

LOCALISING IRRIGATION EFFICIENCY[†]

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ABSTRACT

Conventional (or classical) and “effective” (or neoclassical) concepts of irrigation efficiency are valid in different situations as long as the data, terms, circumstances and purposes of those situations are carefully defined. Recent thinking has usefully promoted a basin perspective of water based on effective irrigation efficiency, arguing that agricultural production is best expressed from depleted water. However, given the need to engage with the specifics affecting water management and productivity, a case is made for improving the understanding of the classical approach or “local irrigation efficiency”. The paper explores 13 issues which affect, or are affected by, local efficiency, and that support the case. Some of these issues are: the relevancy of scale in water management; the separation of design, management and monitoring activities; the relationship between efficiency and timing; and the coupling of net requirements and recovered and non-recovered losses. The paper introduces the term “attainable efficiency”, and posits that classical irrigation efficiency has significant utility because it reflects observations made by irrigation professionals and farmers that local efficiencies critically affect water management and productivity within a river basin system. Copyright © 2006 John Wiley & Sons, Ltd.

KEY WORDS: assessment; efficiency; design; irrigation; performance; productivity; water management

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RÉSUMÉ

En ce qui concerne les concepts d'efficacité de l'irrigation, les approches conventionnelles (ou classiques) et effectives (ou néoclassiques) sont valables dans différentes situations dès que les données, conditions, circonstances et objets des situations sont soigneusement définis. Récemment, et de manière utile une approche par bassin versant a été promue basée sur l'efficacité de l'irrigation effective, mettant en avant qu'il faut exprimer la production agricole à partir de l'eau consommée. Néanmoins, étant donnée la nécessité de prendre en compte les spécificités de la gestion et de la productivité de l'eau, un argument est développé pour améliorer la compréhension de l'approche classique ou «efficacité locale de l'irrigation». 13 cet article analyse qui affectent ou sont influencées par l'efficacité locale, et qui construisent l'argumentaire. Quelques unes de ces situations sont: la pertinence de l'échelle en gestion de l'eau, la séparation des activités de conception, de gestion et de surveillance, la relation entre l'efficacité et la planification, et le lien entre les besoins nets, et les pertes récupérées et non récupérées. Ce papier introduit le terme d'«efficacité atteignable», et émet l'hypothèse que l'efficacité de l'irrigation classique a une utilité significative parce qu'elle reflète les observations des professionnels de l'irrigation et des agriculteurs que les efficacités locales influent considérablement sur la gestion et la productivité de l'eau au sein d'un bassin versant. Copyright © 2006 John Wiley & Sons, Ltd.

MOTS CLÉS: évaluation; efficacité; conception; irrigation; performance; productivité; gestion de l'eau

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[†]Localisation de l'efficacité de l'irrigation.

INTRODUCTION

The subject of irrigation efficiency and productivity sits at the heart of one of the most topical water debates today – how to share water for human and environmental purposes. Water saving in agriculture has been suggested to be the solution to meet other sectors' needs, particularly in developing countries (IWMI, 2002a). Potential water savings are said to exist in surface irrigation systems, accounting for about 90% of total irrigation worldwide (Kay, 1986) where wastage is often quoted to be excessive (World Bank, 1993; Jones, 1999). In addition, irrigation has been promoted as a key mechanism that can meet future global food demands (FAO, 2002). Thus to meet both intersectoral allocation and produce more food and fibre, irrigation efficiency and productivity must increase. In this regard, the International Water Management Institute (IWMI, 2002b) initiated a Challenge Programme on Water and Food arguing that; “In order to achieve a secure water future and food we must improve the efficiency of water use by getting more crop per drop.”

Mechanisms to increase efficiency are underpinned by a theory of efficiency – how to understand, describe, model, measure and interpret it. The debate is not just one of details over field methodologies but goes to the very heart of the significance of efficiency, encapsulated by the question ‘does efficiency matter?’ (Kay, 1999; Perry, 1999; Cai *et al.*, 2001). Although considerable energies have been spent on constructing different models and viewpoints, as yet knowledge about irrigation efficiency and productivity suffers from two critical gaps: (a) an agreed theoretical exposition of the topic that applies to different scales of water use and purposes to which efficiency is put to use; and (b) a lack of an operable methodology that connects theory, field measurement, interpretation, design, management and assessment of irrigation systems. An agreed theory of irrigation efficiency is important because while many commentators comment on the widespread inefficiency of surface irrigation (e.g. Wallace, 2000) and hint at the progress waiting to be made, this position is commonly unfounded and ill-informed. Also of concern is that an opposing viewpoint (that local inefficiencies are unimportant and the improvement of local irrigation efficiency is unnecessary) might become mainstream thinking¹ as a generalisation. This belief is worrying because efficiency at the local level is bound up with equity, timing and scheduling, affecting the performance and costs of irrigation and drainage, and with perceptions of water misuse, affecting policy choices and conflicts. Two positions have arisen on local efficiency, both potentially leading to misunderstandings and incorrect interventions to raise efficiency and productivity.

The dual-sided nature of irrigation efficiency is summed up as: if water reuse (recapture) is not included then lower measures of efficiency are obtained. If, on the other hand, these losses are accounted for in recapture then higher measurements of efficiency are found. The first position is described by conventional or classical irrigation efficiency (CIE), defined by the International Commission on Irrigation and Drainage (ICID, 1978) as a ratio of average depth of water beneficially used to average depth of water applied, while Bhuiyan (1982) defined irrigation efficiency as a ratio of net irrigation requirement to the supply. Using these and other similar computations, efficiency of surface irrigation is held to be around 40%² (Postel, 1992; World Bank, 1993; Gowing, 2002).

The second position is described by the neoclassical model (Seckler *et al.*, 2003) or ‘effective irrigation efficiency’ (EIE), promulgated by various authors (Keller and Keller, 1995; Keller *et al.*, 1996; Perry, 1999; Molden *et al.*, 2003; Seckler *et al.*, 2003). The EIE model³ posits that classical definitions do not include assessment of water that is potentially available for reuse downstream, arguing that in river basins where drainage waters are reused, a water multiplier effect results in high irrigation efficiency when assessed at basin level. The key insight was to distinguish between diverted water and depleted water, the latter being truly lost from further reuse in the basin. Thus, classical irrigation efficiency considers diverted water at the field scale, but if the boundaries are redrawn to include a larger area, some of the drainage water is recovered for reuse (Gowing, 2002). Accounting for

¹One of the World Bank's Chief advisers on water, Stephen Foster of the British Geological Survey, is horrified by the idea that making irrigation more efficient will free water for other uses. “It has the makings of a very dangerous myth,” he says. There is, he adds, “a horrible flaw in the argument. Most of the water being ‘saved’ is never truly wasted in the first place. Some, it is true, is lost to evaporation. But most—the water that seeps underground from fields and canals—eventually finds its way to nature's underground water reservoirs, from which millions of farmers subsequently pump water to supplement river water for irrigation.” *The Independent* (UK), “The Great Water Myth” by Fred Pearce, 28 Jan 2004.

²Literature on irrigation in Tanzania exhibits a “received wisdom” that irrigation efficiency is less than 30%, sometimes as low as 15%.

³References to this EIE model label it as the IWMI paradigm (Perry, 1999).

only depleted water means assuming reuse. In such situations, the EIE may increase to more than double. Keller *et al.* (1996) termed savings that attempted to minimise losses that were anyway recaptured as being “paper savings”.

