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EVALUATING IRRIGATION SYSTEM PERFORMANCE WITH MEASURES OF IRRIGATION EFFICIENCIES

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EVALUATING IRRIGATION SYSTEM PERFORMANCE WITH MEASURES OF IRRIGATION EFFICIENCIES

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Contents **Page**

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Leslie E Small

1. INTRODUCTION

In many developing countries huge investments in irrigation have been made over the past three decades. These investments, in conjunction with new agricultural technology in the form of fertiliser-responsive varieties, have helped fuel significant increases in agricultural production over this period of time. Even so, a widespread perception exists that irrigation projects typically perform far below their potential. This has led to many operational interventions and research activities designed to diagnose problems and remedy deficiencies.

In spite of the considerable efforts that have been made to improve the performance of irrigation systems, there is surprisingly little agreement on how this performance should be assessed. Disciplinary biases are often evident in the choice of performance measures. Some social scientists place considerable emphasis on the nature and extent of farmer participation in irrigation decisions. Economists are likely to approach the problem through some form of benefit-cost analysis. Agronomists may focus on production, while engineers often focus on irrigation efficiencies.

Small and Svendsen (1990; 1991) have developed a conceptual framework designed to establish a context in which the great variety of different approaches to irrigation performance assessment can be understood and related to one another. This framework takes a systemic viewpoint, in which irrigation is considered to be a system operating within broader agricultural and socio-political systems. Within this framework, performance measures are categorised according to whether they focus on the irrigation system's internal *processes* (in which inputs are transformed into outputs), on its *outputs* (the amount, timing, uniformity and quality of water delivered to the fields and provided to the root zone of the crops), or on the system's *impacts* on the larger agricultural and socio-political systems in which it exists. The framework also distinguishes between *achievement* measures of performances, where the focus is on some desired output or outcome, and *efficiency* measures of performance where desired outputs or outcomes are related, usually in the form of a ratio, to certain inputs (Small and Svendsen, 1991).

In addition to categorising the types of performance measures, Small and Svendsen emphasise the importance of normative standards in the assessment of irrigation performance. Regardless of which type of assessment measure is chose, evaluation of performance can only proceed when it is possible to compare the observed value of the performance indicator against some standard that is established for the indicator. All such standards are derived from explicit or implicit value judgments, as a result, value judgments are an inherent part of all assessment of irrigation performance.

Indicators of irrigation efficiency comprise one set of performance measures commonly used, particularly by agricultural scientists and engineers. An irrigation efficiency measure of performance relates the output of irrigation water at some place in the system to the input of irrigation water at some other place[2]. Irrigation efficiency is thus considered to be "a parameter to assess the performance of irrigation water use from a water conservation perspective" (Bos and Wolters, p 268). Furthermore, because it is a ratio of water outputs to water inputs, it is often considered to be a "technical" measure of efficiency (Hillel, 1990, p 27). As such, irrigation efficiency is often presumed to be free of the kinds of social value judgments that underlie concepts such as economic efficiency. This is, perhaps, why it is sometimes seen as a more appropriate or "objective" indicator of irrigation performance.

But "technical" efficiency measures also utilise value judgements and standards. The statement, quoted above, relating irrigation efficiency to "a water conservation perspective" implies a set of broad value judgments associated with conservation. Furthermore, a careful examination of the concept of irrigation efficiency reveals the existence of several specific value judgments and standards, some of which have important implications for the

[2] There is some confusion in the literature over the use of the terms "irrigation efficiency" and "water use efficiency". The two terms are sometimes used interchangeably in the physical engineering sense of a ratio of water outputs to water inputs (see, for example, Heermann et al., 1990, pp 132-133). Generally, however, the latter term is used in a very different biological sense to indicate a ratio of crop production outputs to water inputs (Hillel, 1990, p 27; Howell et al., 1990, p 94; Jensen et al., 1990, p 48).

use of irrigation efficiency as a performance indicator. These value judgements and standards are of two types: those embodied in the very definition of efficiency itself, and those used as normative "yardsticks" against which empirical measurements of efficiency can be compared. It is the purpose of this paper to examine critically these two categories of value judgments and standards with respect to their implications for the use of irrigation efficiency as an indicator of irrigation performance.

