0,60	0,60

4. CONCLUSIONS

4.1. Critical aspects of the administrative system

In theory, the irrigation administration in the Province of Mendoza is an orderly system organized according to guidelines provided by the DGI; its uniform system for recording expenditures and resources makes it possible to compare the WUAs' management performance and, thus, to conduct a critical analysis of the whole. It is the product of a 20-year-old process by which the DGI has been taking over functions formerly discharged by the WUAs (Chambouleyron et al., 1995).

However, deeper analysis of the administrative system reveals a number of inequities borne especially by the users who comply with their obligations: canal cleaning and regular payment of the irrigation water rate to the DGI. The fulfillment of these obligations has permitted the continued operation of the central agency and of the respective WUA in charge of distributing and managing water.

The total (final) cost of irrigation water shows large differences when the area of the WUAs is taken into consideration: the smaller ones bear higher costs.

In addition, the system, conceived more than 100 years ago, is by definition highly participatory. Participation --the users' real protagonism in their respective WUA's management-- decreases when the number of administrative levels increases. This is the case of the WUAs which have joined the Federation as now there are four administrative instances: the WUA, the Federation, the respective Subdelegation, and the DGI.

Though in theory this should render the system more efficient, the fact is that it excludes individual users from the places where decisions are taken.

Moreover, it has a remarkable secondary effect in that it increases bureaucratic costs due to the need to pay for the operation of the new administrative levels. Again, the smaller WUAs bear the heavier burden, a fact which aggravates their economic condition in a context of increasing difficulties. For example, as already pointed out, the item **Contribution to the Federation of WUAs** is a new expenditure increasing the WUAs' budgets.

4.2. A proposal for budgetary management

In view of the above, it is herein proposed to analyze the administrative costs of Mendoza's irrigation system in depth in order to reduce them to the minimum required for its efficient operation. This will mean reducing the present number of administrative instances to truly decentralize functions to the WUAs, as stipulated in the legislation in force.

Besides, the DGI's bureaucratic costs should have the same relative weight for all irrigators, i.e., those in small WUAs as well as those in the larger ones.

It is necessary to revise the present budgetary system in order to re-design the WUAs' Expense Budget and Financial Calculations. The current scheme, which is imposed by the DGI, is highly complex and contains an excessive number of items: 19. Budget items should be reduced to the most important management aspects: 1) personnel, 2) system repairs and maintenance, 3) minor works, 4)

purchase and repairs of machines and vehicles, 5) fees for special services (administrative and technical), 6) office equipment and expenditures, and 7) communications. In this way, it would be possible to eliminate many of the budget items that either have insignificant appropriations or no appropriation at all.

4.3. A proposal to improve collection and participation levels

The budget scheme suggested above should be easier for the users to understand; it should enable them to evaluate the expenditures anticipated for the current fiscal year and the way they are to be met. In short, this will facilitate the effective participation of the users, who are the ones who finance the system.

According to historical data, collection levels reach only between 50% and 60% of the total (Chambouleyron et al., 1995). This shows, firstly, that users' participation is weak *--and this is the basis of the irrigation system--* and, secondly, that the WUAs are unable to invest in the irrigation system's maintenance and improvement. Thus, a vicious circle is formed bringing about the system's deterioration, dissatisfaction, less participation on the part of the irrigators, and further deterioration.

Motivating users to participate and fulfill their obligations will most likely depend on proposals with stronger emphasis on infrastructure and system management investments rather than on bureaucracy. This could be achieved through the permanent discussion and programming of the necessary works, which should be selected according to the priorities identified by the users themselves during the Assemblies.

In this way, the WUAs' budgets and the corresponding pro rata will be applied to the essential activities which the provincial Constitution and the Water Law assign to the WUAs: maintain, improve and administer the irrigation system, and distribute water with equity and efficiency.

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PERFORMANCE OF WATER USERS' ASSOCIATIONS IN THE LOWER TUNUYÁN AREA

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1. INTRODUCTION

The decentralized and participatory water administration system in the Province of Mendoza is over a hundred years old. The Provincial Constitution and the Provincial Water Law, both of which date back to the year 1884, laid down the guidelines for water administration.

In accordance with them, it is the responsibility of the General Irrigation Department (DGI) see to all matters pertaining to water policy as well as to irrigation water management at the river, dam and main canal levels. The management of secondary, tertiary and quaternary canals, on the other hand, falls within the corresponding Water Users' Association jurisdiction. Inspectors act as water judges in their respective jurisdictions and prepare the budgets to meet the expenses required for intakes and works maintenance as well as for water distribution. They are responsible for the money they administer, being accountable to the DGI. They also perform surveillance and water police functions within their respective systems and may impose fines to those users who infringe the Water Law. They are authorized by law to discontinue the irrigation water service to those users who fail to pay the water rate (Chambouleyron et al. 1995).

The system succintly described above institutes a truly decentralized provincial irrigation water management based on users' participation and on the Water Users' Associations' self-management. Through time, the DGI gradually centralized functions originally pertaining to the Water Users' Associations (WUAs), thus distorting the legal-administrative scheme in force (Chambouleyron et al. 1995).

To obtain information on the level of knowledge and training of WUA Inspectors in the province a study was devised. Through a survey, it aims at assessing the Inspectors' training to meet their responsibility for administering the waters conveyed by the irrigation network. The selected study area is the Lower Tunuyán River command area, which has a very modern and complete water infrastructure to supply all of the oasis water needs.

The Tunuyán River rises in the Andes mountain range and irrigates some 17,000 hectares (ha) in its upper sub-basin before reaching the study area. The Lower Tunuyán River oasis comprises 85,000 ha and is irrigated by the river of the same name, which derives its waters from the *El Carrizal Dam*, the regulating capacity of which is 360 hm^3. The irrigated area has a 60 m^3/s derivation dam which, along a 50 km lined main canal, supplies both the secondary and the tertiary irrigation system.

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made up of earthen canals (some 100 km) and of a drainage collector network (about 300 km). The latter is also used for irrigation purposes in the lower-lying areas of the oasis.

There are four cities in the area (San Martín, Rivadavia, Junín and Palmira) with an aggregate population of 300,000. Agrifood industries, which process the production of the agricultural sector, constitute one of the region's main economic activity.

For water administration purposes at the secondary and tertiary canal levels, the area is divided into 23 Water Users' Associations (WUAs), corresponding to the different canals.

At present, WUA Inspectors have neither the administrative infrastructure nor the funds necessary to efficiently discharge their legal duties --much less so those obligations which complement and strengthen the main function of **administering the WUA's secondary and tertiary canals**. Despite the said circumstances, the Inspectors continue distributing water and maintaining the irrigation network for agricultural uses. This activity makes an efficient use of water --given the conditions of a context that calls for an in-depth analysis in order to introduce the changes that the dynamic productive structure of the province requires. One of the aspects characterizing the context and seriously affecting the above-mentioned functions is the low collection levels of the irrigation water rate attained by the WUAs (Maure et al., 1996). Strictly speaking, Inspectors do not manage or look after the WUAs' resources; rather, they serve as employees of the central agency (DGI), from which they receive instructions.

Nowadays, one of the objectives of the decentralization process under way is to restore to the WUAs a more autonomous water management capacity as originally envisaged in the 1884 Water Law.

This type of management requires a body of knowledge and know-how which should be underpinned and made legitimate with social practice. Such practice should be characterized by types of behavior that aim at efficiently meeting the requirements of an increasingly complex society, in which water uses have diversified and are no longer decidedly agricultural but urban-energy-agricultural-recreational-industrial.

In view of the above as well as of the great responsibility Inspectors have before society, this paper sets out to obtain information on their know-how, their customs, how fast new techniques are adopted or not, their control by social practice, an on the subordination relations defining this process. After characterizing the present know-how of WUA Inspectors, it should be possible to detect their limitations to meet the demands of an increasingly complex society. Finally, this research work seeks to formulate guidelines for a training proposal to adequately fill the gaps in know-how (knowledge and management) as well as for restructuring relationships between the DGI, the WUAs and the users.

2. MATERIAL AND METHODS

The survey methodology consisted in the complementary use of **in-depth interviews and structured questionnaires**, WUA Inspectors being the unit of analysis. The universe under study was the 23 WUAs of both the Upper and Lower Tunuyán rivers, of which 19 Inspectors were interviewed. Figure 1 shows the location of the 13 Lower Tunuyán WUAs.

Unstructured interviews were conducted to identify the knowledge and know-how of the WUA Inspectors, the way they perform their social practice, the technological ways that know-how has combined, and the way the Inspector makes use of them in discharging his specific duties.

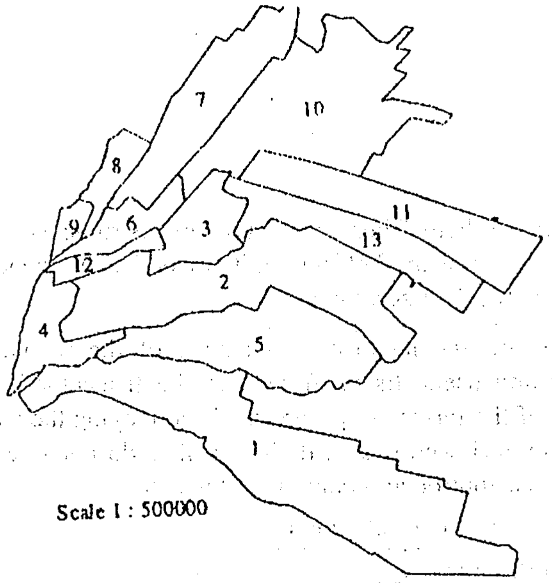

Figure 1. Water Users' Associations. Lower Tunuyán River

On the basis of accounts by the selected informants and by means of a previously recorded "interview guide", the topics for the survey were explored. Their analysis revealed a body of knowledge and know-how that form the basis of the Inspectors's social practice, as well as their practical and meaningful goal. The terms in which the Inspectors define their practice were also identified.

For each question different answer categories --as meaningful to the actors as possible-- were proposed.

The qualitative analysis of the interviews also yielded conceptual categories that represent the different meanings used in the social reproduction networks of the said know-how. The following meaningful categories will later be used to interpret the data obtained through the questionnaires:

1) **Knowledge to distribute water.** Identification of owner and location of property; "bottom-up" and "top-down" rotation systems; use of information from the users' register; etc.
2) **Knowledge to identify users' needs.** Crop types prevailing in the WUA's area; percent of the farm's area irrigated with each turn; canal water level; etc.
3) **Useful knowledge for management and control.** Design of rotation schedules.
4) **Knowledge to collect the irrigation water rate.**

To analyze the Inspectors' performance as water managers and obtain further information on their knowledge and know-how for the job, the authors designed a survey on the basis of a structured questionnaire (89 items) given to the whole universe of Inspectors in the Mid- and Lower Tunuyán River areas. The structure of the questionnaire is based on the following topics:

- Physical Location of the WUA
- Inspector's seniority
- Water flow received
- WUA's irrigated area
- Use of technology to identify users, distribute water according to the rotation system, adapt to users' needs, etc.
- Characteristics of the WUA's *Water Culture* and social supervision
- Management
- Characteristics of the Inspectors' Social Practice

3. RESULTS

3.1. Knowledge to distribute water

Identification of the users

Distributing water to the users implies identifying them. There is a couple of instruments which have proved useful to this end: (a) a **schematic drawing** of the WUA's limits made by the Inspector on the basis of his empirical knowledge of the region; (b) the **users' register**.

The schematic drawing contains information on the location and course of the secondary, tertiary and quaternary canals, location of intakes and users. Its usefulness to the Inspector lies in providing a quick reference to the physical location of the farms along the canals conveying the water. As can be seen in Table 1, 58% of the Inspectors interviewed use it; the other 42% do not --despite the fact that it contributes to a more efficient water distribution and canal maintenance.

Table 1. Use of a schematic drawing to locate the farms

USE	N° of Inspectors	%
Yes	11	57,9
No	8	42,1
Total	**19**	**100**

As regards the users' register, it is solely used to identify the owners. Yet, this vital management information is not primarily used to this end, as Table 2 shows.

This seems to indicate that the Inspectors' performance aims mostly at meeting the users' needs of irrigation water. Thus, use A (preparation of the rotation schedule was selected in the first place and use B (identification of owners) in the second place. One could say that the use made of the users' register corresponds to the Inspectors' performance, as they limit their duties to irrigation water distribution based only on information on the number of hectares to be irrigated and ignoring the rest.

This might be explained by the fact that, in general, users' registers are not updated, which further reduces the usefulness of the information they contain.

Table 2. Use made of the users' register (%)

Uses	Order of Importance 1	2	3	4	5	6	NE Ns/Na	Total choices
A	57,80	10,50	15,50	-------	5,2	-------	10,50	100
B	21,05	36,80	-------	21,05	5,2	-------	15,70	100
C	5,20	21,05	15,78	10,52	5,2	5,2	36,80	100
D	-------	5,26	26,31	15,78	21,05	0,526	31,57	100
E	5,26	5,26	10,50	5,26	20,5	31,57	31,57	100

References:

A. Used to prepare the rotation schedule
B. Used to identify owners
C. Used to update the users' register
D. Used to distribute the water rate bills
E. Used to calculate the number of users in arrears
NS Not selected
NA Not answered

3.2. Knowledge to identify users' needs

Water distribution is carried out according to a rotation schedule, the preparation of which is the Inspector's responsibility. This rotation system means that every farmer uses the water for a specified time (expressed in minutes) established by the Inspector acting on instructions from the

corresponding DGI Subdelegation. The rotation schedule establishes who is to use the water and for how long it is to be delivered at a farm's intake.

The rotation turns is a tool designed on the Inspector's knowledge of a number of items: water volume received by the dam, number of irrigated hectares, the way water distribution --or the rotation-- is performed (defined by the Inspectors as "bottom-up" or "top-down"), etc.

The permanent updating of the users' register is an essential management tool for the Inspector's decisions concerning water distribution to be equitable and with due regard for users' needs. It was considered necessary to find out whether the Inspectors assume the responsibility of updating the register, as the information they get from the DGI is usually outdated. The results are shown in Table 3: only 53% of the Inspectors have updated the register.

Table 3. Number of Inspectors who have updated the users' register

Update Register	Number of Inspectors	%
Yes	10	52,6
No	9	47,4
Total	**19**	**100**

As regards whose is the responsibility for updating the register, the data shown in Table 4 make it possible to state that it lies with the DGI, through the corresponding Subdelegation.

Table 4. Responsibility for udpating the register

Who Updates the register		%	TOTAL
Inspector and gatekeepers	3	15,8	(14)
Subdelegation	9	47,4	(14)

The reasons for updating the register were also examined and the results are given in Table 5. Basically, they are the Inspector's need to distribute water in accordance with the reality of the users' register and with due regard to the changes in the number of owners and/or in the number of registered hectares for irrigation purposes.

Table 5. Reasons for updating the register

Reasons	Number of Inspectors	%
1	8	42,1
2	1	5,3
3	1	5,3
4	9	47,4
TOTAL	19	100

Reference:

1. Changes in the irrigated area
2. Preparation the rotation schedule
3. DGI information
4. NA (No answer)

NB: The 47.4 % in category NA [Category NA's 47.4%]corresponds to the Inspectors who have not updated the register.

All the results point to the fact that this management guideline is not working well. In general, information is not promptly incorporated to the users' register, and in the cases that it is included in the rotation schedule it does so in an informal manner. The information updated by the DGI that reaches the WUAs is scarce.

If the "updated register" variable is cross-referenced with the "irrigation monitoring" variable, the results reveal: (a) a self-management irrigation control based on solidarity relationships in the case of the WUAs that DO NOT UPDATE THEIR REGISTERS (83.3%); and (b) monitoring by gatekeepers in the case of the WUAs that DO UPDATE THEIR REGISTERS.

Table 6. Type of water distribution monitoring register updating

Irrigation monitoring by	Register Updating					
	Yes	%	No	%	TOTAL	
Gatekeepers	7	70%	3	30%	10	100%
Users	1	16.7%	5	83.3%	6	100%
Gates Closing	1	100%	0	-----	1	100%
Complaints	0	-----	1	100%	1	100%
NA	----------		----------		1	100%

As already stated, users' needs are met by means of a solidarity system since, as a rule, the WUAs do not have updated registers. Nowadays, with the collapse of the solidarity system due to the crisis of the agricultural model, those needs can be met only by updating the registers and with greater control on the part of the WUAs (thus replacing the solidarity system).

To prepare the rotation schedule -technology essential for water distribution-, the Inspector must know how much water is to be distributed that year. But, to be able to apply that knowledge to the preparation of the schedule, the Inspector must first have internalized it. There are at least two ways to calculate the volume to be distributed and they have different levels of precision. One of them is qualitative and it is expressed as depth of water in the canal (**in centimeters**). The other one is quantitative, it is expressed as **liters per second or cubic meters per second** -both representing flow- and it could help overcome the above-mentioned problems.

According to the first one, rotation is performed with no consideration for the volume of water received by the WUA and no control of it being correct. Thus, the Inspector knows qualitatively (i.e., by comparison) whether the volume received by his WUA is the same as in the previous year or not, but he cannot compare it with the volumes received by other WUAs and, thus, he cannot ascertain whether distribution is correct or not.

The emerging management guideline could be described as **water distribution according to supply**, as users' demands are not known; a situation that again assumes the existence of a solidarity system. Among its unwritten rules is that, when faced with water shortages, **the neighbors help one another** by distributing what flow they have available.

As regards the second way of calculating the volume to be distributed, and even when the rotation is performed on the basis of the water supplied -with no consideration for different user requirements -, the Inspector has additional information which enables him to assess the volume of water supplied more accurately. The Inspector will have internalized that information insofar as he manages -with the rotation schedule- to distribute the water among the users in an equitable manner. This methodology, however, assumes technical assistance from the DGI, and the incorporation of new knowledge to the Inspector's traditional know-how, a situation which demands considerable effort for the required process of change. Table 7 shows how Inspectors measure water

Table 7. Types of flow measurement

Type of Measurement	Number of Inspectors	%
Quantitative	5	26,32%
Qualitative	8	42,11%
NA	6	31,58%
TOTAL	19	100%

The 42% corresponding to the qualitative type of measurement plus the 32% of those who do not know how much their WUAs receive clearly indicates that water distribution is formal, according to local ways and customs, and quite inaccurate.

This knowledge (measuring flow in liters per second) can be used in developing a performance parameter for the Tunuyán River Subdelegation. This indicator relates the volumen of water received at the farm intake to the user's crop requirements as a function of the volume received at his plot or farm intake, among other variables.

As can be seen in Table 8, the volumes received in 1996 by the different WUAs as well as the users' potential productivity show considerable variations --depending on which WUA they belong to.

Table 8 -according to information provided by the Inspectors on the volume received at the WUAs' intakes and the registered hectares- also shows differences in the depth of water applied in cultivated plots: from 100 to almost 300 mm/ha. This situation clearly points to the fact that water is not distributed in a proportional and equitable manner as stipulated in the legislation in force, and that there are not enough flow measuring devices in the irrigation network.

From further analysis of the information in Table 8, it is observed that the total flow is applied in 10 to 12 days' turns which the same farm is irrigated again, and that the flow is generally used on a third of the farm. As the minimum number of turns received in a given property is 8, flow -expressed as a gross depth of water per hectare- is the product of the unit times 8 applications. The calculation of the depth of water depends on field application and tertiary canal conveyance efficiencies. The value used was 56% (Chambouleyron, 1995).

If the gross depth of water is multiplied by the efficiency, the result obtained is the net depth received by the crop to which it was derived, in the agricultural year. In like manner, by taking this depth into account and using the production functions obtained for the area (Chambouleyron, 1995), it is possible to calculate the potential production of the "criolla" variety of grapes.

Depths stored in the soil profile explored by the roots (amount of water available to the plant) are also highly variable from one WUA to another. It should be borne in mind the fact that, if a crop's potential evapotranspiration (Epc) is 1041 mm per year, in most of the cases under study that value is not reached. This points to the fact that the water applied is usually less than what is required.

The crop coefficient (Kc) is on averge 0.8, which, when applied to the production functions calculated for the study area, would indicate an average production of 272 quintals per hectare ("criolla" grapes trellis system). This value is too low in view of current market prices and it explains the economic crisis of the model.

Table 8. Flows derived from Inspections' intakes And annual water depths at farm intakes

INSPECTION	Flow 1	Registered area 2	Irrigate area 3	Water depth 4	Number irrigations 5	Water depth 6	Ea = water depth =0,56 7	Etp = Ea/1041 8	Yield 9
1) Canal La Paz	2,00	2500	1/2	206	8	1648	992	0,953	330
2) Norte Cañada de Moyano	1,00	1774	1/2	146	8	1168	654	0,628	100
3) Matriz San Martín	12,00	25000	1/3	124	8	992	555	0,533	75
4) Sta. Rosa	4,30	3900	1/2	285	8	2280	1276	1,226	400
5) Rama Dormida	3,50	4500	1/3	201	8	1608	900	0,865	320
6) Matríz Constitución	6,00	11000	1/3	142	8	1136	636	0,611	100
7) Medrano	2,18	3216	1/3	175	8	1400	784	0,753	180
8) Matríz Independiente	8,00	10000	1	207	8	1656	927	0,890	300
9) Rama Montec.	6,00	8600	1/3	180	8	1440	806	0,770	200
10) Chimbas	4,50	4880	1/3	239	8	1912	1070	1,028	400
11) Rama Henríquez	0,50	498	1/4	242	8	1936	1084	1,041	400
12) Cauce Otoyanes	0,40	515	1/3	201	8	1608	900	0,865	300
13) Rama Sauce	2,00	2540	1/3	204	8	1632	913	0,877	300
14) Rama Godoy	1,20	1492	1/4	194	8	1552	869	0,835	270
15) Rama Norte Alto Verde	3,90	4926	1/2	205	8	1640	918	0,882	300
16) Cruz Bodega	1,00	1244	1/3	208	8	1664	932	0,895	310
17) Tramo Medio	6,00	7500	1/2	207	8	1656	927	0,890	310
18) Dársena	0,05	60	1/3	216	8	1728	968	0,930	310

1. Flow at the Inspection's intake ($m^{3/s)}$
2. Inspection's registered area (ha)
3. Area section within the farm irrigated in each rotation system
4. Gross water depth applied per irrigation (mm)
5. Number of irrigations per year in the same plant
6. Gross water depth applied per ha in a farm during the vegetative period (mm)
7. Water depth affected by the irrigation efficiency, net seasonal consumption per ha (mm)
8. Ratio between real evapotranspiration and crop's potential for the area
9. Vines potential yield taking into account the water depth applied (Q/ha)

3.3. Control of the irrigation rotation system

As has already been pointed out, the rotation system chart contains information concerning to whom water is delivered and for how long. The inspector uses this chart to control water distribution and is organized on the basis of a calculation mechanism devised from bottom up and viceversa. A canal inspector stated:

"... every ten days, 6 hours, 48 minutes. Then you irrigate and you know that you will irrigate again within 10 days, 6 hours, 48 minutes. If water does not reach you within 10 days, 6 hours, 48 minutes, then what happened to the water?

- Somebody must have my water. Is that so?

- Yes

-.... This helps irrigators to attain self-control"

When analyzing the type of communication that is established between the Inspector and the canal users of an Inspection, it can be seen that it reaches the producer in many different ways (Table 9). These different forms of communication indicate whether there is or not an adaptation to the user's needs and if he can control the efficiency of the distribution system. The item " **is delivered in writing**" means that the information on when and for how long water is delivered to each user reaches him through a rotation system chart. The Inspector is supposed to have an updated irrigators' register and to know how many irrigated hectares the Inspection has in each agricultural cycle. The user can check if the amount of water that was delivered to him is correct and if he received it in due time.

If, on the contrary, the irrigator knows beforehand when he will be delivered the water by means of a **written or verbal notice from the gateman** or if he does not receive any notice because the rotation system **is always the same**, it is assumed that the rotation system has a certain periodicity and duration. It can also be assumed that the Inspector delivers water without taking into account the changes that may have taken place in the register of each Inspection during each agricultural cycle and that the irrigator -who does not have a written rotation system chart - cannot control the efficiency or the equity of water distribution.

Table 9. Type of communication of water distribution and register's updating

	ACTUALIZACION DEL PADRON DE REGANTES				
Type of Communication	**Yes**	**%**	**No**	**%**	**Total**
A written rotation system chart is handed over	2	66,7	1	33.3	**3 100%**
Verbal, written or other type of notice	8	53,3	7	46,7	**15 100%**
NA	--		1	100,0	**1 100%**

The data show a correlation between the rotation system chart, which is delivered in writing, and the updated register: 66,7% against 53,3% who receive verbal communication from the gateman or do not receive it at all and do not update the register.

This rotation system from "bottom up" is based on the solidarity system whose main assumption is that irrigators can control the use of water. Therefore, distribution through rotation is based on a "**self-control management guideline**". The Inspector defines these solidarity bonds on which the control system is based as "good neighbours relations". The information obtained to measure this variable illustrates in this respect (Table 10).

Table 10. Type of relations of the solidarity system

	Number of Inspectors		
Types of relation which guide management	Yes	No	Total
A	5 (26,3)	12 (63,2)	17
B	9 (47,4)	7 (36,8)	16
C	1 (5,3)	15 (78,9)	16
D	6 (31,6)	10 (52,6)	16

Note:

A) Irrigators are good neighbours
B) Neighbours self-control themselves
C) Workers know the costums
D) All irrigators have written information with the rotation system chart

Due to the fact that the agricultural society on which this system is based is changing, solidarity systems are no longer effective. As the system of relationships among equals has changed and became a system of relationships which does not include among its main actors the producers categorized as "capitalized relatives" but "societies of national or foreign capital", solidarity vanishes. The rotation system chart operates as a true norm since it determines how each task should be performed. Canal Inspectors assume that this norm is observed since most farmers irrigate taking into account the rotation system (47,4%), as shown in the following table. In the case of category D. the rotation system is respected not only for solidarity reasons but also for other more democratic management guidelines.

The norm that lays the basis of the self-control management guideline is based on a minimum supervision by the Inspector and his team (mainly gatemen), 52,6% of the cases.

When this is not so, the canal Inspector acts as a water judge. The execution of these activities shows us how the control systems are operating as regards water distribution in the Lower Tunuyán Inspections and who are the users who pose control problems to the Inspections. The results obtained in this connection are shown in Tables 11 and 12.

Table 11. Inspectors' performance as water judges according to preferences by type of measures taken

	Inspector's preference
Type of measure	Firstplace
A	42,1
B	57,9
NA	26,8

Note:

A) Inform the Irrigator
B) Discuss with the Irrigator the solution of problems

It is evident that when Inspectors act as water judges, they prefer to discuss with the irrigator the solution of problems (57,9%).

Table 12 shows that though users irrigate more or less well, small-scale producers have problems in observing pre-established norms. This could be interpreted as a restriction of the management efficacy of the Inspection in connection with a parcel structure of low productivity with a high percentage of abandoned fields.

Table 12. Type of producers who pose control problems

Size (hectares)	Inspector's reponse	Percentage
0 - 10	11	57,9
11 - 25	1	5,3
+ de 25	3	15,8
NS/C	4	21,1
Total	19	100

3.4. Knowledge to collect the irrigation rate

Another management guideline which was explored in the survey is based on the definition of the irrigation rate and its collection.

The administrative accounting knowledge on which the irrigation rate is based is connected with the expenses which are taken into account when the budget is being prepared. With respect to the results obtained - which are shown in Table 13 - canal inspectors possess knowledge on the following items: gatemen salaries, quota cleaning, per diem expenses, minor works (bridges, gates, etc), number of default payers, purchase of tools, vehicle repairs and purchase of machinery.

Table 13. Know how applied to budget planning

	Inspectr's preference		
Type of expenditures	Yes	No	Total
Gatemen salaries	78,9% (15)	21% (4)	100 %
Quota cleanings	73,7% (14)	26,3% (5)	100 %
Per diem expenses	68,4% (13)	31,6% (6)	100 %
Minor works	68,4% (13)	31,6% (6)	100 %
Number of default payers	63,2% (12)	36,8% (7)	100 %
Purchase of tools	63,2% (12)	36,8% (7)	100 %
Vehicles repairs	36,8% (7)	63,1% (12)	100 %
Purchase of machinery	31,6% (6)	68,4% (13)	100 %

Budget spending is based on the knowledge of the Inspection's collection. According to the data obtained, the most important items in the budget are: salaries, quota cleaning, per diem expenses and minor works. In order to be able to explain how Inspectors grant priority to budget spending, this variable was crossed with the collection level, the parcel structure and the reasons that prevent the payment of the irrigation rate, considering that it is this know how which conditions and guides the establishment of expenditures priorities. This is shown in Table 14.

So those that have an average collection level have a parcel structure which is not very fragmented (higher percentage of Inspections with less than 60% of its area made up of properties from 0 to 10 ha large). In those with a high collection level, this tendency increases. In those with a low collection level, none of the parcel structures prevail, but the obstacles to pay the irrigation rate are the abandonment of fields and the lack of knowledge of the service rendered by the Inspection. The weight of these reasons in this stratum is heavier than in the average collection stratum. In the high collection stratum the parcel structure is not so fragmented and these reasons acquire weight though in a different order; the lack of knowledge of the tasks performed by the Inspection comes first. This could be due to the lack of participation of larger producers who, according to Chambouleyron et al (1995), are not "contained" in the administration model.

In keeping with the above, there is a management guideline which grants priority to expenditures according to the above mentioned know how: in low collection inspections the budget is spent in salaries, the per diem expenses item remains constant in the three strata and the percentage of works is more important in the inspections with a high collection percentage.

Table 14. Priority of expenditures in budget spending according to collection percentages

Collection percentage	Parcel structure (absolute values)			Reasons why payments are not made (absolute values)		Percentage of the budget spent		
	Non fragmented	Fragmented	Total	Abandoned fields	Lack of knowlege of the	Salaries	Per diem	Works
Baja (30 - 49%)	3	3	6	5	4	62	8	13
Media (50 - 79%)	4	3	7	2	2	42	9	6
Alta (80 - 86%)	4	2	6	4	5	41	8	40
TOTAL	11	8	19					

Note:

1. Weighted averages per area (hectares) of the Inspection

4. DISCUSSION OF RESULTS

It is evident that it is necessary to redefine the role of the State in water resources management by modernizing its structure, defining water use policies and establishing new relationships with users' organizations and - through them - with the users of the system. The State should also develop large transformation projects and provide essential comptroller services. It should also modernize users' organizations so that they can assume responsibility for the direct, efficient and fair provision of services to the users. This policy is required not only because of the need to reduce the cost of the public structure but also because of the need to improve the efficiency of the system which from the start was designed to be administered by the users themselves. The essence of the system did not contemplate the possibility that the state Agency (General Department of Irrigation) retained so many responisiblities. This aspect prevented the provision of services to the users with the quality and timeliness that productive activities require, bringing about higher production and maintenance costs (Herrera, 1992).

