PERFORMANCE INDICATORS FOR IRRIGATION AND DRAINAGE

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ABSTRACT

This paper summarises the performance indicators currently used in the **R**esearch **P**rogram on **I**rrigation **P**erformance (RPIP). Within this Program field data are measured and collected to quantify and test about 40 multidisciplinary performance indicators. These indicators cover water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio-economics and management. The indicators now are sufficiently mature to be recommended for use in irrigation and drainage performance assessment.

1 *INTRODUCTION*

This paper summarises the performance indicators currently used in the **R**esearch **P**rogram on **I**rrigation **P**erformance (RPIP). Within this Program field data are measured and collected to quantify and test about 40 multidisciplinary performance indicators. These indicators cover water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio-economics and management.

The starting set of indicators has been described by Bos e.a. (1993). Field experience with these indicators will be reported upon in various papers (Vos et al 1997, Bustos et al 1997; Marre et al 1997). The indicators in this paper now are sufficiently mature to be recommended for use in irrigation and drainage performance assessment. In general, it is not recommended to use all described indicators under all circumstances. The number of indicators you should use depend on the level of detail with which you need to quantify performance (e.g. research, management, information to the public) and on the number of disciplines with which you need to look at irrigation and drainage (water balance, economics, environment, management). To compare the performance of the considered system with other systems, however, it is recommended to select from the indicators listed in the following sections.

During earlier work on performance assessment (Murray-Rust & Snellen 1993; Bos e.a. 1993) three levels of organization, having different objectives, were distinguished:

- irrigation and drainage **system** level,
- **agency** level,
- and the planning and policy environment at **sector** level.

Despite the differences in objective sets for each level of organization, a common definition of performance was proposed:

- the degree to which an organization's products and services respond to the needs of their customers or users; and
- the efficiency with which the organization uses the resources at its disposal.

Recognizing that there are different customers or users, makes it easier to distinguish between objectives of such diverse groups as donors, politicians, system managers and farmers. As mentioned above, it is not recommended to use all described indicators under all circumstances. The number of indicators you should use also depend on the audience.

2 *THE PROCESS OF PERFORMANCE ASSESSMENT*

The process of performance assessment hinges around the capacity of the managers of an organization to answer two simple questions:

- **"Am I doing things right?"**, which asks whether the intended level of service (that has been set and agreed upon) is being achieved. This is the basis for good operational performance.
- **"Am I doing the right thing?"**, a question that aims at finding out whether the wider objectives are being fulfilled, and fulfilled efficiently. The latter is part of the process of assessment of strategic performance.

Operational performance is concerned with the routine implementation of the agreed (or pre-set) level of service. It specifically measures the extent to which intentions are being met at any moment in time, and thus requires that actual inputs and outputs are measured on a regular basis.

Strategic Performance is a longer term activity that assesses the extent to which all available resources have been utilized to achieve the agreed service level efficiently, and whether achieving this service also meets the broader set of objectives. Time-series of the indicator and its rate of change commonly are used in this activity. Available resources in this context refers not merely to financial resources: it also covers the natural resource base and the human resources provided to operate, maintain and manage irrigation systems. Strategic management involves not only the system manager, but also higher level staff in agencies and at national planning and policy level.

At all levels, performance must be assessed using a combination of **targets**. Each of these targets have an acceptable range of values around that target. Neither targets nor the range are likely to be uniform.

Targets reflect the objectives of managers at different levels. A system manager is most likely to base targets on the outcome of the annual or seasonal planning process. Higher level agency managers are more likely to use design criteria as their targets, because these were the basis for initial investment decisions. Policy makers concerned with very broad objectives may think in terms of potential performance with respect to the use of natural resources.

Both, targets and the related acceptable ranges reflect site specific conditions. They are influenced by the overall ecological conditions, and the size of the irrigation system or sub-system.