Both positions are theoretically sound in certain situations and this site-relevancy aspect of efficiency is discussed by Wichlens (1999) and Willardson *et al.* (1994). However, of importance to the debate on water savings and intersectoral allocation are issues to do with the “policy response”; how the situation changes giving rise to different types of losses, whether losses are easily and economically recoverable and how losses affect the timing of water movement through the landscape. Substantive questions remain: do local efficiencies matter, how do we interpret efficiency figures and if efficiencies are already high at basin scale what potential exists for savings and therefore what are the appropriate technologies, policy tools and interventions?

These questions and their answers might explain why classical efficiency persists within the methodological toolbox of irrigation professionals. Seckler *et al.* (2003) ponder on the “remarkable fact” that neoclassical concepts have not been accepted, conjecturing that this is explained by ongoing training in old ideas, a sense of professionalism constructed around classical ideas, by funding and financial incentives and by other political intentions. Yet, it is worth asking whether the paradigm has not shifted because the case is not closed; that classical and neoclassical efficiency are valid in many situations – but only if they are more carefully understood. Thirteen subsections below explore some issues related to the application and validity of classical and effective irrigation efficiency.

On the issue of scale, “local” in this paper refers to single irrigation systems, or parts thereof down to the field level, or to neighbouring multiple systems within areas of less than 500–1000 km². A distinguishing characteristic is that these systems are fed by a single source of water or multiple sources that come together to create a resource that is closely shared. In addition, local has an institutional flavour, constituting users that either talk to each other or have the potential to via water user associations. “Basin” is also an approximate term, covering either bounded river catchments, aquifers, or groupings of irrigation systems at scales of 500–1000 km² and above, where because of distances, they are less likely to interact institutionally.⁴

KEY ISSUES IN IRRIGATION EFFICIENCY

1. Measurement and assumption errors

Arguments on both sides of the debate are built on frequently imprecise assumptions made about surface irrigation because of insufficient accurate quantitative data. Measuring irrigation efficiency is difficult and time consuming, covering the amount of net or gross inflows into the system; seepage; representative rainfall figures; losses in the distribution system and at the field level; the amount of water consumed by the crop (evapotranspiration); evaporation; and the amount of water returned to its source river. These measurements need to capture different scenarios such as wet and dry seasons and wet and dry years, during which the crop water requirement, irrigation need, command area and efficiency all change. A complete and accurate determination of efficiency is rarely conducted, obliging engineers to make assumptions, often using generalised figures from the literature.

Much of the earlier work on classical efficiency by Bos and Nugteren (1990) and Wolters (1992) relied on a questionnaire approach. They found efficiencies existed between 15 and 42%, yet no assurance is given regarding the nature of primary fieldwork used to arrive at these figures either by the researchers or by their respondents. Of the 159 questionnaires many could not be used for accurate calculations (rates of incomplete data for conveyance, distribution and application efficiencies were in the order of 70, 75 and 55% respectively).

I suggest that a “debate problematic” exists from the use of circular logic; assumptions made regarding low efficiency during design give figures that are then used to report efficiency as being low. Thus when protagonists of effective efficiency critique interventions to “save losses by lining canals” (e.g. Perry, 1999, p 48) as being examples of paper savings rather than real savings, it is critical to know the validity and significance of both types of losses. In other words, the local efficiency of irrigation might already be very high. Here, both CIE and EIE protagonists are incorrectly assuming the nature of the losses to be saved both in reality and on paper. It is often very

⁴Distances and areas are relative and approximate, and are locally contextualised; plus WUA coverage will depend on a variety of factors.

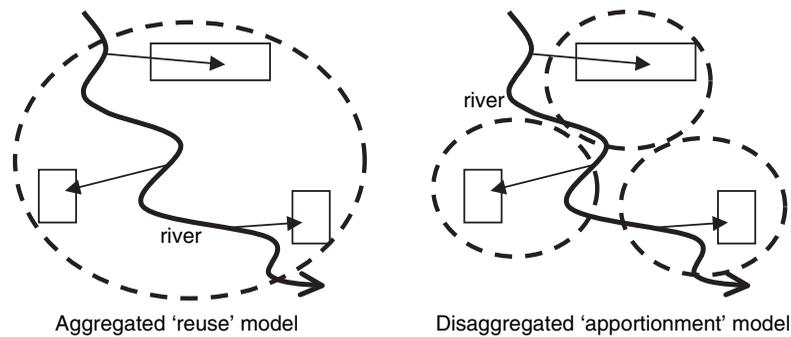


Figure 1. Aggregated and disaggregated productive units in river basins

difficult to correctly identify where losses are occurring, particularly those arising from system operation, but on the other hand commonplace to assume that they stem from seepage from canal walls because of prevailing beliefs, design and an observable lack of maintenance. I therefore question whether the lack of such specifics permits what might be called “false but accurate corollaries” that “most water is not lost” (Seckler *et al.*, 2003, p. 38) to be applied to the generalised basin scale without first assessing what exactly is happening at the local scale – that perhaps ‘most water is not lost at the local scale’.⁵

2. River basin perspectives: reuse or prior apportionment?

In suggesting that local efficiencies do not matter, the EIE model implicitly supports the notion that it is acceptable or unremarkable that water first passes through an irrigation system before an “inefficient” fraction becomes available for reuse. This is satisfactory provided systems and losses are aggregated at the river basin scale with no net loss in water productivity (irrigation, wetland or otherwise) or loss of useful information and therefore no impingement on the scope or impetus for the improvement of water management. This aggregation is depicted on the left-hand side of Figure 1.

Yet we can disaggregate the river basin, regarding productivity as the sum of individual “local” productive units – irrigation systems, wetlands, etc. This disaggregation can be seen as an apportionment model, where each unit receives its own fraction or packet of water (right-hand side of Figure 1). A more “classically” efficient management of water lowers the demand of each productive unit so that less water is diverted to it, allowing the non-diverted water to remain in the river or aquifer for other units.

A disaggregated view reflects how irrigation systems and their subsystems constitute a river basin and, it is argued, is more quantitatively accurate, productive and policy-informing than an aggregated reuse model because of various reasons argued in this paper. Namely: apportioned water moves more quickly to the lower system in the river rather than passing via an irrigation system; non-recovered losses are theoretically higher in the aggregated, reuse model because of unmanageable or difficult-to-manage coupling of non-recovered to recovered losses; the apportionment model helps modularise the river basin, allowing a much more transparent identification of where losses occur and who is responsible for these (assisting conflict resolution); the apportionment model suggests lower design costs if canals and turnouts are sized according to water efficient assumptions and targets; and the apportionment model allows us to compare usefully between systems’ efficiencies.

How we view river basins and irrigation efficiency together is subtle but revealing. Willardson *et al.* (1994) describe many cases of where inefficient irrigation in river basins leads to artefacts such as groundwater recharge and wetlands. The authors present an aggregated view of water in the landscape where such artefacts arise as by-products of the current management system rather than as carefully managed units parsimoniously supplied. The

⁵In various unpublished studies during the last 20 years, the author has measured surface/gravity irrigation efficiency in Swaziland, Malaysia and Tanzania, to find classical whole system efficiencies commonly in the range of 60–85%, when the prevailing opinion was that efficiency was in the range of 40–70%.

pattern of water division and reuse in a river basin can be thought of as a scaled-up version of an irrigation system where the management of a limited supply of water aims to allocate the right amount of water to each part of the irrigation system, without relying on internal recycling to generate that supply. This requires good control of both quantity and timing in the conveyance, distribution and field systems. Similarly, in a basin where limited water is to be allocated in a timely manner, managers need to judge how that best happens, either via a network of rivers, canals and pipes, or whether by slower zones of seepage and recapture, whilst accounting for beneficial or non-beneficial evaporation, costs, delays, water availability and associated social issues.