At present the performance of canal inspectors as local administrators is directly connected with the daily reality of a society of agricultural producers who, as irrigation users, get together with a concrete objetive in mind. Its dynamics reflects the specific characteristics of these local societies: their history, culture, production and consumption relations, and conflicts.

These local societies have a structure that socially distributes persons and groups. Canal inspectors occupy a power position due to their social practice in these societies of agricultural.

The knowledge or know how acquired in connection with water management and water distribution refers to the way our agricultural society carries out its agricultural practices, including relationships with nature, among people, networks and social groups, inside and outside its boundaries.

This know how can be defined as the self directory of knowledge, socially produced, executed through work and transmitted from the interior and/or exterior of each generation, which endows individuals with the power to perform technical functions related to water distribution . Basically, it is an instrumental know how validated in practice and which is presented to the subject as something given. It is a specific knowledge which implies not only to know how to do but also that it should be done this way. It is a know how fit for a concrete performance, which is produced and updated through experience.

This know how is not static, any new technique or knowledge based on a new social practice and in the satisfaction of a new social need can be incorporated into it, although its uses can be redefined within each local context. Canal inspectors have knowledge and know how which relate to the old water management system, where the inspector keeps a filial relationship with the DGI, so his know how only relates to irrigation water distribution and canal maintenance. It is essential to quickly incorporate into this set of know how the new knowledge and techniques which are indispensable so that the social practice of canal inspectors is kept in force. As representatives of a participatory and decentralized management, it is necessary that they respond with efficacy and equity to the new needs posed by the set of functions of that new reality, characterized by difersified water uses, increase of requirements for agricultural production in a globalized world and the need to ensure the quality of the resource in the same or higher degree as its quantity.

However, in the case of our canal inspectors, the application, transfer and acquisition of new knowledge have limitations which stem from the different forms of control. These are the result of the functions that the state had assigned and of the logical power relations in which this process takes place.

The social production of know how has a close relationship with the subordination relations which canal inspectors have with the state (DGI).

The public and private have different practices and regulations, and they have a know how which institutionalizes the ways of knowing and interpreting. The interpretation of this know how, which would require a decentralization process. will depend on the power relations of this process. If it is based on the subordination relations that do not contribute to release the social practice of canal inspectors from the institutional forms. technical know how that is not legitimated and validated in its own social practice will hardly be incorporated into this figure. The daily know how cannot be separated from those structures which define the limits within which the social practice of individuals take place. The access to knowledge will be socially controlled. Therefore, it it not important to know the origen of the know how but its form of appropriation and use. It is the uses of the know how which define the performance of canal inspectors. The application of this know how or the different uses is determined by management guidelines. They can be defined as norms or "ways of doing" acquired in the long term and consolidated by the use itself. These guidelines "direct the daily behaviors of inspectors and characterize their management". As a consequence. homogeneous and standardized behaviors take place in connection with the way water is distributed and the system is maintained. On the contrary, there are no homogeneous management guidelines which should be fulfilled according to the legislation in force and according to the requirements of an ever complex society.

5. CONCLUSIONS

From the evaluation of the data obtained. it can be concluded that:

1) The know how that canal inspectors possess is not sufficient to ensure an efficient and decentralized management of an agency that performs multiple functions. These functions have to do with complex water uses, which have been diversified in accordance with the transformation of a society eminently agricultural to an urban-agricultural-industrial one. Canal inspectors have empirically stored a set of know how related to the primary function of distributing, managing and maintaining the water system. This know how does not comprise the complex reality which this new type of society entails and the decentralization process that will transform its social practice. Together with this transformation, we can mention the problem of water pollution and water use diversification. In view of this, the new profile of these "managers" and the know how and knowledge that should characterize their management should respond to these new realities.

2) With respect to the other great function, the management of financial resources which make it possible to fulfill the objectives of each inspection, it can be said that the knowledge that characterizes the inspector's administrative-accounting practice is restricted to a set of routine activities that he carries out without changes. Most of these practices have been imposed through time by the DGI as the product of a paternalistic relationship that it maintains with the inspectors, where management technologies are not incorporated. This technology is necessary to complete the decentralization process which gives back to the inspections their autonomy. thus generating a space of free decision.

3) Given the eminently practical formation of inspectors, the "local" qualities assigned to them by the irrigators (to know the area and be an irrigator by birth) as fundamental attributes of their profile and the subordination relation to the DGI's decisions, **it can ben concluded that:**

   - the conditions are not adequate for a training process to have an impact on the real management performance of users' associations
   - that the efforts directed towards the provision of training to inspectors should be addressed to the formation of a **new managerial profile** that will train them to manage the complexity of the system (water distribution for multiple uses, pollution control, soil use planning, environmental enhancement, adequate human resources management, financial resources planning, etc.)

In brief, it is necessary to **professionalize the management** of canal inspectors by lending the support of technical staff that will advise and plan the inspectors' decisions without loosing their natural leadership and users' representativeness.

The feasibility of this process would be given by the incorporation of all water related activities into the management space of the inspection and by the generation of a continous flow of funds that will make it possible to consolidate this new management profile and efficiently manage water economy.

In turn, the DGI. once released from these functions, will be able to devote its efforts to an efficient and equitable allocation and to water pollution prevention and control. moderating its impact on the productive capacity of the economic model of the oasis.

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ECONOMIC PARAMETER DEFINITION IN IRRIGATION INSPECTION MONTECASEROS, MENDOZA

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Key words: irrigation water, costs, economic parameters, production volume.

SUMMARY

The objective of this work is to measure, by means of economic parameters, the following: production value per m3 of irrigation water; production value per each $ (u$s) spent on irrigation water; relative value of irrigation water cost with respect to the total operative cost of production; gross margin obtained per m3 of irrigation water applied and amount of kg. harvested per m3 of water applied.

Parameter definition has been performed using averages of secondary data from the area and primary data obtained through questionnaires given to producers in a smaller area.

No significant differences were observed between both sets of parameters, except when the analysis was conducted by separating small farms with little technology from large farms with more technology and a better use of resources.

INTRODUCTION

In the province of Mendoza, Argentina, agricultural activity is practiced under irrigation and represents approximately 6% of the Internal Gross Product (IGP). The main crop is grapevines with about 60% of the total cultivated area in the Province.

Due to the importance of irrigation, a series of works have been carried out to evaluate the performance of one of the irrigation inspections: the Inspection of the Irrigation District of the Montecaseros Canal, located in San Martín County, to the east of Mendoza. Such evaluation has been conducted by means of physical, operational, sustainability, social, economical and administrative parameters. The present work corresponds to the economic parameter definition.

The importance of this definition is established by the need to assess the functioning of the different areas to compare them with each other and with those in other countries that irrigate their crops with surface water.

This need for assessment becomes obvious from the fact that water is a limited resource in arid and semiarid zones. Therefore, it is an economic good and it has to be treated as such.

METHODOLOGY

This work is divided in four stages:

1. Collection and analysis of secondary data:

The source of primary data used was the last Agricultural National Census (1988), the National Viticulture Census (1991 and its updates) and the Fruticultural Census of Mendoza Province (1992).

2. **Economic Evaluation:**
   To perform the economic evaluation of crops in the area under study, the cost data was provided by the Department of Socioeconomic Science, School of Agricultural Science, UNC; INCYTH, and key informants from the private sector. The data concerning prices paid to producers was obtained from the area farmers.
3. **Parameter calculation:**
   The parameters chosen were those that came up during the discussion within the working team. They involve the following variables: the economic value of production, the cost of irrigation water, the amount of water applied, the volume produced and the operative costs of crop production.
4. **Field testing of parameters:**
   In order to test and compare the economic parameters calculated from secondary data, field questionnaires were conducted in one sector of the area under study. This sector corresponds to the Chivilcoy district in San Martín County and corresponds to the area of study of the parameters in the other areas (social, accounting, technical, etc.)

Information Processing

The processing and Interpretation of the results was performed by the Department of Socioeconomic Science, School of Agricultural Science, UNC. The data obtained was transferred to spreadsheets designed in QPRO.

RESULTS

AREA UNDER STUDY: DISTRICTS: ALTO SALVADOR, CHAPANAY, MONTECASEROS, CHIVILCOY. SAN MARTIN COUNTY, MENDOZA, ARGENTINA. (analyzed with secondary data)

To have an overview of the area irrigated by the Montecaseros canal, secondary data from the different sources consulted was used, and a general parameter definition was carried out.

The cultivated area in each of these districts is approximately 16,000 hectares, whereas the area irrigated by the Montecaseros Inspection is 8,602 hectares.

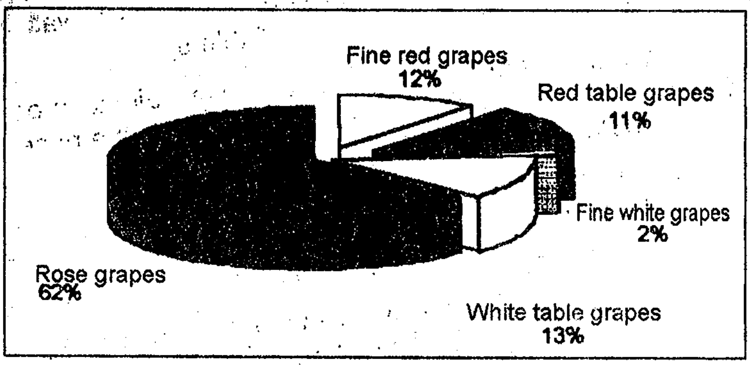
The most important crop in the Province of mendoza is grapes. Eighty percent of the surface of San Martín County is covered with vineyards, 10% with fruit trees, and the remaining 10% with other crops.

Since the agricultural activity of this zone is grape and fruit-growing, the economic analysis has been performed for these two crops.

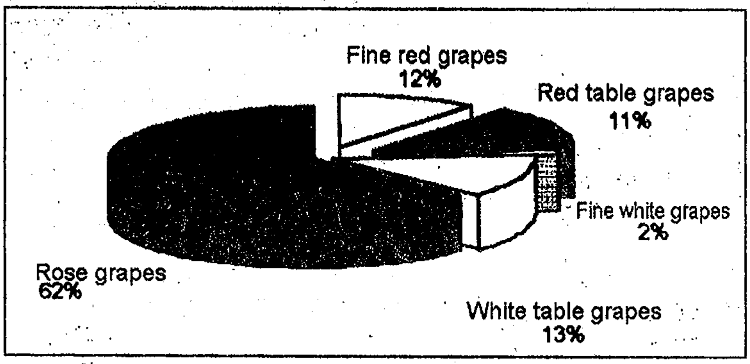
Viticulture Description

Graph #1 shows a predominance of rose grapes (higher yield, lower price), which is the raw material for table wines. These grapes are almost exclusively used to this end. A small percentage is destined to fresh consumption and concentrated musts.

Graph #2 shows that 70% of these vineyards are trellises. The average size of the farms is between 6 and 10 hectares with a higher frequency of farms between 1 and 10 hectares. (table 1)



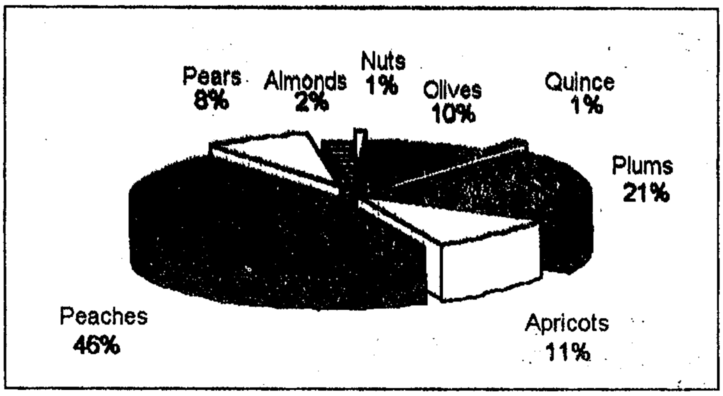
Graph 1. Surface with Vineyards



Graph 2. Vineyard Climbing Systems (in hectares)

Fruticultural Description

The most widely grown crops are peaches, plums and apricots (graph #3), but they are not as economically relevant as vineyards in this area.



Graph 3. Fruit-cultivated Surface (in hectares)

The average fruiticultural surface per farm is between 3 and 7.5 hectares with a larger number of small farms in the San Salvador and Chivilcoy districts.

Prices Paid to Producers and Production Value

a) Viticulture. The price considered is that of the product on the farm. Prices were provided by key informants from the Winers´ Association and the producers of the area. (Table 3) The difference in prices for the same variety in different grape-growing areas was always taken into

account. These prices multiplied by the estimated production result in the value of viticulture production shown in Table 4. The production of the area was obtained from the product of censed areas and the average estimated yield. (Table 5)

b) Fruticultural. Product prices correspond to those paid to producers in 1994/5, 1995/6 and 1996/7, taking into account an estimated average between the price paid by the industry and that paid for fresh consumption.. (Table 3)

Production was estimated from the cultivated surface and the average yields for the area, obtained from the estimations performed by the key informants from the Department of Fruticulture, School of Agricultural Science, UNC, and the producers of the area.

Production value was calculated multiplying the price paid per kg to producers times the total estimated production for each crop. (Tables 6 and 7)

Calculation of Operative Production Costs. The values considered correspond to the average costs per hectare estimated by the Department of Socioeconomic Science, School of Agricultural Science, UNC. (Table 8) These figures include supply expenses (agrochemicals, fuel, electricity, etc.), hand labor (including harvest), maintenance of machinery, property tax and irrigation fees. In the case of fruit crops, the fact that on 50% of the surface there is frost control has also been taken into account.

Amount of Water Supplied by the Montecaseros Inspection. This information, supplied by INCYTH, according to its flow measurements, was 99.036.205 m3/year for 8,602 registered hectares; that is to say, 11.513 m3/hectare/year.

Water cost. According to the calculations performed by the Inspection, the cost of water paid by producers is $100/hectare/year, and it includes: irrigation fees, inspection costs ($66) and two workers for canal cleaning (or cleaning quota = "limpieza de cupos") ($34).

ECONOMIC PARAMETERS

a. Gross Value of Production/Irrigation Water Cost. It indicates the gross income obtained from the sale of the products per each $ of surface irrigation water.

1. Viticulture Activity

$$\frac{\text{Gross value of production/hectare}}{\text{Irrigation water cost/hectare}} = \frac{\$2{,}417/\text{hectare/year}}{\$100/\text{hectare/year}} = 24$$

2. Fruticultural Activity

$$\frac{\text{Gross value of production/hectare}}{\text{Irrigation water cost/hectare}} = \frac{3{,}501\ \text{hectare/year}}{\$100/\text{hectare/year}} = 35$$

3. Viticulture and Fruticultural Activities. For the calculated parameter to reflect the situation of the area, a mean of grape and fruit production value was considered and estimated according to surface per crop.

$$\frac{\text{Value of total production/hectare}}{\text{Surface irrigation water cost/hectare}} = \frac{\$2{,}523/\text{hectare/year}}{\$100/\text{hectare/year}} = 25{,}23$$

b. Value of Production/m3 of Surface Irrigation Water: It indicates the gross production value obtained from the sale of the products per m3 of water applied.

1. Viticulture Activity

$$\frac{\text{Value of Viticulture production/hectare}}{\text{m3 applied/hectare}} = \frac{\$2{,}417\text{/hectare/year}}{11{,}513 \text{ m3/hectare/year}} = 0.21 \text{ \$/m3}$$

2. Fruticultural Activity

$$\frac{\text{Value of fruticulture production/hectare}}{\text{m3 applied/hectare}} = \frac{\$3{,}501\text{/hectare/year}}{11{,}513 \text{ m3/hectare/year}} = 0.30 \text{ \$/m3}$$

3. Viticulture and Fruticultural Activities.

$$\frac{\text{Estimated mean of total production value/hectare}}{\text{m3 of water applied/hectare}} = \frac{\$2{,}523 \text{ /hectare/year}}{11{,}513 \text{ m3/hectare}} = 0.22$$

c. Irrigation cost/hectare/operative cost/hectare of production: it shows the incidence of irrigation costs in the operative cost of production.

1. Viticulture Activity. The cost corresponds to the average cost/hectare estimated from the surface cultivated according to the vineyard climbing system.

$$\frac{\text{Irrigation cost/hectare/year}}{\text{operative cost of production/hectare/year}} = \frac{\$100}{\$ 1{,}720} = 0.058 \ (5.8\%)$$

The irrigation cost represents 5.8% of the total operative cost of grape-growing.

2. Fruticultural Activity

$$\frac{\text{Irrigation cost/hectare/year}}{\text{operative cost of production/hectare/year}} = \frac{\$100}{\$ 1{,}500} = 0.066 \ (6.6\%)$$

3. Viticulture and Fruticultural Activities

$$\frac{\text{Irrigation cost/hectare/year}}{\text{operative cost of production/hectare/year}} = \frac{\$100}{\$ 1{,}698} = 0.059 \ (5.9\%)$$

d. Volume produced/m3 applied: it shows the amount of kg. harvested per cm3 of water applied.

1. Viticulture Activity

$$\frac{\text{Volume produced}}{\text{m3 applied}} = \frac{21300 \text{ kg/hectare}}{11513 \text{ m3/hectare}} = 1.85 \text{ kg/m3}$$

2. Fruticultural Activity

$$\frac{\text{Volume produced}}{\text{m3 applied}} = \frac{8420 \text{ kg/hectare}}{11513 \text{ m3/hectare}} = 0.73 \text{ kg/m3}$$

3. Viticulture and Fruticultural Activities.

$$\frac{\text{Volume produced estimated average}}{\text{m3 applied}} = \frac{20040 \text{ kg}}{11513 \text{ m3/hectare}} = 1.74 \text{ kg/hectare}$$

e. Gross margin/m3 applied: it shows the gross margin per m3 of water applied.
Gross margin = income-direct costs
Income: production value
Direct costs: in this work all operative expenses are considered to be direct.

1. Viticulture Activity

$$\frac{\text{Gross margin/hectare}}{\text{m3/hectare}} = \frac{\$2417/\text{hectare}-1720/\text{hectare}}{11513 \text{ m3/hectare}} = 0.06 \text{ \$/m3}$$

The gross margin per 100m3 applied is $6

2. Fruticultural Activity

$$\frac{\text{Gross margin/hectare}}{\text{m3/hectare}} = \frac{\$3501/\text{hectare} -\$1500/\text{hectare}}{11513 \text{ m3/hectare}} = 0.06 \text{ \$/m3}$$

The gross margin per 100m3 applied is $17

3. Viticulture and Fruticultural Activities.

$$\frac{\text{Gross margin/hectare(estimated average)}}{\text{m3/hectare}} = \frac{\$2523/\text{hectare/year} -\$1698/\text{hectare}}{11513 \text{ m3/hectare}} = 0.072\text{\$/m3}$$

The gross margin for the area is $7.2 per 100m3 of water applied.

AREA SURVEYED

The area covered by this work was presented in a blueprint followed by a land surveillance of the farms that would participate in the study. The area chosen for this study is located between Carril Costa Canal Montecaseros, Carril Chivilcoy, Calle Anzorena and Carril Buen Orden. The farms were selected by INCYTH and correspond to those were its experimental fields are located. No sampling of the area was performed, since all the area farms were surveyed. Seven farms were fully surveyed using a questionnaire, but this figure was extended to 20 in order to obtain a bigger corpus of economic data.

The design and review of the questionnaire was conducted by the Department of Socioeconomic Science, School of Agricultural Science.

Description of Productive Structure

The surveyed area included approximately 438 hectares corresponding to 5% of the total registered area with irrigation rights. Eighty tree percent of the soil is cultivated, whereas 1% is systematized land without definitive use and 16% is abandoned land due to soil salinization. Of the total cultivated area, 77% is grown with grapes and 23% with fruit trees (12% peaches, 11% plums). Seventy percent of the surveyed farms are presently registered as personal property, whereas the remaining 30% belong to some kind of society. Forty five percent of the farms are run by administration and 55% by a contract system. The mediation system is not significant. In all cases the landowners exercise direct control on the farm.

Technology

* **Crop support system:** The predominant system is the trellis in 83% of the area. The remaining 17% corresponds to espaliers, most of them low. Fruit trees are V-shaped since no other forms of support system have been found.

The quality of irrigation water is of particular importance in arid zones where temperature extremes and low relative humidity give rise to high evaporation rates, with the ensuing deposition of salts which tend to accumulate in the soil profile. The physical and mechanical properties of the soil, such as dispersion of particles, stability of aggregates, soil structure and permeability, are very sensitive to the type of exchangeable ions present in irrigation water. Thus, when effluent use is being planned, several factors related to soil properties must be taken into consideration (EPA, 1992).

Another aspect of agricultural concern is the effect on plant growth of dissolved solids (TDS) in irrigation water. Dissolved salts increase the osmotic potential of soil water and an increase in osmotic pressure of the soil solution also increases the amount of energy which plants must expend to take up water from the soil. As a result, respiration increases and plant growth and yields decline progressively as osmotic pressure increases. Although most plants respond to salinity as a function of the total osmotic potential of soil water, some plants are susceptible to specific ion toxicity.

Many of the ions which are harmless or even beneficial at relatively low concentrations may be toxic to plants at high concentrations, either through direct interference with metabolic processes or through indirect effects on other nutrients, which might be rendered inaccessible. Morishita has reported that irrigation with nitrogen-enriched pollution water can supply considerable excess of nutrient nitrogen to growing rice plants and can result in a significant loss of rice yields through lodging, failure to ripen and increased susceptibility to pests and diseases due to over-luxuriant growth. He further reported that non-polluted soil, having around 0.4 and 0.5 ppm cadmium, may produce about 0.08 ppm Cd in brown rice, while only a little increase up to 0.82, 1.25 or 2.1 ppm of soil Cd can produce heavily polluted brown rice with 1.0 ppm Cd.

Important agricultural water quality parameters include a number of specific properties of water that are relevant in relation to crop yields and quality, maintenance of soil productivity and protection of the environment. These parameters include certain physical and chemical characteristics of water. The following table presents a list of some of the most important physical and chemical characteristics that are taken into account in the evaluation of agricultural water quality and the main wastewater quality parameters from an agricultural viewpoint:

Parameters used in the evaluation of agricultural water quality

Parameter	Symbol	Unit
Physical		
Total Dissolved Solids	TDS	mg/l
Electrical conductivity	EC	dS/m[1]
Temperature	T	°C
Colour/Turbidity		NTU/JTU[2]
Hardness		mg. equiv. $CaCO_3$/l
Sediments		g/l
Chemical		
Acidity/Basicity	pH	
Type and concentration of anions and cations:		
Calcium	Ca^{++}	me/l[3]
Magnesium	Mg^{++}	me/l
Sodium	Na^{+}	me/l
Carbonate	CO_3^{2-}	me/l
Bicarbonate	HCO_3^{-}	me/l
Chloride	Cl^{-}	me/l
Sulphate	SO_4^{2-}	me/l
Sodium Adsorption Ratio	SAR	
Boron	B	mg/l[4]
Trace metals		ppm
Heavy metals		ppm
Nitrate-Nitrogen	NO_3 - N	mg/l
Phosphate Phosphorus	PO_4 - P	mg/l
Potassium	K	mg/l

[1] dS/m = deciSiemen/metre in SI Units (equivalent to 1 mmhos/cm)
[2] NTU/JTU = Nephelometric Turbidity Units/Jackson Turbidity Units
[3] me/l = milliequivalent per litre
[4] mg/l = milligrams per litre = parts per million (ppm); also,
mg/l ~ 640 x EC in dS/m

Source: Kandiah (1990a)

* **Average yield:** The average yield stated by producers is found in table 9. Vineyards are in full production. There are still some very old ones which contrast with young fruit plantations already in full production. However, in both cases the yield is far from ideal for a plantation, since farms are not worked using adequate technology or practices.

* **Agrochemicals:** Large farms carry out fertilization tasks programmed according to crop age and type. Phytosanitation treatment is preventive and healing when necessary. Herbicides are also used on farms (the product used is Glifosate). On small farms no necessary fertilization is carried out for each crop and sanitation treatment is healing; that is to say, there is no programming of tasks and there is only reaction before a certain plague or disease. Traditionally copper products are used on vineyards in an adequate concentration but with an insufficient number of applications.

* **Frost Control:** Sixty percent of the surveyed farmers perform no active frost control, only some passive measures (weeding). The most serious damage is to fruit trees (about 65%) Those farmers who perform active control, do it by means of atmospheric warming with gasoil. In this case the losses are no higher than 10% (large farms with fruit crops).

* **Trimming:** Those farmers who produce fruit for fresh consumption perform trimming. The results are good on large farms as opposed to small farms where the results are not satisfactory due to the fact that the trimming is carried out untimely.

* **Hail:** the damage caused by hail is variable. In Montecaseros it has been very little in the past three years (5 to 10%). One of the farms has a special system to cover the crops (plastic fabric) and thus protect them from hail. In the Chivilcoy district the incidence increases to 20%.

* **Soil Salinization:** Eighty percent of the surveyed farmers mention salinization problems. No exact percentage of damage can be established but it is estimated between 20 and 50% increasing toward the center of the area under study. Farmers have not stated this as a concrete problem this year, but it rather changes from year to year. This season subsurface water has not risen due to the water shortage Mendoza is undergoing. This situation has repeated itself in the last two seasons. However, irreversible damages can be observed in grapes and plums resulting from salinity and causing low yields, plant death, shriveling and early fall of leaves.

* **Irrigation:** The area surveyed is registered and has irrigation rights. The intervals between shifts show a variation of 10 to 15 days according to water availability. The farmers surveyed state that the water is insufficient, and that they need at least two shifts to complete the irrigation of the land. The most commonly used method is irrigation by borders. There are irrigation wells in 80% of the farms, but 40% of these wells have fallen in disuse. In the 40% that have an active well, the quality of water ranges from fair to bad. The pumping period extends from September to March and afterwards it is only used to supplement shift water. The average volume of water from the wells is 120,000 liters/hour; the average depth is 150 mts, and the power source is 100% electricity.

* **Machinery:** The average of tractors per farm is 1.6, with an average power of 45 hp. Tractors and machinery date from 1975-78. The farms have traditional tools and machines: plowshares, disc plows, weeders, border trimmers, graders, sprayers, atomizers and sprinklers. No tractor or any other machinery is rented.

* **Cultural Work:** The main soil work carried out consists of plowing vineyards, which consumes the most hand labor (6 hours/hectare). Plowing is another time-consuming activity both in vineyards and fruit crops, with an average of 4 hours/hectare. Spraying is performed in different ways according to how the land is cultivated.

Use of hand labor: The number of workers per hectare used for the different cultural tasks shows variations according to crop and management style. A mean was obtained of 32 permanent workers per hectare per year and 14 temporary workers per hectare per year. In the case of large fruit-cultivated farms, the work is carried out by administration, with 34 workers per hectare per year (18 permanent and 16 temporary per hectare per year.) Grape and fruit-cultivated farms devote 37 workers per hectare per year, whereas grape-cultivated farms devote 35 workers per hectare per year. The values are very similar and no significant differences were observed. Both grape and fruit-cultivated farms are worked by contractors. On small grape and fruit-cultivated farms, the workers per hectare per year go up to 50. As regards employed hand labor per cultivated hectare, there are 45 permanent workers per hectare per year and 19 temporary workers per hectare per year. This increase is due to the incidence of non-cultivated areas on each of the farms.

Marketing. Prices

Grapes: Mixed varieties are predominant. No clear varietal difference can be established. They are table grapes for wine-making with a higher proportion of red grapes. The average price for table grapes is $0.15/kg. There is a case of Bonarda grape at $0.28/kg. Third-party wine-making is predominant. The gross income per hectare is $2,790 on average.

Fruit crops: Peaches are marketed for fresh consumption and the average price is $0.20/kg. Plums are also sold for fresh consumption and the price is $0.35/kg, whereas for industrial processing the price is $0.12/kg.

Calculation of Operative Production Costs (Table 10). The operative production cost for each crop type was calculated from the primary data obtained through the questionnaires. The farms were divided in large (over 10 hectares) and small (less than 10 hectares). Within each group was calculated the cost for fruit-growing, grape-growing and fruit and grape-growing farms. Taking into account the prices and average yields of the area, the gross income was calculated for each crop type. The gross margin was calculated as the difference between the gross income and the operative cost of production.

ECONOMIC PARAMETERS (Calculated from primary data obtained through questionnaires given to farmers)

Farms were divided in large (over 10 hectares) and small (less than 10 hectares). For yields and prices of fruit crops the averages obtained in the questionnaires were considered. The cost of irrigation water is $100/hectare/year, taking into account the fees that each user pays the General Irrigation Department, the District Inspection and the payment of two workers for canal cleaning (or cleaning quota = "limpieza de cupos)($34). The volume of water received in the area is on average 11.513 m3/hectare/year.