3 *THE AGREED SERVICE LEVEL*

As mentioned above, the intended service (or product) being delivered by an (irrigation) organization to its customers (water users) depends on the 'agreed service level'. Key elements to be taken into account are:

- An irrigation and drainage organization is service oriented if it (1) makes every effort to provide irrigation and drainage services that are well adapted to the farmers needs, (2) aims to provide these services at the lowest possible cost to the farmers, and (3) is accountable to farmers on the above issues (1) and (2).
- A service agreement between an irrigation organization and its users specifies (1) the service that will be provided, (2) the payments or other resources that will be contributed by the users in return for these services, (3) the procedures that will be used to check whether services are provided and payments are made as agreed, (5) the authority that will be adressed to settle conflicts, and (6) the procedures that will be used for updating and improving the agreement.
- In large-scale irrigation systems, irrigation water is often handled by an Irrigation Agency and by a Water Users Association before it reaches the individual farmer. Such systems require a separate service agreement for each level where water is transferred from on organization to the next. The set of Irrigation Service Agreements regulate the dual role of the WUA as both 'customer' and 'organization'.

- Organizations need to have the legal authority to make service agreements. Their organizational charter must specify rules for behaviour within an organization. In addition to specifying procedures related to the service agreement, it describes the purpose of the organization, the organizational structure, the procedures for electing council members and appointing functionaries, the rights and duties of council members, functionaries and regular members.

- Service oriented management of an irrigation and drainage system is a process of identifying, designing and implementing the technical and institutional modifications needed for sustained operation of the system on the basis of an appropriate set of service agreements and organizational charters.

Combining these five issues in terms of a service level that is intended to be given by an organization to its customers results to:

$$\textit{Agreed Service Level} = \frac{\textit{Intended Level of Delivered Resource}}{\textit{Required Level of Considered Resource}}$$

For each of the considered disciplines, the agreed service level thus quantifies the intended value of a considered sub-set of parameters. The Agreed Service Level may differ from month to month. It is recommended to define the Agreed Service Level for all sub-command areas on a monthly basis. Depending on the method of water supply, a shorter period (10 days or less) might be needed during some critical periods.

The main purpose of the agreed service level is to quantify the 'intended level of the delivered resource' with respect to a (user) selected reference level. The reference level should be relevant for the related irrigated area and remain constant in time. Its actual value is less important. If the 'intended level of (a) delivered resource' cannot be determined, there will be no yardstick against which performance can be measured! As such, the description of 'the agreed service level' has priority. As mentioned above, the agreed service level does not remain constant in time. It is due to be revised with a change in the availability of resources (e.g. water, energy, manpower, funds).

4 *GENERAL FEATURES OF PERFORMANCE INDICATORS*

A true performance indicator includes both an actual value and an intended value that enables the assessment of the amount of deviation. It further should contain information that allows the manager to determine if the deviation is acceptable. It is therefore desirable wherever possible to express indicators in the form of a ratio of the actually measured versus the intended situation. Hence

$$\textit{Performance Indicator Level} = \frac{\textit{Actual Level of Delivered Resource}}{\textit{Intended Level of Considered Resource}}$$

A fuller description of desirable attributes of performance indicators is given in Table 1.

It is important to ensure that the indicators selected for a system will describe performance in respect of the objectives established for that system. It is this process that links the use of indicators to the overall performance assessment framework (Bos et al 1993). Failure to take this into account may lead to managers being assessed in terms of activities that were not included in their initial brief.

A good indicator can be used in two distinct ways. It tells a manager what current performance is in the system, and, in conjunction with other indicators, may help him to identify the correct course of action to improve performance within that system: in this sense the use of the same indicator over time is important because it assists in identifying trends that may need to be reversed before the remedial measures become too expensive or too complex.

Table 1 Properties of Performance Indicators

Scientific basis

The indicator should be based on an empirically quantified, statistically tested causal model of that part of the irrigation process it describes. Discrepancies between the empirical and theoretical basis of the indicator must be explicit, i.e., it must not be hidden by the format of the indicator. To facilitate international comparison of performance assessment studies, indicators should be formatted identically or analogously as much as possible (Bos & Nugteren 1990, ICID 1978, Wolters 1992).