2. VALUES AND STANDARDS EMBODIED IN THE DEFINITION OF IRRIGATION EFFICIENCY

Measures of efficiency are never simply measures of total outputs to total inputs. The laws of thermodynamics imply that for any system, total outputs must equal total inputs. Efficiency becomes a meaningful concept only when it compares *useful* or *desirable* outputs to inputs. All efficiency measures, including those considered to measure efficiency in some "technical" sense must therefore incorporate explicit or implicit value judgments associated with the identification or definition of "useful outputs".

In their definitive work on irrigation efficiencies, now in its fourth edition, Bos and Nugteren (1990) define three irrigation efficiency measures (application efficiency, tertiary unit efficiency and overall or project efficiency) that incorporate a common measure of useful output: the "volume of irrigation water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants throughout the growing cycle" (p 18). At least three value judgments are involved in this definition.

First, implicit in the definition is the value judgment that *all* water provided for evapotranspiration (with the exception of any water in excess of the amount that would be needed to prevent undesirable water stress) is a useful output of an irrigation system, regardless of the ultimate impact that this water has on crop production. Given this definition, it is, as Hall has noted, "entirely possible always to irrigation with an application efficiency of 100% and still fail to grow a decent crop" (1960, p 75). Even in the extreme case of a crop that fails to produce any economically useful output because of severed water stress, most or all of the irrigation water delivered, having been used for evapotranspiration by the failed crop, would still be considered to have been a useful output. For this situation one might suggest, as an alternative and perhaps more intuitively plausible value judgment, that the irrigation water had been wasted.

This is not to say that this particular value judgment implied in the definition of irrigation efficiency is "wrong" or "bad", but rather to note its existence, and its somewhat peculiar and counter-intuitive nature. As in the medical situation suggested by the old saw that "the operation was a success, but the patient died", a failure to fully comprehend the value judgments involved in "technical" measures of performance easily results in misleading interpretations.

A second value judgment implicit in the definition of irrigation efficiency is that *only* irrigation water used for evapotranspiration is part of the "useful output" of the irrigation system. Yet in addition to supporting evapotranspiration, irrigation water plays many other useful roles in the sense that it creates value to the irrigators and to society. This is perhaps most obvious in the frequent case of irrigated rice grown under flooded conditions. Flooding of the fields, which results in such non-evapotranspiration uses of water as lateral seepage and deep percolation, can affect rice production through its effects on the physical and chemical properties of the soil, and on fertilisers and pesticides incorporated into the soil. In regions where temperatures are high, continuously flowing irrigation water may increase yields by reducing soil temperature (De Datta, 1981, p 322). Water may also substitute for mechanical or chemical means of weed and pest control (ibid., pp 300, 314). In many areas, water also plays an extremely important role in land preparation. By softening soils that have become hard during a dry season, water often substitutes for mechanical power in land preparation. Water used to facilitate land preparation often accounts for roughly 40% of the total amount of water used to produce an irrigated rice crop (IRRI, 1978; Wickham and Sen, 1978).

Water may also create value in its roles in the transport of those water molecules that are actually used for evapotranspiration. In irrigation channels, for example, water may substitute for certain types of costly conveyance structures or improvements, such as closed pipes or lined channels. On individual farm fields, water may substitute for land levelling with the result that in order to flood the higher parts of a field, lower areas are flooded to a greater depth than would otherwise be necessary.

Water thus creates economic value in a variety of ways that are arbitrarily excluded from the "useful output" identified by the commonly-accepted

definition of irrigation efficiency. The definition's narrow linkage of the concept of useful output to the biophysical process of evapotranspiration represents only one of many possible value judgments that could be used. The advantage of this value judgment is that it ties the concept of efficiency to biophysical ("technical") processes that are the same throughout the world. The disadvantage, however, is that it ignores much of what makes irrigation water valuable[3].

One alternative value judgment would be to consider all water that creates any positive economic value in the production process to be a "useful output" of irrigation. Under this definition, irrigation water would be considered useful as long as the value of its marginal product were greater than zero. Another alternative value judgment would be to limit the concept of "useful output" to water for which the value of the marginal product is greater than its marginal cost. Both of these alternatives would move the definition of irrigation efficiency in the direction of systematic incorporation of economic considerations.