Large Farms

a) Fruit-growing:

1) $\dfrac{\text{Production value}}{\text{irrigation water cost \$100}} = \dfrac{\$3794}{} = 37.94$

2) $\dfrac{\text{Production value}}{\text{Amount of water applied}} = \dfrac{\$3794}{11.513 \text{ m3}} = \$0.33/\text{m3}$

3) $\dfrac{\text{Production volume}}{\text{Amount of water applied}} = \dfrac{\$12941 \text{ kg}}{11.513 \text{ m3}} = \$1.12 \text{ kg/m3}$

4) $\frac{\text{Cost of irrigation water}}{\text{Operative cost of production}} = \frac{\$100}{\$1800} = 0.056$ (5.6%)

5) $\frac{\text{Gross margin}}{\text{m3 water applied}} = \frac{\$1994}{11.513 \text{ m3}} = 0.17$ \$/m3

b) Grape-growing

1) $\frac{\text{Production value}}{\text{irrigation water cost}} = \frac{\$3750}{\$100} = 37.50$

2) $\frac{\text{Production value}}{\text{Amount of water applied}} = \frac{\$3750}{11.513 \text{ m3}} = \$0.33$/m3

3) $\frac{\text{Production volume}}{\text{Amount of water applied}} = \frac{\$25000 \text{ kg}}{11.513 \text{ m3}} = \$2.17$ kg/m3

4) $\frac{\text{Cost of irrigation water}}{\text{Operative cost of production}} = \frac{\$100}{\$1900} = 0.053$ (5.3%)

5) $\frac{\text{Gross margin}}{\text{m3 water applied}} = \frac{\$1859}{11.513 \text{ m3}} = 0.16$ \$/m3

Small Farms

a) Fruit-Growing

1) $\frac{\text{Production value}}{\text{rrigation water cost}} = \frac{\$2300}{\$100} = 23$

2) $\frac{\text{Production value}}{\text{Amount of water applied}} = \frac{\$1800}{11.513 \text{ m3}} = \$0.20$/m3

3) $\frac{\text{Production volume}}{\text{Amount of water applied}} = \frac{\$7890 \text{ kg}}{11.513 \text{ m3}} = \$0.69$ kg/m3

4) $\frac{\text{Cost of irrigation water}}{\text{Operative cost of production}} = \frac{\$100}{\$1700} = 0.058$ (5.8%)

5) $\frac{\text{Gross margin}}{\text{m3 water applied}} = \frac{\$613}{11.513 \text{ m3}} = 0.05$ \$/m3

b) Grape-Growing

1) $\frac{\text{Production value}}{\text{irrigation water cost}} = \frac{\$2250}{\$100} = 22.5$

2) $\frac{\text{Production value}}{\text{Amount of water applied}} = \frac{\$2250}{11.513 \text{ m3}} = \$0.20$/m3

3) $\frac{\text{Production volume}}{\text{Amount of water applied}} = \frac{\$15000 \text{ kg}}{11.513 \text{ m3}} = \$1.30$ kg/m3

4) $\frac{\text{Cost of irrigation water}}{\text{Operative cost of production}} = \frac{\$100}{\$1320} = 0.076\ (7.6\%)$

5) $\frac{\text{Gross margin}}{\text{m3 water applied}} = \frac{\$900}{11.513\ \text{m3}} = 0.08\ \$/\text{m3}$

c) Total Surveyed Area (all farms)

1) $\frac{\text{Production value}}{\text{irrigation water cost}} = 36$

2) $\frac{\text{Production value}}{\text{Amount of water applied}} = 0.31\ \$/\text{m3}$

3) $\frac{\text{Production volume}}{\text{Amount of water applied}} = 1.83\ \text{kg/m3}$

4) $\frac{\text{Cost of irrigation water}}{\text{Operative cost of production}} = 0.059\ (5.9\%)$

5) $\frac{\text{Gross margin}}{\text{m3 water applied}} = 0.15\ \$/\text{m3}$

COMPARISON OF PARAMETERS IN THE TWO STUDIED AREAS:

Table 11 is a summary of all the calculated parameters, with little difference between both areas.

CONCLUSIONS

* The main activity in the area studied is grape-growing (80%) followed by fruit-growing with a much lower percentage (20%)
* In general the data obtained through questionnaires ratifies the parameters calculated using secondary data.
* The greatest difference was found in the parameters calculated on the basis of fruit-and grape-growing activities together. This is due to the fact that in the surveyed area, there is a larger amount of big farms with high MBs, both in the grape and in the fruit-growing activities.
* The cost of irrigation water represents approximately 6% of the operative production cost..
* Small farms have parameter values (calculated from primary data) lower than the average for the area (calculated from secondary data) , whereas large farms have higher parameter values.
* Fruit-growing farms have a larger gross margin per m3 of water applied because their MB/hectare are higher than for grape-growing farms with a larger amount of rose grapes (lower price per kg.)
* In the area where secondary data was analyzed, the general gross margin (grape and fruit-growing activities) comes close to the grape-growing gross margin since most of the cultivated area corresponds to this activity.
* In the surveyed area, the gross margins are similar for large farms, and they are lower for smaller farms with fruit-growing activities due to the lack of adequate technology.

Table 1. Distribution of grape-growing farms by area range. San Martín County

Districts	Alto Salvdor		Chapanay		Montecaseros		Chivilcoy	
Strata (hectares)	Farm #	Vineyard surface (hectares)	Farm #	Vineyard surface (hectares)	Farm #	Vineyard surface (hectares)	Farm #	Surface
< 1	39	23	69	38	44	27	8	7
1 - 5	104	275	167	491	292	871	65	179
5 - 10	35	249	98	741	132	1008	26	188
10 - 15	14	178	55	698	68	853	9	106
15 - 25	14	256	56	1094	100	1942	5	94
25 - 50	6	215	34	1234	38	1249	4	139
> 50	1	70	12	835	13	825	2	128
x		**5.94**		**10.45**		**9,86**		**7.06**

Source: Viticulture Census 1991 and updates

Table 2. Distribution of fruit-growing farms per area range

	Number of fruit-growing farms		
Districts Strata	Alto Salvador	Chapanay	Montecaseros
0 - 5	10	9	13
5 - 10	7	9	10
10 - 15	2	9	6
15 - 25	4	19	9
25 - 50	5	21	18
> 50	2	14	10
Total	30	81	66
Average surface/farm (hectares)	3.31	7.51	6.99

Source: Fruticultural Census 1992

Table 3. Prices/kg paid to farmers

Grapes	$/kg	Fruit crops	$/kg
wine red	0.20	plums	0.21
white	0.17	peaches	0.28
table white and red	0.14	pears	0.18
rose	0.10	apricots	0.13
		olives	0.40

Source: Agricultural Administration and key informants

Table 4. Value of Grape Production

Varieties	Production (Kg)	$/kg	Production Value ($)
wine red	16.570.000	0.20	3.314.000
table red	27.594.000	0.14	3.863.160
wine white	3.250.000	0.17	552.500
table white	32.994.000	0.14	4.619.160
rose	226.475.000	0.10	22.647.000
Total			34.824.320

Source: Tables 6 and 7

Table 5. Production of grapes for wine-making (thousands of kg.)

Varieties	Surface (kg)	kg/ha	Production (thousands of kg)
wine red	1.657	10.000	165.700
table red	1.533	18.000	28.594
wine white	325	10.000	3.250
table white	1.833	18.000	32.994
rose	9.059	25.000	226.475
Total	14.407		

Source Viticulture Census 1991 and its updates. Key informants

Table 6. Total production of fruit crops (thousands of kg)

District	Plums	Peaches	Pears	Apricots	Olives
Alto Salvador	287	619		190	69
Chapanay	1.058	4.650	424	1.176	304
Montecaseros	1.576	3.552	2.820	464	44
Chivilcoy	3.924	1.980	1.780	156	345
Total	6.845	10.801	2.486	1.986	762

Source: Tables 9 and 4

Table 7. Total production and value of fruit production

Species	Plums	Peaches	Pears	Apricots	Olives	Total
Production (kg)	684500	10801000	2486000	1986000	762000	13160000
$/kg	0.21	0.28	0.18	0.13	0.40	
Production value ($)	1437450	3024280	447480	258180	304800	5472190

Source: tables 6 and 10

Table 8. Operative costs of production

	Grapes		Fruits crops					
	high espalier	low espalier	Trellis	Plums	Peaches	Pears	Apricots	Olives
Operative cost ($/hectare)	1.500	1.600	1.800	1.500	1.500	1.500	1.500	1.500
Yield (kg/hectare)	10.000	18.000	25.000	12.000	15.000	20.000	12.000	5.000

Source: Department of Socioeconomic Science and Department of Fruticulture

Table 9. Yield according to farm size (in kg/hectare)

Species	Large farms				Small farms			Average
	fruit growing	grape growing	Fruit and grape growing		Grape growing	Fruit and grape growing		
			fruit	grape		fruit	grapes	
Peaches	20.000		12.000			10.000		12.000
Plums	120.000		9.000			8.000		10.000 (*)
Grapes		30.000		25.000	14.000		15.000	15.000

Source: questionnaires to farmers

(*) 9000 kg/hectare for plums for industrial processing and 11000 for fresh consumption

Table 10. Production cost: estimation according to questionnaire

Type of exploitatio crops	Large Farms				Small Farms		
	Adm. fruit	Contract			Contract		
		Fruti and grape		Grape	Grape	Fruit and grape	
		grape	fruit			grape	fruit
1.OPERATIVE COSTS	1964	1826	1980	2032	979	1747	1663
1.1. Speciial Expenses (SE)	1233	399	326	527	88	387	315
1.1.1. Agrochemicals	331	175	102	199	9	256	110
1.1.2. Fuel	813	179	179	283	34	86	160
1.1.3. Electircity	90	45	45	45	45	45	45
1.2. Wages (W)	646	1332	1559	1394	812	1285	1274
1.2.1. Permanent	266	207	144	240	23	148	181
1.2.2. Commission	0	666	864	634	403	756	648
1.2.3. Temporary	192	240	324	264	252	216	252
1.2.4. Social Laws (40%)	158	179	187	202	110	146	173
.1.3. Maintenance (4%)	30	40	40	55	24	20	20
1.4. Taxes and fees	55	55	55	55	55	55	55
AVERAGE GROSS INCOMKE	6000	3600	3000	3600	2240	3000	2400
AVERAGE GROSS MARGIN	4036	1853	1337	1568	1261	1174	420

Table 11. Summary comparative chart of the calculated economic parameters

	All districts (secondaty data)					Surveyed area (primary data)									
	VP/water cost	VP/m³ water	Irrig. cost/ CO prod.	kg/m³ water	MB/m³ water	VP/water cost		VP/m³ water		Irrig.cost/ CO prod.		Kg/m³ water		MB/m³ water	
	$/$	$/m³	%	kg/m³	$/m³	$/$		$/m³		%		kg/m³		$/m³	
						Small farms	Large farms	Small farms	Large farms	Small farms	Large farms	Small farms	Large farms	Small farms	Large farms
Grape-growing	24	0.21	5.8	1.85	0.06	22	37	0.20	0.33	6.8	4.7	1.36	2.17	0.08	0.16
Fruit-growing	35	0.30	6.6	0.73	0.17	23	37	0.20	0.33	5.2	5.8	0.69	1.12	0.05	0.17
Grape and fruit growing	25	0.22	5.9	1.74	0.07		36		0.31	5.9		1.83			0.15

THE CHANGING WATER QUALITY FROM THE STORAGE RESERVOIR TO THE IRRIGATED FIELD, TUNUYÁN SYSTEM, ARGENTINA

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INTRODUCTION

Water quality problems have increased through time due to the growth and concentration of populations and industrial centers. Often, these problems have been viewed as inevitable consequences of community development and, sometimes, have even been accepted as evidence of affluence and progress. Only after recognizing that serious health impacts could result from uncontrolled wastewater discharges did we finally initiate systematic water pollution control activities. Although health is still an important consideration today, it has been recognized that the impacts of water pollution are far more complex than on health alone. In fact, most pollution control programs are now based on reasons only remotely, if at all, related to health.

The word pollution implies undesirable quality, but it may be interpreted in various ways by different individuals. This may be attributed partly to emotional reactions but often involves substantive differences about our goals in using water resources and quality characteristics desired or needed to meet those goals. The presence of constituents that may be viewed as pollution by someone seeking a municipal supply could be acceptable or desirable to someone else who wishes to use the resource for swimming or fishing. From this statement it can be seen that water quality cannot be evaluated meaningfully without considering specific uses to which it will be put. Based on that fact, it is possible to define pollution as "the presence of materials in water that interfere unreasonably with one or more beneficial uses of it" (Lamb, 1985).

Water quality is, by definition, the set of physical, chemical and biological characteristics in the natural condition or after they are modified by man. This definition points to the fact that the study of water quality encompasses mainly the characteristics of natural waters, the changes caused by man's intervention, the effects of those changes, and pollution quality control methods (Cubillos, 1988).

The effect of a water constituent depends on its concentration. If it is sufficiently dilute, it would exert no adverse impact on water uses. In fact, many water constituents that could be objectionable at high concentrations may actually be beneficial, or even necessary, for some uses. As the concentration of a constituent increases, water quality may be adversely affected for some beneficial uses and, ultimately, may become unsuitable for virtually all desirable uses.

Although any water constituent, if sufficiently high in concentration, could interfere with the use of the resource, it could be misleading to refer to it as a pollutant. Often, a chemical or other constituent does not pollute water in the sense outlined before, because its concentration is below that which would cause objectionable quality or because the change in quality does not interfere with a reasonable use for that watercourse.

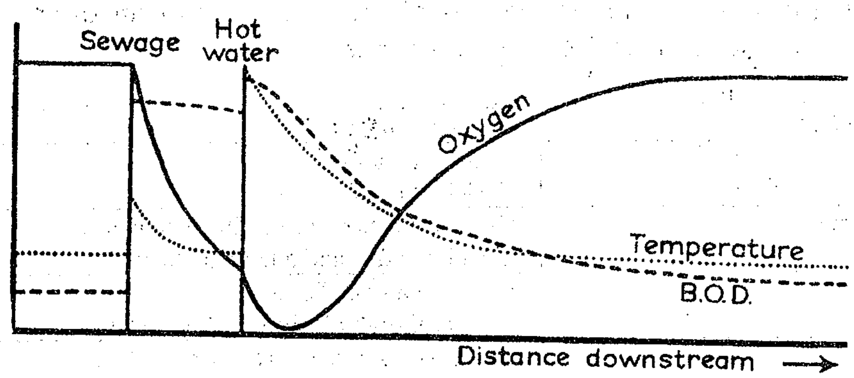
A rational approach for some authors is to consider every water constituent as suspect until its concentration is demonstrated to be below a level that creates an unreasonable quality problem by impacting beneficial uses that should be protected. Accordingly, it is preferable to refer to water constituents as "potential pollutants", as having the potential for causing water quality problems, but not necessarily always doing so (Lamb, 1985).

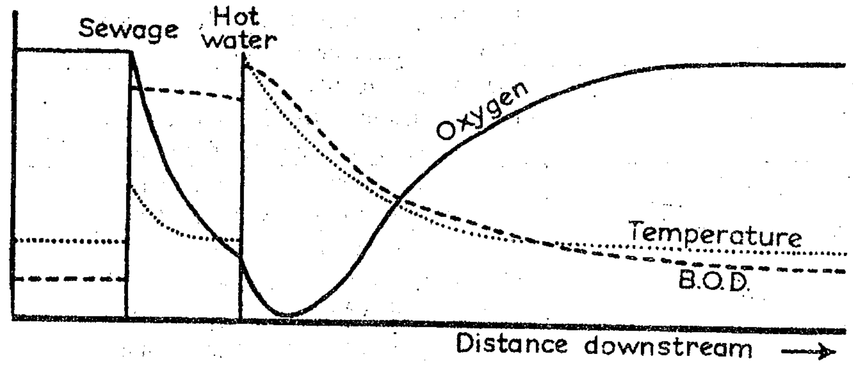
The general list of potential water pollutants include:

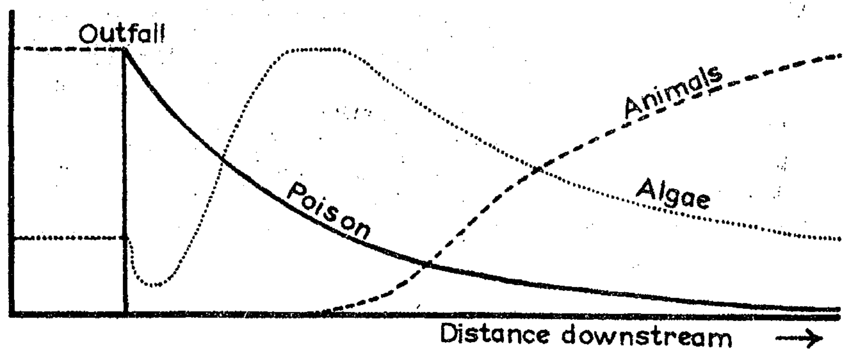
- Infectious and toxic agents
- Oxygen-demanding substances
- Persistent organic chemicals
- Plant nutrients
- Minerals and chemicals causing specific problems
- Suspended matter
- Radioactive substances
- Heat

Behavior of water quality parameters

The next figures show the behavior of selected chemical, physical and biological water quality parameters as the water flows downstream from an effluent discharge point (e.g. sewage or outfall). These curves show what the behavior of a particular water pollutant might be.


Sewage
Hot water
Oxygen
Temperature
B.O.D.
Distance downstream →


Sewage
Hot water
Oxygen
Temperature
B.O.D.
Distance downstream →


Outfall
Animals
Algae
Poison
Distance downstream →

The following table includes a detailed list of some of the most important water pollutants as well as the main problems they may arise:

Chemical	Potential problems
Arsenic	- Toxicity to humans - Toxicity to aquatic life
Chlorine	- Organic reactions form trihalomethanes - Toxicity to fish and other aquatic life
Calcium	- Causes "hardness"of water - May result in scale formation in pipes
Iron	- Causes stains in laundry and on fixtures - May kill fish by clogging their gills
Ammonia	- May accelerate eutrophication in lakes - May improve productivity of the water - May be toxic to aquatic life
Nitrates	- May be toxic to babies - May accelerate eutrophication in lakes - May improve productivity of the water
Dissolved Oxygen	- Low concentrations harmful to fish - Low concentrations may cause odor
Phenolics	- Tastes and odors in drinking water - Can cause tainting of fish flesh - May be toxic to aquatic life
Sulfides	- Objectionable odors in and near water - May be toxic to aquatic life - May corrode concrete through acid formation - Oxidation to sulfate exerts an oxygen demand
Sulfites	- React with dissolved oxygen and exert oxygen demand
Sulfates	- Increase water corrosiveness to metals - Decompose anaerobically to form sulfides - Salty taste and laxative effects

Important agricultural parameters

When water is mainly used for agriculture, the principal causes or sources of pollution and the most common parameters to be determined are:

PROBLEM	MAJOR CAUSES/SOURCES	COMMON MEASUREMENT VARIABLES
Elevated temperature	Irrigation withdrawal, drainage, Reservoir warming	Temperature
Salinity	Drainage, Reservoir evaporation	Specific Conductance, Dissolved Solids
Nitrates	Inorganic fertilizers, Feedlots	Nitrates
Sanitary quality	Feedlots, Slaughterhouse wastes, Livestock grazing	Faecal coliforms, Faecal Straeptococci, E. coli, others
Decomposable organic wastes	Feedlots, Slaughterhouse wastes, Dairy operations, Food processing, Pulp and paper mills	DO, BOD, COD, Ammonia, Suspended solids
Erosion/Sedimentation	Intensive cultivation, lumber production, Livestock grazing	Suspended sediments, Bed sediment accumulation
Nutrient enrichment	Fertilizers, Feedlots, Food processing, Pulp and paper mills	Nitrates, Nitrites, Ammonia, Total phosphorus, Orthophosphorus, Algae, Chlorophyll
Toxic trace sediments	Irrigation drainage	Selenium, Arsenic, Molibdenum, Boron, Lithium
Pesticides	Applied herbicides and insecticides	Atrazine, Alachlor, Chlordane, DDT. Malathion, Parathion, many others

Some selected environmental effects of agriculture on water quality are listed below in order to depict the different sources of pollution from this activity:

Agricultural practices	Soil	Groundwater	Surface water
Land development, land consolidation programmes	Inadequate management leading to soil degradation	Other water management influencing groundwater table	Soil degradation, siltation, water pollution with soil particles
Irrigation, drainage	Excess salts, waterlogging	Loss of quality (more salts), drinking water supply affected	Run-off leaching or direct discharge leading to eutrophication
Tillage	Wind erosion, water erosion		Run-off leaching or direct discharge leading to eutrophication
Mechanization: large or heavy equipment	Soil compaction, soil erosion		Run-off leaching or direct discharge leading to eutrophication
Fertilizer use			Run-off leaching or direct discharge leading to eutrophication
Nitrogen		Nitrate leaching affecting water	Run-off leaching or direct discharge leading to eutrophication
Phosphate	Accumulation of heavy metals (Cd)		Run-off leaching or direct discharge leading to eutrophication
Manure, slurry	Excess: accumulation of phosphates, copper (pig slurry)	Nitrate, phosphate (by use of excess slurry)	Run-off leaching or direct discharge leading to eutrophication
Sewage sludge compost	Accumulation of heavy metals, contaminants		Run-off leaching or direct discharge leading to eutrophication
Applying pesticides	Accumulation of pesticides and degradation products	Leaching of mobile pesticide residues and degradation products	Run-off leaching or direct discharge leading to eutrophication
Input of additives, medicines	Possible effects		
Modern building (e.g. silos) and intensive livestock farming	See slurry	See slurry	See slurry

Source: Adapted from OECD, 1985

The quality of irrigation water is of particular importance in arid zones where temperature extremes and low relative humidity give rise to high evaporation rates, with the ensuing deposition of salts which tend to accumulate in the soil profile. The physical and mechanical properties of the soil, such as dispersion of particles, stability of aggregates, soil structure and permeability, are very sensitive to the type of exchangeable ions present in irrigation water. Thus, when effluent use is being planned, several factors related to soil properties must be taken into consideration (EPA, 1992).

Another aspect of agricultural concern is the effect on plant growth of dissolved solids (TDS) in irrigation water. Dissolved salts increase the osmotic potential of soil water and an increase in osmotic pressure of the soil solution also increases the amount of energy which plants must expend to take up water from the soil. As a result, respiration increases and plant growth and yields decline progressively as osmotic pressure increases. Although most plants respond to salinity as a function of the total osmotic potential of soil water, some plants are susceptible to specific ion toxicity.

Many of the ions which are harmless or even beneficial at relatively low concentrations may be toxic to plants at high concentrations, either through direct interference with metabolic processes or through indirect effects on other nutrients, which might be rendered inaccessible. Morishita has reported that irrigation with nitrogen-enriched pollution water can supply considerable excess of nutrient nitrogen to growing rice plants and can result in a significant loss of rice yields through lodging, failure to ripen and increased susceptibility to pests and diseases due to over-luxuriant growth. He further reported that non-polluted soil, having around 0.4 and 0.5 ppm cadmium, may produce about 0.08 ppm Cd in brown rice, while only a little increase up to 0.82, 1.25 or 2.1 ppm of soil Cd can produce heavily polluted brown rice with 1.0 ppm Cd.

Important agricultural water quality parameters include a number of specific properties of water that are relevant in relation to crop yields and quality, maintenance of soil productivity and protection of the environment. These parameters include certain physical and chemical characteristics of water. The following table presents a list of some of the most important physical and chemical characteristics that are taken into account in the evaluation of agricultural water quality and the main wastewater quality parameters from an agricultural viewpoint:

Parameters used in the evaluation of agricultural water quality

Parameter	Symbol	Unit
Physical		
Total Dissolved Solids	TDS	mg/l
Electrical conductivity	EC	dS/m[1]
Temperature	T	°C
Colour/Turbidity		NTU/JTU[2]
Hardness		mg. equiv. $CaCO_3$/l
Sediments		g/l
Chemical		
Acidity/Basicity	pH	
Type and concentration of anions and cations:		
Calcium	Ca^{++}	me/l[3]
Magnesium	Mg^{++}	me/l
Sodium	Na^{+}	me/l
Carbonate	CO_3^{2-}	me/l
Bicarbonate	HCO_3^{-}	me/l
Chloride	Cl^{-}	me/l
Sulphate	SO_4^{2-}	me/l
Sodium Adsorption Ratio	SAR	
Boron	B	mg/l[4]
Trace metals		ppm
Heavy metals		ppm
Nitrate-Nitrogen	NO_3 - N	mg/l
Phosphate Phosphorus	PO_4 - P	mg/l
Potassium	K	mg/l

[1] dS/m = deciSiemen/metre in SI Units (equivalent to 1 mmhos/cm)
[2] NTU/JTU = Nephelometric Turbidity Units/Jackson Turbidity Units
[3] me/l = milliequivalent per litre
[4] mg/l = milligrams per litre = parts per million (ppm); also,
mg/l ~ 640 x EC in dS/m

Source: Kandiah (1990a)

PHYSICAL, CHEMICAL AND MICROBIOLOGICAL ANALYSIS

The water pollution parameters analyzed in this research, the analytical methods used as well as an explanation of their meaning are presented below.

Temperature: in the field and at the laboratory, with thermometer
pH:until October 1995, it was determined with indicative paper in the field and at the laboratory. As of December 1995, a pH meter was used in the laboratory.
Organoleptic characteristics description: color, smell and aspect.
Electrical Conductivity: conductivity meter.
Dissolved Oxygen: Winkler method.
Total, Fixed and Volatile Solids: dissecation in stove to 100 ± 2°C to constant weight. (AOAC Method, 1984).
Biochemical Oxygen Demand (BOD_5): according to the AOAC Method, 1984.
Total Nitrogen: Method of Kjeldahl (AOAC, 1984).
Chemical Oxygen Demand (COD): according to the method described in Berman, 1984.
Settleable Solids in 10 minutes and in 2 hours: Inhoff cone.
Nitrites, Nitrates and Phosphates: colorimetric determinations using Merck kits.
Aerobic Mesophile Bacteria (CFU/ml): inventory in plate (Swarthy, 1982)
Coliform Bacteria inventory: MPN/100 ml.(Swarthy, 1982)
Faecal Coliform bacteria inventory: MPN/100 ml (Swarthy, 1982)
Escherichia coli inventory: MPN/100 ml (Swarthy, 1982)

NOTE: as from October 1996, analyses of Chrome, Lead, Mercury and Arsenic were also included in some of the samples. Due to the cost of the analyses, they were repeated in samples taken during the months of March and April 1997.

Temperature

This parameter, in combination with the ambient temperature, may be used as an indication of pollution. In this way, possible pollutants can be detected if they have an influence in these values.

pH

It represents a measure of the acidity/alkalinity status of water. Is an indicator and it is rarely important for itself. The pH value is important for a quick assessment of the normal condition of the water body. Optimum pH values in irrigation water range between 6.5 and 8.4.

Total, Fixed and Volatile Solids

They are directly related to the solid material carried by water, to the flow and to water velocity. Fixed solids represent the inorganic fraction and volatile solids the organic fraction.

Settleable Solids

They represent the fraction of the solid material that can be divided by sedimentation. Measurement after 10 minutes gives an indication of the thicker inorganic matter (sand) and after 2 hours of the suspended organic matter.

Dissolved Oxygen

It shows the aerobic condition of the water body. Depending on its concentration, life development may or may not be possible. The minimum level required for life development is 4 mg/l (Kupchella, 1993).

Chemical Oxygen Demand (COD)

This parameter shows the organic matter in the water that can be degraded by chemical action.

Biochemical Oxygen Demand (BOD_5)

It shows the amount of oxygen that aerobic germs require for organic matter decomposition in one liter of water after five days in the dark at a temperature of 20° C.

Total Nitrogen, Nitrites and Nitrates

Nitrates and Nitrates are important water pollution indicators. Nitrogen (N_2) is an essential element for life. When living organisms die, proteins are mineralized. As a result of this process, Nitrogen is found as Ammonium (NH_3) or Ammonia (NH_4^+). Oxidation processes transform these compounds into Nitrites (NO_2^-) and then into Nitrates (NO_3^-). They are absorbed by plants and other organisms that use them to produce new proteins, thus closing the Nitrogen Cycle. In terms of health, a high content of Nitrites is a sign of biological activity. When high contents of Nitrates are found it can be assumed that the source of pollution is far from the sampling location, which means that there has been enough time to produce the total oxidation of nitrogen compounds.

High concentrations of nitrates and phosphates (PO_4^{3-}) have to be carefully studied, because they can trigger the so called eutrophication process in the receiving water bodies. Over extended periods of time, eutrophication can produce accumulations that can change the characteristics of a water body (i.e. lakes) permanently, thus increasing its organic content and community of organisms and ultimately converting it into marsh lands. At present, some studies are being carried out on El Carrizal dam in order to determine the trophic status of water. It is assumed that strong eutrophication processes might be taking place.

Phosphorus

In general, the same considerations for Nitrogen hold for this element.

Electrical Conductivity (EC)

Electrical Conductivity (EC) is widely used to indicate the total ionized water constituents. It is directly related to the sum of the cations (or anions), as determined chemically, and is closely correlated with the total salt concentration. The salinity of soil water is related to, and often determined by, the salinity of irrigation water. Accordingly, plant growth, crop yield and quality are affected by the total dissolved salts in the irrigation water. Likewise, the rate of salt accumulation in the soil, or soil salinization, is also directly affected by the salinity of irrigation water. EC is a rapid and reasonably precise determination and values are always expressed at a standard temperature of 25° C to enable comparison of readings taken under varying climatic conditions. It should be noted that the EC of solutions increases by approximately 2% per °C increase in temperature. The unit used is dS/m

MICROBIOLOGICAL PARAMETERS

<u>Indicator organisms</u>

Indicator organisms are usually non-pathogenic, they always occur in large quantities in feces, and are relatively easy to detect as compared with water-borne pathogens whose diagnosis is much more complicated and time consuming, and hence less suited for routine investigations. Assuming that in cold surface waters pathogens die off faster than indicator organisms, the absence of the latter or their presence in very low numbers ensures that no pathogens are present. The indicator organisms most widely used are the so-called coliform bacteria, which by definition include all aerobic and facultative anaerobic, Gram-negative, non-spore forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hs at 35° C.

The microbiological examination of water also comprises a test, called Standard Plate Count, which is indicative of the total number of microbes present per unit of volume in a water sample. The plate count is only indicative of the total number of living microbial cells in a volume of water. The rationale for this test is threefold:

1.A high content of bacteria, even non-pathogenic, indicates that there are significant amounts of biodegradable organic matter which reduces the conveyance capacity of pipes through wall growth, pieces of which also may get disloged and end up in the consumer's tap water.
2.When drinking water is used for industrial processes, e.g. in the food industry, a low non-pathogenic bacterial count is often desirable.

3.When performed on a routine basis and together with the hygienic safety test results, the plate count can provide valuable additional criteria for judging the performance of the water purification process and of the conveyance system. Malfunctioning leading, for instance, to the introduction of non-pathogenic bacteria would not show up as a result of the hygienic safety tests alone.

Coliform and Faecal coliform bacteria

The Coliform group of bacteria comprises mainly species of the genera *Citrobacter*, *Enterobacter*, *Escherichia* and *Klesbsiella* and includes Faecal Coliforms, of which *Escherichia coli* is the predominant species. Since several Coliforms can grow outside the intestine, especially in hot climates, their quantification is unsuitable as a parameter. The Faecal Coliform test may also include some non-faecal organisms which can grow at 44° C, so the *Escherichia coli* count constitutes the most satisfactory indicator parameter.