The indicator must be quantifiable

The data needed to quantify the indicator must be available or obtainable (measurable) with available technology. The measurement must be reproducible.

Reference to a target value

This is, of course, obvious from the definition of a performance indicator. It implies that relevance and appropriateness of the target values and tolerances can be established for the indicator. These target values (and their margin of deviation) should be related to the level of technology and management (Bos et al. 1991).

Provide information without bias

Ideally, performance indicators should not be formulated from a narrow ethical perspective. This is, in reality, extremely difficult as even technical measures contain value judgements (Small 1992).

Provide information on reversible and manageable processes

This requirement for a performance indicator is particularly sensible from the irrigation manager's point of view. Some irreversible and unmanageable processes could provide useful indicators, although their predictive meaning may only be indirect. For example, the frequency and depth of rainfall is not manageable, but information from a long time series of data may be useful in planning to avoid water shortage; and information on specific rainfall events may allow the manager to change water delivery plans.

Nature of the indicator

An important factor influencing the selection of an indicator has to do with its nature: the indicator may describe one specific activity or may describe the aggregate or transformation of a group of underlying activities. Indicators ideally provide information on an actual activity relative to a certain target value. The possibility of combining such dimensionless ratios into aggregate indicators should be studied, in much the same way that many indicators used for national economic performance are composites.

Ease of use and cost-effectiveness

Particularly for routine management, performance indicators should be technically feasible, and easily used by agency staff given their level of skill and motivation. Further, the cost of using indicators in terms of finances, equipment, and commitment of human resources, should be well within the agency's resources.

5 WATER BALANCE INDICATORS

Water balance performance indicators are concerned with the assessment of the water supply function of the irrigation system. They cover the volumetric component that is primarily concerned with matching water supplies to irrigation water demand, as well as the rather more subjective concept of reliability that may affect the users' capacity to manage water efficiently, and the socially oriented aspects of equity. These three aspects all represent facets of the concept of the **Level of Service** being provided to water users.

This Section focuses on this "core business" of the organization managing the irrigation system; the diversion and conveyance of water to the WAU's in the irrigation system; the supply of water to the tertiary units within the lateral command area; the delivery of water to the quartenary units of the tertiary unit; and the distribution of water to farms within one quartenary unit.

The primary task of the managers of the 'Irrigation System', and of the managers of the sub-systems (the WUA) is to deliver water in accordance with a plan (as intended). Indicators in this section are therefore those that guide managers in respect to water delivery performance.

5.1 Water Delivery Performance

The simplest, and yet probably the most important, hydraulic performance indicator is (Clemmens and Bos 1990; Bos et al. 1991):

$$\text{Water Delivery Performance} = \frac{\text{Actually Delivered Volume of Water}}{\text{Intended Volume of Delivered Water}}$$

This measure enables a manager to determine the extent to which water is delivered as **intended** during a selected period (may range from second to year) and at any location in the system. The primary utility of the Water Delivery Performance ratio is, that it allows for checking of whether the flow at any location in the system is more or less than intended. It is obvious that if the actually delivered volume of water is based on frequent flow measurements, the greater the likelihood that managers can match **actual** to **intended** flows.

Over a sufficiently long time frame (e.g., monthly, or over three or four rotational time periods) it can be assumed that; **if** the Water Delivery Performance ratio is close to unity, **then** the management inputs must be effective. If the Water Delivery Performance ratios for different units within the considered command area have about the same value, the uniformity of water delivery must (because of the concept of conservation of mass of the available water resources) be good. The uniformity of actual water delivery may be quantified by calculating the standard deviation of the *WDP* values.

5.2 Water Balance Ratios

In general, the water balance indicators deal with the volume of water delivered within a set time period (in m^3/period), rather than the instantaneous flow rate (in m^3/s). The ratios quantify components of the water balance in a spatial context over a specific time period. As such, the same data on flow rates are needed as above.

5.2.1 Field Application Ratio

The ICID (1978) standard definition for the field application ratio (efficiency), R_a, is

$$\text{Field Application Ratio} = \frac{V_m}{V_f}$$

V_m = the volume of irrigation water needed, and made available, to avoid undisirable stress in the crops throughout (considered part of) the growing cycle.
V_f = the volume of irrigation water delivered to the fields during the considered period.