3. *The purpose of efficiency; design, management, assessment*

To debate the theory of irrigation efficiency requires a clarification of the purpose of efficiency. The effective model of efficiency focuses on assessing the efficiency of water management of river basins while another important scale is the irrigation system. Furthermore, efficiency is used for three purposes; designing, assessing (or modelling) and managing systems. Perry (1999, p. 46) reminds us that classical efficiency “is correct and appropriate for planning, designing and operating irrigation projects but is often dangerously misleading for understanding water resource systems”.

Regarding design, irrigation infrastructure has to be sized correctly with efficiency correction factors, or the water requirement for the command area would not be met. In addition, engineers minimise structure dimensions to reduce costs. Design employs the classical irrigation efficiency method, but often low figures of efficiency are chosen. This happens either because engineers build in safety margins or because they assume low efficiencies exist in reality. A “low efficiency” can lead to large intakes being deployed, which because of *actual efficiency* can lead to reuse of drain water (a point made above). Alternatively, if this water is not reused, it can be drained back to the water source—and in this case the lower design efficiency figure means the canals, intakes (or pumps) are oversized.

Returning to the question—which method should therefore be used? The answer, as the following examples show, is mainly the classical method.

- When sizing a pump for a borehole supplying 10 ha of land, the recapture of seepage water to the aquifer is irrelevant to the design of the borehole capacity. Seepage reduces classical efficiency, meaning the borehole capacity has to compensate upwards to supply its command area.
- To design the intake for a hill irrigation system where land has been located 2 km from a river, classical irrigation efficiency is used because the conveyance and field application losses need to be accounted for.
- With a drip or micro-sprinkler system where losses are not recaptured the classical efficiency model applies.
- In smallholder rice systems, field-to-field irrigation means that water draining from one field cascades to the next one. Classical irrigation efficiency does not adequately explain this process as there are few secondary and tertiary canals and no final single “field”, because reuse is an intrinsic part of field-to-field irrigation (though not arising from systemic inefficiencies). The classical design method if conventionally applied⁶ is particularly weak when it sees an individual field plot as the final target for water supply rather than a collection of plots that defines, over time, the bounded zone of reuse and depletion.

In the last example, it was implied that the reuse/neoclassical paradigm might be useful in certain cases. However, an inspection of this method shows that while it might be good at explaining how efficiency increases with reuse, it does not currently lend itself to design planning. One reason is because the designer cannot know the partition of losses to true sinks (such as evaporation and non-recovered seepage) and those that are recaptured and reused. A second reason is that the “collection of plots” mentioned in the previous paragraph experiences as an entity losses that are both recovered and non-recovered, meaning that the classical design method, which captures both types, applies. The design challenge is to delineate the boundaries of this final target area for supply. Nevertheless, this example indicates that a more nuanced application of the “local” model of efficiency is required.

Secondly, efficiency plays a part in assessment and modelling. Assessment is the monitoring of the accuracy and efficacy of design and management of chosen outcomes (e.g. area irrigated, days in deficit, volume applied).

⁶Multiplying assumed field and canal losses to arrive at a static picture of system losses.

Modelling is grouped with assessment because of the manner in which performance can be estimated from variables in a model. At the irrigation system level both can be used; CIE is one criterion of evaluating the performance because it is relevant to the operation of that system, while EIE may be determined as a step in assessing the ratio of recovered and non-recovered losses. At the basin level, effective efficiency is relevant. However, it would also prove possible to determine a picture of the basin from a cumulative picture of the individual disaggregated systems, in which case CIE also is relevant.

The third purpose requiring the utilisation of efficiency is the management of water. Management utilises information to operate infrastructure to schedule the right amount of water to the correct location at the right time, increasing overall performance. Here I argue that classical irrigation efficiency is an integral part of that information which improves water control and irrigation scheduling, in agreement with Perry's statement given at the beginning of this subsection. However, regarding Perry's comment, "[CIE] is often dangerously misleading for understanding water resource systems", I argue that on the contrary our understanding of water resource systems is built up from an appreciation of factors alongside water assessment at an aggregated basin level. Classical efficiency is part of the understanding of water resources because it applies to the design, operation and assessment of irrigation systems and to a disaggregated picture of irrigated basin performance. These are substantive parts of the water management picture.

4. *The conflation of efficiency and productivity*

The productivity emphasis in the IWMI publications draws our attention to multi-use/user benefits from water reuse as well as consumption providing conjunctive benefits. For example, people using water for both irrigation and fisheries clearly contribute to their livelihoods and to the regional economy. Productivity proponents point out that, firstly, it is important to focus on the *benefits* of water (income, jobs, crop production) as a ratio of water used. Secondly, there is the recognition that since water is reused sequentially in a river basin, these benefits should be expressed against a volume of water that moves from user to user. Therefore, it is less necessary to express benefits as a ratio of net water used in any one particular area of the basin (e.g. a field or irrigation system), and instead it is expressed as a proportion of the total water depleted from the whole basin. These are powerful arguments in favour of distinguishing depleted from diverted water.

However, this paradigm shift should not obscure an important question; is efficiency a sufficiently different issue from irrigation productivity to be of importance in water management? Here, it is argued, the debate has to recognise differences between efficiency and productivity, and the significance of that difference for water management. Productivity is an expression of the bio-economic output from the gross amount of water depleted. Examples of this are demonstrated by the nine indicators of performance analysis of irrigation systems developed by IWMI (Molden *et al.*, 1998). While productivity is an important indicator, it underplays the role of the denominator in establishing the productivity and fails to recognise the details and management of, and policy work related to, the efficiency of water. The key point is that efficiency rather than productivity links more directly to the complications of the management of irrigation water. Another pertinent point here is that if a river basin is dominated by irrigation, then the efficiency of water management becomes critical in shaping the productivity of that basin or in defining how much water might be available to other users by making savings within irrigation.

5. *The presence and expression of recovered and non-recovered losses*

Key to the debate on the relevancy of the EIE model is an understanding of recovered and non-recovered losses where the latter are losses to sinks or non-beneficial evaporation in the EIE model. Table I contains a simple framework of recovered and non-recovered losses (see also "reusable and non-reusable" in Willardson *et al.*, 1994⁷), each with three types of losses; seepage, runoff and evaporation. Table I shows that non-recovered losses, particularly under non-beneficial evaporation, are very real possibilities in irrigation.

The authority of the EIE paradigm is partly related to how it arose, reflecting the geographical origins of work on Asian and South East Asian irrigation, dominated by continuously cropped and irrigated rice (Seckler, 1985). In

⁷Although the same in definitional terms, I believe that losses should be described as "recovered" or "reused", rather than conditionally as "reusable".