Other indicator organisms are Faecal Streptococci and *Clostridium perfringens*

Pathogenic parameters can only be considered when wastewater is used for irrigation, and provided suitable laboratory facilities and trained staff are available. They are *Salmonella sp.*, Enteroviruses, Rotaviruses, and Intestinal Nematodes.

ORGANOLEPTIC CHARACTERISTICS OF WATER

Color: it is produced by colloidal particles, especially organic acids resulting from organic matter decomposition. In this paper, this parameter has been reported according to laboratory observations.

Odor: it is produced by gases released from organic matter decay. Here they are also reported according to laboratory observations.

Turbidity

Turbidity in water may be produced by suspended materials, especially of colloidal and dispersed nature, generated by erosion processes, wastes, microorganisms, etc. In fact, turbidity measures absorption or dispersion of the light crossing the water depth. It affects the aesthetics of water.

TRACE ELEMENTS AND HEAVY METALS

A number of elements are normally present in relatively low concentrations, usually less than a few mg/l, in conventional irrigation waters and are called trace elements. They are not normally included in routine analysis of regular irrigation water, but attention should be paid to them when using sewage effluents, particularly if contamination with industrial wastewater discharges is suspected. These include Aluminum (Al), Beryllium (Be), Cobalt (Co), Fluoride (F), Iron (Fe), Lithium (Li),

Manganese (Mn), Molybdenum (Mo), Selenium (Se), Tin (Sn), Titanium (Ti), Tungsten (W) and Vanadium (V). Heavy metals are a special group of trace elements which have been shown to create definite health hazards when taken up by plants. Under this group, Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg) and Zinc (Zn) are included. These are called heavy metals because in their metallic form, their densities are greater than 4 g./cc.

PEST CONTROL AGENTS

As a result of pests, man has been confronted with diseases, discomfort and great economic losses. Some of the methods for insect control date back to many centuries ago. Ancient agriculturalists relied almost entirely on the use of natural products and by-products.

Since the turn of this century, synthetic pesticides have exerted a great impact on food and fibre production, both as regards quality and quantity, and have improved and saved human health and lives. The so called "pesticide revolution" dates back to 1942 when DDT was first used as an insecticide. Since that time, an increasing number of synthetic organic pesticides have been produced and have been widely used all over the world.

Pesticides are now part of daily life since most people are plagued, to some extent, by living pests that are troublesome, destructive, or that are vectors of human or animal afflictions. Since unsanitary conditions create an ideal environment for the spread of many diseases, pesticides have widespread beneficial uses in preventive medicine for the control of insect vectors of diseases, ectoparasites, etc., not only in the tropics but also in temperate zones. Therefore, conventional chemical pesticides have become the most powerful and dependable tool to control pest populations; research on alternatives has not yet produced anything that can replace these indispensable chemicals. On the other hand, society has become increasingly critical of the extensive and indiscriminate use of various chemicals, including insecticides. It has been argued that the only reliable way to avoid hazards from pesticides would be to ban them completely. This, of course, is unrealistic; at present, it has been acknowledged that chemical pesticides constitute an important part of integrated pest management.

Pesticides include a wide variety of chemical or biological substances. Although these substances are developed to control pests, the possibility of acute and chronic adverse effects on humans following an excessive exposure is an inherent feature of many of these compounds, especially insecticides.

Each successful use of pesticides to control human diseases creates an additional demand of pesticides in agriculture and crop protection. Those who will not die from malaria or some other vector-borne disease do not later die of starvation or malnutrition. In all these activities, pesticide treatment should be considered as a supplement to basic sanitation and, like drugs, pesticides should always be used with discretion and together with many other general measures in order to achieve effective pest control.

It is essential that the hazards to human health posed by pesticides be viewed in relation to the benefits rendered by their use. In addition, economical use of an insecticide calls for the use of the smallest quantity of the active ingredient compatible with the desired efficacy.

A pest control agent is defined as a substance or a mixture of substances intended to destroy, repel or reduce the harmful effects of pests. A pesticide is a substance or a mixture of substances intended to kill a pest (but the term is often erroneously used to mean "pest control agent"). The term "pest" includes harmful, destructive or troublesome animals, plants or microorganisms except those found in association with live animals or man. The essential component of a pest control agent is the active ingredient. At present, more than 1000 active substances are incorporated in over 10,000 pest control preparations. They include both organic and inorganic chemicals (and more recently bacterial and viral and other living pathogens) of variable composition and function.

Pesticides are used in many fields of human activity, public health and agriculture, this being the most important. The type of untoward effects of a pest control agent on man does not differ whether it is used in agriculture or public health.

The use of agents which persist for a longer period than is necessary to control a given pest, contributes to the contamination of food and the environment, and possibly adversely affects non-target species. On the other hand, an agent which does not persist long enough to effect control is useless. To compromise, a scientifically founded risk-benefit assessment is essential.

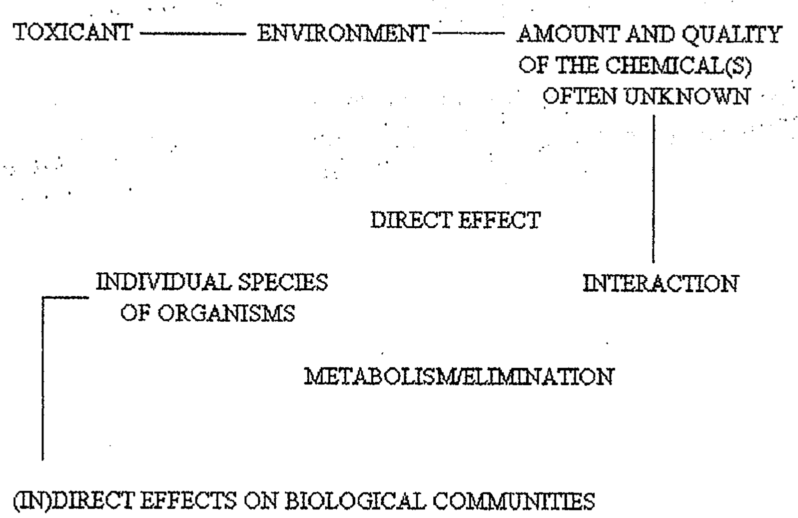
Based on the organism they control, pest control agents may be grouped as:

- acaricides
- attractants
- defoliants
- dessicants
- fungicides
- herbicides
- insecticides
- larvicides
- miticides
- molluscicides
- nematicides
- plant growth regulators
- repellents
- rodenticides

Toxicology and ecotoxicology

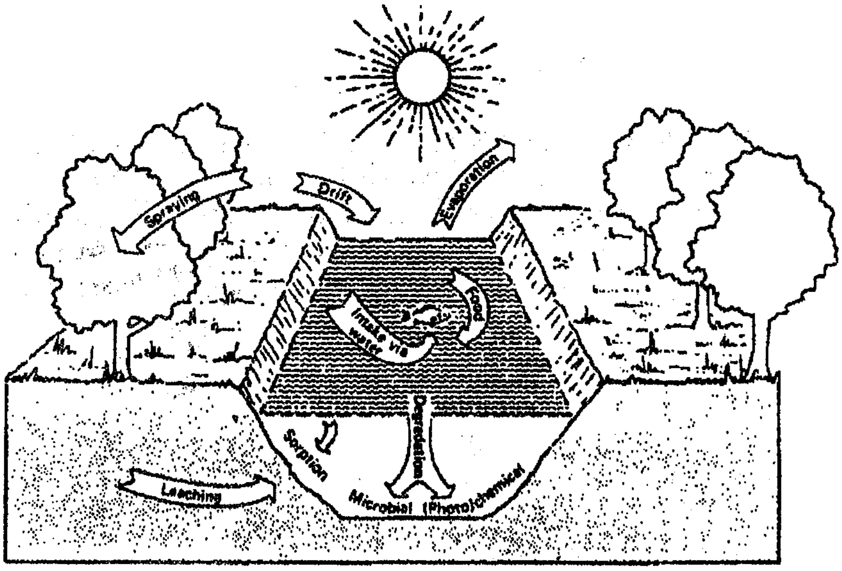
A striking difference between general toxicology and ecotoxicology (the fate of chemical substances in the environment in general) is that the chemical identity and the dose are often unknown. Once a toxicant is introduced into the environment, qualitative and quantitative changes can take place. In this way, one toxicant can generate an unknown number of new chemicals. The toxicant and its metabolites can go from one environmental compartment to another, thereby altering their concentrations.

A second difference is the choice of the target organism. In general toxicology, the main target organism is man and domestic animals. In ecotoxicology, the main targets are all kinds of organisms living in complex ecosystems (the biological community). In this respect, an ecotoxicologist not only has to deal with the interaction of the toxicant with single species, but he must also consider the new properties that are added at the higher levels of the community organization. The difference is visualized in the following figure:



Processes that affect the environmental concentration of toxicants

The next figure shows the processes that may play a role in the dispersion, elimination or concentration of a pesticide used for insect control in an orchard.



Abiotic and biotic processes playing a role in the dispersion, (bio)chemical changes and accumulation of pesticide sprayed in an orchard

The different processes that may affect the concentration of a toxicant in water, air, soil and organisms after being released into the environment are listed below:

Evaporation	volatilization into the atmosphere (volatile compounds; very hydrophobic compounds despite their very low vapour pressure)
Transport	diffusion ·. flow (in molecular form or "bound" to organic material and clay minerals) in water, soil and air ·. transport via biota (e.g. lead, DDT, PCB's in worms, birds, etc.)
Transformation	by physical-chemical processes: oxidation (hydrolysis) ·. reduction ·. photodegradation ·. dissociation (some organics) ·. speciation (metals) by biological processes: metabolism and breakdown
Accumulation	by physical-chemical processes: sorbtion ·. ion exchange ·. precipitation by biological processes: bioaccumulation (= bioconcentration) ·. biomagnification

Further details of these processes are beyond the scope of this paper and will not be discussed here. It can be concluded that the amount, fate and rate of uptake of a toxicant depend on the physical and chemical state of the toxicant and on the organism itself: its morphology, physiology and habitat being the main factors.

THE LOWER TUNUYÁN IRRIGATION AREA

The Province of Mendoza, located in the arid west of Argentina, has an annual rainfall of less than 250 mm. For this reason, the agricultural, urban and industrial activities are distributed in five irrigated oases.

The Tunuyán river area concentrates large part of the provincial productive potential and important urban settlements (San Martín, Rivadavia, Junín). The main characteristics of the area are: high population density, an industrial area distributed all over the oasis, the presence of a pollutant sector at the head of the river and a close contact between water and people (Chambouleyron, 1989). The total area of the oasis of the Lower and Middle Tunuyán is approximately 85,000 ha. The irrigation network is 1000 km long.

Between 1992 and 1994, research was carried out on the pollution levels in six secondary canals, in the Upper Tunuyán watershed, in El Carrizal dam (that receives water from the Upper Tunuyán River), in the Tiburcio Benegas diversion dam, and in six collectors (Chambouleyron, 1995). Lack of funds and time did not make it possible to carry out a more exhaustive monitoring to arrive at valid conclusions in such a vast area. For this reason, a secondary canal, which crosses an important urban center, and a tertiary canal ("hijuela") derived from the former were chosen. The Montecaseros canal crosses the city of San Martín, the most important town of the oasis, until reaching the Cuarta Chivilcoy hijuela. From this

canal, water is diverted into several branches ("ramos"). Two properties were selected: one of them receives water from the lower sector of the hijuela and the other receives water from a Collector (Colector Moyano) which is used for irrigation.

In order to draw a comparison between the water quality in this area and the water quality in the upper part of the system, some other sites were selected for regular sampling. These are located on the Canal Matriz Margen Izquierda (a few meters downstream from the Tiburcio Benegas diversion dam) and on the Canal San Martín (a few kilometers before the water crosses the city of San Martín).

The objectives of this research are:

- To assess changes in water quality as the water runs from the diversion dam to the field along the normal agricultural cycle.
- To formulate recommendations for the adequate use of water.
- To identify and test indicators that can be used to quantify and
- qualify the performance of irrigation and drainage.

MATERIAL AND METHODS

Selection of sampling sites

Water samples were collected from seven sites which are described below; the abbreviations used in the tables and graphs are indicated in brackets.

Canal Matriz Margen Izquierda (Matriz): it is a lined canal where water runs at high velocity. A site located some 50 meters downstream from the Tiburcio Benegas diversion dam was selected. There are no agricultural fields in the vicinity of the site. The results of the samples taken at this site show what the quality of the water entering the system is like.

Canal San Martín (San Martín): it is an earthen canal where, in spite of the high volume of water, the water velocity is remarkably lower than in Canal Matriz. The site selected to take water samples is a sector where the canal runs beside the Chileno Herrera street. In the vicinity of the site there are some agricultural properties planted with approximately 80 % of vineyards, 15 % of olive trees and 5 % of fruit trees. The results of the analysis of the samples show the degree of pollution in the upper part of the irrigation system.

Canal Montecaseros (Montecaseros): it is a lined canal where water runs at high velocity. A sampling site was selected downstream from the city of San Martín, a few meters before the diversion to hijuela Cuarta Chivilcoy. This is a typical agricultural area devoted almost entirely to vineyards. No houses were observed in the vicinity of this site. Samples from this site show the pollution levels produced by an urban - industrial center.

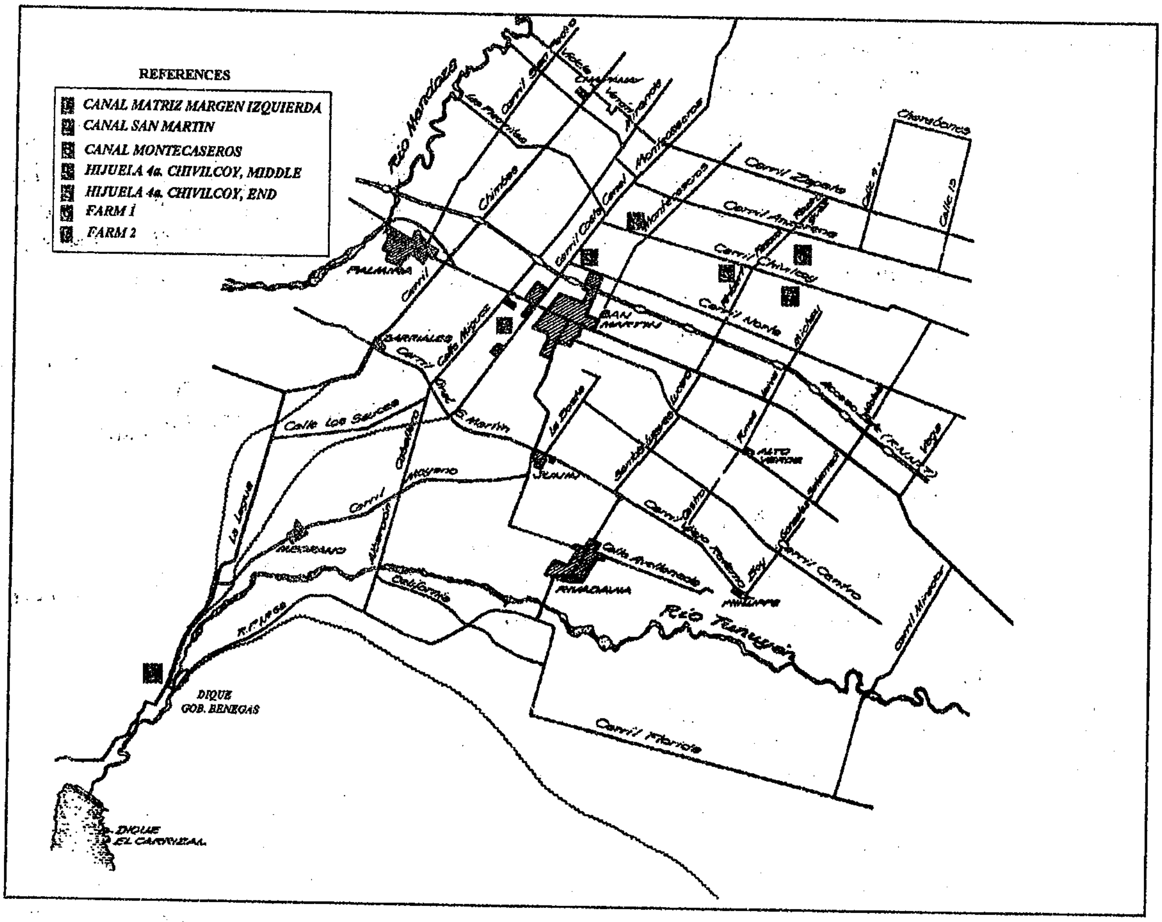
Hijuela Cuarta Chivilcoy, Middle (Hijuela M): this is an earthen canal with a relatively little flow. Sampling is carried out in a site located between Tropero Sosa and Lavalle streets. There are few agricultural properties, which are devoted only to vineyards, and a large number of houses. Sometimes the canal is used for recreational purposes. The water drawn from this canal is used mainly for domestic purposes.

Hijuela Cuarta Chivilcoy, End (Hijuela E): the sampling site is located some 300 meters upstream from Robert street. The agricultural characteristics of this zone are similar to the area previously described. Water drawn from this canal is used for different purposes other than irrigation. The data on this site indicates pollution levels near the end of the unit.

Farm 1 (F 1): sampling is performed at farm level. Irrigation water is diverted from the previously described "hijuela" and conveyed to the farm by a "ramo" (4th level canal). Fruit trees (mainly plum trees), vineyards and corn are grown in this area. The samples show the quality of the water that is used to irrigate the crops.

Farm 2 (F 2): the samples are collected from water conveyed by the Cañada del Moyano collector canal. The farms here are devoted to the cultivation of vineyards, and water is used only for irrigation. As from September 1996, no samples from this site were collected. In fact it does not belong to the irrigation network ending in the "ramos". Furthermore, and after several analysis of samples coming from this site were made, it can be concluded that the water is of good quality.

The following map shows the Lower Tunuyán system with the sampling sites.

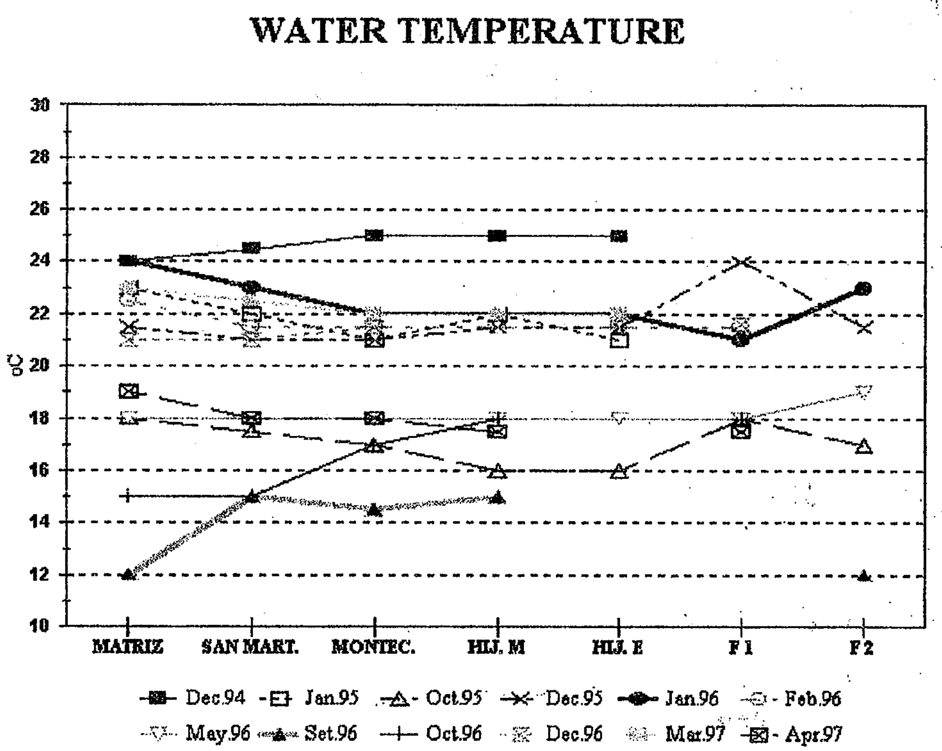

REFERENCES
CANAL MATRIZ MARGEN IZQUIERDA
CANAL SAN MARTIN
CANAL MONTECASEROS
HIJUELA 4a. CHIVILCOY, MIDDLE
HIJUELA 4a. CHIVILCOY, END
FARM 1
FARM 2
Río Mendoza
PALMIRA
SAN MARTIN
Calle Los Sauces
Cerril Norte
Cerril Chivilcoy
Cerril Zapata
Cerril Centro
Calle Avellaneda
RIVADAVIA
Río Tunuyán
Cerril Florida
DIQUE GOB. BENEGAS
DIQUE EL CARRIZAL

RESULTS AND DISCUSSION

Sampling began in December 1994. Due to operational problems in the irrigation system, samples were not collected in November 1995 and March 1996. Results of water analyses for the 1994/1995 and 1995/1996 agricultural cycles have already been reported in previous RPIP documents (see Annexes). Results corresponding to samples taken in September and October 1996 are presented in the following table:

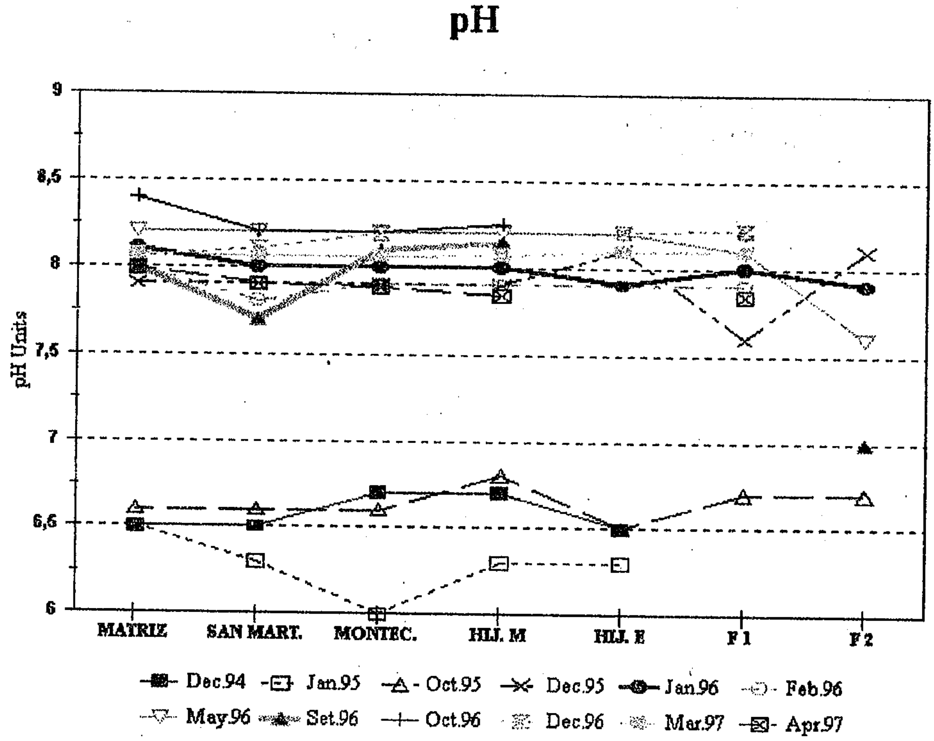
Water temperature

The differences between sites are related to the different air temperatures. The time difference between the first and the last sampling is of more than 3 hours.



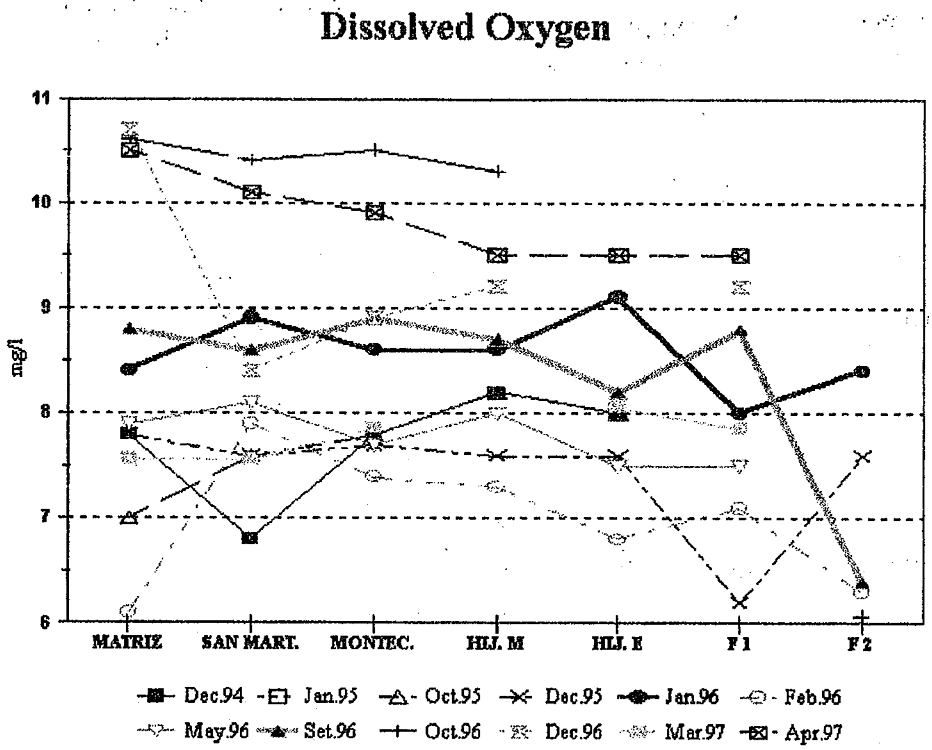
pH

In general, there are small fluctuations in pH values which vary between 7.6 and 8.1. These values show that water is suitable for irrigation and for aquatic life. The differences in the set of values before and after October 1996 are due to the different methods used to measure the pH.



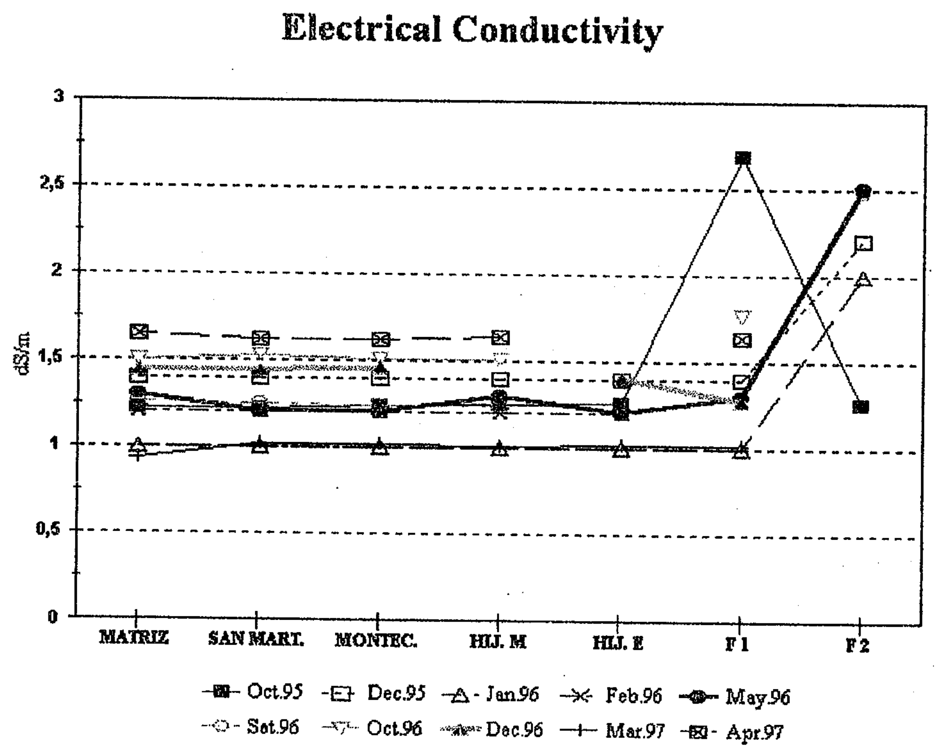
Dissolved oxygen

The available dissolved oxygen ranges between a minimum of 6.1 mg/l and a maximum of 10.7 mg/l. The limit to make life possible is 4 mg/l. From this point of view, all the samples are satisfactory.



Electrical Conductivity

During the irrigation season, EC values vary from 1.0 and 1.77 dS/m. These values show that any kind of crops can be cultivated in the sandy loam soils of the area under study. Though the values rendered by the samples taken in F 2 (drainage water) are higher, up to almost 3 mg/l, even sensitive crops can be irrigated.



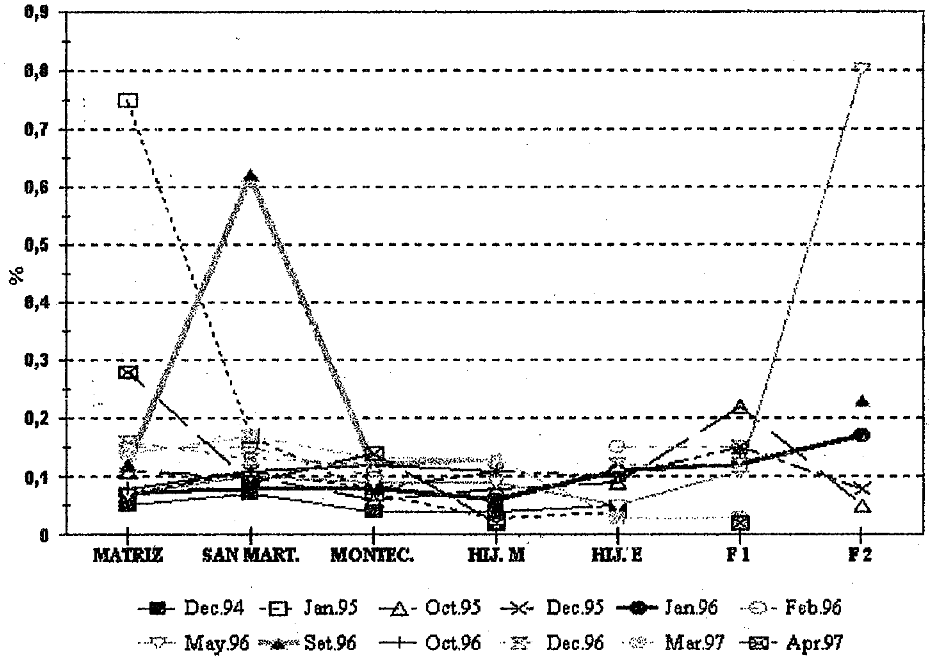
10-minute settleable solids and 2-hour settleable solids

The low values yielded by the 10' analysis and the degree of turbidity show that water does not carry any sediments. Very low values rendered by 2-hour settleable solids (most of them are 0) also show that there is a low amount of organic matter in the water. The results are presented in the attached Annexes.