The value of V_m is difficult to establish on a real time basis because many complicated field measurements would be needed. The method which is used to quantify V_m, however, is not so very important provided that the same (realistic) method is used for all command areas (lateral or tertiary units) within the irrigated area. For practical purposes we may assume that V_m equals the evapo-transpiration by the irrigated crop minus the effective part of the precipitation: $ET_p - P_e$. The value of $ET_p - P_e$ can be calculated by use of models like CRIWAR (Bos e.a. 1996) and CROPWAT (Smith e.a. 1991). We thus recommend the field application ratio to read:

$$Field\,Application\,Ratio = \frac{ET_p - P_e}{Volume\ of\ Water\ Delivered\ at\ Field(s)}$$

The target water requirement at the field inlet then equals

$$V_{f,target} = R_{a,target}\ x\ (ET_p - P_e)$$

The target value of the field application ratio depends on the level of technology used to apply water, on the climate, and on whether you grow dry-foot crops or ponded rice (Bos e.a. 1996).

5.2.2 *Tertiary Unit Ratio*

The irrigation water requirement at the intake of a tertiary unit depends on the crop irrigation water requirements ($ET_p - P_e$) in the unit, on the water delivery performance in the unit, on canal seepage, and on the (average) value of the above field application ratio. The tertiary unit ratio, R_u, (effciency) is defined as (ICID 1978)

$$Tertiary\ Unit\ Ratio = \frac{V_m + V_3}{V_d}$$

For practical purposes we may replace V_m by $ET_p - P_e$, and assume negligible non-irrigation water deliveries from the distribution system ($V_3 = 0$).

5.2.3 *Overall Consumed Ratio*

The overall (or project) consumed ratio, R_p, quantifies the fraction of irrigation water evapo-transpirated by the crops in the water balance of the irrigated area (Bos and Nugteren 1974; Willardson e.a. 1994). Assuming negligible non-irrigation water deliveries, it is defined as (Bos & Nugteren 1974):

$$Overall\ Consumed\ Ratio = \frac{ET_p - P_e}{V_c + V_l}$$

V_c = volume of irrigation water diverted or pumped from the river or reservoir
V_l = inflow from other sources to the conveyance system

The value of ($ET_p - P_e$) for the irrigated area is entirely determined by the crop, the climate and the interval between water applications. Hence, the actual value of the overall consumed ratio varies with the actual values of V_c and V_l being the volume of irrigation water delivered to the sub-command area.

Because the inflows V_c and V_l are among the very first values that should be measured, together with the cropped area, the cropping pattern and meteorological data, the overall consumed ratio is the first water balance indicator that should be available for each irrigated area. For water management within an existing irrigated area is recommended to set a target R_p-value, and to measure the actual overall consumed ratio at a monthly (or 10-day) and annual basis.

5.2.4 Conveyance Ratio

The conveyance ratio, R_c, quantifies the water balance of the main, lateral and sub-lateral canals, including related structures, of the irrigation system. It is defined as:

$$\textit{Conveyance Ratio} = \frac{V_d + V_2}{V_c + V_1}$$

V_c = volume of irrigation water diverted or pumped from the river or reservoir (source of surface water)
V_d = volume of water actually delivered to the distribution system
V_1 = inflow from other sources to the conveyance system
V_2 = non-irrigation deliveries from the conveyance system

The conveyance ratio should be calculated over a short (week, month) and a long (season) period. The rate of change of the ratio is an indicator for e.g. the need of maintenance (see also Section 6). For large irrigation systems it is common to consider the conveyance ratio of parts of the system. Hence, we consider (i) the conveyance ratio of the upstream part of the system as managed by the Irrigation Authority and (ii) of the WUA managed canal.

