1. **Irrigation system indicators.**

The working group on irrigation efficiency formed by ICID in 1974 has collected the following irrigation indicators (Bos, 1985):

(i) **Conveyance efficiency:** efficiency of canal and conduit networks from the reservoir, river diversion or pumping station to the off-takes of the distribution system:

\[ Ec = \frac{V_d + V_2}{V_o + V_1} \]

with 
- \( V_o \) = volume diverted or pumped from the water source (m³),
- \( V_d \) = volume delivered to the distribution system (m³),
- \( V_1 \) = inflow from other sources (m³),
- \( V_2 \) = non irrigation deliveries from conveyance system (m³)

(ii) **Distribution efficiency:** efficiency of distribution of canal and conduits supplying water from the conveyance network to individual fields.

\[ Ed = \frac{V_f + V_3}{V_d} \]

with 
- \( V_f \) = volume of water supplied to the field (m³),
- \( V_3 \) = non irrigation deliveries from distribution system (m³).

(iii) **Field application efficiency:**

\[ Ea = \frac{V_m}{V_f} \]

with 
- \( V_m \) = volume of irrigation water needed and made available for evapotranspiration
- \( V_m = \text{we} - \text{Pe} \)
- \( \text{we} \) = crop water requirement in mm. This is the total depth of water required, during a specific time period (rainfall and/or irrigation), when soil water is maintained so that it does not limit plant growth.
- \( \text{Pe} \) = effective rainfall.

(iv) **Tertiary unit efficiency:** combined efficiency of the water distribution system and of the water irrigation process:

\[ Eu = \frac{V_m + V_3}{V_d} \]

(v) **Overall efficiency:**

\[ Ep = \frac{V_m + V_3 + V_2}{V_o + V_1} \]

- First of all, indicators should be capable of providing realistic criteria; in other words, they must be simple enough to make comparisons possible between different systems. (no ambiguity on
the entities to be measured and feasibility of the measures.). The indicators mentioned above satisfy these requirements.

- The precision of the indicators depends on the constituting parameters which vary thoroughly according to the type of device being used and the location of the sites. Therefore it seems hazardous to work on the values taken by these indicators without considering their confidence intervals.

Ec, the conveyance efficiency gives a global value, which will not give a true account of the variation of this ratio as a function of
- the discharge ahead,
- the total length of canal or gross area irrigated,
- local defaults of the conveyance system,...

The availability of such information (Ec(L)=f(Q,L), where L is the distance between the point in which you are computing efficiency and the head of the distribution system, would be very helpful in building an adequate diagnosis and improvement of the system.

The distribution efficiency is a good indicator though it may produce a bad value due to water stealing.

Concerning the field application efficiency, the indicator seems far less adequate although theoretically convenient, it is far less practicable.

To measure water application to each field as well as soil water content before every application, requires a very intense measuring organisation. Besides, consumptive use and good meteorological data are seldom available in most of the sites. The accuracy of such an indicator is bound to be poor or at least not quite relevant. As a matter of fact, the soil root zone available for water storage increases with the development of the culture and, moreover, great spatial variations occur within one field.

Consumptive use scheduled per month, seems a very rough proxy.

The next two efficiencies are second order efficiencies, cumulating all the drawbacks of the first order efficiencies and are not very informative. They give only a rough estimate; yet they are the sole parameter used for evaluation, by the decision makers.

2. AGRICULTURAL SYSTEM INDICATORS

(i) Application efficiency at field level.

\[ \text{Ea} = \text{Nf}(V_m, V_f) \]

The target application efficiency as expressed above is always below 100% since leaching or deep percolation is compulsory in some cases to maintain an acceptable salt balance and suitable aeration in the root zone. It is not correct to say that this volume of water is not necessary for crop production. The water requirements for a crop are distinct from the consumptive use of a plant.

(ii) Irrigation efficiency IE:

\[ \text{IE} = \text{N}(V_c, V_d) \]

with \( V_d = \text{volume delivered} \) and \( V_c = \text{volume beneficially used} \), is a theoretical parameter,
difficult to evaluate since the benefits may be of various types. Since one has to cope with non uniformity of water application, the following indicators are suggested.