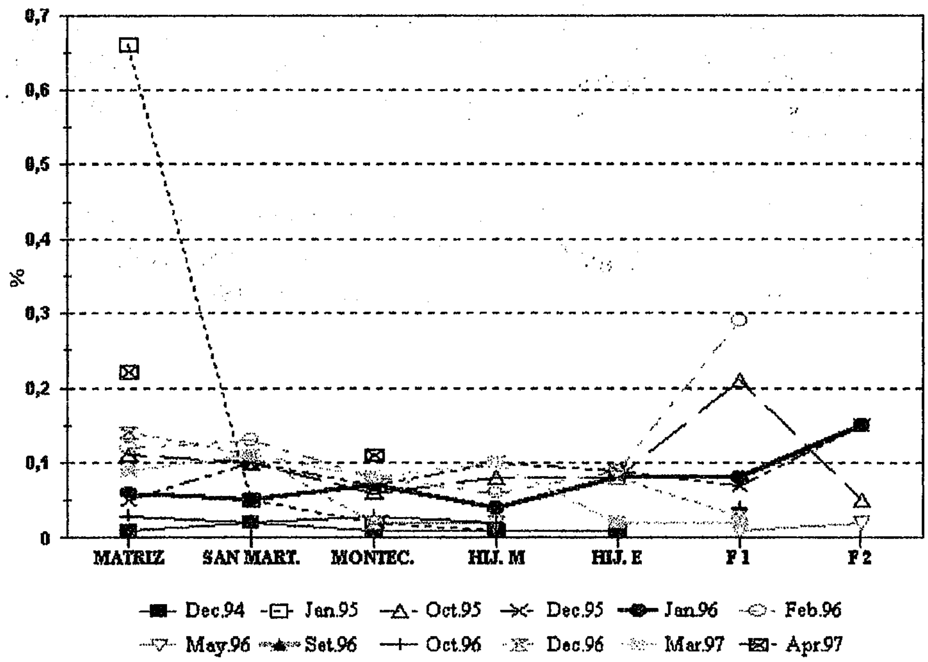
Total, Fixed and Volatile solids

Results show values that range between 0.05 and 0.23 mg/l for total solids. High values for fixed solids correspond to high EC values.

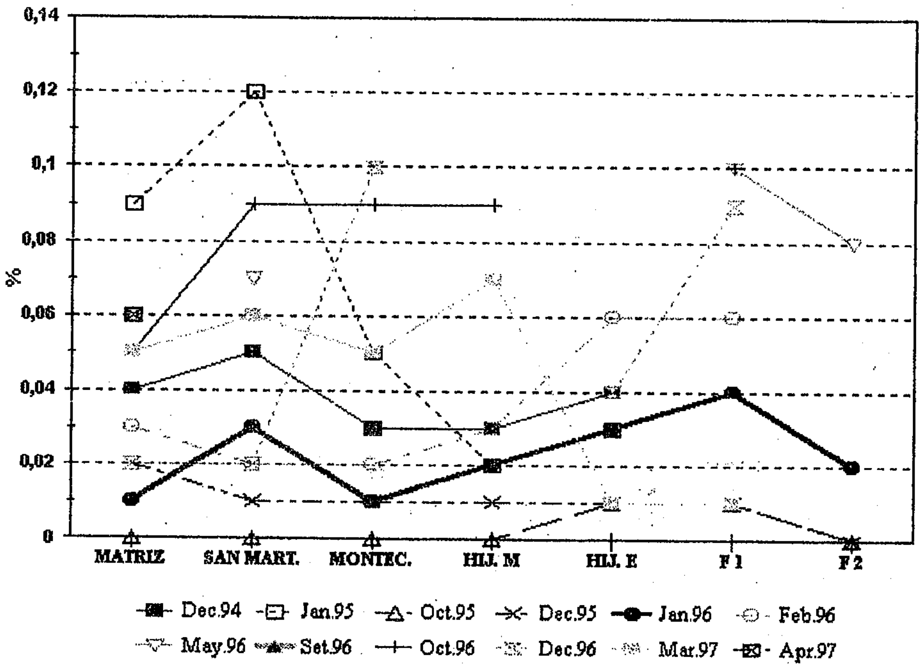
Total Solids



Fixed Solids



Volatile Solids

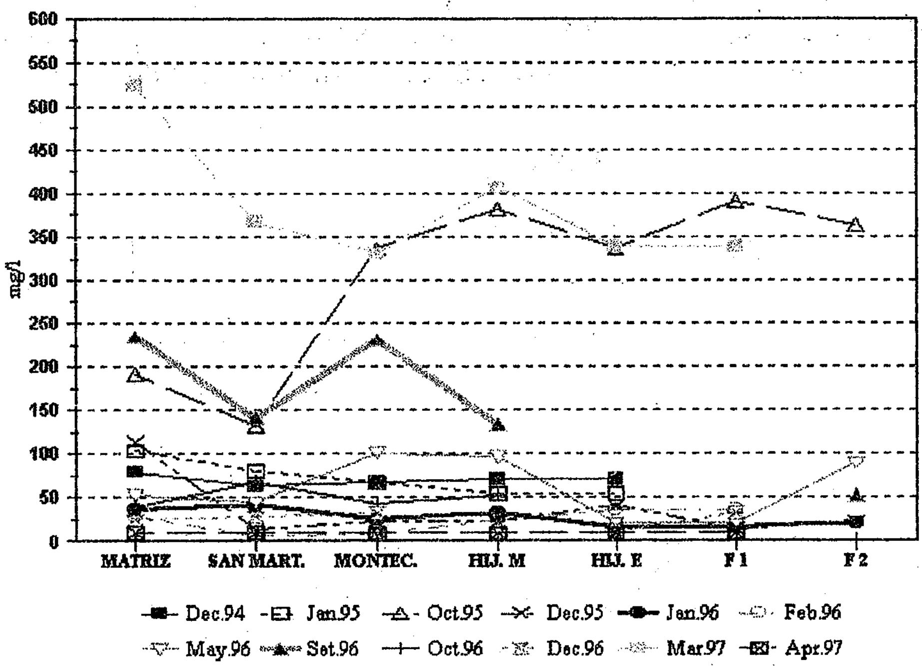


COD and BOD_5

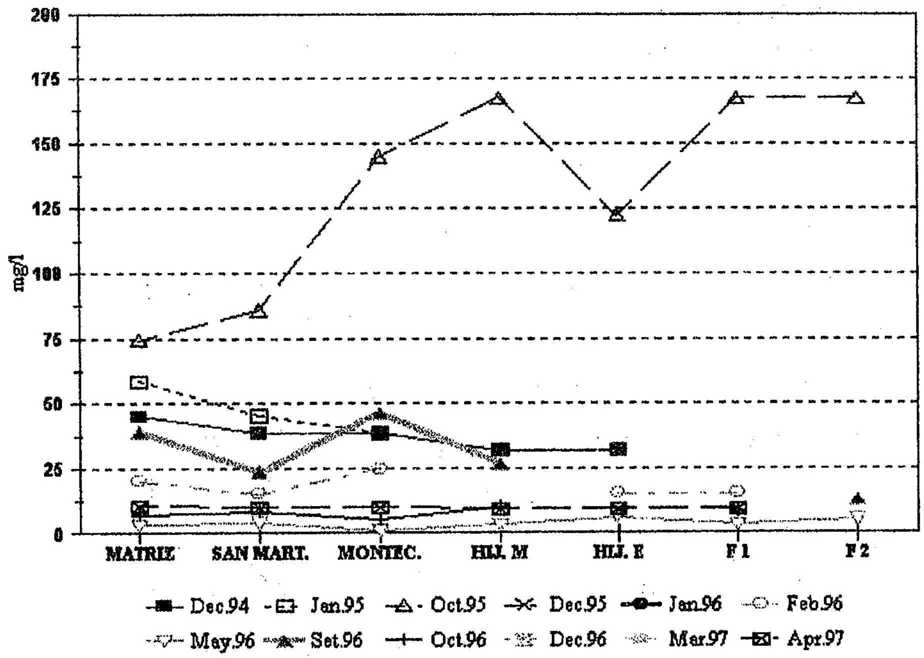
A slight decrease in COD values can be observed from the beginning to the end of the irrigation season. According to the Dissolved Oxygen values reported before and to the COD and BOD_5 values, it can be inferred that an important self-depuration process is taking place in the system.

Water can be used to irrigate any kind of crop (except for vegetables), but cannot be used either for drinking purposes (BOD_5 < 4 mg/l according to Cubillos, 1988) or for direct human contact (critical BOD_5 < 4 mg/l according to Cubillos, 1988).

Chemical Oxygen Demand (COD)



Biochemical Oxygen Demand (BOD 5)

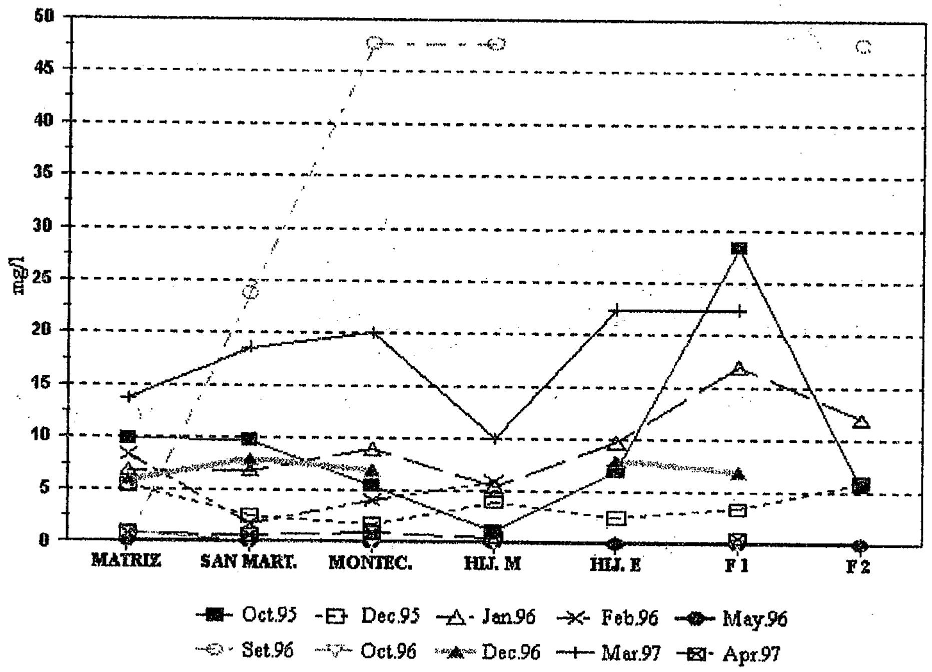


Total Nitrogen, Nitrites and Nitrates

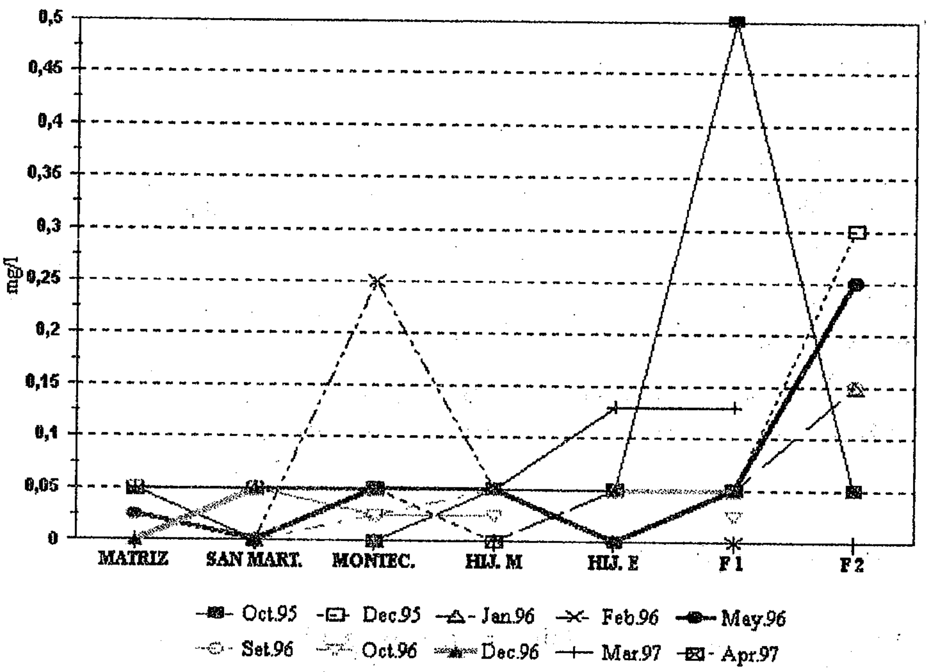
Since there are great fluctuations in the Total Nitrogen content in the samples, no conclusions can be drawn at this time. After the whole period of analysis is completed, we hope to be able to understand how Nitrogen behaves in the system.

Nitrites and nitrates values were lower than the critical values required for drinking water in Argentina: 0.1 mg/l for nitrites and 45 mg/l for nitrates (C.A.A., 1984). The presence of these elements in irrigation water is due to agricultural activities in the upper basin of the Tunuyán river and will probably benefit the crops in the lower parts of the system.

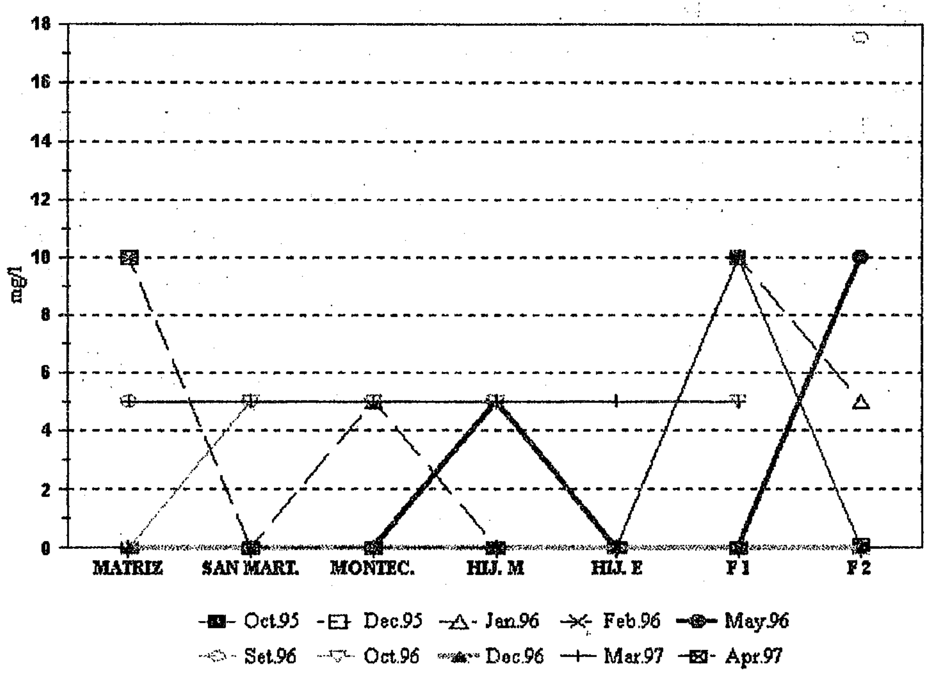
Total Nitrogen



Nitrites



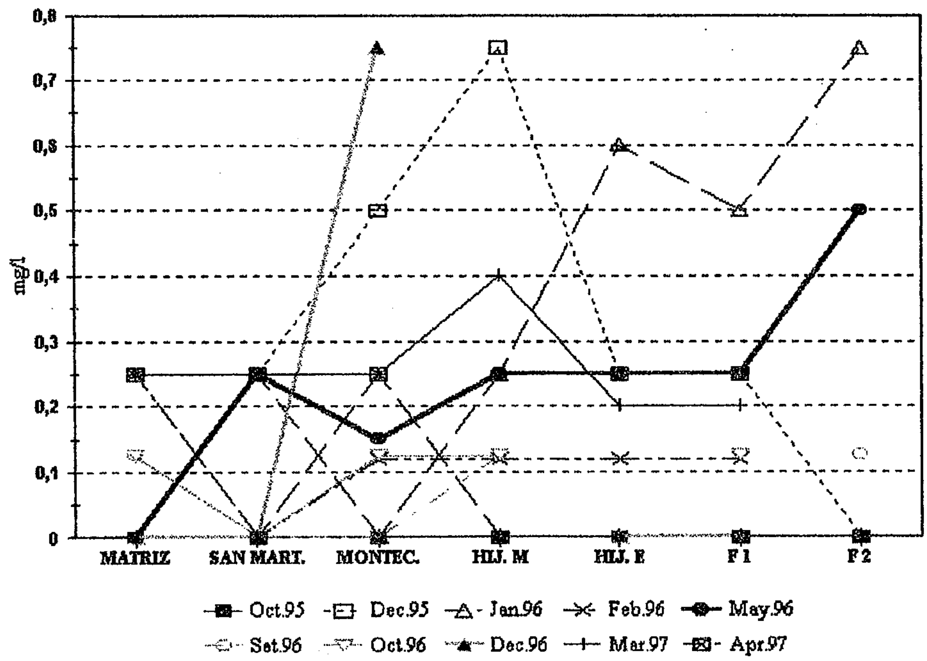
Nitrates



Phosphates

Phosphate samples also showed large fluctuations. According to the Water Resources Secretariat of Argentina, no limits are set for this parameter when water is used for irrigation, drinking purposes or direct human contact.

Phosphates

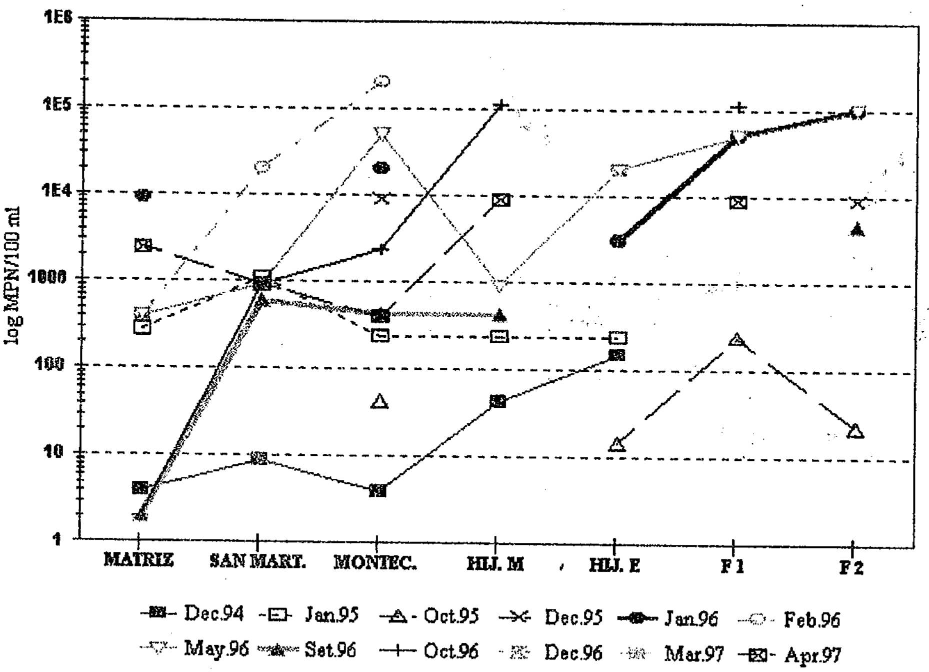


MICROBIOLOGICAL ANALYSIS

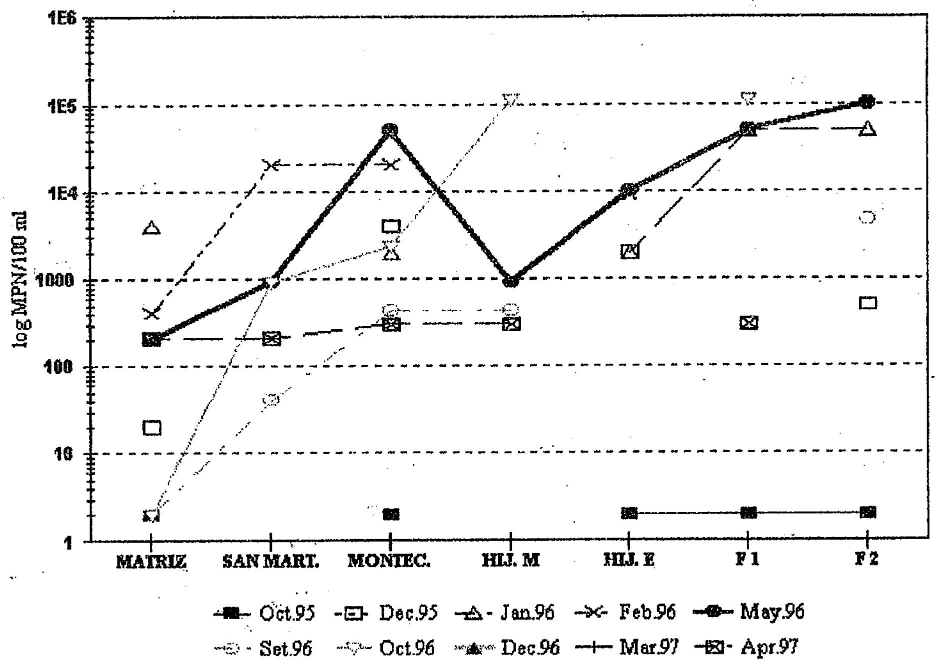
Microbiological analyses have shown large variations through time as well as in different sites along the irrigation network. However, especial attention should be paid to Total Coliform results. They were, many times, higher than the critical value of 200 (which is the limit in case of water used for human contact) and even of 500 (which is the limit for animal use). This, together with the high *Escherichia coli* inventory and the inventory of faecal coliform bacteria, shows that water is polluted by sewage efluents. The analyses also indicate that pathogenic organisms such as *Salmonella, Shigella,* etc., are present.

It must be pointed out that microbial pollution has already been detected in the upper reaches of the Tunuyán system. This shows that pollution starts in the upper basin, concentrates in El Carrizal dam, and then enters the lower system.

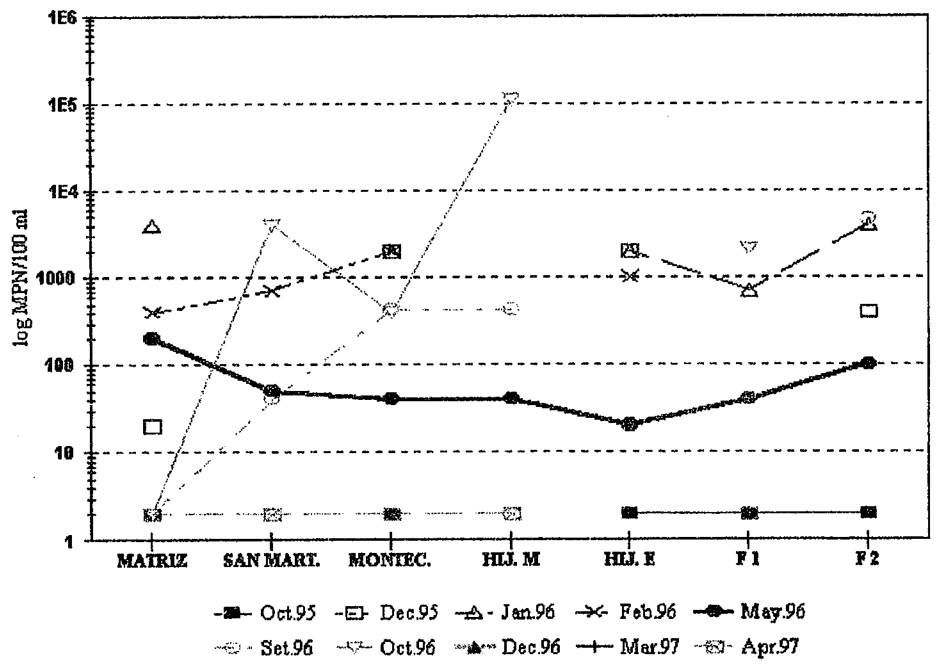
Total Coliform Bacteria

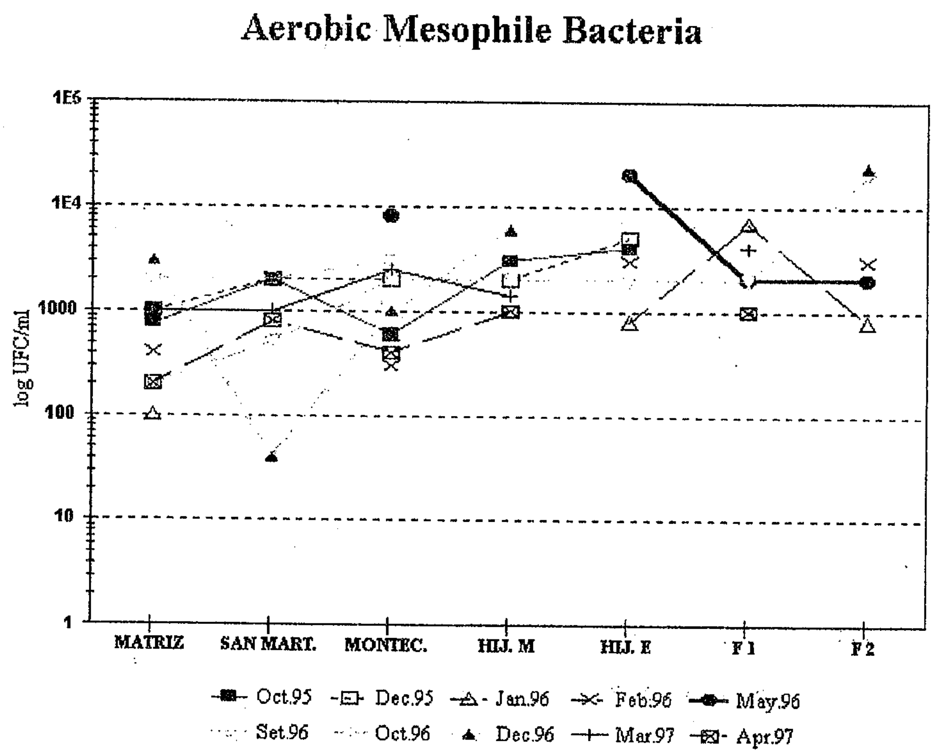


Faecal Coliform Bacteria



Escherichia coli

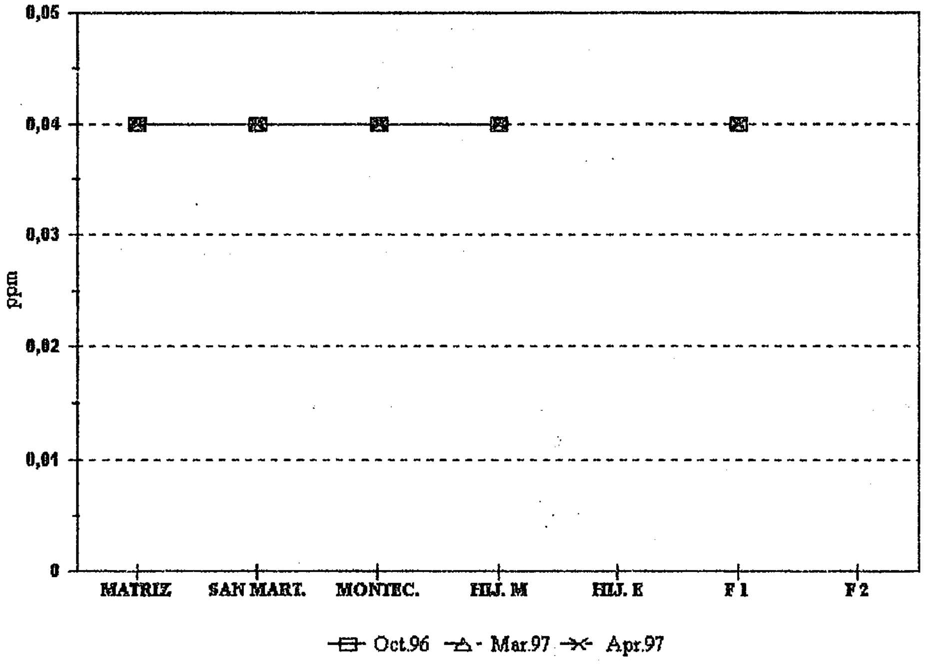




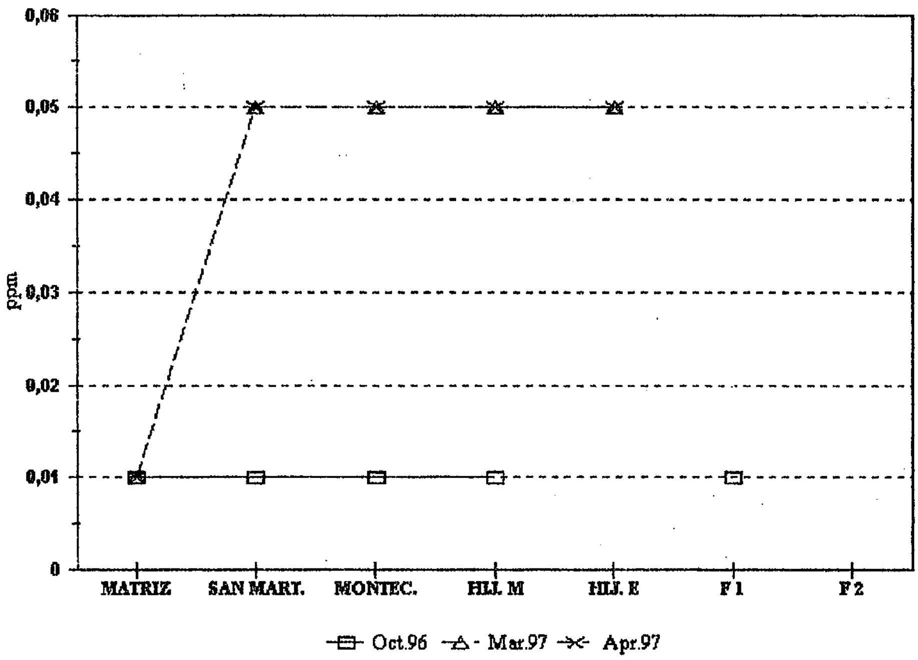
Aerobic Mesophile Bacteria
log UFC/ml
1E6
1E4
1000
100
10
1
MATRIZ
SAN MART.
MONTEC.
HIJ. M
HIJ. E
F 1
F 2
Oct.95
Dec.95
Jan.96
Feb.96
May.96
Set.96
Oct.96
Dec.96
Mar.97
Apr.97