5.2.5 Distribution Ratio

The distribution ratio, R_d, quantifies the water balance of the canal system downstream from the conveyance system up to the inlet of the fields. It thus quantifies the water balance of the canal system at tertiary unit level. The distribution ratio is defined as:

$$\textit{Distribution Ratio} = \frac{V_f + V_3}{V_d}$$

If the distribution ratio is determined for all tertiary units within the considered irrigated area, the uniformity of water delivery by the WUA can be expressed by the standard deviation of the distribution ration values. If all tertiary units receive a (colour) code for a given subdivision of ratio values this uniformity of water supply can be visualized on a map.

5.3 Dependability

The pattern in which water is delivered over time, is directly related to the overall consumed ratio of the delivered water, and hence has a direct impact on crop production. The rationale for this is that water users may apply more irrigation water if there is an unpredictable variation in volume or timing of delivered water, and they may not use other inputs such as fertiliser in optimal quantities if they are more concerned with crop survival than crop production.

The primary indicators proposed for use in measuring dependability of water deliveries are concerned with the duration of water delivery compared to the plan, and the time between deliveries compared to the plan. They are:

$$\textit{Dependability of Duration} = \frac{\textit{Actual Duration of Water Delivery}}{\textit{Intended Duration of Water Delivery}}$$

and

$$\text{Dependability of Irrigation Interval} = \frac{\text{Actual Irrigation Interval}}{\text{Intended Irrigation Interval}}$$

In addition to dependability in terms of timing, it is strongly recommended that the predictability of the flow rate or the (canal) water level be included in this part of the assessment. For many irrigation activities the flow rate (or water level) must be near the intended value for water use to be effective (Clemmens & Bos 1990).

The simplest method to assess predictability of flow rate (or flow rate times duration of flow) is to determine the standard deviation of the water delivery performance ratio (Section 5.1). The period over which observations are compared in this analysis will vary depending on the type of water delivery pattern adopted. In most irrigated areas, monthly or bi-weekly data appear to give a good indication of whether the discharge is more or less predictable.

6 *ENVIRONMENTAL SUSTAINABILITY AND DRAINAGE*

6.1 *Sustainability of Irrigation*

Aspects of physical sustainability that can be affected by irrigation managers relate primarily to over- or under-supply of irrigation water leading to waterlogging or salinity. The simplest measure of sustainability is therefore:

$$\text{Sustainability of Irrigable Area} = \frac{\text{Current Irrigable Area}}{\text{Initial Total Irrigable Area}}$$

The initial area refers to the total irrigable area in the design of the system or in the latest rehabilitation. Where it is appropriate, this ratio can be modified to specifically refer to waterlogged or saline areas as a percentage of the total irrigable area. At a later stage we will, of course, need to know the cause of land being lost from production. Hence, is agricultural land lost because of salinity, water shortage, low profitability of agriculture, or due to urban and industrial development?

6.2 *Depth to Groundwater*

Many of the adverse environmental impacts of irrigation are related to the rate of change of the depth to the groundwater table.

- Because of ineffective drainage, or delay in constructing drainage systems in comparison to the surface water supply infrastructure, the groundwater table often rises into the root zone of the irrigated crop. In (semi-)arid regions this often leads to the increase of capillary rice over seepage, resulting to salinity in the root zone.
- If groundwater being pumped for irrigation exceeds the recharge of the aquifer the groundwater table drops. As a result, energy cost for pumping may increase to such a level that water becomes to expensive (see Section 7.#), or groundwater mining may deplete the resource.

In both cases the sustainability of irrigation can be determined a study of time-series of the ratio

$$\text{Relative Groundwater Depth} = \frac{\text{Actual Groundwater Depth}}{\text{Critical Groundwater Depth}}$$

For waterlogging and salinity, the critical groundwater depth mostly depends on the (effective rooting depth) of the crop, the efficiency of irrigation water use (Section 5) and on the hydraulic characteristics of the soil. In the case of mining the critical depth depends on the cost of pumping water, the value of the irrigated crop and on the depth of the aquifer. If the actual groundwater depth is near the critical depth, the time interval between readings of the ratio should be near one month. One year is suitable for most other purposes.

6.3 *Pollution of Water*

Within the context of (irrigation) water performance assessment we distinguish between the *consumption* and the *use* of water.