A third value judgment implicit in the definition of the useful output of irrigation as the "volume of irrigation water needed, and made available, for evapotranspiration by the crop to avoid undesirable water stress in the plants" involves the meaning given to the phrase "undesirable water stress". This phrase, in fact, opens the door to the possibility of excluding some of the water used for evapotranspiration from the definition of useful output. But what is to be excluded depends on one's perspective regarding "undesirable water stress".

Somewhat surprisingly, those who incorporate this phrase in their efficiency definitions (Bos and Nugteren 1990; Heermann et al., 1990) provide no

[3] Although Boss and Nugteren's (1990) linkage of "useful output" to crop evapotranspiration is consistent with fairly widespread usage (see, for example, Hillel, 1990; Stewart and Hagan, 1973), the American Society for Civil Engineers has developed a broader definition of irrigation efficiency that incorporates, in addition to evapotranspiration, water used for leaching to maintain a favourable salt balance in the soil, water used to protect the crop from frost or from excessive heat, and water used in the process of applying fertiliser or pesticides (American Society for Civil Engineers, 1978 as cited in Heermann et al, 1990, pp 132-133). But by arbitrarily incorporating only a small subset of the many non-evapotranspiration uses of water which create economic value, this broader definition would seem even more problematic, having given up the advantage of the narrower definition that is limited to biophysical processes that are the same throughout the world, while still sharing with that definition the disadvantage of ignoring many ways in which irrigation water creates economic value.

discussion of its meaning[4]. It is clear, however, that different meanings, each reflecting different value judgments, could exist. One might, for example, consider stress to be undesirable only as long as it causes a reduction either in the total dry matter production of the plant (a value judgment based on biological considerations) or in the production of the economically useful portion of the plant (a value judgment based on a combination of biological and economic considerations). From either of these perspectives, water used for additional evapotranspiration associated with zero or negative changes in production would be excluded from "useful output"[5].

Another possibility stems from the recognition that many plants can tolerate small amounts of water stress with minimal negative effects on production. Agricultural scientists sometimes identify a critical soil moisture content level for a corp. As long as soil moisture does not fall below this critical level, the stress on the plant has a minimal effect on evapotranspiration, and thus on yields. But if the soil moisture falls below this critical level, a sharp negative effect on both evapotranspiration and crop yield can be expected (James, 1988, pp 4-6). Although the concept of critical soil moisture content is based in biological considerations, economic value judgments also come into play in the actual delineation of this level in any given situation. It has been suggested, for example, that the critical soil moisture level should be set at

[4] Although they do not discuss the meaning of this phrase, Bos and Nugteren (1990) include an appendix in which they give an example, based on the actual questionnaire data they collected under an international survey, of the calculation of irrigation efficiencies. The numerator for their efficiency calculations (i.e the "useful output" of irrigation), is calculated to be equal to the crop's total "consumptive use" of water - which is essentially the same as total evapotranspiration (James, 1988, pp 9-10) - minus an adjustment to reflect the contribution of rainfall. The calculations thus ignore the possibility, incorporated into the author's definition of irrigation efficiency, that an excessive amount of water could be used for evapotranspiration.

[5] Because yields are generally considered to rise linearly with evapotranspiration (ET), reaching a maximum at a level often referred to as "ET_{max}", the idea that ET could increase even after yields had reached their peak might appear to be incorrect "ET_{max}" is not actually defined as the maximum possible ET, however, but rather as the *minimum* ET associated with maximum yields (Stewart and Hagan, 1973). For example, in experimental treatments where irrigation was deliberately designed to be excessive, Steward and Hagan observed the actual ET to exceed, by 25 mm, the ET at which yields were maximised. Accordingly, the empirical value that they assigned to "ETmax" was 25 mm less that the maximum ET actually observed.

higher levels in situations where "market conditions require the highest possible yield per land area" (ibid, p 6).