Table I. Irrigation loss partitions or fractions

Loss partition	Class of loss	Examples
Loss recovered	Evaporation	Note: Unless greenhouses are utilised, evaporation cannot be recovered in field situations
	Seepage	Lateral seepage from a field, possibly accentuated by poor maintenance and compaction of bunds Below root-zone seepage that feeds a water table that is reused or that then supplies surface water downstream that is then tapped
	Runoff	Excessive drain water from fields reused downstream Drain water that comes from meeting the depth of application required at tail end of fields
Loss not recovered	Evaporation	Evaporation from canal and field conveyance of water to meet net demands arising during growth period Excessive wetting up during field preparation delays, resulting in non-recovered non-beneficial evaporation Evaporative losses of water from poor field definition and irregular boundaries Excessive period of field watering at the beginning and end of net crop season—water eventually evaporates at end of season Excessive depth of water, evaporated at the end of season in paddy basins, also related to poor uniformity of field water depth Depth of water related to wedge/delta of water to create head difference to drive field-to-field conveyance
	Seepage	Field seepage to deep percolation which is not recovered within defined system boundary (e.g. becomes saline, or enters geological aquifers for weathering of parent material or re-emergence beyond zone of interest)
	Runoff	Drain water that exits reuse system zone (either as surface flow or ponding followed by evaporation) without being captured. For example, the drain might be too deep to allow for abstraction.

See also Willardson *et al.* (1994) for their analysis of irrigation fractions.

addition, observations from irrigation systems in the USA explain the trade-offs between upstream efficiency savings and reduced water sent downstream (Seckler, 1996). Thus the paradigm works well where near-surface aquifer and floodplain agriculture combine to constitute a significant proportion of the river basin system, or where the hydrological and geographical endowment “creates” recovered losses. Here, water recapture is more a part of the system, where large and continuous flows of water used in irrigation lead to drainage for other irrigators to tap. In other words, the proportion of water that constitutes local non-recovered loss is sufficiently small for it not to be of concern in basin-level computations of irrigation efficiency.

Thus the reuse scenario of EIE applies to situations where discernible recovery exists,; i.e. field-to-field irrigation where excess use in one field drains to supply another field, or scaling up slightly, where excess water in one irrigation system feeds a peripheral irrigation system dependent on that water. The total production of both systems needs to be accounted for in a water productivity analysis. A third clear example exists when aquifer water is tapped for irrigation which then, via local “inefficiencies”, drains back into the ground, resupplying the aquifer to be reused. Fourthly, EIE is expedient where “complicated” recovery and reuse exist; in river basins where myriad streams, rivers and drains both supply and are supplied by a complex mosaic of irrigation systems, lakes, aquifers and towns (Willardson *et al.*, 1994 describe an example). Depending on the investigative resources available, the modelling challenge presented by such a system might best be met by taking an overall basin view.

In other cases, the EIE model, or rather the generalisations drawn from it, may not apply so accurately. In Usangu, south-west Tanzania for example, rice irrigation occurs on relatively impermeable soils of a savannah plain (Lankford and Beale, forthcoming; Franks *et al.*, 2004). Here although tail-end farmers pick up drainage water, the major part of losses occurs via sinks and non-beneficial evaporation (Machibya, 2003). In this case the generalisation that local losses do not matter and that most losses are recaptured does not hold true. In such cases, improving the classical efficiency of water management results in real water savings.

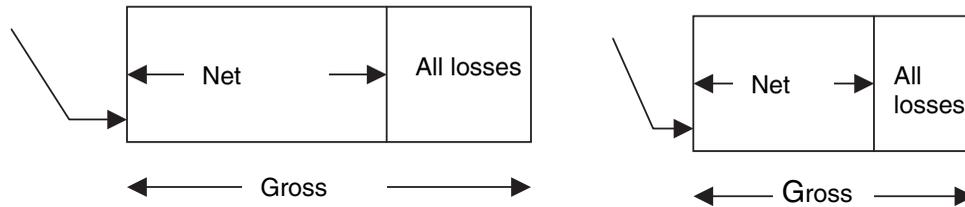


Figure 2. Coupling of net demand and losses

6. Coupled losses

I argue that for a given net irrigation dose at the field level the recovered and non-recovered losses are closely linked or “coupled”. For example, better in-field control and deficit irrigation reduces the total dosage per irrigation by reducing both net irrigation demand and losses. By accumulation, the “per irrigation” event coupling adds up to a seasonal and system coupling. This idea is expressed in Figure 2, where a larger net dose, on the left-hand side, is associated with a larger proportion of losses.

The degree to which net irrigation and losses are coupled probably depends on the nature of the irrigation system, crop and soil type, hydrology and topography. In turn, the coupling might be disproportionate, proportionate or minimal. Thus in micro-drip irrigation, the coupling might be minimal but proportionate, since a larger net dose gives rise to larger losses. In complex large irrigation systems with few canals, coupling might be more pronounced and disproportionate, with losses becoming much larger as the net dose gets bigger.

In addition, the recovered and non-recovered types of losses are closely coupled in irrigation systems (Figure 3), where higher recovered losses are linked with higher non-recovered losses. An example from Usangu originates with the head difference required to drive water from plot to plot (with high friction losses) on a system with very few canals (Figure 6 helps visualise this discussion). The coupling exists because the water volume held in the head difference “wedge of water” (or delta) in the non-canal system then later passes to tail-end plots (i.e. recovered losses) while part evaporates (non-recovered losses) at the end of the cropping season. A canal network, on the other hand, stores less water, requires less of a head difference, loses less water via coupling of the recovered and non-recovered losses, and provides better control over location and timing of water deliveries.

In another example from Usangu, the duration that water stays in a field demonstrates losses coupling. Top-end farmers irrigate fields for 170 days, while tail-enders manage with 145 days (both growing a similar variety requiring about 140 days to mature). The longer the time, the greater the non-recovered losses via non-beneficial evaporation and vertical seepage through surface colluvials into the fractured geology of the East African Rift Valley, coupled with the recovered losses of lateral seepage into drains.

The key insight here is that because the two types of losses are coupled, it becomes important to minimise the recovered losses to reduce the non-recovered losses. Classical efficiency which accommodates both types of losses

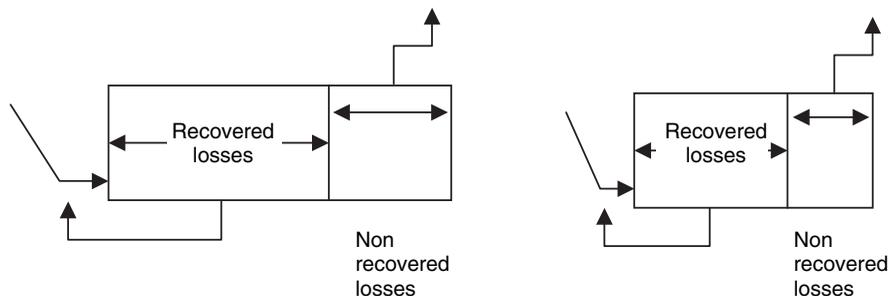


Figure 3. Coupling of recovered and non-recovered losses

is relevant here. The notion that inefficient irrigation is beneficial when it recharges aquifers should very carefully be unpacked—because the linked losses plus crop evapotranspiration will cyclically deplete rather than recharge the aquifer, unless substantial rainfall and excess river flows are present to replenish the aquifer in which case judgement on efficiency is seasonally and spatially determined (a point made below).

7. *Attainable efficiency: avoidable and unavoidable losses*

Managing efficiency requires us to judge whether losses and efficiency gains are manageable (avoidable) or unmanageable (unavoidable). One facet of both classical and effective efficiency is that the numerator of the equation is often the net crop water requirement and the denominator includes all losses, whether or not they are manageable. Achieving 100% efficiency becomes impossible. Should we set numerators and denominators that make interpretation of results more realistic and useful?