- If water is *consumed* by (the crop) it leaves the considered part of the system, and cannot be consumed or reused in an other part of the considered system. For example, if the field application ratio (efficiency) for a considered field is 56%, this means that 56% of the applied water is evapotranspirated and that the other 44% either becomes surface run-off or recharges the aquifer. Part of this 44% may have been *used* to serve other purposes, e.g. simplify farm management, leaching, etc.

- During the irrigation process water can be *used* for a variety of other purposes. These may be directly related with irrigation (facilitate management, silt flushing, leaching, seepage, etc.), or be related with other user groups (energy production, shipping, urban and industrial use, recreation, etc.). As a general rule we may assume that the quality of water decreases upon its use. The indicators in this section quantify the effect of user activities on water quality.

In this Section we only recommend to monitor some pollutants of which the concentration can be determined at low cost per (laboratory) measurement. We tentatively assume that if none of these indicators have a value approaching critical levels, that other pollutants (e.g. heavy metals, pesticides, etc.) will not cause a problem. This assumption, however, should be checked for the month during which pollution is highest.

6.3.1 *Salinity*

Because of the leaching of salts, etc. from the root zone, and because of groundwater re-use, the quality of groundwater in an irrigated area tends to deteriorate. Also the water quality of the water in the irrigation system tends to deteriorate due to return flow of drainage water. The relative change of salinity at considered locations within the irrigated area can be quantified by:

$$\text{Relative EC Ratio} = \frac{\text{Actual EC value}}{\text{Critical EC value}}$$

The critical EC-value depends on the salt tolerance of the irrigated crop(s). If we want to quantify the effect of a certain user (or group of users) on the salinity of the irrigation water in the canal system, we recommend to measure the EC upstream and downstream of the user.

The time interval between measured EC-values depends on the studied trend. One month is suitable to evaluate seasonal trends; one year is suitable for most other purposes.

6.3.2 *Organic Matter*

The (rate of change of the) concentration of organic matter in irrigation water mainly results from two sources; (1) the natural fall of leaves and branches from trees and vegetation along the canal, and (2) the disposal of trash by humans along the canal. We recommend to measure: total dissolved organic matter (vol %), floating matter (vol %), colour and smell. An equivalent ratio as shown for the EC value should be used.

6.3.3 *Biological Pollution*

The major source of micro biological pollution is (untreated or partially treated) urban and industrial sewage water flowing into the canal system. We recommend to measure the Biochemical Oxygen

Demand (m/l) and the Chemical Oxygen Demand (m/l). Equivalent ratios as shown for the EC value should be used.

6.3.4 Chemicals

The major sources of chemical pollution may have either a non-agricultural or an agricultural source; urban and industrial sewage water flowing into the canal, and pesticides plus fertilizer leached from the root zone. We recommend the measurement of at least the concentration of Nitrates (NO_3^{-1} in meq/l) and of Phosphorus (P in meq/l). Measurement of other concentrations may be needed for specific locations. Equivalent ratios as shown for the EC value should be used.

7 MAINTENANCE INDICATORS

7.1 General

Maintenance is designed to accomplish three main purposes: safety, keeping canals in sufficiently good condition to minimize seepage and sustain canal water levels and designed discharge-head relationships, and keeping water control infrastructure in working condition.

In irrigation systems the conveyance efficiency provides the best way of assessing whether canal maintenance is required. By tracking the change in conveyance efficiencies over time it should be possible to establish criteria that will indicate when canal cleaning or reshaping is necessary. In many systems this is undertaken subjectively on appearance rather than using a more analytical approach.

7.2 Sustainability of Water Level and Head-Discharge Relationship

During the design of a canal system, a design discharge and related water level is determined for each canal reach. The hydraulic performance of a canal system depends greatly on the degree to which these design values are maintained. For example, higher water levels increase seepage and the danger of overtopping of the embankment. Both, lower and higher water levels alter the intended water division at canal bifurcation structures. The magnitude of this alteration of the water distribution depends on the hydraulic flexibility of the division structures (Bos 1976). This change of head (level) over structures in irrigation canals is the single most important factor disrupting the intended delivery of irrigation water (Bos 1976, Murray-Rust & van der Velde 1994).