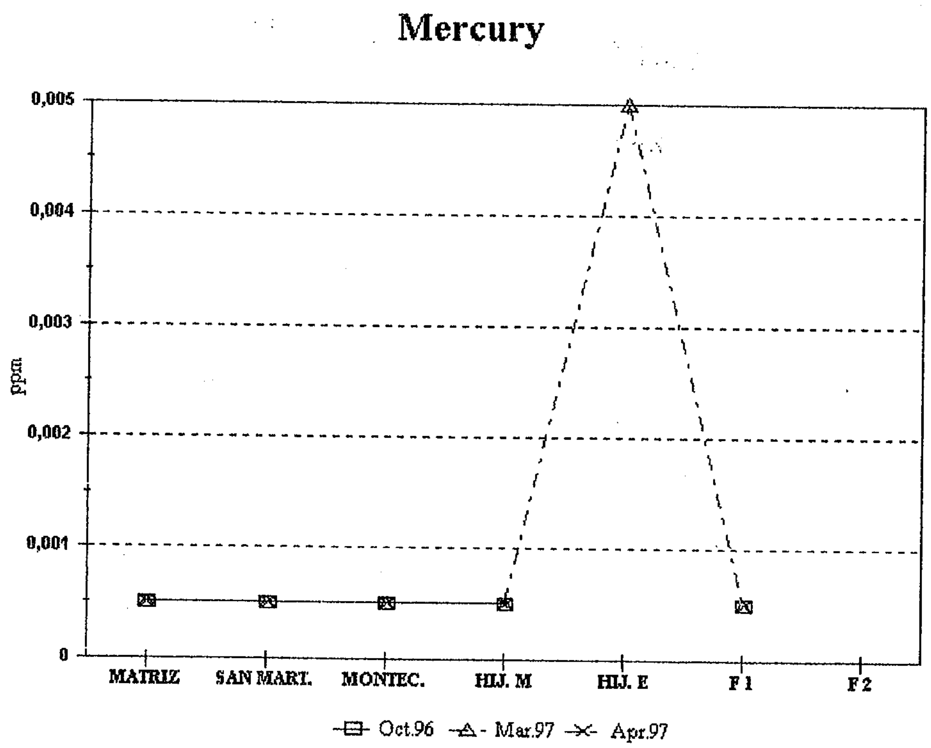
OTHER RESULTS (TRACE ELEMENTS AND HEAVY METALS)

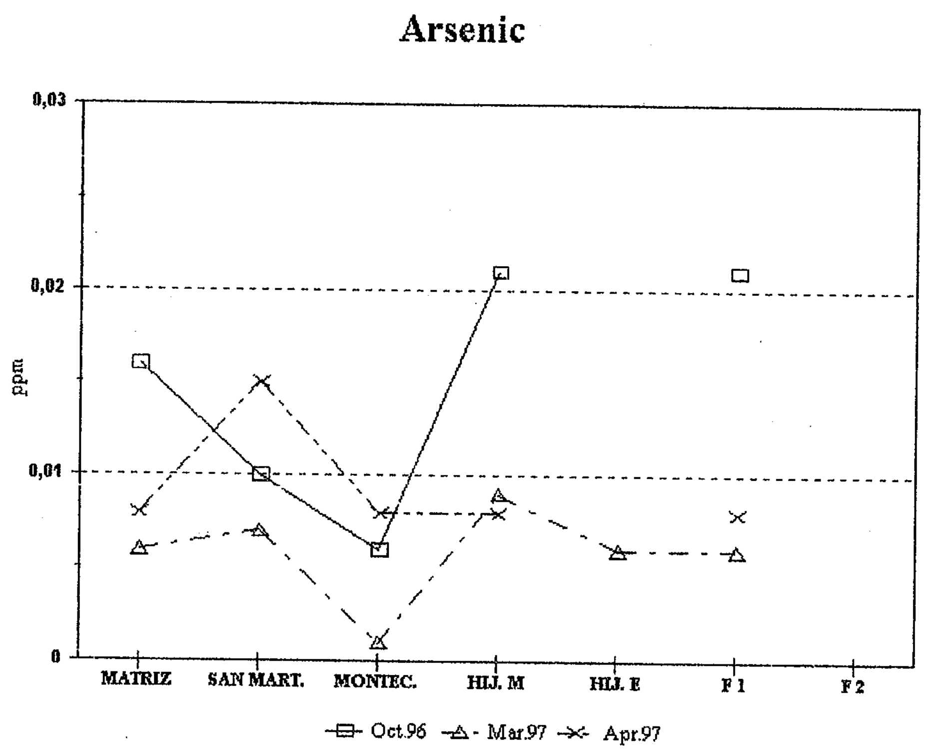
Chrome



Lead




Mercury
ppm
0,005
0,004
0,003
0,002
0,001
0
MATRIZ
SAN MART.
MONTEC.
HIJ. M
HIJ. E
F 1
F 2
Oct.96
Mar.97
Apr.97


Arsenic
ppm
0,03
0,02
0,01
0
MATRIZ
SAN MART.
MONTEC.
HIJ. M
HIJ. E
F 1
F 2
Oct.96
Mar.97
Apr.97

WATER POLLUTION INDICATORS

As shown in previous reports, some of the selected water pollution parameters (EC, BOD_5, COD, total Nitrogen, Phosphates and CFU) were calculated in two different ways.

First, the indicators were calculated following the procedures described at the beginning of this program:

$$\frac{\textbf{New Value - Old Value}}{\textbf{Old Value}}$$

New Value: on-site
Old Value: upstream

Since the above calculation rendered unsuitable results, it was necessary to carry out a second calculation, expressed as follows:

$$\frac{\textbf{Actual Value}}{\textbf{Critical Value}}$$

Actual value: resulting from the analysis of the sample
Critical value: limiting value according to certain criteria

Calculation procedures and indicator values for some selected parameters are herein presented according to the second calculation. Tables containing the results of the original indicators are included in the attached Annexes.

1.Relative change of EC

$$\text{Relative change of EC} = \frac{\text{real EC}}{\text{critical EC}}$$

Critical EC: 0.75 dS/m

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	-	-	-	-	-	-	-
Jan.'95	-	-	-	-	-	-	-
Oct. '95	1.63	1.63	1.65	1.67	1.68	3.57	1.68
Dec.'95	1.69	1.71	1.68	1.69	1.69	1.71	3.04
Jan.'96	1.41	1.40	1.41	1.39	1.41	1.41	2.63
Feb.'96	1.59	1.59	1.59	1.59	1.57	1.57	-
Set. '96	1.68	1.67	1.65	1.65	-	-	3.31
Oct. '96	2	2.04	2.01	2.01	-	2.36	-
Dec. '96	1.92	1.92	1.96	1.95	1.71	1.88	1.71
Mar. '97	1.25	1.36	1.35	1.36	1.35	1.36	1.36
Apr. '97	2.2	2.16	2.16	2.19	-	2.19	-

2. Relative change of BOD_5

$$\text{Relative change of } BOD_5 = \frac{\text{real } BOD_5}{\text{critical } BOD_5}$$

Critical BOD_5: 4 mg/l

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	11.3	9.6	9.6	7.9	7.9	-	-
Jan.'95	14.6	11.3	9.6	8.0	8.0	-	-
Oct. '95	18.6	21.4	36.2	41.9	30.6	41.9	41.9
Dec.'95	-	-	-	-	-	-	-
Jan.'96	-	-	-	-	-	-	-
Feb.'96	5.1	3.8	6.2	-	3.8	3.8	-
Set. '96	9.79	5.9	11.55	6.63	-	-	-
Oct. '96	1.82	2.07	1.325	2.57	-	-	-
Dec. '96	-	-	-	-	-	-	-
Mar. '97	-	-	-	-	-	-	-
Apr. '97	1.25	1.475	1.475	1.125	-	1.125	-

3.Relative change of Nitrates-N

$$\text{Relative change of Nitrate-N} = \frac{\text{Real Nitrate-N}}{\text{Critical Nitrate-N}}$$

Critical Nitrate-N: 30 mg/l

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Oct. '95	0	0	0	0	0	0.33	0
Dec.'95	0	0	0	0	0	0	0.0033
Jan.'96	0	0	0.167	0	0	0.33	0.167
Feb.'96	0	0	0	0.167	0	0	-
Set. '96	0.167	0.167	0.167	0.167	-	-	0.583
Oct. '96	0	0.167	0.167	0.167	-	0.167	-
Dec. '96	0	0	0	0	0	0	0
Mar. '97	0.11	0.11	0	0.11	0.11	0.11	0.11
Apr. '97	0.33	0	0	0	-	0	-

4.Relative change of CFU

$$\text{Relative change of CFU} = \frac{\text{real CFU}}{\text{critical CFU}}$$

Critical CFU: 100

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	7.5	20.0	6.0	30.0	40.0	-	-
Jan.'95	10.0	20.0	20.0	20.0	50.0	-	-
Oct. '95	70.0	8.0	-	8.0	6.0	0.1	-
Dec.'95	4.0	-	30.0	-	-	30.0	30.0
Jan.'96	10.0	-	80.0	-	160.0	20.0	20.0
Feb.'96	20.0	20.0	30.0	-	70.0	-	-
Set. '96	30	0.4	10	60	-	-	24
Oct. '96	10	10	25	14	-	40	-
Dec. '96	14	40	50	20	50	20	-
Mar. '97	20	70	100	100	400	400	-
Apr. '97	2	8	4	10	-	10	-

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the results yielded by the water analyses, the following conclusions and recommendations can be made:

1. As regards Temperature, pH and Dissolved Oxygen, the water in the system is suitable for life development and there seems to be a good self-purification mechanism.
2. EC values and sandy-loam soils render it possible to cultivate any kind of crop.
3. On the basis of settleable solids analyses and BOD5 and COD values, the organic matter load seems to be low. The last two parameters in samples taken during the first month of the irrigation season are high.
4. Farmers, the local population and consumers of some crops such as vegetables grown in the area are confronted with the risk of contracting diseases. This means that water can be used to irrigate vineyards, olive trees and fruit trees as long as sprinklers are not used. As for vegetables, it is recommended to use groundwater. The local population must be warned about the risk of using water from the canal for domestic or recreational uses. If faced with the need to use such water, it should be previously boiled or chlorinated.
5. For other parameters, like Total N, Nitrites, Nitrates and Phosphates, no conclusions can be drawn so far until they are further analyzed.
6. A comparison of the two above mentioned calculations shows that the second (which uses critical values) is better. This is so because, in this case, a positive value can always be calculated for the first site upstream. However, it is sometimes very difficult to define critical values as is the case of Total Nitrogen and Phosphates. These elements, which are present in irrigation water, are beneficial to crops and as such there is no limiting value for them. There are no critical values either, when water is used for human contact (swimming, bathing, etc.).
7. New critical values must be set for some parameters according to local conditions. If limiting values are lacking, it will be necessary to calculate them according to some quality criteria.
8. In order to assess irrigation water quality, EC, BOD5, COD, CFU, MPN of Faecal Coliform bacteria and pH values should be analyzed.
9. If water quality must be assessed for domestic or recreational uses, analyses of Nitrates, Nitrites, Dissolved Oxygen and *Escherichia coli* should be added to the above mentioned parameters.
10. As regards sampling and analysis frequencies, every two months seems to be a reasonable period. The collection of samples should made during the first month of each irrigation season.

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ANNEXES

WATER POLLUTION INDICATORS (first calculation)

1.Relative change of EC= $\frac{\text{New EC value - Old ECvalue}}{\text{Old EC value}}$

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	-	-	-	-	-	-	-
Jan.'95	-	-	-	-	-	-	-
Oct. '95	-	0	0.016	0.008	0.008	1.127	-
Dec.'95	-	0.008	-0.015	0.008	0	0.008	-
Jan.'96	-	-0.009	0.009	-0.019	0.019	0	-
Feb.'96	-	0	0	0	-0.008	0	-
Set. '96	-	- 0.0079	0.008	0	-	-	-
Oct. '96	-	0.02	- 0.013	0	-	-	-
Dec. '96	-	0	0.021	0.014	- 0.123	0	-
Mar. '97	-	0.09	- 0.01	0	- 0.01	0.01	-

2.. Relative change of BOD_5 = $\frac{\text{New } BOD_5 \text{ value - Old } BOD_5 \text{ value}}{\text{Old } BOD_5 \text{ value}}$

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	-	-0.146	0	-0.174	0	-	-
Jan.'95	-	-0.227	-0.150	-0.173	0	-	-
Oct. '95	-	0.144	0.690	0.155	-0.269	0.367	-
Dec.'95	-	-	-	-	-	-	-
Jan.'96	-	-	-	-	-	-	-
Feb.'96	-	0.621	-	-	-	0	-
Set. '96	-	0.015	0.95	-0.426	-	-	-
Oct. '96	-	0.137	-0.36	0.94	-	-	-
Dec. '96	-	-	-	-	-	-	-
Mar. '97	-	-	-	-	-	-	-

3. Relative change of COD = $\frac{\text{New COD value - Old COD value}}{\text{Old COD value}}$

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	-	-0.200	0.063	0.057	0	-	-
Jan.'95	-	-0.227	-0.165	-0.175	0	-	-
Oct. '95	-	-0.307	1.542	0.135	-0.120	0.160	41.9
Dec.'95	-	-0.880	0.669	0	0.802	-0.667	-
Jan.'96	-	0.030	-0.399	0.331	-0.500	0	-
Feb.'96	-	-0.778	0.286	2.00	0.502	0	
Set. '96	-	0.0025	0.011	0.0025	-	-	-
Oct. '96	-	0.7	0.0095	0.027	-	-	-
Dec. '96	-	0.16	- 0.28	0.14	0	- 0.625	-
Mar. '97	- 0.3	- 0.011	- 0.01	0.23	- 0.17	- 0.17	

4. Relative change of Total N = $\frac{\text{New Total N value - Old Total N value}}{\text{Old Total N value}}$

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	-	-	-	-	-	-	-
Jan.'95	-	-	-	-	-	-	-
Oct. '95	-	-0.01	-0.44	-0.782	4.833	3.042	-
Dec.'95	-	-0.527	-0.308	1.222	-0.350	0.308	-
Jan.'96	-	0	0.304	-0.389	0.782	0.735	-
Feb.'96	-	-0.786	1.277	0.463	-	-	-
Set. '96	-	-	0.084	0.021	-	-	-
Oct. '96	-	0	-	-	-	-	-
Dec. '96	-	0.33	- 0.12	- 0.12	0	0.14	-
Mar. '97	-	0.36	0.14	0.07	- 0.5	1.24	-

5. Relative change of Nitrate-N = $\frac{\text{New Nitrate - N value - Old Nitrate - N value}}{\text{Old Nitrate - N value}}$

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Oct. '95	-	-	-	-	-	1	-
Dec.'95	-	-	-	-	-	-	-
Jan.'96	-	-	-	-	-	1	-
Feb.'96	-	-	-	-1	-1	-	-
Set. '96	-	-	-	0	-	-	-
Oct. '96	-	-1	-	0	-	-	-
Dec. '96	-	0	0	0	0	0	-
Mar. '97	0	- 1	0	0	0	0	-

6. Relative change of Phosphates = <u>New Phosphates N value - Old Phosphates value</u>

Old Phosphates value

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	-	-	-	-	-	-	-
Jan.'95	-	-	-	-	-	-	-
Oct. '95	-	0	0	0	0	0	-
Dec.'95	-	0	1	0.5	-0.66	0	-
Jan.'96	-	0	-1	0	1.40	-0.167	-
Feb.'96	-	-1	0	0	0	0	-
Set. '96	-	0	0	-	-	-	-
Oct. '96	-	0	0	0	-	-	-
Dec. '96	0	-	-	- 1	0	0	-
Mar. '97	0	0	0	0.6	- 0.5	- 0.5	-

7. Relative change of CFU = $\frac{\text{New CFU value - Old CFU value}}{\text{Old CFU value}}$

Indicators:

	Matriz	San Martín	Montec.	Hijuela M	Hijuela E	Farm 1	Farm 2
Dec.'94	-	-	-	-	-	-	-
Jan.'95	-	-	-	-	-	-	-
Oct. '95	-	-0.866	-	-	-0.25	-0.833	-
Dec.'95	-	-	-	-	-	-	-
Jan.'96	-	-	-	-	-	-0.875	-
Feb.'96	-	0	-0.5	-	-	-	-
Set. '96	-	-0.99	24	5	-	-	-
Oct. '96	-	0	1.5	-0.44	-	-	-

RESULTS OF WATER ANALYSES

December 1994

	MATRIZ.	SAN MARTÍN.	MONTEC.	HIJUELA	HIJUELA E
temp. (oC)	24	24,5	25	25	25
pH	6,5	6,5	6,7	6,7	6,5
S.S.10' (mg/l)	0,01	0,01	>>0.01	0,01	0,01
S.S.2 hs (mg/l)	0,01	0,01	>>0.01	0,01	0,01
Tot. Sol. (%)	0,05	0,07	0,04	0,04	0,05
Fixed Sol. (%)	0,01	0,02	0,01	0,01	0,01
Vol. Sol. (%)	0,04	0,05	0,03	0,03	0,04
Diss.Oxy.	7,8	6,8	7,8	8,2	8
COD (mg/l)	79,4	63,5	67,5	71,4	71,4
BOD 5 (mg/l)	45,1	38,5	38,5	31,8	31,8
MPN/100 ml	>3	9	>3	43	150
UFC/ml	750	2000	600	3000	4000

January 1995

	MATRIZ	SAN	MONTEC.	HIJUELA	HIJUELA E
temp. (oC)	23	22	21	22	21
pH	6,5	6,3	6	6,3	6,3
S.S.10' (mg/l)	0,01	>>0,01	0,01	0,01	0,01
S.S.2 hs (mg/l)	0,01	>>0,01	0:01	0,01	0,01
Tot. Sol. (%)	0,75	0,17	0,07	0,03	0,04
Fixed Sol. (%)	0,66	0,05	0,02	0,01	0,01
Vol. Sol. (%)	0,09	0,12	0,05	0,02	0,03
Diss.Oxy.	7	7,6	7,8	8,2	8
COD (mg/l)	103,6	80,1	66,9	55,15	55,15
BOD 5 (mg/l)	58,6	45,3	38,6	31,9	31,9
MPN/100 ml	280	1100	240	240	240
UFC/ml	1000	2000	2000	2000	5000

October 1995

	MATRIZ	SAN	MONTEC	HIJUELA	HIJUELA	F 1	F 2
temp. (oC)	18	17,5	17	16	16	18	17
pH	6,6	6,6	6,6	6,8	6,5	6,7	6,7
S.S.10' (mg/l)	<<0.01	<<0.01	<<0.01	<0.01	0,1	0,1	<<0.01
S.S.2 hs (mg/l)	<<0.01	<<0.01	<<0.01	<0.01	0,1	0,1	<<0.01
Tot. Sol. (%)	0,11	0,1	0,06	0,08	0,09	0,22	0,05
Fixed Sol. (%)	0,11	0,1	0,06	0,08	0,08	0,21	0,05
Vol. Sol. (%)	0	0	0	0	0,01	0,01	0
Diss.Oxy. (mg/l)	7,8	7,6	7,7	7,6	7,6	6,2	7,6
COD (mg/l)	190,9	132,3	336,3	381,7	336,3	390,8	363,5
BOD 5 (mg/l)	74,5	85,75	145	167,5	122,5	167,5	167,5
MPN/100 ml	<3	n.d.	43	n.d.	15	240	23
UFC/ml	100	n.d.	600	n.d.	800	7000	800
Fae.colif. (MPN/100	<3	n.d.	<3	n.d.	<3	<3	<3
E.coli (MPN/100 ml)	<3	n.d.	<3	n.d.	<3	<3	<3
NO2- (mg/l0	0,05	0	0	0,05	0,05	0,5	0,05
NO3- (mg/l)	0	0	0	0	0	10	0
PO4 3- (mg/l)	0	0	0	0	0	0	0
E.C. (dS/m)	1,22	1,22	1,24	1,25	1,26	2,68	1,26
Total N (mg/l)	98,56	98,56	54,88	10,84	69,44	98,56	54,88
Color	c.less	c.less (lake)	c.less	c.less	c.less	c.less	c.less
Odor	o.less	o.less	o.less	o.less	o.less	o.less	o.less
Turbidity	0/+	0/+	0/+	0/+	0/+	0/+	0/+

December 1995

	MATRIZ	SAN	MONTEC	HIJUELA	HIJUELA	F 1	F 2
temp. (oC)	21,5	21	21	21,5	21,5	24	21,5
pH	7,9	7,9	7,9	7,9	8,1	7,6	8,1
S.S.10' (mg/l)	<<0.1	<<0.1	<<0.1	0,1	0,1	0,1	<<0.1
S.S.2 hs (mg/l)	0	0	0	0	0	0	0
Tot. Sol. (%)	0,07	0,11	0,08	0,11	0,1	0,15	0,08
Fixed Sol. (%)	0,05	0,1	0,07	0,1	0,09	0,07	0,15
Vol. Sol. (%)	0,02	0,01	0,01	0,01	0,01	0,01	0
Diss.Oxy. (mg/l)	8,4	8,9	8,6	8,6	9,1	8	8,4
COD (mg/l)	113,6	13,6	22,7	22,7	40,9	13,6	22,7
BOD 5 (mg/l)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MPN/100 ml	400	n.d.	9000	n.d.	20000	n.d.	9000
UFC/ml	400	n.d.	300	n.d.	3000	n.d.	3000
Fae.colif. (MPN/100	20	n.d.	4000	n.d.	2000	n.d.	500
E.coli (MPN/100 ml)	20	n.d.	2000	n.d.	2000	n.d.	400
NO2- (mg/l0	0,05	0,05	0,05	0	0,05	0,05	0,3
NO3- (mg/l)	0	0	0	0	0	0	0,1
PO4 3- (mg/l)	0,25	0,25	0,5	0,75	0,25	0,25	0
E.C. (dS/m)	1,4	1,4	1,4	1,4	1,4	1,4	2,2
Total N (mg/l)	5,5	2,6	1,8	4	2,6	3,4	6
Color	c.less	c.less	c.less	c.less	c.less	c.less	c.less
Odor	o.less	o.less	o.less	o.less	o.less	o.less	o.less
Turb.	0	0	0	0	0	0	0

January 1996

	MATRIZ	SAN	MONTEC	HIJUELA	HIJUELA	F 1	F 2
temp. (oC)	24	23	22	22	22	21	23
pH	8,1	8	8	8	7,9	8	7,9
S.S.10' (mg/l)	0,07	0,05	0,1	0,1	0,1	<0,1	<0,1
S.S.2 hs (mg/l)	0	0,05	0,02	0	0,05	0	0
Tot. Sol. (%)	0,07	0,08	0,08	0,06	0,11	0,12	0,17
Fixed Sol. (%)	0,06	0,05	0,07	0,04	0,08	0,08	0,15
Vol. Sol. (%)	0,01	0,03	0,01	0,02	0,03	0,04	0,02
Diss.Oxy. (mg/l)	6,1	7,9	7,4	7,3	6,8	7,1	6,3
COD (mg/l)	36,7	40,8	24,5	32,6	16,3	16,3	20,4
BOD 5 (mg/l)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MPN/100 ml	9000	n.d.	20000	n.d.	3000	50000	100000
UFC/ml	1000	n.d.	8000	n.d.	20000	2000	2000
Fae.colif. (MPN/100	4000	n.d.	2000	n.d.	2000	50000	50000
E.coli (MPN/100 ml)	4000	n.d.	2000	n.d.	2000	700	4000
NO2- (mg/l0	0	0	0	0	0,05	0,05	0,15
NO3- (mg/l)	0	0	5	0	0	10	5
PO4 3- (mg/l)	0,25	0,25	0	0,25	0,6	0,5	0,75
E.C. (dS/m)	1	1	1	1	1	1	2
Total N (mg/l)	6,9	6,9	9	5,5	9,8	17	12
Color	c.less	c.less	c.less	c.less	c.less	c.less	c.less
Odor	o.less	o.less	o.less	o.less	o.less	o.less	o.less
Turbidity	0	0/+	0/+	0/+	0/+	0/+	0

February 1996

	MATRIZ	SAN	MONTEC	HIJUELA	HIJUELA	F 1	F 2
temp. (oC)	22,5	21,5	21,5	21,5	21,5	21,5	n.d.
pH	8	7,8	7,9	7,9	7,9	7,9	n.d.
S.S.10' (mg/l)	<<0.1	0,2	0,1	<0,1	0,2	0,2	n.d.
S.S.2 hs (mg/l)	0	0	0	0	0	0	n.d.
Tot. Sol. (%)	0,15	0,15	0,1	n.d.	0,15	0,15	n.d.
Fixed Sol. (%)	0,12	0,13	0,08	0,06	0,09	0,29	n.d.
Vol. Sol. (%)	0,03	0,02	0,02	0,03	0,06	0,06	n.d.
Diss.Oxy. (mg/l)	7,9	8,1	7,7	8	7,5	7,5	n.d.
COD (mg/l)	28,4	6,3	8,1	24,3	36,5	36,5	n.d.
BOD 5 (mg/l)	20,3	15,3	24,8	n.d.	15,3	15,3	n.d.
MPN/100 ml	400	20000	200000	n.d.	20000	n.d.	n.d.
UFC/ml	2000	2000	3000	n.d.	7000	n.d.	n.d.
Fae.colif. (MPN/100	400	20000	20000	n.d.	9000	n.d.	n.d.
E.coli (MPN/100 ml)	400	700	2000	n.d.	1000	n.d.	n.d.
NO2- (mg/l)	0,05	0	0,25	0,05	0	0	n.d.
NO3- (mg/l)	0	0	0	5	0	0	n.d.
PO4 3- (mg/l)	0,25	0	0,12	0,12	0,12	0,12	n.d.
E.C. (dS/m)	1,2	1,2	1,2	1,2	1,2	n.d.	n.d.
Total N (mg/l)	8,4	1,8	4,1	6	n.d.	n.d.	n.d.
Color	c.less	c.less	c.less	c.less	c.less	c.less	n.d.
Odor	fish	o.less	vague	soil	o.less	o.less	n.d.
Turbidity	0	0	0	0	0	0	n.d.

May 1996

	MATRIZ	SAN	MONTEC	HIJUELA.	HIJUELA	F 1	F 2
temp. (oC)	18	18	18	18	18	18	19
pH	8,2	8,2	8,2	8,2	8,2	8,1	7,6
S.S.10' (mg/l)	<<0,05	<<0,05	<<0,05	0,05	<<0,03	0,05	0,2
S.S.2 hs (mg/l)	0	0	0	0,05	0	0	0
Tot. Sol. (%)	0,07	0,1	0,09	0,09	0,05	0,11	0,8
Fixed Sol. (%)	n.d.	n.d.	0,02	0,02	n.d.	0,01	0,02
Vol. Sol. (%)	n.d.	0,07	n.d.	0,07	n.d.	0,1	0,08
Diss.Oxy. (mg/l)	8,8	8,6	8,9	8,7	8,2	8,8	6,4
COD (mg/l)	52,7	44,6	101,3	97,3	20,3	20,3	89,2
BOD 5 (mg/l)	3,1	4,1	1	3,1	6,1	3,1	5,1
MPN/100 ml	400	900	50000	900	20000	5000	100000
UFC/ml	200	500	2000	2000	2000	2000	20000
Fae.colif. (MPN/100	200	900	50000	900	10000	5000	100000
E.coli (MPN/100 ml)	200	50	40	40	20	40	100
NO2- (mg/l0	0,025	0	0,05	0,05	0	0,05	0,25
NO3- (mg/l)	0	0	0	5	0	0	10
PO4 3- (mg/l)	0	0,25	0,15	0,25	0,25	0,25	0,5
E.C. (dS/m)	1,3	1,2	1,2	1,3	1,2	1,3	2,5
Total N (mg/l)	0	0	0	0	0	0	0
Color	c.less(alga	c.less(lake)	c.less	c.less	c.less	c.less	c.less
Odor	o.less	o.less	o.less	o.less	o.less	o.less	o.less
Turbidity.	0/+	0/+	0/+	0/+	0/+	0/+	0/+

September 1996

	MATRIZ	SAN	MONTEC	HIJUELA.	HIJUELA	F 1	F 2
temp. (oC)	12	15	14.5	15	n.d.	n.d.	12
pH	8.0	7.7	8,1	8,15	n.d.	n.d.	7,0
S.S.10' (mg/l)	<<0.1	<<0.01	<<0.1	<0.1	n.d.	n.d.	0,8
S.S.2 hs (mg/l)	<<0.1	<<0.1	<<0.1	0.1	n.d.	n.d.	1.1
Tot. Sol. (%)	0,12	0.62	0.12	0.13	n.d.	n.d.	0.23
Fixed Sol. (%)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Vol. Sol. (%)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Diss.Oxy. (mg/l)	10.6	10.4	10.52	10.3	n.d.	n.d.	6.07
COD (mg/l)	235	141.8	231	133.7	n.d.	n.d.	52.7
BOD 5 (mg/l)	39.17	23.67	46.20	26.53	n.d.	n.d.	13.2
MPN/100 ml	<3	600	430	430	n.d.	n.d.	4600
UFC/ml	3000	40	1000	6000	n.d.	n.d.	24000
Fae.colif. (MPN/100	<3	40	430	430	n.d.	n.d.	110000
E.coli (MPN/100 ml)	n.d.	40	430	430	n.d.	n.d.	4600
NO2- (mg/l0	0-0.05	0	0-0.05	0.05	n.d.	n.d.	0.15
NO3- (mg/l)	0-10	0-10	0-10	0-10	n.d.	n.d.	10-25
PO4 3- (mg/l)	0-0.25	0	0	0-0.25	n.d.	n.d.	0-0.25
E.C. (dS/m)	1.26	1.25	1.24	1.24	n.d.	n.d.	1.77
Total N (mg/l)	0	23.8	47.6	47.6	n.d.	n.d.	47.6
Color	c.less	c.less	c.less	c.less	n.d.	n.d.	dark-
Odor	o.less	o.less	o.less	o.less	n.d.	n.d.	fish
Turbidity.	0	0	0	+	n.d.	n.d.	++++

October 1996

	MATRIZ	SAN	MONTEC	HIJUELA.	HIJUELA	F 1	F 2
temp. (oC)	15	15	18	18	n.d.	n.d.	18
pH	8.4	8.2	8,2	8,25	n.d.	n.d.	8.2
S.S.10' (mg/l)	<<0.05	<0.1	<<0.05	<0.05	n.d.	n.d.	0.1
S.S.2 hs (mg/l)	0	0	0	0	n.d.	n.d.	0
Tot. Sol. (%)	0.08	0.11	0.12	0.11	n.d.	n.d.	0.14
Fixed Sol. (%)	0.03	0.02	0.03	0.02	n.d.	n.d.	0.04
Vol. Sol. (%)	0.05	0.09	0.09	0.09	n.d.	n.d.	0.1
Diss.Oxy. (mg/l)	10.7	8.4	10.2	9.2	n.d.	n.d.	9.2
COD (mg/l)	40	68	12	52	n.d.	n.d.	32
BOD 5 (mg/l)	7.3	8.3	10.3	10.3	n.d.	n.d.	8.3
MPN/100 ml	<3	900	2300	110000	n.d.	n.d.	110000
UFC/ml	1000	1000	2500	1400	n.d.	n.d.	4000
Fae.colif. (MPN/100	<3	900	2300	110000	n.d.	n.d.	110000
E.coli (MPN/100 ml)	<3	4000	400	110000	n.d.	n.d.	2100
NO2- (mg/l0	0.05	0.05	0.05	0-0.05	n.d.	n.d.	0-0.05
NO3- (mg/l)	0	0-10	0	0-10	n.d.	n.d.	0-10
PO4 3- (mg/l)	0-0.25	0	0	0-0.25	n.d.	n.d.	0-0.25
E.C. (dS/m)	1.50	1.53	1.47	1.51	n.d.	n.d.	1.77
Total N (mg/l)	0.95	0	0.95	0	n.d.	n.d.	0
Color	c.less	c.less	c.less	c.less	n.d.	n.d.	dark-
Odor	o.less	fish	fish	gamexane	n.d.	n.d.	dirty
Turbidity.	0	0	0	0	n.d.	n.d.	0/+
Chrome (ppm)	<0.05	<0.05	<0.05	<0.05	n.d.	<0.05	n.d.
Lead (ppm)	<0.02	<0.02	<0.02	<0.02	n.d.	<0.02	n.d.
Mercury (ppm)	<0.001	<0.001	<0.001	<0.001	n.d.	<0.00	n.d.
Arsenic (ppm0	0.016	0.01	0.006	0.021	n.d.	0.021	n.d.