(iii) uniformity coefficient:
\[ Ud = \frac{\sqrt{\text{VAR}(V_1, 4)}}{V} \]

with
\( \text{VAR}(V_1, 4) \) is the volume of water infiltrated in the lower quarter of the field,
\( V \) is the average volume received in any quarter of the field.

Such a ratio is relevant for furrow or basin irrigation.

(iv) Christiansen's uniformity coefficient, \( U_{cc} \) is expressed by:
\[ U_{cc} = 1 - \sqrt{\text{SDO}(1, \Sigma n) \left( y_i \cdot y_i \right) / (n \cdot \bar{y})} \]

with
\( y_i \) is the depth of absorbed water representative of the one \( n \)th of the irrigated field,
\( \bar{y} \) is the mean of the absorbed water in \( n \) fields.

(v) field application efficiency defined by the ICID, taking account of variability is as follows:
\[ E_a, \text{target} = \frac{V_m}{(V_m + s \cdot T_p)} \]

with
\( V_m \) = volume of water required to maintain the soil moisture above the minimum level for the crop.
\( s \) = standard deviation of the depths of water applied to the field at the observed grid points,
\( T_p \) = the value that is exceeded by a random variable, normally distributed with 0 mean and unit standard deviation, with the probability \( p \).

This new target value allows an increased mean field application, reducing thus the under irrigated part of the field. \( p \) is the accepted threshold value. The assumption of normal distribution of water may not be representative especially under heterogeneous conditions.

Three other parameters are commonly being used to characterise field application (Gideon Peri & Al, 1979):

(vi) Delivery efficiency at the field level:
\[ E_d = \frac{V_i}{V_d} \]

with
\( V_i \) = volume of infiltrated water,
\( V_d \) = volume of delivered water.

This ratio gives a measure of the losses due to other factors than runoff, i.e. wind drift, tail water reuse system, evaporation, etc.

(vii) Deep percolation efficiency: This parameter is a measure of the water lost to deep percolation
\[ E_p = \frac{V_{sr}}{V_i} \]

with

\[ V_{sr} = \text{volume of water stored in the root zone water storage.} \]

It is very difficult to obtain measures of the percolation losses, and practically this parameter is rarely made use of.

(viii) Storage efficiency is the fraction of available root zone water storage (at the time of irrigation) that is filled by irrigation. It gives a measure of the adequacy of the irrigation.

\[ E_s = \mathcal{N}(V_{sr}, V_s) \]

with

\[ V_s = \text{the available root zone water storage.} \]

These indicators are still insufficient; they are based on external knowledge assumed to describe properly the developing process of the crops; but the only real estimate of the irrigation efficiency is the yield of a crop.

(ix) The \([\text{Yield/Evapotranspiration}]\) (ICID) and \([\text{Yield/water supply}]\) are defined as:

\[ \text{Rye} = \mathcal{N}(y_i - y_r, \text{ET}_i - \text{ET}_r) \]

\[ \text{Ryw} = \mathcal{N}(y_i - y_r, W_f) \]

with

\[ y_i = \text{mass of marketable crop produced with irrigation,} \]

\[ y_r = \text{mass of marketable crop that could be produced without irrigation,} \]

\[ \text{ET}_i = \text{mass of water evapotranspired by the irrigation crop.} \]

\[ \text{ET}_r = \text{mass of water that would be evapotranspired by the same crop if not irrigated.} \]

\[ W_f = \text{water delivered to the field} \]

These parameters are built with assumed values on what might be the situation without irrigation; Gross assumptions of these values are being done knowingly to influence opinions or sometime unknowingly.

The marketable crop, if measured by its sole mass or dry matter mass does not allow differences between main crop produce and byproducts. The introduction of costs and prices (§3) will account for it.