An indicator that gives practical information on the sustainability of the intended water level (or head) is:

$$\textit{Relative Change of Water Level} = \frac{\textit{Change of Level}}{\textit{Intended Level}}$$

For closed irrigation and drainage pipes (visual) inspection of heads (pressure levels) is complicated. The functioning of a conduit, however, should be quantified by the measured discharge under a measured head-differential between the upstream and downstream end of the considered conduit (as used in the original design), versus the theoretical discharge under the same head differential. Hence, conduit performance can be quantified by the ratio:

$$\textit{Discharge Ratio} = \frac{\textit{Actually Measured Discharge}}{\textit{Design Discharge}}$$

The same discharge ratio can be used to quantify the effective functioning of structures in the canal system. Depending on the type of structure, the actual discharge then must be measured under the same (design) differential head (submerged gates, culverts, etc.) of under the same upstream sill-referenced head (free flowing gates, weirs, flumes, etc). Generally, a deviation of more than 5% would signal the need for maintenance or rehabilitation for flow control structures.

As mentioned above, maintenance is needed to keep the system in operational conditions. For this to occur, (control) structures must be operational as intended. Hence, maintenance performance can be quantified by the following ratio:

$$\text{Effectivity of Infrastructure} = \frac{\text{Number of Functioning Structures}}{\text{Total Number of Structures}}$$

The above three ratios immediately indicates the extent to which the manager is able to control water. For the analysis to be effective, however, it must divide structures up into their hierarchical importance (Main, Lateral, Tertiary and Quartenary) and the analysis completed for each level.

8 *SOCIO-ECONOMIC PERFORMANCE*

This set of indicators relates to longer term impacts of pursuing a particular set of operational and agricultural strategies. These indicators have been divided into three primary categories: those relating to economic viability, those relating to social viability and those associated with sustainability of the physical environment for irrigation.

8.1 Economic Viability

Each of the primary participants in the irrigation sector, i.e., planners and policy makers, agency personnel and farmers, has a different perspective on what is meant by economic performance. Each, therefore, requires a separate set of indicators that reflects these different objectives. The system manager is most likely to be concerned with the financial resources available at system level and the source of those funds, possibly rather less concerned with the overall profitability of agriculture, and least concerned about the overall profitability of the irrigation project that created the system (unless it is owned by a private firm in which he is a shareholder).

8.1.1 Financial Viability of Irrigation Systems

One set of indicators concerns with efforts to raise revenues from water users that help support management, operation and maintenance (MO&M) costs, and often some or all of the capital costs of individual irrigation systems. The first of these indicator describes the overall financial viability of the system:

$$\text{Financial Self Sufficiency} = \frac{\text{Actual Income}}{\text{Total } MO + M \text{ Requirements}}$$

The total MO+M requirements should be based on a detailed budget. The indicator is admittedly subjective because "requirements" greatly depend on the number of persons employed by the Agency per unit irrigable area (see Bos & Nugteren 1974 for ranges). However, it gives an indication of the extent to which the agency is expected to be self financing. The above income of the Agency (users group, irrigation district, irrigation department, etc.) may have different sources of income, e.g.; central government, water charges, sale of trees along canals, hydraulic energy, etc.

To quantity the effectiveness of the irrigation agency with respect to the actual delivery of water (operation) and the maintenance of the canals (or pipe lines) and related structures, the O & M Fraction is used.

$$O + M \text{ Fraction} = \frac{\text{Cost of Operation} + \text{Maintenance}}{\text{Total Agency Budget}}$$

This indicator deals with the salaries involved with the actual operation (gate men, etc.) plus maintenance cost and minor investments in the system (replacement of canal or pipe sections and of damaged structures). To quantify the O+M Fraction, we need the annual budget as **proposed** by the Irrigation Authority (for its total MO&M) and from the WUA of the selected command area (for its MO&M), the budgets as **approved** (allocation per item), and the **actually** realized income over the related year.