This goes to the heart of defining beneficial and non-beneficial process depletion and non-process depletion (developed by IWMI), which can also be addressed by the concepts “Irrigation Sagacity” (see below) or “attainable irrigation efficiency” (AIE). Attainable efficiency is based on the concept that some losses (which may be recovered or non-recovered) can easily be reduced, while others cannot unless considerable effort is expended. Thus, evaporation from canals during conveyance is unavoidable but evaporation occurring from a long period of presaturation wetting of a rice field is avoidable and manageable. Attainable efficiency is the result of dividing “low dose” irrigation by “high dose” irrigation:

$$\text{AIE}\% = [\text{low dose irrigation}]/[\text{high dose irrigation}]$$

“Low dose” (LD) is defined here as the attainable “efficient” amount of water depleted (or diverted) in growing a crop, expressed at the system level. “Low dose” is normally taken from observations of farmers practising irrigation where water is in short supply and care is taken to minimise losses, perhaps at the tail ends of systems. “High dose” (HD) irrigation is defined as the existing “inefficient” amount of water diverted or depleted based on observations of more profligate water use, seen more commonly at the top end of irrigation systems. Note both depleted and diverted water can be used, and amounts can be expressed in millimetres depth equivalent.

Determining who is a low or high dose irrigator depends on local circumstances. For example in tail-end areas in Usangu, farmers transplant only 3 days after first receiving water, while top end farmers do this in 7 days, and nearby formal state farms wet their fields for 30 days before transplanting. In each case non-beneficial evaporation increases from 3 to 7 to 30 days’ worth, becoming an increasingly higher proportion of the total depletion. “Low dose” includes 3 days of water while “high dose” uses 30 days (whereas the classical method would assume zero days in the numerator). Fieldwork by Machibya (2003) measured water-short tail-end smallholders growing approximately 3–4 t ha⁻¹ rice from 927 mm water; top-end smallholders growing approximately 4–5 t ha⁻¹ from 1385 mm; and state farms producing approximately 2.5–3.5 t ha⁻¹ from 2544 mm. Thus when compared to their water-short neighbours, the top-end smallholders and state farms have attainable irrigation efficiencies of 67% and 54% respectively.

In some respects, attainable irrigation efficiency is similar to “Irrigation Sagacity”, where “*IS is based on a partition of irrigation water between uses that are sagacious (either beneficial or reasonable) or non-sagacious (neither beneficial nor reasonable). Reasonable uses are those that, while not directly benefiting agronomic production, are nonetheless reasonable under prevailing economic and physical conditions*” (Solomon and Burt, 1999, p. 137).

However, attainable efficiency differs from Irrigation Sagacity by being based on two neighbouring cases of water management; “low dose” and “high dose” which informs the decision about “sagacity” rather than the 20-step procedure given by Solomon and Burt. Irrigation Sagacity is the [beneficial water used reasonably] over a denominator of [water applied], whereas attainable efficiency is [water used reasonably] over [water used unreasonably]. This difference in the AIE computation (diverted or depleted water goes on both sides of the equation) means that the judgement on what is reasonable is made by local comparison. Thus in rice, the unavoidable and “reasonable” seepage loss below the root zone (say 2 mm day⁻¹), often included in the net field level demand calculation, goes into both the “LD” numerator and “HD” denominator. However the unreasonable and non-beneficial evaporative losses of the extensive presaturation period (30 days) goes into the denominator.

More importantly, attainable efficiency informs how efficiency might be improved economically because the two cases are taken from similar farming systems. The practices followed by the “LD” irrigators (who tend to be poorer tail-enders) are financially within the reach of the “HD” irrigators (who tend to be wealthier top-enders) and could be discussed locally by stakeholders as examples on how to save and share water and improve productivity.

While each situation provides cases that allow such judgements on the manageability of losses to be made—the key point here is that judgements on the local nature of efficiency are required, leading to the specification of the local or regional “attainable efficiency”. The calculation of local efficiencies communicates to local users, scientists and policy-makers information about the manageability of losses and ways of discussing practical improvements.

8. Farmer responses to efficiency

As suggested above, farmers behave and organise in ways that demonstrate local efficiency matters but according to their perspectives under differing conditions of water scarcity. Examples from Usangu, Tanzania, taken from the period 1999–2005 include tail-enders on the Kimani irrigation system who felt their top-end neighbours were wasteful because water “should be ankle depth, whereas they take more”. Following a drought on the Kapunga Smallholder Scheme, farmers drew up new guidelines to tackle absentee growers that caused empty plots to be wetted up without being planted to rice. In the Mkoji Subcatchment, dry season irrigation concentrated around the intake because seepage in canals meant that after about 1 or 2 km, the water supply dwindled (and there was no shallow aquifer from which to abstract this loss except for domestic purposes). Farmers in the same area applied a local land tax to curtail excessive land cultivation, thereby intensifying production on a reduced command area (in another village, a variation on this decreed that no more than 0.2 ha (0.5 acre) should be planted per farmer). Tail-end irrigators on the Kioga system dug small furrows across upstream harvested bunded plots to channel water to their crops, thereby reducing evaporation and seepage. Also in the Kioga area, farmers spent considerable sums of their own money repairing a collapsed 10 m section of the main canal, but had no desire to line the canal, perceiving no gain for the potential cost involved. This contrasts with the government of Tanzania’s ongoing interest in canal lining as a means to address irrigation efficiency (MAFS, 2005). The salient issue is to realise that these viewpoints on the efficacy of canal lining are both classically informed—the difference is “whose money”, and the accuracy of prediction of how much water will be saved locally. Thus, as discussed in the previous subsection, observations of field practices point to the fact that local efficiencies and associated economics play an important part in water management and productivity.

9. Relationships between efficiency, productivity, time and timing

A substantive limitation of the EIE perspective that recovered losses do not need to be accounted for in basin productivity is that the time aspect of efficiency is largely omitted. Since water-related benefits accrue to *living* things (humans, crops, plants, animals), timeliness of water arrival is of paramount importance. Put crudely, if water arrives a week after a crop has permanently wilted, then no amount of water will resuscitate it. The notion that “most of the water is not lost” (Seckler *et al.*, 2003) as an underpinning of effective efficiency misses the point that users and systems are strongly connected to each other by their inefficiency of both *water use* and *release*. Three scales – field, irrigation system and river basin—show the relevance of the timeliness of water to the discussion on efficiency and productivity, as discussed below.

At the field scale, the objective is to keep as much of the available supply as possible for effective, timely watering work. In rotational irrigation systems, efficiency affects the ability to schedule irrigation on time, and in continuously supplied systems, it affects the ability to achieve wetting up within narrower rather than longer time frames. The relationship between water losses on timing of water delivery is complex but essentially arises from the rearrangement of the following continuity equation (Lankford, 1998; Cackett, 1984):

$$\text{Hectares irrigated} = [1\text{s}^{-1} \times \text{hours} \times 0.36 \times \% \text{efficiency}] \text{mm applied}^{-1}$$

$$\text{Hours} = [1\text{s}^{-1} \times \text{ha} \times 0.36 \times \% \text{efficiency}] \text{mm applied}^{-1}$$

This means that time taken is related to the dose, area, efficiency and flow rate of the rotational leadstream (main d'eau). Here efficiency is taken as "classical" as applied to the subunit being investigated because it is highly unlikely that the reusable losses are recovered to the same irrigation subunit within the appropriate time slot. If the soil-holding capacity of 65 mm is to be refilled over a rotational block area of 90 ha, using a flow of 701 s^{-1} , then with an efficiency of 100%, a cycle time of 9.7 days or 232 h on a 24 h cycle is required. From now on most key variables are fixed; the evaporative rate, the soil moisture replacement target, the flow rate, and therefore the hours to complete the cycle. If the efficiency drops to 80%, the time to complete increases to 290 h, and evaporative rate implied by this is now 5.4 mm day^{-1} . Hence, a lower efficiency, which can arise either across the whole rotational unit, or from one or two fields within it, can impair the ability to schedule water on time, and as such, the delays in rate of progress of irrigation can be converted to millimetres of stress below the "management allowed deficit". This is a telling computation, indicating that if the leadstream supply is regulated downwards, then efficiency has to increase to maintain rotational progress (see Lankford, 1992, for further discussion on this).