December 1996

	MATRIZ	SAN	MONTEC	HIJUELA.	HIJUELA	F 1	F 2
temp. (oC)	21	21	21.5	n.d.	n.d.	n.d.	21.6
pH	8.05	8.11	8,2	n.d.	n.d.	n.d.	8.21
S.S.10' (mg/l)	<0.1	<0.1	0.20	n.d.	0.20	n.d.	0.1
S.S.2 hs (mg/l)	<0.1	<0.2	0.20	n.d.	0.20	n.d.	0.1
Tot. Sol. (%)	0.16	0.13	0.12	n.d.	0.12	n.d.	0.12
Fixed Sol. (%)	0.14	0.11	0.02	n.d.	0.08	n.d.	0.03
Vol. Sol. (%)	0.02	0.02	0.1	n.d.	0.04	n.d.	0.09
Diss. Oxy. (mg/l)	7.56	7.56	7.86	n.d.	8.06	n.d.	7.86
COD (mg/l)	24.19	28.22	32.26	n.d.	12.09	n.d.	32.26
BOD 5 (mg/l)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MPN/100 ml	280	7000	280	11000	28000	11000	n.d.
UFC/ml	1400	4000	5000	2000	5000	5000	n.d.
Fae.colif. (MPN/100	< 3	700	280	2800	2800	2800	n.d.
E.coli (MPN/100 ml)	< 3	280	40	280	280	280	n.d.
NO2- (mg/l0	0	0.05	0.05	n.d.	0.05	n.d.	0.05
NO3- (mg/l)	0	0	0	n.d.	0	n.d.	0
PO4 3- (mg/l)	0	0	0.75	n.d.	0	n.d.	0
E.C. (dS/m)	1.44	1.44	1.46	n.d.	1.41	n.d.	1.28
Total N (mg/l)	6.0	8.0	7.0	n.d.	8.0	n.d.	7.0
Color	c.less	c.less	c.less	n.d.	c.less	n.d.	c.less
Odor	soil	soil/lake	lake	n.d.	rotten	n.d.	lake
Turbidity.	0	0	0	n.d.	0	n.d.	0

March 1997

	MATRIZ	SAN	MONTEC	HIJUELA.	HIJUELA	F 1	F 2
temp. (oC)	23	22.5	225	22	22	22	n.d.
pH	8.07	8.06	8.05	8.07	8.10	8.10	n.d.
S.S.10' (mg/l)	0.1	0.1	0.2	0.2	0.2	0.1	n.d.
S.S.2 hs (mg/l)	0	0	0.05	0.1	0.1	0.1	n.d.
Tot. Sol. (%)	0.14	0.17	0.13	0.13	0.03	0.03	n.d.
Fixed Sol. (%)	0.09	0.11	0.08	0.1	0.02	0.02	n.d.
Vol. Sol. (%)	0.05	0.06	0.05	0.07	0.01	0.01	n.d.
Diss. Oxy. (mg/l)	10.5	10.1	9.9	9.5	9.5	9.5	n.d.
COD (mg/l)	524	367	331	407	339	339	n.d.
BOD 5 (mg/l)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MPN/100 ml	400	11000	280	10000	4600	4600	n.d.
UFC/ml	2000	7000	10000	10000	40000	40000	n.d.
Fae.colif. (MPN/100	70	280	110	4600	280	280	n.d.
E.coli (MPN/100 ml)	< 3	< 3	< 3	< 3	< 3	< 3	n.d.
NO2- (mg/l0	0.05	0.05	0.05	0.05	0.13	0.13	n.d.
NO3- (mg/l)	5	5	5	5	5	5	n.d.
PO4 3- (mg/l)	0.25	0.25	0.25	0.40	0.20	0.2	n.d.
E.C. (dS/m)	0.936	1.02	1.02	1.01	1.02	1.02	n.d.
Total N (mg/l)	13.7	18.6	20	10	22.4	22.4	n.d.
Chrome (ppm)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	n.d.
Lead (ppm)	<0.01	<0.1	<.01	<0.1	<0.1	<0.1	n.d.
Mercury (ppm)	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	n.d.
Arsenic (ppm0	0.006	0.007	0.001	0.009	0.006	0.006	n.d.

April 1997

	MATRIZ	SAN	MONTEC	HIJUELA.	HIJUELA	F 1	F 2
temp. (oC)	21	22	21	21	n.d.	21	n.d.
pH	7.99	7.90	7.89	7.84	n.d.	7.84	n.d.
S.S.10' (mg/l)	0.5	0.1	0.1	0.1	n.d.	0.1	n.d.
S.S.2 hs (mg/l)	0.5	0.1	0.1	0.1	n.d.	0.1	n.d.
Tot. Sol. (%)	0.28	0.09	0.14	0.02	n.d.	0.02	n.d.
Fixed Sol. (%)	0.22	n.d.	0.11	n.d.	n.d.	n.d.	n.d.
Vol. Sol. (%)	0.06	n.d.	0.03	n.d.	n.d.	n.d.	n.d.
Diss. Oxy. (mg/l)	8.5	8.8	9.2	8.1	n.d.	8.1	n.d.
COD (mg/l)	42.9	43.3	40.8	43.5	n.d.	43.5	n.d.
BOD 5 (mg/l)	5.0	5.9	5.9	4.5	n.d.	4.5	n.d.
MPN/100 ml	2400	930	400	9000	n.d.	9000	n.d.
UFC/ml	200	800	400	1000	n.d.	1000	n.d.
Fae.colif. (MPN/100	210	210	300	300	n.d.	300	n.d.
E.coli (MPN/100 ml)	< 3	< 3	< 3	< 3	n.d.	< 3	n.d.
NO2- (mg/l0	0.05	0.00	0.00	0.05	n.d.	0.05	n.d.
NO3- (mg/l)	10.0	0.00	0.00	0.00	n.d.	0.00	n.d.
PO4 3- (mg/l)	0.25	0.00	0.25	0.00	n.d.	0.00	n.d.
E.C. (dS/m)	1.65	1.62	1.62	1.64	n.d.	1.64	n.d.
Total N (mg/l)	0.8	0.7	1.0	0.6	n.d.	0.6	n.d.
Chrome (ppm)	<0.05	<0.05	<0.05	<0.05	n.d.	<0.05	n.d.
Lead (ppm)	<0.1	<0.1	<.01	<0.1	n.d.	<0.1	n.d.
Mercury (ppm)	<0.001	<0.001	<0.001	<0.001	n.d.	<0.001	n.d.
Arsenic (ppm)	0.008	0.015	0.008	0.008	n.d.	0.008	n.d.

References:

n.d.=	no data
o.less=	odorless
c.less=	colorless

INFLUENCE OF PHREATIC DEPTH AND SOIL SALINITY ON CROP YIELD
CASE STUDY: TERTIARY CANAL CHIVILCOY
MENDOZA -ARGENTINA

Ing. Carlos Mirábile
INA-CRA

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1-INTRODUCTION

Those areas developed by means of surface irrigation seldom reach an efficiency higher than 60%, which indicates that, at best, 40% of the irrigation water is not used by the crops. The water leaks in subsurface manner in those places with impermeable layers, causing problems of phreatic level rising and bringing about a dicrease in the volume of air in the soil and an increase in salinity.

Irrigated soils receive a large amount of dissolved salts, either provided by irrigation water or by subsurface water.

Areas with that problem have been detected in the region irrigated by the Tunuyán Medio river (East Oasis). One of the most affected areas is that irrigated by the tertiary canal Chivilcoy. These limitations cause, at first, a dicrease in crop yields. Afterwards, due to their increase or persistence, they cause crop death.

For this reason, the area chosen to carry out the " **Research Program On Irrigation Performance "(RPIP)** involves irrigated areas in India, Pakistan, Egypt, Morocco and Argentina. The objective of this project is, among others, to obtain performance parameters of the irrigated areas as to environmental sustainability and drainage, including factors like soil and water salinity, ground water depth and quality, crop yields, etc.

It is important to point out that although the program started in 1992, this study was launched in December 1996.

The area under study is located within the irrigation area of the Tunuyán inferior, between carriles Chivilcoy-Anzorena-Costa canal Montecaseros and Pasera street. It is 8.4 km long, east to west, and 2,7 km wide, north to south. (Graph 1)

It has a cultivated surface of 1540 hectares, mainly with grapevines in the form of trellis and espalier. Next come fruit crops like plums, although the number of these has decreased in the last 10 years due to the fact that they have died out of root asphyxia and/or saline intoxication, both caused by the saline phreatic level rising.

Grapevines are more resistant to salinity and adapt their root system to the changes in phreatic water; that is why they have withstood this problem better. Although in the

critical areas they are no longer grown, in the rest of the area they are still grown with low yields.

At present, approximately 10 % of the surface is uncultivated, and in the west of the area, along Tropero Sosa street up to carril Montecaseros, 25% of the farms were abandoned due to the problems mentioned above.

Tertiary Canal Chivilcoy is under a continuous shift seven days a week, and it supplies 13 tertiary canals. Each of these receives in its shift all the volume of the Chivilcoy canal. The shift time of each canal is 10 minutes per hectare with irrigation rights.

2-BACKGROUND

Several studies have been conducted in the area irrigated by the Tunuyán inferior river, where the area irrigated by the Tertiary Canal Chivilcoy is located.

Jorge Chambouleyron (1982) has developed for the area a model of operation and enhancement of the distribution of the hydric resource. This model divides the zone in 10 polygons, each corresponding to the area irrigated by a secondary canal. In turn, each of these polygons has been subdivided into nodes of approximately 1000 hectares.

Chambouleyron's model takes into account external and internal efficiencies and makes it possible to know the water depth that reaches each polygon or node from the water depth released by the diversion dam.

Salatino, E. (1985) designed a texture map of the first meter of depth of the soil, obtaining depth maps for 0-0.50 and 0.50-1mt

Mirábile,C. (1985) developed a map of soil salinity for 0-0.50 and 0.50-1mt depth, as well as maps of surface and ground water salinity through nodes and polygons.

Mirabile,C. (1985) launched a study of zone drainage and phreatic monitoring with monthly readings during the first two years, followed by bimonthly readings until 1995. Data are also obtained on a yearly basis about phreatic salinity and the composition of salts.

Mirabile,C. (1987) developed a model for saline hydric balance that takes into account the water depth applied to the polygon and/or node, soil and irrigation water salinity, texture, effective precipitation and evapotranspiration. This model also allows to know percolated water depth, the variation in soil salinity and the salt leaching water necessary to keep salinity constant or to reach the desired level. This makes it possible to know dynamically the process of salinization or desalinization according to the irrigation system used and the efficiency with which farmers irrigate their crops.

Mirabile,C. (1997), conducted a study on the factors that limit soil productivity in the area under study, analyzing the physical and chemical characteristics of the soil, the surface and subsurface water resource, the saline hydric balance and the problem with the level and quality of the phreatic water. In his conclusions he infers that, once the

degradation problem has been detected, it is necessary to quantify its effect on crop yields.

3-OBJECTIVES

* To determine the incidence of soil salinity and phreatic levels on the yields of grapevine and plum crops.
* To correlate the factors mentioned above.
* To determine performance parameters related to phreatic depth, soil salinity and crop yields.

4- MATERIAL AND METHOD

Performance Parameters

The performance parameters adopted were those proposed by Bos M.
Phreatic depth:

$$\text{Relative phreatic depth} = \frac{\text{Real phreatic depth}}{\text{critical phreatic depth}}$$

Soil salinity:

$$\text{Relative EC ratio} = \frac{\text{Real EC value}}{\text{critical EC value}}$$

Farm Selection:

In September and October 1996, the area under study was surveyed in order to observe existent crops, their varieties, support systems, type and intensity of cultural work applied by farmers to their crops, technological capacity, soil types and their different limitations, etc.

It was observed that the most widely cultivated crops are grapevines (espaliers and trellises with "criollas" grapes (Creole grapes), D'Agen plums (for processing) and Santa Rosa plums (for fresh consumption), and peaches for processing.

The criterium adopted for farm selection was that they have crops of the same variety, similar age and cultural management. The only difference had to be soil salinity and phreatic depth.

Due to this homogeneity criterium, farms grown with peaches had to be left out , since most farmers grow a large combination of varieties using several different types of cultural management.

Finally, 12 farms were selected, grown with grapevines and plums on soils with different degrees of salinity. These farms were classified into good, fair and bad.(Graph 2)

Field work was conducted according to the following scheme:

crop	variety	farm type
grapevine (trellis)	Criollas	Good Fair Bad
grapevine (espalier)	Criollas	Good Fair Bad
plums	D'agen	Good Fair Bad
plums	Santa Rosa	Good Fair Bad

Installation of Phreatimetric tubes

In order to determine the variations in phreatic levels throughout the agricultural cycle, a network of 10 phreatimetric tubes 3 mt deep was installed in reticule shape in the area under study to relate the data measured in the field. (Chart 3).

Readings of phreatic levels were conducted in January, March, May, July and September, and they will continue to be performed every other month until completion of the study in April 1998. The salinity of the samples obtained (EC) has also been determined.(Chart 1-2).

As regards phreatic levels, up to the moment only phreatimetric tubes # 3 and 4 have been observed to show levels above 3 mt. Both are located on callejon Rodriguez between Tropero Sosa st. (to the west) and carril Montecaseros (to the east), a depressed area which had high phreatic levels until a few years ago. At present, those phreatimetric tubes register values between 2.30 and 2.70 mt.of depth and electric conductivity is around 6.9 dsm^{-1} for # 3 and 4.8 dsm^{-1} for # 4.

It should be pointed out that on callejón Rodriguez are located several farms whose perennial crops are semi-derelict or have been completely abandoned due to soil degradation caused by the presence of a highly saline surface phreatic water during the 80's and the first years of the present decade.

Extraction of soil samples:

The objective of sample extraction is to determine soil electric conductivity. Samples were taken in three different stages of the vegetative cycle of the selected crops: **beginning of the cycle** (august), **full cycle** (December) and **harvest** (January-February) for plums and (March-April) for grapes. Likewise, due to the root depth of these crops, samples were taken at two different depths: 0-0.70 y 0.70-1.40 mt. So far field samples have been taken and laboratory analyses have been performed corresponding to full cycle 1996, harvest 1996/97, and beginning of the cycle 1997/98. (Chart 3).

Field Measurements of Yields:

From mid-February to the end of April, the determination was performed of crop yields in each of the chosen farms. It corresponded to the harvest of the 96/97 vegetative cycle. (Charts 4 and 5).

As a complement to this determination , specially designed forms were analyzed, which had previously been given to the farmers of the chosen farms to record any climatic accident that might occur during the cycle, as well as a decrease in yields these may cause. In our area the most common accidents are: frost, hail, zonda wind, etc.

5-<u>RESULTS</u>

In spite of the short evaluation time so far, and the fact that the few data obtained can only be considered as trends, the following can be mentioned:

The salinity of surface water does not suffer variations in the different sectors of the area under study or throughout time, and the value of its electric conductivity is 1,3 dsm^{-1}.

Ground water, which supplements the irrigation shift (surface water) when the former is insufficient, is pumped from three different levels: superficial: 60-1.30 mt (bad quality water with 3,8 dsm^{-1}); middle: 1.30-1.80 mt, (fair quality with 1.7 dsm^{-1}) and deep: 1.80-3.00 mt. (better quality with 1.2-1.3 dsm^{-1}).

The static level of the acquifer in the area under study has not experimented considerable variations in spite of a hydrologic cycle of drought that started 4 to 5 years ago. Variation is small, approximately 1 mt only, and it is due to the fact that the area is far from the recharge zone of the acquifer, and that it is completely flat.

In the sector of the oasis close to the recharge zone, instead, the variation in static levels is approximately 40 mt., according to the information provided by the Centro de Aguas Subterráneas (Groundwater Center).

At present the area does not present problems with phreatic levels, since, out of the phreatimetric tubes installed, only two register phreatic levels. These phreatimetric tubes are placed relatively deep (2.70mt.), even in critical periods like the end of fall and spring.

There is no clear tendency in the dynamics of salinity between full cycle and harvest, since the amount of samples whose electric conductivity value increases is very similar to those whose value decreases.

Instead, there is a clear indication that at the beginning of the cycle (97/98), salinity is higher than it was during the harvest time (96/97).

It has also been noticed that in grape growing, both trellis and espalier, there is a similar behavior of salinity according to the different types of farms. In those labeled "bad", the high salinity of the soil continues increasing.

In "fair" farms, salinity during harvest decreased compared with full cycle and an increase in the harvest (increase in yields).

Conversely, in "good" farms, during harvest time salinity is higher than in full cycle and that at the beginning of the next cycle.

As to the relationship between salinity values and sampling depth, in the soils grown with grapevines there is no defined trend, which is otherwise noticeable in the soils grown with plums. In this case salinity increases with depth, and the higher the salinity of the soil, the higher the increase.

Even in good farms, the yields of the crops measured are lower than the potential yields obtained in those conditions. This may be due to the fact that, judging from their age, the crops have been planted and have grown during a period in which phreatic water was very high, and its salt content has deteriorated the soil. The crops, therefore, have had a restricted growth and development. Only in the last four years has there been a decrease.

6-CONCLUSIONS

The main conclusion is that the period of time devoted so far to taking samples is insufficient. Sampling has been carried out to evaluate results that interact with complex factors such as crop yields, soil salinity and depth, and quality of phreatic water.

The study performed so far requires at least 2 or 3 agricultural cycles for data collection. Likewise, the partial results obtained will make it possible to adjust the methodology for obtaining data about the parameters involved in order to achieve a better correlation.

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Fig 1

Distribution of farms irrigated from somes tertiary canal of Montecaseros's secundary canals

Fig 2

PROPERTIES LOCATION

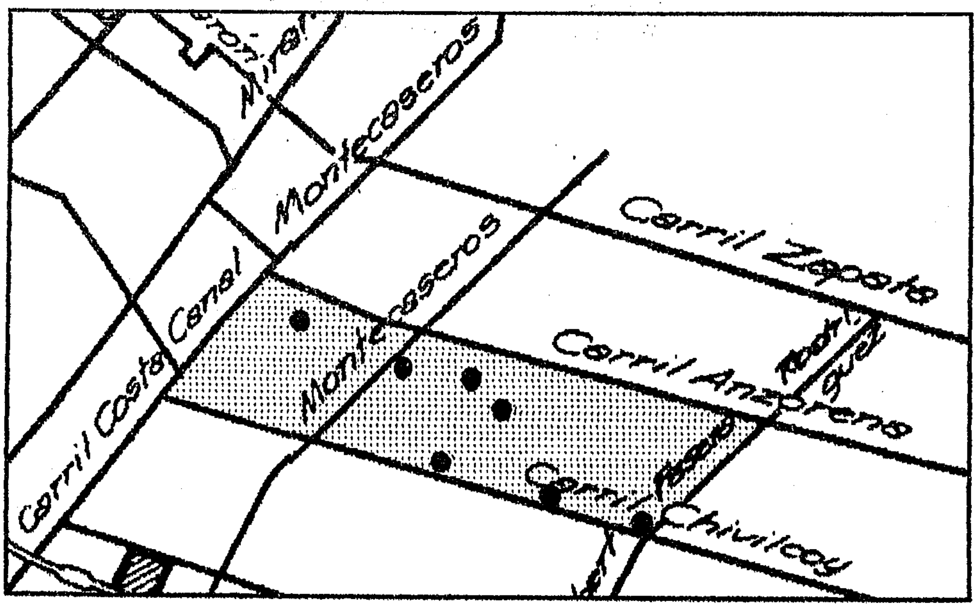
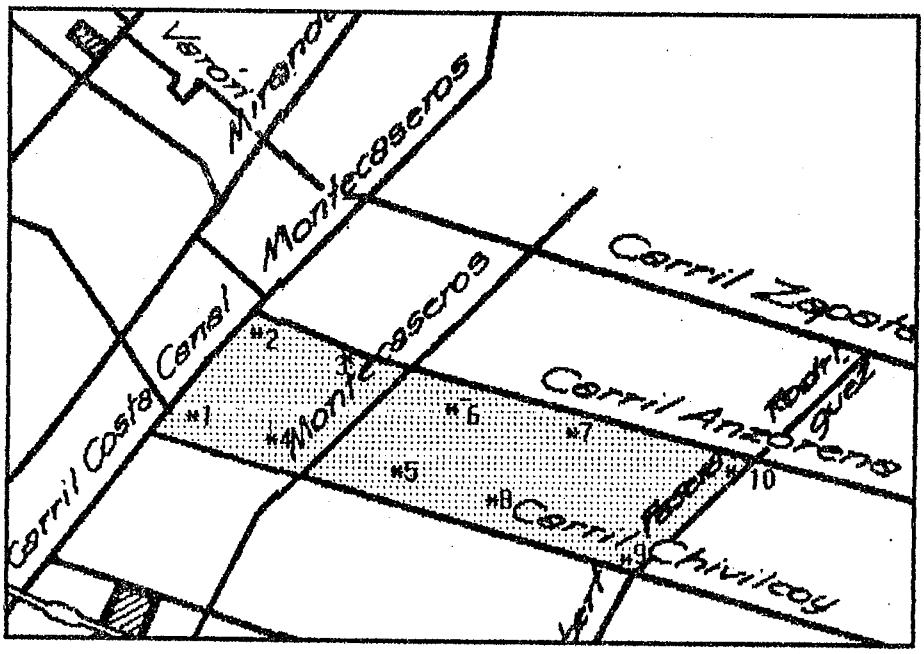


Fig 3

STUDY AREA AND SCHEME OF PHREATIMETRIC TUBE LOCATION.



APPENDIX

Chart #1: Phreatic Levels

values in meters

1997	1	2	3	4	5	6	7	8	9	10
January			2.40	2.20						
March			2.50	2.70	2.70					
May			2.50	2.70						
July										
September				2.50						
November										
1998										
January										
March										

Chart #2: Phreatic Salinity
Values in ds/mt-1

1997	1	2	3	4	5	6	7	8	9	10
January			6.9	4.8						
March			n/a	n/a						
May			n/a	n/a						
July			n/a	n/a						
September				4.70						
November										
1998										
January										
March										

Note: n/a means that it was not possible to take a sample to determine electric conductivity.

Chart # 3

Table of soil salinity.

value in ds/m.

Property	Crop	December'96		March'97		August'97		December'97		March'98	
		depth 0,75	depth 1,40	depth 0,75	depth 1.40	depth 0,75	depth 1,40	depth 0,75	depth 1,40	depth 0,75	depth 1.40
Terreni	Vid	7.52	5.65	10.40	9.4	16.5	14.3				
Pepe	Parral	4.87	4.91	3.20	3.05	8.21	6.10				
Fontana		3.78	4.11	2.91	6.24	3.20	3.29				
Callejon	Vid	5.77	5.62	8.57	9.05	22.6	11.4				
Pepe	Viña	2.69	4.30	2.76	3.20	3.57	3.29				
Fontana		3.11	3.00	8.53	3.05	2.45	3.97				
Galvan	Ciruela	5.82	12.4	2.17	7.80	10.9	13.00				
Pepe	Dágen	2.31	2.68	1.10	1.12	1.61	3.72				
Balestra		2.65	2.89	3.50	4.03	4.57	3.76				
Terreni	Ciruela	4.24	4.73	6.07	4.26	9.90	6.63				
Cardenas	Santa Rosa	3.85	4.14	11.1	7.61	6.43	8.06				
Balestra		2.71	2.95	3.20	1.73	3.83	3.78				

Chart #4: Crop yield (kg/hectare)

Trellis	Harvest ´97	Harvest ´98
Terreni	800 Kg/hectare	
Pepe		
Fontana	10000 kg/Hectare	

Espalier	Harvest ´97	Harvest ´98
Callejón		
Pepe		
Fontana	6000 kg/Hectare	

D´ agen Plum	Harvest ´97	Harvest ´98
Galván	3697 Kg/hectare	
Pepe	1660 kg/hectare	
Cárdenas	20000 kg/hectare	
Balestra	12000 kg/Hectare	

Santa Rosa Plum	Harvest ´97	Harvest ´98
Terreni	20000 Kg/hectare	
Cárdenas	19200 kg/hectare	
Balestra	12000 kg/Hectare	

Chart #5: Surface of plots under study

Farm	Crop	Area
Terreni	Parral	2 hectares
Pepe	Parral	12 hectares
Fontana	Parral	7 hectares
Callejón	Espalier	0.7 hectares
Pepe	Espalier	1.2 hectares
Fontana	Espalier	1 hectare
Galván	Dágen	0.648 hectares
Pepe	Dágen	9 hectares
Balestra	Dágen	10 hectares
Cardenas	Dágen	0.625 hectares
Balestra	Santa Rosa	5 hectares
Terreni	Santa Rosa	0.8 hectares
Cardenas	Santa Rosa	1.5 hectares

IRRIGATION EFFICIENCY AS A PERFORMANCE PARAMETER IN THE COMMAND AREA OF THE MIDDLE AND LOWER TUNUYÁN RIVER MENDOZA, ARGENTINA

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INTRODUCTION

The Province of Mendoza (Argentina) comprises the largest area under irrigation in the country (360,000 hectares), with the exception of areas under supplementary and/or complementary irrigation. Due to its desertic [desert-type ? desert-like ?] climate and a practically non-existent mean annual precipitation (180 mm), agriculture in its oases depends solely on the water of its five snow-fed [snowmelt-fed ?] mountain rivers. The capital city of Mendoza is built on the Mendoza River, with an urban population of over 500,000 inhabitants. The Middle and Lower Tunuyán River command area has become an important agricultural center, with its own cities and industrial and services infrastructure. Both these rivers and their command areas constitute what is known as the northern oasis; the Diamante and Atuel rivers, in the southern part of the province, form the other two (Fig. 1). An important and increasingly exploited aquifer feeds a large number of wells, the so-called "sixth river".

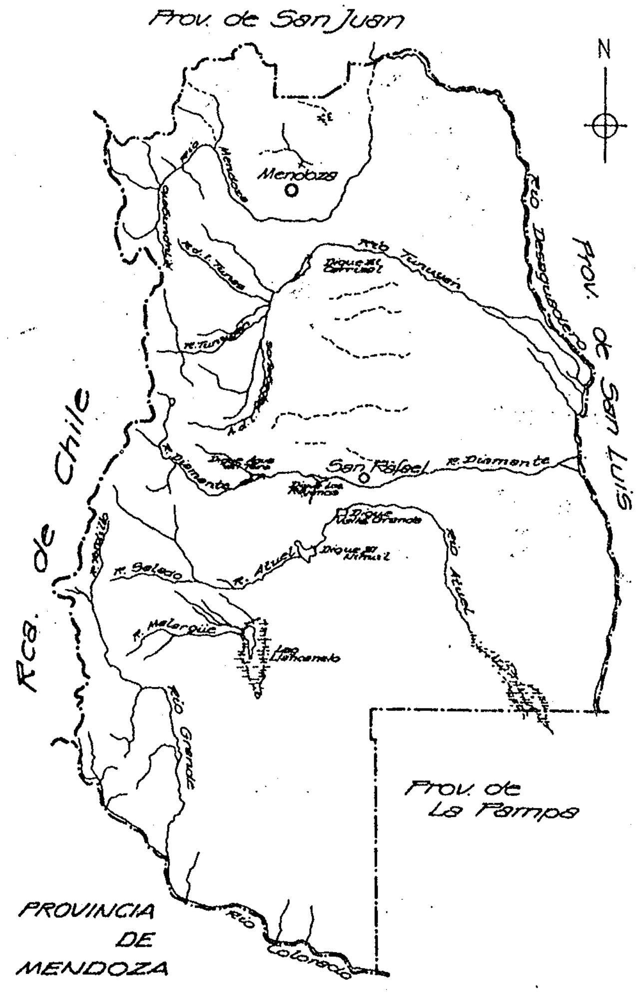


Figure 1. Irrigated oases in the Province of Mendoza

Surface irrigation, with furrows or borders (100 m long) and with neither slope nor runoff, prevails. Vineyards (espalier system), fruit and olive trees, and vegetables are irrigated by means of furrows of variable width (0.50-0.80 m for the former and 0.20-0.50 for the vegetables). When fully grown, vineyards (trellis system) and seed and stone fruits are irrigated by means of borders, the width of which ranges from 6-7 m to 15-20 m.