In many irrigated areas, water charges (irrigation fees) are collected from farmers. The fraction of the annual fees (charges) due to be paid to the WUA and (or) the Irrigation District is an important indicator for level of acceptance of irrigation water delivery as a (public) service to the customers (farmers). The indicator is defined as:

$$\mathit{Fee\ Collection\ Performance} = \frac{\mathit{Irrigation\ Fees\ Collected}}{\mathit{Irrigation\ Fees\ Due}}$$

The ratio should be quantified for all Water Users Associations in the considered irrigated area.

8.1.2 Profitability of Irrigated Agriculture

Independently of the economic viability of a particular investment, or the viability of the agencies supplying water and other inputs, farmers must primarily be concerned with the profitability of their actions at the level of their individual farm. It is quite possible for sector or system level economic analyses to show negative returns, largely through the high cost of capital, and yet find farmers in those systems consistently making profits. Two indicators are proposed that address different aspects: profitability in terms of land, and profitability in terms of water delivered.

$$\mathit{Yield\ vs\ Water\ Cost\ Ratio} = \frac{\mathit{Added\ Value\ of\ Crop}}{\mathit{Cost\ Applied\ Irrigation\ Water}}$$

This indicator requires evaluation of the value of the produced crop with irrigation minus the value of the crop (that could be) produced without irrigation. The cost of applied water can be modified to include or exclude the discounted value of the capital cost of the system depending on whether or not capital is considered a sunk cost.

Within most irrigated areas, however, water is the scarcer resource. Hence it is logical to substitute water for land in the above equation:

$$\mathit{Yield\ vs\ Water\ Supply\ Ratio} = \frac{\mathit{Added\ Mass\ of\ Marketable\ Crop}}{\mathit{Mass\ of\ Irrigation\ Water\ Delivered}}$$

Here again the added mass of marketable crop should be determined. If viewed from the farmers perspective the mass of water delivered is measured either at the farm inlet or at the head of the field, depending on his views.

From the perspective of the farmer the (socio-)economics of irrigation can also be quantified by the relative cost of irrigation water:

$$\mathit{Relative\ Water\ Cost} = \frac{\mathit{Total\ Cost\ of\ Irrigation\ Water}}{\mathit{Total\ Production\ Cost\ of\ Major\ Crop}}$$

The total production cost includes cost of water (including fees, energy for pumping), seeds, fertilizer, pesticides, labour, etc. For surface irrigation this ratio often ranges betwee 0.03 and 0.04; if pumped groundwater is used the ration may become as high as 0.10. If the ratio become higher, farmers tend to abandon irrigation.

8.2 Social Capacity

Social capacity refers to the social (as distinguished from physical, biological, or economic) capacity of people and organizations for managing and sustaining the irrigated agriculture system. We tested two indicators:

$$\textit{Technical Knowledge Staff} = \frac{\textit{Knowledge Needed for Job}}{\textit{Actual Technical Knowledge of Staff}}$$

and

$$\textit{U'sers Stake} \in \textit{Irrigation System} = \frac{\textit{Active Water Users Organizations}}{\textit{Total Numbers of W.U. Organizations}}$$

The required technical knowledge (and related skills) should be part of the job description of the staff members. Actual technical knowledge of staff could be ascertained through tests related to regular training programs. Also, annual evaluation reports can be used.

The "activeness" of water users associations can be quantified using acquired data, such as percentage of WUA's holding regular (or the minimum required) meetings, percentage of water users participating in meetings, or number of organizations fulfilling agreed upon tasks, such as fee collection, maintenance, or distributing water.

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These partners do research on the performance of the Middle Tunuyan Irrigation Project in Mendoza Province. The objectives of the research program are:

- To identify and test indicators that can be used to quantify and qualify the performance of irrigation and drainage. The focus will be on actual irrigation and on irrigation management.
- Based on the research program interventions may be formulated in irrigation techniques and in irrigation management procedures.
- The impact of accepted interventions on performance will be monitored.

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