In a continuously supplied rice irrigation system, a deeper standing water layer in a proportion of the irrigation area can hold back water from arriving and supplying a tail-end area. For example, an area of 900 ha utilising 22 cm of water instead of 12 cm stores an excess volume of $900\,000 \text{ m}^3$. (These differences in depth were not unusual in top-end fields in Tanzania.) Assuming that in wetting up new lands, 250 mm is required in presaturating the soil and an additional 120 mm is required for the standing water layer, this $900\,000 \text{ m}^3$ could supply an extra area of 243 ha, a gain of 27% in area. However, the argument here is not that an extra area is supplied (itself a bonus), but that these 243 ha receive water earlier. Thus, the rate of transplanting is partly controlled by efficiency.

At the irrigation system level of the hydrological system, delays arising from excessive water usage in one upstream irrigation system may result in impaired productivity in a downstream system. Here, water that moves through an inefficient upper system takes more time to arrive at the lower system—although once it has arrived, the flow is then steady. A case study from southern Tanzania explains (Machibya, 2003). A large-scale state farm of 3000 ha is surrounded by a peripheral ring of smallholder farmers occupying some additional 640 ha. The drainage water from the state farm supports the tail-end farmers. There are timeliness issues associated with the fact that water has spent time on the state farm before routing via drains to the peripheral farmers. In this case the productivity is lowered because the lower system is planted nearly 30–60 days later, resulting in lower yields due to photosensitivity and seasonality, and due to 25% lower market prices. What this also highlights are the interactions between local efficiency, land area, transplanting timing, labour and inputs. Farmers, given the choice, would wish to plant earlier to catch better prices.

At the basin scale, the presence of irrigation consumption and losses affect timeliness and the shape of downstream hydrographs. Thus, water that routes via irrigation schemes back into the source river rather than remaining in the source river is subject to delays. These delays occur via two routes: water moving in surface channels and water moving to groundwater. First, in Usangu, water moving in canals and drains that are choked with weeds and blocked for fishing, and via fields to drains can take between 6 and 10 days to reach tail-end farmers. A simple calculation based on actual measurements demonstrates this. A range of river flow measurements gives an average velocity of 0.8 m s^{-1} in Usangu—thus water in a river takes about 8 h to travel 25 km. This contrasts with approximately 55 h when water moves across bunded field plots at slower speeds of about $0.3\text{--}0.05 \text{ m s}^{-1}$.

Secondly, water moving via groundwater seepage and recharge of rivers can take weeks and months. Focusing on the IWMI argument that groundwater losses are recaptured, it is not clear that the groundwater flow in Usangu is to places where it brings timely desirable outcomes. Prior to the 1990s the Great Ruaha River was perennial, and now it is seasonal, dry for between 2 and 6 weeks per year. If water is being returned via a groundwater movement, it is not evident in that particular stretch of the river. Instead, the Usangu recharge may be supplying a number of smaller springs along the East African Rift Valley that provide local benefits but not the large-animal and aquatic ecology previously found in the river.

The EIE model depicts water movement as continuous or instantaneous. This applies to agro-ecological zones where a stable balance between supply and demand exists throughout the annual cycle. Either the climate is tropical and allows year-round cropping, for example in parts of South East Asia, or in subtropical regions, the water supply is sufficiently consistent to allow the same, for example in the lower reaches of the Nile. The effect of these climatic/water supply factors is to create a calendar where differences between seasons and months are relatively minor, or more "forgiving" of delays in water arrival. In such agro-ecological zones, rice can be continuously cropped, or the

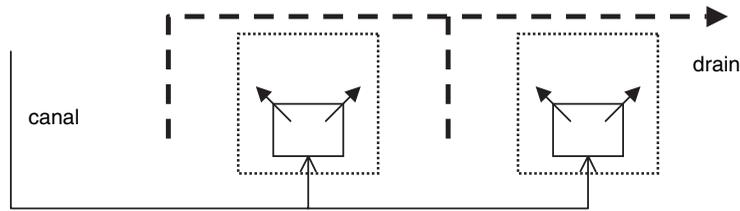


Figure 4. Savings in irrigation efficiency occur upstream since spare land exists on farms where savings are made

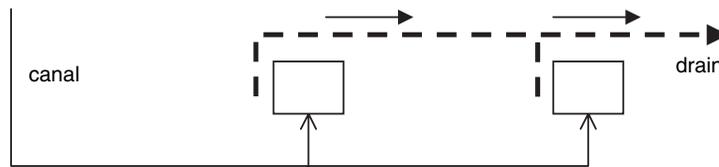


Figure 5. Savings in irrigation efficiency occur upstream, but without any area to expand into these savings are sent downstream

start and finish dates of a rice/wheat cycle slide into each other. However, in areas with marked seasonal changes, or where groundwater is not rapidly returned to surface hydrology (or abstracted by pumping), then losses within irrigation systems, and associated routing paths, can result in shifts of the hydrograph detrimental to downstream users. Classical efficiency reminds us that water may have to be used or delivered within a specific window of opportunity.

10. Interactions with command area dynamics

The role of command area in irrigation efficiency is rarely explored, yet command area, efficiency and productivity are connected in three ways. Firstly, command areas are related to irrigation efficiency, through the continuity equation.⁸ The equation says that if all else is fixed, as efficiency increases, the area irrigated goes up. Thus, in Keller *et al.* (1996), the improvement in efficiency results in expansion of those farms where efficiency savings have been made, resulting in less water moving downstream. However, and secondly, the area response to efficiency is dependent on the configuration of irrigated area and irrigable (or expandable) area because this determines where expansion occurs. The local expansion observed by Keller *et al.* (1996) is because a local irrigable area existed (Figure 4). Yet this configuration need not always apply; instead the irrigable area could lie downstream, which could then become irrigated with the saved water delivered from upstream areas (see Figures 5 and 6), provided water allocation instruments such as rights also promoted this.

Thirdly, equitable allocation *between* command areas on the basis of efficiency improvements is necessary because of the productivity function of water. This expresses the crop response to increasing amounts of water and the diminishing returns to greater applications of water; not all water is equally productive. An under-irrigated field results in poor yields, but excessive water to another field does not yield excessively compensating for the under-irrigated field (see Figure 7). It makes sense to even up the productivity of water so that for water used in a command area, maximum yield is obtained. The reason that efficiency is involved here is that by design or by management a flow-to-area ratio correct at the secondary level may be divided incorrectly at the tertiary level to compensate for inefficiency in a tertiary part. More efficient management of water in Block A in Figure 7, would, if adjusted for at the division box, cascade water to Block B.

In summary, the configuration of current and expandable irrigated areas and how savings are either fed downstream or become depleted upstream have important implications for the choice of CIE and EIE in making decisions about whether local efficiency matters. On the basis of this discussion the default position should be that

⁸Hectares irrigated = $[1 \text{ s}^{-1} \times \text{hours} \times 0.36 \times \% \text{ efficiency}] \text{ mm applied}^{-1}$.