After adding certain amount of water, the additional yield due to incremental dose of water will decrease, resulting in the reduction of overall yield per unit of water. Moreover some crops give higher yields with less water. The following parameters try to give measures allowing meaningful comparisons:

- Yield per unit of ha
- Yield per unit of water
- Water use efficiency:

\[ \text{net WUE} = \mathcal{N}(\text{crop production (kg)}, \text{evapotranspiration from planting to harvest}) \]

The comparison of mass harvested for different crops is very poor: fodder, oil seed, sugarcane, cereals, pulses, even two varieties of the same crop do not provide the same type of matter. High opportunity cost, or a particular strategy (individual or public) may justify going for less efficient crops (§3).

The quality of the crop itself may be decreased by irrigation:
some varieties of ragi, when irrigated give a less nutritious grain.
Besides WUE is not a complete indicator, for example, millet has a very good water efficiency, but only one crop can be grown round the year, whereas rice water use efficiency is low but the short duration of rice allows 2 to 3 crops a year in the same plot.
All these parameters consider water scarcity conditions but even under such conditions, we may find in the same location excess water conditions and as such there is no specific detector of such a situation, neither measures of the attempts to cope with it. The ratios per unit of water are a step towards it.

The timing adequacy of irrigation is another aspect barely approached by most authors:

(x) The interval ratio and the depth ratio are defined respectively as:
INR = \( \frac{R_I - A_I}{R_I} \) and IDAR = \( \frac{R_D - A_D}{R_D} \)

where:
- \( R_I \) = recommended intervals between irrigations
- \( A_I \) = actual interval between irrigation
- \( R_D \) = recommended depth of application
- \( A_D \) = actual depth of application.

Evaluation of these parameters is based on two irrigation scheduling parameters:
- The time of irrigation,
- The irrigation requirements, which depends on the crop stage, the soil type.

The delivery of water for the crop development is characterised by:
- Its adequacy, whether the amount meets the requirements
- Its timeliness, whether the delivery occurs whenever is required,
- Its reliability, if amounts are delivered when expected and needed it contributes to reliability, but since these aspects are very changing ones, they are quite difficult to assess.

(xi) Water availability index, WAI (Wijayaratna, 1985):
This index is computed to analyse the water inputs, taking into account both amount and timing; 5 different ranges of water supply are differentiated and given a different weight:
- \( x_1 \) = severe shortage of water (soil cracking).
- \( x_2 \) = moderate shortage (soil dry).
- \( x_3 \) = saturated conditions (soil wet)
- \( x_4 \) = standing water,
- \( x_5 \) = flowing water.

WAI is calculated adding the number of days in each category weighted with \( x_1, x_2, x_3, \) etc. This is done first for all the cropping season, and then only for the critical periods, according to the phenologic stage of the culture. This index can be calculated for the fields, the channels or the whole irrigated area.

It is quite difficult to find relevant indicators to measure some correlative negative effects of irrigation (see §5); in the agricultural system for example, its effect on weeds and pests is well known, but not quantified.
3. **ECONOMIC INDICATORS**

(i) The first well-known indicator, is the yield water-cost ratio:

\[ R_{yc} = \frac{C_i - C_r}{C_f} \]

with

- \( C_i \) = value of crop under irrigation
- \( C_r \) = value of crop (and by products) that could be produced without irrigation
- \( C_f \) = cost of applied irrigation water, including amortisation, labour and supplementary production costs. (ICID)

Very often when an economic evaluation is made, the actual state of the irrigation system is considered as the result of a previous project characterised by some investments (dam, channels, etc...) and the objective is to estimate the returns on investments, the ability of the system to self-fund its maintenance cost, paying back the initial investments (whether it is decapitalising or not) and the income it provides to each and every farmer. The charges and net product per acre, per volume of water or per volume of harvest are broadly used as indicators, though the type of assessment they bring is very rough without consideration of the production context. The present situation may also be analysed in connection with future planned investments on projects. Under such conditions cost-benefit ratio is computed and net returns are estimated. Benefits and costs to farmers, to the project authority, to the state and to the national economy are computed, the expected income level, water rates, and internal rentability rate (actualisation rate for which the actualised benefit equals zero) allow the planners to make a comparison between various projects; the internal rate of rentability is very commonly used but the justification of the chosen rates or terms allowed for depreciation are seldom justified. But none of these well known indicators, give a cost utility analysis which tends to assess non quantifiable consequences (satisfaction) as well as indirect impact (externalities).