If one accepts the idea that water stress is not undesirable in situations where it causes only a very small decline in yields, then economic factors come to the fore in the precise determination of this optimal level of stress. A farmer who must purchase irrigation water under a volumetric pricing system, for example, would consider the optimal amount of stress to be that which equated the value of the marginal production of irrigation water with its price[6]. "Undesirable water stress" would thus exist in any situation in which the value of water's marginal product exceeded its price. One implication of the use of this economic value judgment in defining "undesirable" stress is that irrigation efficiency could not be determined independently of such economic considerations as crop prices and the prices of water and other production inputs.

More generally, the operational definition of "undesirable" plant stress would need to reflect judgments that involve an effort to balance considerations about the value of the crop loss prevented by irrigation, on the one hand, with those about the cost of providing the amount of irrigation water required to avoid that loss, on the other. This leads directly to the economist's definition of undesirable stress, namely, stress such that the value to society of the marginal product of water exceeds society's marginal opportunity cost of providing and applying the water. Such a definition implies, however, a concept of irrigation efficiency that would hardly be considered to be a technical concept.

It thus appears that if irrigation efficiency were to be defined as a "technical" measure that could be determined independently of economic values, it would have to be based on the qualitative biological relationship between water and crop production. This implies that for the purpose of defining irrigation efficiency, water stress leading to *any* reduction in production, however tiny, would have to be considered undesirable. Although there would be nothing inappropriate about the use of this value judgment, it should be recognised that it implies a very narrow and specialised meaning for the term "undesirable", and that most irrigators, as well as those who operate irrigation systems, probably have rather different operational definitions of "undesirable water stress".

[6] In fact, however, as discussed by Small and Carruthers (1991) farmers rarely pay for irrigation water on this basis.

3. STANDARDS USED TO EVALUATE MEASURED IRRIGATION EFFICIENCIES

If irrigation efficiencies are to be used to assess irrigation performance, it is important that some type of performance standards be identified against which empirical measurements of irrigation efficiencies in actual irrigation systems can be compared. In the complete absence of standards, it becomes impossible to evaluate the performance implications of any particular measured irrigation efficiency. As with the case of value judgments discussed in the previous section, standards may be either explicit or implicit.

One of the greatest dangers in the use of most efficiency measures of performance is the tendency to use an implicit standard of 100% efficiency. Even though one may recognise that 100% efficiency is unobtainable, it is easy to assume that the closer an observed efficiency is to 100%, the better. This is the trap of the implicit efficiency standard.

It is particularly easy to fall into this trap in the case of irrigation efficiency, which, as noted at the beginning of this paper, is a performance parameter reflecting a water conservation perspective. Superficially, it would seem that from this perspective, more conservation (i.e higher efficiency) is better. That this is not necessarily true has long been recognised by agricultural experts, who are aware that high efficiencies may simply reflect situations where water shortages are severe and yields are extremely low (Hall, 1960). The value judgments implicit in the water conservation perspective involve the desire to "save" water while simultaneously using it to produce an agricultural crop; therefore, an irrigation system that operates in ways that conserve water but lead to crop failures cannot be considered to be performing well.

Once it is recognised that the implicit irrigation efficiency standard of "more is better" is not appropriate, the importance of defining explicit standards becomes evident. It is difficult, however, to find any examples of carefully defined efficiency standards. In part this may reflect the fact that irrigation specialists have not always recognised the problem of the implicit efficiency standard. For example, one writer states that it has been proven that an irrigation efficiency of 90% is "possible" with "proper management", and that therefore there is much room for improvement for most irrigation systems (Hillel, 1990, p 28). This is basically just another version of the implicit efficiency standard: a version that recognises the near impossibility of attaining 100% efficiency, and replaces that figure with a modestly lower one

that is arguably attainable. It is very doubtful, however, that a 90% standard for irrigation efficiency is appropriate for most irrigation systems. Efforts to achieve such a standard could generally be expected to involve much economic waste.

But the failure of most irrigation experts to carefully define explicit irrigation efficiency standards reflects an additional complexity regarding the use of irrigation efficiency as a measure of performance. The problem is that efficiency standards for acceptable performance would need to vary according to a large variety of conditions. For example, because of all the useful non-evapotranspiration functions of water in the case of flooded rice production, irrigation efficiency standards for systems supporting rice production would generally need to be lower than standards for systems in which crops are grown under non-flooded conditions. A host of other considerations, not all of which are easily identifiable, would also affect the standards to be used. Examples include project size, abundance of irrigation water relative to the irrigable area, extent of opportunities for re-use of drainage water, soil texture, extensiveness and nature of control structures in the main canals, climate, and method of irrigation (sprinkler, flooding, furrow, drip, etc)[7]. The task of developing explicit standards that are useful and appropriate for all of these varying situations is daunting indeed. Ultimately, one might conclude that separate standards are needed for each individual irrigation project.