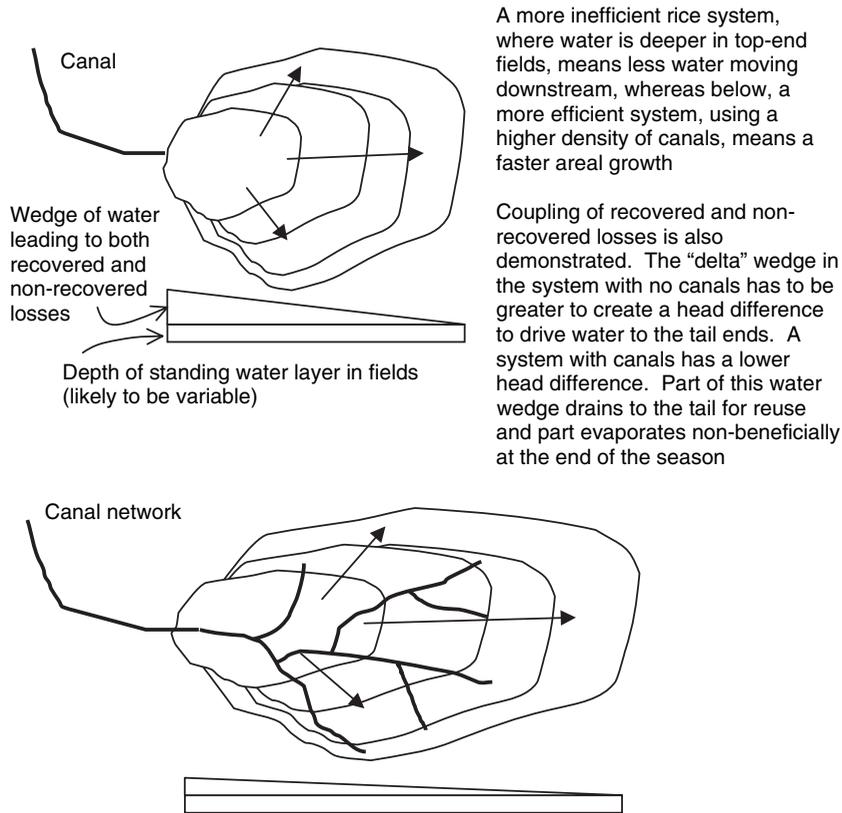


Figure 6. Concentric expansion occurs faster downstream as savings are applied in areas that have already received their water.

saving water locally is desirable to allow those savings to be purposefully used elsewhere (even if on the same farm). This is preferable to a situation where water “finds” itself somewhere else by complex and possibly unknown pathways of seepage, drainage, recapture and reuse.

11. Water, livelihoods and landscape interactions

Water flows through the agrarian landscape, playing a linking and defining role within and between agriculture, other sectors, livelihoods, land, economics and productivity. Judicious, timely apportionment of water and its

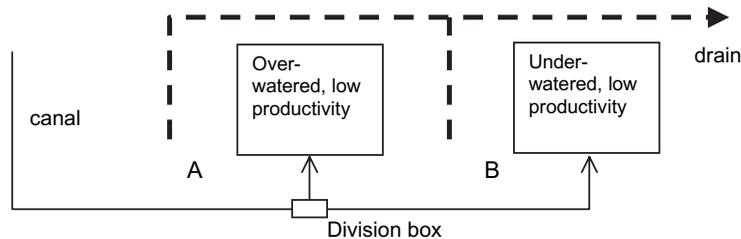


Figure 7. Effect of inequitable ratio of flow to area on efficiency and productivity. Block A is less efficient, but is taking B's water, so total productivity is reduced

efficient use connect a variety of other qualities or dimensions of water resources, such as *predictability* (giving farmers the means to plan livelihood activities around irrigation); *soil and water quality* (although EIE recognises the role of salts in reducing the units of drain water useable downstream this was treated in Keller *et al.* (1996) as an exercise in modelling rather than as a negative externality to be managed); *economics* of technology change or design of infrastructure (reducing costs); *soil fertility* (farmers in Usangu disliked water passing through their harvested plots to irrigate downstream plots feeling that it leached nutrients from soils that needed to be rested for a fallow break); and *productivity* (as mentioned above, late arrival of tail-end water brought late cropping and lower farm prices).

Although this is a brief list of some dimensions affected by irrigation efficiency, questions of whether and how we focus on these local and basin-scale interactions require critical engagement. I contend that “efficiency system zones” exist at the local scale. Each zone contains characterising systems of economics, livelihoods, infrastructure, institutions and agro-ecology that in turn influence the dimensions of water resources mentioned in the previous paragraph that then influence and are influenced by water and its efficiency of use. To raise irrigation efficiency in one zone requires an understanding of the systems nature of efficiency, found in different parts of a river basin (see also the next subsection).

12. *The role and permeability of boundaries*

Boundaries play a critical role in the theory of efficiency. Water accounting is applied to a unit with a relatively impermeable boundary across which water tends not to flow (e.g. river basin interfluves or a field acting as a sink). In classical efficiency, boundaries are implicitly defined at the field level. In effective efficiency, boundaries are implicitly set at the basin level. However, five boundary types refine the basin limits implied by effective irrigation efficiency; these are: geopolitical, irrigation typology; sectoral, subsurface and surface drainage. The point behind boundary identification is that many basins in effect can be broken into zones or subunits within which local water accounting becomes more relevant – and when this is the case, the water sharing, timing and rotational outcomes of classical irrigation efficiency within those subunits increase in significance.

The presence of international or other geopolitical borders cutting drainage lines might define the limit of the extent of reuse of water in any given analysis. Thus irrigation efficiency is described as a national or geopolitical phenomenon. Such a situation can be found in the northern part of Swaziland, where drainage from sugar cane estates directly and immediately flows into South Africa. This water is reused, but from the perspective of the sugar estates; it cannot be taken into account when assessing the latter’s efficiency. This is because the drainage water is not recaptured into Swaziland, and neither can the resulting agricultural produce be claimed as Swaziland’s.

A shift in irrigation typology might also define boundaries of reuse. For example, interest in efficiency might be applied to an irrigation system with very specific product, technology and cost. In the Pangani basin in northern Tanzania, flowers are trickle irrigated – although arguably there might be some downstream reuse, the analysis of efficiency of irrigation is strongly defined by the investments made in terms of farming systems, technology, water rights and labour. Organisational or morphological boundaries within basins also define the limits of irrigation efficiency analysis. In the Rufiji basin, the presence of a major wetland, national park and storage dam effectively restricts the analysis of irrigation productivity to the Usangu sub-basin, rather than to the whole Rufiji basin.

Subsurface drainage to aquifers defines a potential reuse zone where boreholes tap a common groundwater body. In reality, groundwater might be highly variable spatially or be held within clay materials with a high matrix potential, precluding sensible or cost-effective reuse. Alternatively, groundwater might be too deep or saline to be economically viable (Willardson *et al.* (1994) discuss this boundary and add the fact that seepage occurring close to oceans may also be lost). We should not assume that seepage below the root zone is automatically available for reuse.

Drainage boundaries might also affect the selection of the reuse area. Often, canals take water by gravity down the contour line of one bank of a river, allowing water to flow across the interfluve and drain into the basin of a neighbouring river. The reuse of this water need not be included in the calculation of productivity of water of the original basin. Here the key insight is that for each case being studied, local boundary conditions need to be explored and defined.