The reduction of risk is a very important prospect of many projects but its economic impact is very difficult to estimate and often the costs for such estimation is very high; the financial criterion computes the variation of the cash capacity of the project.

4. **SOCIAL CRITERIA**

The employment generated or maintained by an irrigation system may contribute to social stability.

In the same way social welfare and equity are two main parameters that most of the projects pretend or try to increase for the sake of humanitarian principles.

(i) ratio similar to the equity ratio is computed as follows:

\[ Re = \sqrt[1/3]{V_{1/3 \text{TAIL}} \div V_{1/3 \text{HEAD}}} \]

with

- \( V_{1/3 \text{TAIL}} \) = volume delivered at one third tail end part of the irrigated area
- \( V_{1/3 \text{HEAD}} \) = volume delivered in one third head part of the irrigated area

(ii) Relative equity ratio (P.S. RAO, 1988):

\[ \text{RER} = \sqrt{(\text{Supply at the head}) \div (\text{Supply at the tail})} = \sqrt{N(\text{percentage of total volume of water,}})\]
percentage of total area) at the head), (\(\sqrt{\text{percentage of total volume of water, percentage of total area}}\) at the tail))

with the subsequent definition of tail and head:

- **head**: All the offtakes in the conveyance and distribution system which are supplied with a volume of irrigation water more than their due share which are proportional to their cultivable area. These areas are over supplied.

- **tail**: All the offtakes that receive less than their due share of water. They are under supplied.

In most of the projects while summarising the benefits expected or achieved, a fuzzy mixture of qualitative social benefit is converted to financial units and added to economical benefits which provide the evaluation assessment with a definitely positive figure supposed to summarise the benefits expected or achieved by this project. Differential benefits among the various socioprofessional categories are evaluated through relevant criteria but not one definite specific index has yet been selected and it seems that till now, no real indicator exists. The sociological analysis is made through a description of situations, which makes comparison or absolute assessment quite difficult.

The cost of equity is seldom low and no trick could possibly maximise simultaneously the social equity, the profit for every individual, and the profit of the irrigated system as a whole. Often the scale of economy and gravity consideration (the most efficient way of using water is said to be using it as much as possible in the upper reaches so that excess water (run off, seepage, collector waters...) might be used again) bring elements against the consideration of equity.

Besides this equity may be looked upon by various criteria; some institutions consider equal volume of water delivered per acre; some consider equal volume per individual, some consider the volume just below the sluices, some in the field itself,... Qualitative parameters that reduce tediousness or duration of work, better predictability lessening the risk factor or the stress on the farmers' mind contribute to improved relations between farmers and the respect of rules, though they are difficult to assess.

Proper indicators to objectively assess social parameters of irrigated system are important; otherwise personal opinions of the people in charge of the performance evaluation assessment (linked with those of the demanding institution) are bound to interfere with the evaluation itself.

5. **Environmental aspects.**

We should not forget to quote the real importance of some global and ecological factors; among these the following indicators are frequently used: whether to assess the rate of collection of water at the watershed level (available water storage/area), and the impact of irrigation works on ecological system:

- % of runoff
- Biomass production/ha
- Water logging problems, ..

Quite often irrigation planners and environmentalists oppose these schemes as their objectives are competing ones and not of complementary nature. Many of these schemes are based...
upon the principle of transferring water from one location to another, concentration of the rainfall in the tank at the bottom of one watershed or even translocation of water resources from one watershed to another one which is bound to produce a modification in the balance of the ecosystem and induce unecological effects. Moreover, excessive irrigation may produce salinisation of upper layers in the soils, depletion of the soil productivity and, in the long term, loss of land for crop production.

As a conclusion we would like to stress that no absolute indicators exist. A correct way of assessing performance evaluation should start with the hierarchical specification of the objectives. Based upon these priorities, the most adequate indicators could be applied and the boundaries of the irrigated system defined.