In the absence of specific performance standards for irrigation efficiency, it may still be possible for experienced irrigation experts to make informed judgments about whether the efficiency of a given project is above, below or somewhere near some vaguely-defined notion of a desirable level. They can do so, however, only by taking into consideration a substantial amount of additional information beyond the data on irrigation efficiency.

This need to take other information into consideration highlights the key limitation of irrigation efficiency as an indicator of irrigation performance. Irrigation efficiency by itself is a descriptive, not a prescriptive measure. It is not possible, in the absence of further information, to judge whether an

[7] The need to incorporate these factors in the efficiency standards is merely a reflection of the fact, discussed in the previous section, that the traditional definition of irrigation efficiency involves a concept of "useful" water output that arbitrarily excludes many functions of water that create economic value. The problem would be eliminated if all truly "useful" functions of water were included in the definition of irrigation efficiency.

irrigation system performing at X percent efficiency is performing well or poorly. Because the measures of irrigation efficiency is affected by many different factors, no single useful performance standard can be set.

It is sometimes suggested that standards, rather than being based on some "desirable" conditions, could be based instead on the average actual performance of some group of irrigation projects. Assuming an appropriate group of projects against which the irrigation efficiency of a given project is to be compared (e.g a project designed to irrigated flooded rice in a semi-humid region compared with a group of projects with these same characteristics), some useful descriptive information may be provided with the use of such "relative" standards. Even in this case, however, the standards are only descriptive, and cannot be used in a prescriptive sense.

The inability to use irrigation efficiency standards in a prescriptive sense can be illustrated by a simple example. Assume a situation in which irrigation efficiency is 40%, but could be increased to 50% either by lining canals or by modifying operating procedures, and could be increased to 60% by doing both. Without examining the economics of each of these alternatives, it is impossible to say whether it would be desirable to undertake either or both of them. Only after the economic analysis had been undertaken and the optimal alternative(s) identified would it be possible to determine a desirable efficiency standard. Such a standard would thus describe or reflect the efficiency implications of the results of the economic analysis of the alternative courses of action. It is the economic analysis that prescribes the appropriate course of action, which in turn defines the efficiency standard.

Irrigation efficiency may have utility because it can be defined in ways that make comparable calculations possible regardless of the nature or location of the irrigation system. But the impossibility of developing standards that are independent of other considerations severely limits the usefulness of irrigation efficiency as a measure of irrigation performance.

4. CONCLUSIONS

Measures of irrigation efficiency represent one set of indicators that may be used to assess the performance of irrigation systems. Irrigation efficiencies are arguably the most widely used performance measures among many irrigation specialists. Although such measures are sometimes considered to be "technical" and therefore free of value judgments, both explicit and

implicit value judgments are involved in using them to evaluate irrigation system performance.

Because the value judgment inherent in the very definition of irrigation efficiencies do not incorporate many of the values that those wishing to evaluate irrigation systems consider to be important, it becomes necessary to account for these values in the efficiency standards that are established as "yardsticks" against which actual efficiencies are to be compared. Standards appropriate to the assessment of performance of one irrigation system may thus differ significantly from those appropriate for the assessment of another. This reflects the fact that irrigation efficiencies are descriptive parameters. They provide certain information about the pattern of water use within the system. But because they cannot provide the information that would be needed to determine the optimal pattern of water use, they have limited usefulness as general measures for evaluating irrigation system performance.

The traditional definition of irrigation efficiencies is widely accepted and used. The discussion in this paper is not intended to argue that the definition should be changed, or the concept abandoned. Rather, its purposes have been to demonstrate the error of the view that irrigation efficiencies are technical, value-free measures of irrigation performance, to emphasise the nature and limitations of the value judgments incorporated, and to explore the implications of alternative value judgments.

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