13. The effects of seasonality on efficiency

Irrigation efficiency is commonly held to be static, as an artefact of various design and management practices. However, research in Tanzania (Machibya, 2003) shows that the climate (wet and dry years) has a considerable effect on the amount of water being received by an irrigation system from both increased canal water and rainfall. This in turn affects the efficiency of the system because of the response to changing scarcity by farmers. The classical efficiency of Kapunga farm in the dry year (rainfall 300 mm) was measured at 48%, and in a wet year at 35% (rainfall 820 mm).

Regarding a local irrigation efficiency perspective, the high spatial variability of rainfall in Usangu (SMUWC, 2001; Machibya, 2003) results in differing levels of sub-catchment and system “aridity”, creating a mosaic of water supply, demand and efficiency across a large river basin. Although seasonality affects both efficiency models similarly, this paper argues that efficiency is highly case, season and location specific. The lower efficiency in the wetter year is comparatively less significant in terms of equity, productivity and scope for allocation precisely because there is more water in the system. This allows for the diverted and depleted water to be more accurately determined and interpreted in each scenario.

SUMMARY DISCUSSION

Table II proposes a simple “purpose” framework for examining the classical and effective perspectives utilising three objectives of design, assessment/monitoring and management, and two scales, local and basin. Attainable efficiency has been included for reference. In addition, a basin perspective can be constructed by assessing water depletion at an aggregated level or by summing the performances of disaggregated individual systems by exploring the water management at the local scale. The latter is useful when we seek to know where and how we can improve the performance of the whole basin by tackling its constituent parts.

The perspectives in Table II frame different policy decisions for proposing interventions to raise efficiency and productivity. Each scale and type of efficiency “theory” has a different utility in this respect. For example, I believe that analyses that adopt a “water depletion” basin perspective (for example Molden *et al.*, 2001, Box 2 on p. 17) explore means to “save water and increase productivity” that while not incorrect, appear less appropriate to the important timing, equity and volumetric issues found at the detailed local scale. The suggestions in Molden *et al.* (2001) are generalised means, rather than arising specifically out of observed field and system-level practices in their case studies.

In contrast, the farmers’ field and system-level improvements in Usangu described in subsection 8 are locally derived, bringing about changes in local fluxes of water leading to new patterns of water distribution at the sub-catchment level. Furthermore, I believe that these daily or weekly farmer struggles to manage gravity/surface irrigation systems in Usangu are highly instructive for irrigation and water specialists in terms of policy. These tests and trials – which can be brought to farmers through the concept of “attainable irrigation efficiency” – represent stage-relevant pathways to improve efficiency and productivity. Plus, interventions stemming from this kind of engagement are *localised*. Even so, these and outside “expert ideas” require a systematic method which prioritises options that are deemed useful and are adopted.

On the other hand, I am sceptical of the commonly stated “productivity recommendations” to switch to precision irrigation involving micro-drip, pipe, bucket and sprinkler technologies (e.g. Molden and de Fraiture, 2004; FAO, 1996). In my experience, these represent challenging step changes that are expensive on a per-hectare basis, fit certain kinds of horticultural crops in specific marketing environments, require project and financial support and attract a high maintenance cost over periods longer than 5 years. Yet, a more complex, less fashionable but possibly more sustainable and appropriate alteration to surface systems might focus on increasing field canal densities so that farmers are grouped into bounded “tertiary cells” where limited water is shared, and bottlenecks and losses can be better identified. The critical element for CIE over EIE is that losses recovered to the basin but not to the vicinity affect local water scheduling – an issue that is of significance to farmers grouped around a single source of water. In effect, however, although in Table II CIE and AIE are proposed as being more appropriate for improving local system management than EIE, this is not a hard and fast rule; informed and critical irrigation observers will

Table II. A framework of irrigation efficiency

Scale and purpose	Notes	CIE	EIE	AIE
Local/system design	Procedures to design infrastructure	✓✓	×	×
Local/system assessment or modelling	Performance monitoring to assist management and consider policy interventions	⇔	⇔	⇔
Local/system management	Activities designed to improve timeliness, equity and reduce losses	⇔	×	✓✓
Basin assessment or modelling: summation of individual systems	Modelling and performance monitoring of whole basin from disaggregated systems	⇔	⇔	×
Basin assessment or modelling: an integrated whole	Modelling and performance monitoring of whole basin from aggregated perspective of individual systems merged	×	✓✓	×
Basin management	Interventions to improve intra- and inter-sector sharing of water performance and productivity	⇔	⇔	⇔

Notes: CIE = classical irrigation efficiency, EIE = effective irrigation efficiency, AIE = attainable irrigation efficiency. ✓✓ = best application, ⇔ = neutral or can be used if modified, × = is generally not utilised but might inform the purpose.

constantly be reflecting on situational issues of water supply, demand, technologies, irrigators, reuse, scale, sinks and boundaries.

CONCLUSIONS

The debate on irrigation efficiency has on occasion been reduced to a summary position: “surface irrigation is very inefficient” or “local inefficiencies do not matter”. The position of this paper is that “efficiency is site, scale and purpose specific and that recovered and non-recovered losses matter locally”. The site-specific nature of irrigation in a river basin and its “fit” with conditions found needs to be examined carefully. A more complex, dynamic and seasonal picture of irrigation efficiency is required if we are to ask questions about how much, when and where spare water can be found from irrigation to supply other users. Judging efficiency indicators for systems should be seen as not straightforward. This site-specificity allows managers to examine locally attainable efficiencies and to tailor interventions accordingly (e.g. where water may be cost-effectively released downstream). Efficiency is also task or purpose specific, distinguishing between designing, managing and assessment. The cumulative but disaggregated effect of local efficiency on local productivity summarised at the basin level is a different conceptual and methodological challenge to taking an aggregated basin perspective.

Related to the “management” task, water should be managed optimally and efficiently where it is being used (accommodating contextual systems of economics, livelihoods, infrastructure and institutions that affect irrigation efficiency). This simple maxim addresses the inefficiencies that farmers and users at the local level observe and articulate, thereby improving returns to water by building on the benefits of “co-operative competition” between local users. In addition, improvements can be fostered year on year. Local care benefits interactions between timing, volume, labour, livelihoods, inputs and charges, land planting, prediction, and soil quality, plus it reduces overall planting schedule and season length, and minimises the proportion of water which goes to non-recoverable losses because recovered and non-recovered losses are coupled. It is this *interaction* between the different parts of the “efficiency system” that merits our attention. Lastly, care ensures that outside the irrigation system, improved timing of water is delivered by rivers rather than by drains, reducing unavoidable losses and water quality consequences. I also argue that improving local efficiency is worthwhile because of the inherent problems associated with recapturing losses from drains. Farmers go to great lengths to obtain water, but tend to neglect water drainage distribution once it has passed beyond their boundaries. Local efficiency matters because this fits closely with making every drop count, implied through the expression “more crop per drop”, whereas the effective

efficiency paradigm seems to equate to tropical water-abundant river basins in which transference by alternative routes matters little in terms of losses or timing.

It is the author's belief that local efficiency matters greatly, but a much more cautious and considered approach to classical efficiency is required, given that there are many definitions and skewed assumptions currently in circulation. More specifically, some of the commonest definitions of classical efficiency, for example expressing crop water requirement against total system water diverted (with the latter derived by multiplying assumed conveyance, distribution and field losses), should be seen as unrealistic and subject to inaccurate measurement and misinterpretation. The challenge is to interrogate classical efficiency more effectively and to seek methodologies of applying, measuring and interpreting local efficiency that provide relevance and accuracy for local water users at that scale, therefore not only allowing it to persist, but placing it correctly within irrigation and basin management and policy.

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