Irrigation water distribution is done mostly with fixed and/or mobile proportional dividers, and either metal or wooden gates. Water delivery, even nowadays, is based on the Inspector's and the gatekeepers' experience and is done according to the number of hectares registered with definitive and/or eventual irrigation rights.

At the provincial level, water is administered by the General Department of Irrigation (DGI), an autonomous and autarchic agency responsible for water policy and water police, in addition to managing and maintaining dams and main canals. The extensive irrigation network (Fig. 2), which criss-crosses several cities, is mostly earthen and usually accompanied with runs parallel to an open wastewater collector network, the maintenance of which is irregular and becomes more intensive in water-rich years.

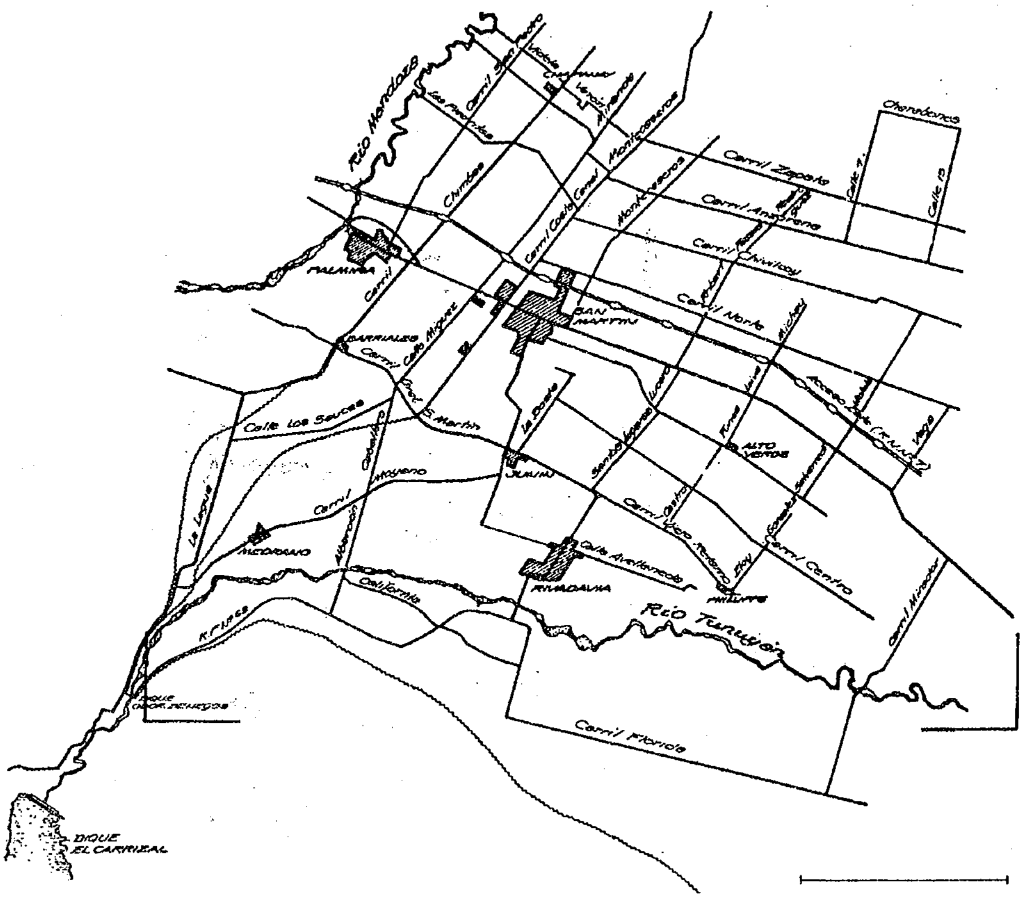


Figure 2. The Middle Tunuyán River's irrigation network

There are Users' Organizations --known in Mendoza as Canal Inspections-- at different levels (consolidated Inspections, associations, and federations). They are responsible for managing irrigation

water at the secondary and tertiary canal level while farmers, in turn, are responsible for cleaning the tertiary and quaternary canals. This unique organizational structure has attracted the attention of the International Irrigation Management Institute (IIMI), as manifested in its Research Program on Irrigation Performance (RPIP), carried out with the cooperation of ILRI (Wageningen) and INA (formerly, INCYTH) in Mendoza, Argentina.

The area under study corresponds to the "Montecaseros" Consolidated Inspection (Fig. 3), which is irrigated by the secondary canal of the same name, derived from the San Martín main canal, and by 13 tertiary canals ("hijuelas"). For this research project the Chivilcoy tertiary canal's command area was selected as it is representative of the different irrigation methods used in the province.

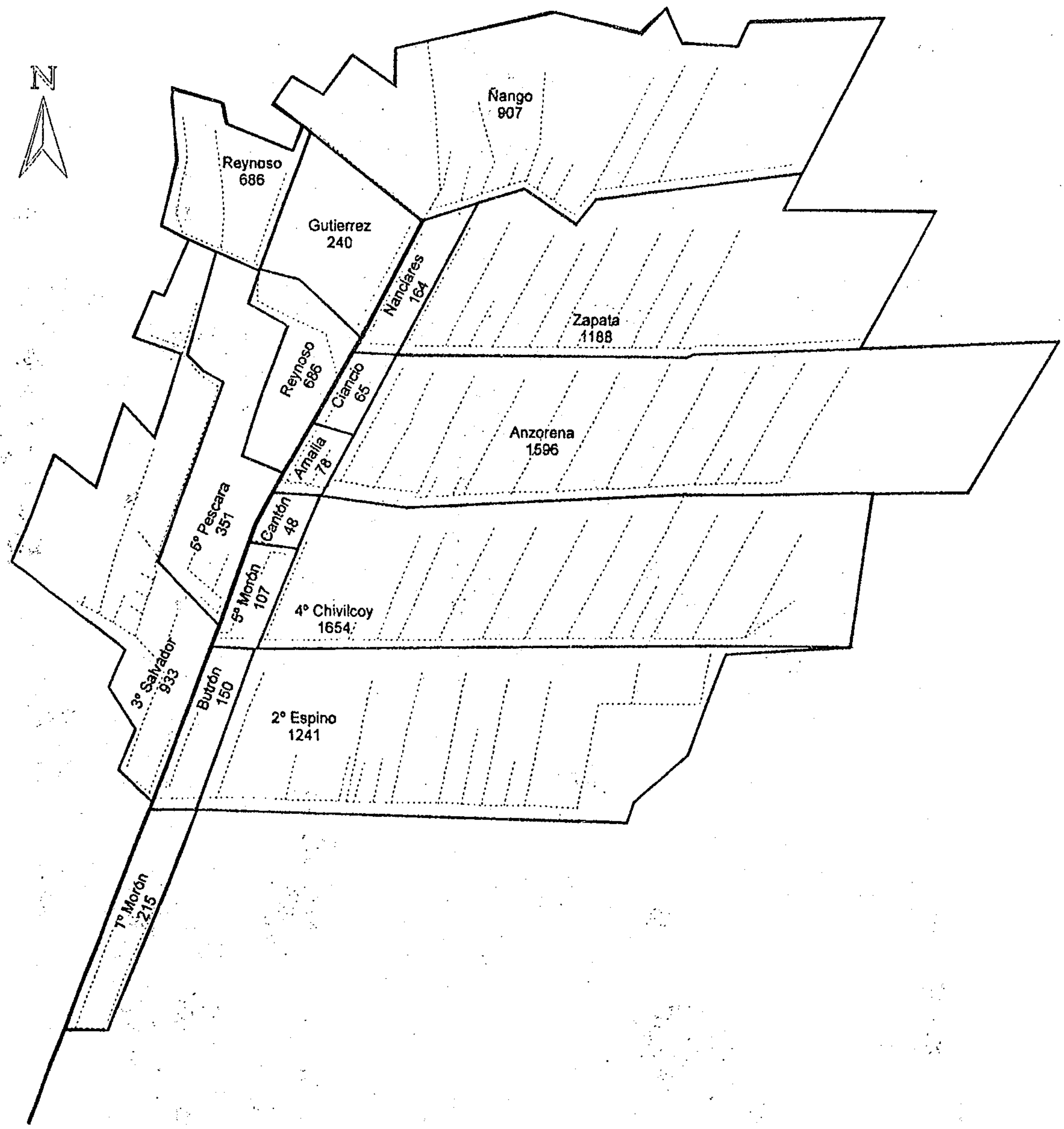


Figure 3. The "Montecaseros" Users' Organization

The predominant crop is grapes of the so-called "common" varieties, produced either for the table or for wine-making for the domestic market. The trellis system is commonly used, and farming plots are divided in blocks 80 to 120 m long, with no slope in the direction of irrigation in order to compensate for the natural west-east slope. As a rule, crops are irrigated by means of broad furrows with no runoff, which become borders in times of greater crop water requirements. This form of crop irrigation together with plot size, farmer characteristics, quality and frequency of labor, average yields, etc. serve to typify the region.

In recent times there has been a dramatic increase in the area farmed with stone fruit trees, especially plum trees, which have thus become the second most important crop. Fruit trees and vineyards (trellis) are furrow-irrigated during their first years; later on the broad furrows become borders. The length of the irrigation units is very similar to those of vineyards, a traditional characteristic is difficult to change. However, the ever-growing availability of farming machinery is gradually making the younger generation of farmers adopt a new criterion.

Figure 4. Furrow-irrigated vegetables in the study area.

Vegetables represent a small percentage of the farmed area (Fig. 4). Tomatoes for the canning industry are the prevailing crop, which --due to the mostly loose soils in the area-- produce good yields. Irrigation efficiency figures, however, are low. In general, farmers ignore the soil depth to be wetted each time and apply water depths that are more suitable to the needs of deep-rooted permanent crops, such as vineyards and fruit trees. As a result, they induce considerable percolation, rising phreatic levels, and inefficiencies.

The average farm size in the study area is 10 hectares (ha), the most important strata being 0-10 ha and 10-25 ha (1988 Agricultural Census).

Most of the owners (80%) no longer live on the property, as they used to do in the first half of the century, but in neighboring towns --Montecaseros and San Martín-- and in central urban areas (the capital city, Guaymallén, Godoy Cruz) or in the city of Junín, east of the oasis. The owner's distance from his property and from the person in charge of its farming and irrigation leads to administrative problems for the Users' Organization, to which the Water Law assigns full responsibility for water management.

MATERIALS AND METHODS

Coordination of the external water network management (turnout) and crop water requirements, together with the training of users, are of the utmost importance for an efficient water use. These elements --rational network management and the adequate training of users-- form the basis for sustainable water use in Mendoza's oases.

The evaluation methodology used was developed by the Department of Irrigation and Drainage of the INA's Andean Regional Center (CRA) (Chambouleyron and Morábito, 1982). It has been designed according to field conditions representative of the irrigation practices of farmers in Mendoza: surface irrigation, furrow or border, with neither slope nor runoff, and perfectly suited to very short administrative times. These conditions, in turn, result in the need to manage large instant flows at plot level.

This methodology focuses on the integrated analysis of water use on the farm from its intake. This approach also affords the possibility of measuring conveyance efficiencies and losses along the irrigation network, from the farm's intake to the diversion itself (Fig. 5).

The methodology makes use of a field survey form. On it, physical data (location, area with irrigation rights, cropped area, area effectively irrigated, etc.) are recorded. Data on surface and underground irrigation water are also collected (flow gauging, turnout, duration of turnout, area effectively irrigated per turnout, conjunctive use --or not--, well flow, pumping equipment efficiency, pump fuel/energy consumption, age of the well, static and dynamic well levels, length of time the pump is in operation, number of irrigations per growing cycle, etc.).

In addition to the above, the survey form includes items on all data that contribute to a description of the crop/s, block by block (area, training system, age, variety, irrigation method, general condition of the crop, fertilizers, mechanization, irrigation infrastructure, yields, farmer's technical know-how, etc.).

The field survey concludes with a detailed description of the irrigation method applied (border or furrow) and with the calculation of physical parameters. The following parameters are measured:

Figure 5. Measuring flows on a farm.

irrigation unit slope, furrow/border length, furrrow/border width, number of furrows/borders irrigated at the same time, area of and flow applied to the irrigation unit, application times, and water front advance and recession times. Also measured are water infiltration velocity (double-ring infiltrometer), and soil moisture content at the time of irrigation in order to relate it to soil texture (Fig. 6) and storage capacity. Thus, it is possible to calculate the irrigation depth that should have been applied when irrigating.

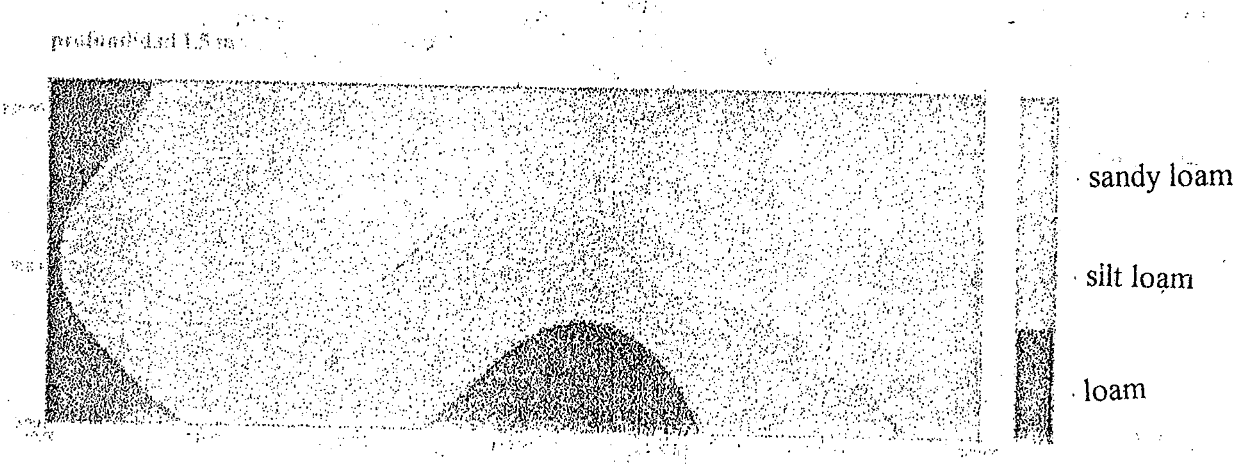


Figure 6. Example of soil texture distribution

With the field data conveniently systematized and processed with models, such as ERFIN and DISEVAL --developed at the Andean Regional Center in Mendoza--, it is possible to calculate the various efficiencies in order to characterize and rank irrigation efficiency at farm level.

The methodology herein described had to be adapted to ICID's instructions and definitions (Bos et Nugteren, 1990), the more common of which are included below. Wherever necessary, ICID acronyms are given between parentheses and next to those corresponding to the local methodology.

Conveyance efficiency (ec). It is the efficiency of canal and conduit networks from the reservoir, river diversion, or pumping station to the offtakes of the distributary system.

Distribution efficiency (ed). It is the efficiency of the water distribution canals and conduits supplying water from the conveyance network to individual fields.

Field application efficiency (ea). It is the relation between the quantity of water furnished at the field inlet and the quantity of water needed and made available for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle.

Overall or project efficiency (ep). It represents the efficiency of the entire operation between river diversion or other source of water and the root zone of the crops.

Tertiary unit efficiency (eu). It is the combined efficiency of the water distribution system and of the water application process.

Irrigation system efficiency (es). It is the combined efficiency of the systems of water conveyance and distribution (this is not an ICID standard term).

As our methodology places special emphasis on the irrigation unit, it is deemed convenient to define the efficiencies resulting from its use.

Application efficiency (EAP). It is the ratio between the water depth stored in the root zone and the water depth derived from the farm inlet.

Storage efficiency (EAL = ES). It is the ratio between the water depth stored in the profile after irrigation and the water depth stored in the profile before irrigation.

Plot distribution efficiency (EDP). It is the ratio between the minimum infiltrated depth and the mean infiltrated depth.

Internal conveyance efficiency (ECI). It is the ratio between the water depth entering the plot and the water depth derived from the farm inlet.

Internal use efficiency (EUI). It is the ratio between the water stored in the root zone and the volume conveyed to the farm.

$$(EUI = EAP \times ECI)$$

Another way of expressing it is:

Farm irrigation efficiency (ERI). It is the irrigation efficiency at the farm level.

(ERI = EAP x ECI).

RESULTS

Regional

PLOT*		AREA*	
Efficiency	%**	Efficiency.	%
ea	67	ec	74
EDP	83	eu	55
ES	61	ep	41

* Ref: * Level of parameter's determination

** Average Value.

Unlike the Mendoza River, the Lower Tunuyán is completely regulated by means of a storage dam (El Carrizal) and a diversion dam (Tiburcio Benegas).

The methodology followed involved gauging the entire irrigation network at a specified time, beginning at tertiary canal level and measuring flow at the farm inlet. The evaluation of conveyance and/or administrative losses is followed by the gauging of secondary and primary canals all the way to the diversion dam (offtakes).

At farm level, and always considering the 80,000 ha of the command area of the Lower Tunuyán River, the Department of Irrigation and Drainage Engineering of the Andean Regional Center of INA (formerly INCYTH) carried out field studies, measurements and evaluations which made it possible to assess irrigation efficiency for each of the prevailing crops in the study area (Chambouleyron et al., 1985).

The values presented in Table 1 show that:

At farm level, the farmers of the command area of the Middle and Lower Tunuyán River irrigate with such low storage efficiencies (if we assume that ES = 80-90% is acceptable for the irrigation method used and for the conditions of the area), that it can be considered as a sub-irrigation. With the inflexibility of the rotation system, a plot is irrigated once every thirty or more days.

The application efficiency of the different irrigations throughout the agricultural crop cycle (ae = 67%) renders, just like storage efficiency, a relatively low value. This is due to the farmers' lack of knowledge of "when" and "how much" to irrigate. Contrary to what happens with storage efficiency, these values could be significantly increased by making a few changes in the area of the irrigation unit and in the water application times.

Distribution efficiency values (DE = 83%) show that the property is adequately systematized and that farmers have experience in irrigated agriculture. In order to increase these values, farmers should only slightly modify the levelling of the irrigation unit at the end of each agricultural cycle, systematize distribution in order to prevent erosion at the head, irrigate without runoff or replace traditional plowing with chemical plowing practices.

At the irrigation system level, both efficiency values in the tertiary canal (ue = 55%) and conveyance efficiency values from the primary canal to the farm's intake (ce = 74%) show great flow losses (deep percolation, canal and/or gate breakage, overflows, obstruction of flow dividers, etc). Though part of this water can be recovered by capillary rise, the damages that water table rises cause on the crops and on the soil, the contribution of salts and the productive deterioration of the area cannot be ignored.

Project efficiency values (pe = 41%) include the failures of the system as well as the expansion

restrictions in the productive area and precludes the possibility of incorporating the irrigated oasis into the increasing demand brought about by the foreign market and the Mercosur.

An evaluation of the electromechanical efficiency of the pumping equipment in the area rendered an average value close to 30% due to aging, obsolescence, over-dimensioning, lack of adequate maintenance and deficient operational management of most wells in the area. This low value points to a significant misuse of groundwater and electricity with the ensuing negative consequences on crops' yields.

Since the irrigation method depends on the farmer, his tradition and knowledge of soils and crops, the efficiency values obtained in the command area of the lower Tunuyán river are representative of the agriculture that prevails in the oasis.

Soil texture in the area is homogeneously distributed (deep loose soils, sandy to sandy-loam texture, without water table or profile salinization problems).

The prevailing crops are vineyards (trellis and espalier), stone fruits, olives, horticultural crops (garlic, onion and tomato), and vegetables.

The average field-measured efficiency values, expressed according to crop type (deep, intermediate and superficial root) and irrigation method (furrow, border without slope and runoff) are:

Table 2. Efficiency values in vineyards (%)

Sistema de conducción	ESPALDERO				PARRAL			
Métodos de riego	EAP (ea)	EDP	ECI	ERI	EAP	EDP	ECI	ERI
Surcos	63	91	96	60	59	86	93	57
Melgas	61	96	89	54	54	93	93	51
Surcos y melgas	63	92	95	58	56	89	93	54

Ref: EAP : application efficiency
EDP: plot distribution efficiency
ECI: internal convenyance efficiency
ERI: farm irrigation efficiency (ERI = EAP x ECI)

Table 3. Efficiency values in stone fruits (%)

METODO RIEGO	EFICIENCIAS			
	EAP	EDP	ECI	ERI
SURCOS	83	83	90	73
MELGAS	60	95	87	52
SURC.Y MEL	70	90	88	61

Table 4. Efficiency values of alfalfa and poplars (%)

METODO RIEGO	EFICIENCIAS			
	EAP	EDP	ECI	ERI
SURCOS	68	83	93	61
MELGAS	56	84	92	52
SUR-MEL	67	83	93	62

Table 5. Efficiency values in horticultural crops (%)

METODO RIEGO	EFICIENCIAS			
	EAP	EDP	ECI	ERI
AJO	35	94	90	31
CEBOLLA	32	91	90	28
TOMATE	50	82	92	45
PROMEDIO	39	89	91	35

As can be observed in tables 2 to 5, efficiency values at farm level clearly show that deep rooted crops are the most efficient. Fruit trees, alfalfa and poplars yield average values close to 60%. Vineyards, an intermediate root crop, yields an average value of 56%, while horticultural crops show very low efficiency values (35%).

Low field-measured efficiency values in shallow root crops are due to similar flows, rotation systems and application times for deep rooted crops, such as vineyards. The natural characteristic of crops with a rather shallow root system calls for the need of a frequent irrigation regime, with small water depths (no more than 50-60 mm) in each irrigation. These water depths are difficult to apply with surface irrigation if there is not a perfect irrigation unit levelling (furrow or border).

Of course, the prevailance of the viticultural and fruit model has given rise to a management system which extends to the rest of the crops without taking into account their specific requirements. Farmers are used to manage a certain flow for a certain number of irrigation units (a number of furrows or borders that are simultaneously irrigated in one or more irrigation fronts). In practice, the water depths are close to 100 mm in each irrigation.

This value, which is almost twice as much the requirements of crops such as garlic, onion or tomato, renders very low application efficiencies. As regards horticultural crops, which require a greater irrigation frequency (which is not achieved with the current rigid rotation system of surface distribution), in most cases groundwater must be used. Finally, it should be pointed out that together with the low efficiency of shallow root crops there is the inefficiency of the pumping equipment.

Tertiary canal level ("hijuela")

Table 6 shows the field-measured efficiency values in the Montecaseros secondary canal (Department of San Martín). They correspond to 14 evaluations carried out in farms that are irrigated with water drawn from tertiary canals ("hijuelas"), on which the respective intakes are located.

Efficiency values at Users' Organizations level (Consolidated Montecaseros Inspection) are compared to the values measured for the whole Middle and Lower Tunuyán river command area (159 evaluations). This is achieved in view of the similarity that exists in the tilling and irrigation practices and in the

Table 6. Efficiencies measured in different crops (%) (Montecaseros Canal, Department of San Martín,

CULTIVO	EFICIENCIAS				
1. VID	ES	EAP	EDP	ECI	ERI
PARRAL	100	35	87	100	35
	100	54	96	100	54
	100	47	97	100	47
	100	26	99	100	26
	78	-	-	-	-
	100	15	99	64	10
ESPALDERO	84	98	98	82	80
	46	-	-	-	-
PROMEDIO	88	46	96	91	42
2.FRUTALES	100	51	100	85	43
	59	-	-	-	-
	44	-	-	-	-
	89	100	100	90	90
	42	-	-	-	-
	91	100	100	97	97
PROMEDIO	71	84	100	91	77
PROM.GRAL	81	58	97	91	53

As a result of this comparative analysis, the following should be pointed out:

Distribution and conveyance efficiencies at tertiary canal level show acceptable similar values (90-95%) to those obtained at Tunuyán river command area and the relative soil homogeneity in the area.

In the case of vineyards, application efficiency values are quite lower than the values measured in the area. The average value obtained in the Montecaseros Inspection is 46%, while the average for the whole area is 59%.

On the other hand, the average values for stone fruits (peaches) in the Inspection is 84%, while in the whole area it is 70%.

As has already been pointed out, application efficiency is a useful parameter that helps to know the exact amount of water that the crop has used. Low EAP values show that farmers do not know how to choose an adequate irrigation opportunity according to soil, climate and crop characteristics and how much water to apply in each irrigation throughout the whole cycle.

However, low efficiencies at farm level are affected by a parameter which is external to the farmer's management: the administrative management of the system (in this case, performed by the Users' Organization, the consolidated Montecaseros Inspection). In fact, the practice is to convey, every 13 days, very high flows (4-5m3/s) in very short periods (10-12 minutes) per ha. This type of conveyance affects smaller properties with only one intake. Farmers must prepare the farm so as to receive in one or more irrigation fronts all the flow and manage it in such a way as to minimize conveyance losses in the internal network of ditches and canals and efficiently apply it to the irrigation unit in such a short time.

As larger properties, on the other hand, have more than one intake, the farmer can make a more rational management since he must not pay so much attention to the systematization of his farm in order to obtain the same results.

SIZE OF THE PROPERTY AND EFFICIENCY

In order to corroborate an assumption directly related to irrigation efficiency and property size, these two variables were correlated (Table 7) taking into account the irrigated area (this information was obtained from "in situ" surveys was carried among the administrators of the UO's of the Middle and Lower Tunuyán river).

The results show that there is a marked difference between properties larger than 10 ha and smaller properties. In Figure 7, it can be seen that the application efficiency parameter tends to increase with the size of the property, reaching a value close to 52% in properties larger than 10ha.

Table 7. Application efficiency values for different strata of irrigated area

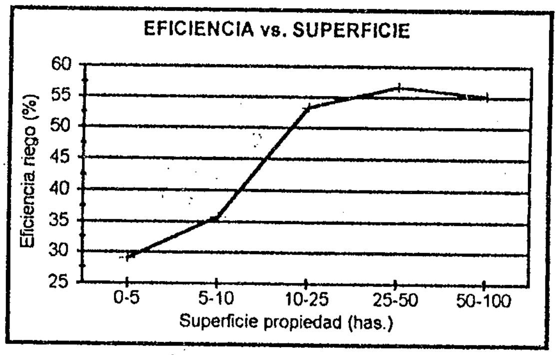
SUP.PROP. (ha) (.)	(%)	EAP (ea)		LIMITE	
		(X)	(S)	SUP.	INF.
0 - 5	26.4	29.0	3.5	22	36
5 - 10	15.1	35.8	4.6	27	45
10 - 25	23.9	53.3	3.6	46	60
25 - 50	16.4	56.7	4.4	48	65
50 -100	18.2	55.2	4.1	47	63

Ref: (X) mean

(S) standard deviation

(.) From Users' Participation (Chapter III) Bustos, R. et al., Mendoza, April 1995

Figure 7. EAP values per stratum of irrigated area



References: From Critical Evaluation of water management, Chambouleyron, J.- The World Bank, Mendoza, 1995.

Low EAP values point to the fact that small farmers, with a few exceptions, lack adequate technical knowledge.

DISCUSSION OF RESULTS AND CONCLUSIONS

At regional level:

The results so far obtained show that there is a clear need to make urgent improvements in the water distribution scheme throughout the long irrigation network. Such improvements include changes in the current rigid irrigation rotation systems and reductions in the flows derived from each rotation system so as to adapt frequencies and delivery times to real crop evapotranspiration demands.

It is well known that the inhabitants of the irrigated oasis of Mendoza are very much concerned about soil and water pollution. Thus, through irrigation efficiency it is possible to determine saline soil pollution and its negative consequences, not only at individual farm level but also on the whole irrigation system.

From the strictly agricultural point of view, large percolated volumes give rise to areas with water table (water-logged areas), which are restrictive to crop growth and development in the region. Generally, these point pollution sources have been gradually expanding and have generated a desertification process which has been difficult to overcome.

The implementation of regional studies will make it possible to improve and optimize water management.

At Montecaseros Inspection level:

When comparing the average values in the Lower Tunuyán area - according to crop types - the Montecaseros Inspection yields distribution and conveyance efficiency values which are similar and acceptable (90-95), though application efficiency values are quite lower than the average in the area.

In the case of vineyards, the average EAP value at the Montecaseros Inspection is 46% while the average for the whole area of the Lower Tunuyán river is 59%. As for stone fruits, mainly peaches, the Montecaseros Inspection yields average values of 58% while the area's total is 70%.

As has already been stated, the EAP is a useful parameter to know the exact amount of water used by the crop. Low application efficiency values indicate a lack of knowledge of the opportunity and amount of water to apply in each irrigation. This concept is closely related to the identification of soil textures on which crops grow, to the soil depth explored by roots and to the specific evapotranspiration rate of each crop.

Farmers should understand the interrelation dynamics of all factors that participate in irrigation: crop, soil, climate, rotation system, etc. in order to be able to irrigate only when it is needed, to replenish the water used by the crops according to evapotranspiration rates and to apply a uniform water depth throughout the irrigation unit.

Small farmers, with few exceptions, work the land and irrigate following a "model" or pattern - which was inherited from their elders - that does not take into account the characteristics of each soil type and of each micro-climate and water requirement variations throughout the crop cycle. In general, they lack the adequate infrastructure to improve water management.

Another reason for the low irrigation efficiency in small farms is the lack of coordination between the administrative canal rotation system and the internal irrigation water rotation system. This situation worsens in the case of horticultural crops with surface roots where severe water losses take place at farm level due to deep percolation.

While the rotation system in the network is from 10 to 12 minutes per ha, the time required to apply a water depth of 150mm to 1 ha is 3 to 4 hours. This calls for the need to apply in each irrigation very heavy water depths which render very low efficiencies due to excessively high flows.

When analyzing the results obtained in the efficiency-property size correlation, it can be clearly seen that properties of less than 10 ha yield very low EAP values (about 30%), while larger properties yield values close to 55% .

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