

METHODS, TOOLS AND INSTITUTIONAL ARRANGEMENTS FOR WATER CONSERVATION AND DEMAND MANAGEMENT IN IRRIGATED SUGARCANE

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Abstract

In this paper, methods, tools and institutional arrangements to facilitate water conservation and demand management (WCDM) in irrigated agriculture are discussed. Case study evaluations of the performance of irrigation system hardware and associated water management systems have shown that there is potential to reduce irrigation water applied by up to 20 percent per annum and to improve sugarcane yields, provided better design, management and maintenance procedures are implemented. Availability of appropriate guidelines and tools to effect water savings is, however, only part of the solution. Institutional arrangements for water allocation and management which provide positive incentives for the adoption of these tools and guidelines are needed. Traditionally, water has often been allocated in terms of a volume per unit time, issued at some estimated level of assurance. Such allocations are then managed using priority-based reservoir and river operating rules. This approach is shown to have significant disadvantages in terms of: ease of management, equitability, and potential to foment conflicts. Critically, it also provides little incentive for WCDM. In contrast, fractional water allocation and capacity sharing, which has been successfully implemented in the Mazowe catchment in Zimbabwe, is presented and shown to enable more efficient, equitable and productive water use and management.

Keywords: irrigation efficiency, models, fractional water allocation, water banking, mobile irrigation laboratory

Introduction

Uncertain water availability and a climate characterised by recurring droughts, provides strong motivation for the sugar industry in southern Africa to strive for continuous improvement in water management. For example, the sugar industry in Zimbabwe which is totally reliant on irrigation, nearly collapsed as a result of crippling water shortages following the 1991/2 drought (Binnie and Partners, 1993; Kaseke, 1998). To help ensure the long term viability of irrigated industries, increased insight into the performance of the various water management and irrigation systems is needed, together with the development and adoption of strategies, tools and guidelines to improve performance. However, adoption of best management practices is dependent, to a large degree on incentives, especially at the individual or farmer level. If reasonable incentives are not in place, adoption of even the best tools and guidelines will likely be limited. Therefore an integrated water conservation and demand management (WCDM) strategy is needed which addresses both tools and guidelines for field level irrigation water management, and also policy and institutional arrangements which provide positive incentives for the adoption of best management practices. In this paper, methods, tools and proposed institutional arrangements to facilitate WCDM in irrigated sugarcane agriculture are presented and their application is discussed.

Tools and Methods for Field Scale Irrigation Water Management

At the field level, irrigation systems performance is mainly affected by:

- the uniformity with which water is applied, the magnitude of the water applications relative to the available soil water store and crop stress thresholds, and the rate at which water is applied relative to soil infiltration characteristics;
- the amount of water lost through wind drift to non-cultivated areas, evaporation from the bare soil surface and evaporation of water when it is sprayed from the irrigation system's emitting device; and
- management, both in terms of the level to which irrigation systems are operated and maintained and via the implementation or non-implementation of an appropriate watering strategy.

Therefore, to effect improvements to the performance of an irrigation project, both the performance of the irrigation hardware and the associated water management approaches need to be assessed. The results of such an assessment should provide a basis for the development and provision of tools and recommendations for improvement.

One way to determine how well the irrigation hardware is performing is to have the system evaluated by a Mobile Irrigation performance evaluation Laboratory (MIL). The data and information acquired using a MIL can be used to calculate 'Irrigation Engineering Performance Indices' (IEPIs). One such IEPI is the distribution uniformity, DU, which is a performance index that describes how uniformly or non-uniformly water is applied (Burt *et al.*, 1997). The DU of applied water can have significant effects on irrigation performance because even if the timing and average magnitude of water applications is well matched to crop water demand and soil water storage capacity,

non-uniformity results in some areas receiving relatively higher water applications and other areas receiving relatively lower water applications. Excessive runoff and deep percolation losses are likely on the areas receiving the relatively higher water applications and reductions in crop yield can be expected on the areas receiving the relatively lower water applications. Depending on how well an area is drained, reductions in crop yields can also occur on the areas receiving excess water.

MILs also check numerous other aspects of a system hardware, from the suction arrangements of a pump through to the performance of emitters in the field. Measurements including: operating pressures, nozzle wear, emitter flow-rates and power consumption, are all aimed at ensuring that the system hardware is performing according to design specifications and accepted standards (Koegelenberg and Breed, 2002). Whilst such measurements are valuable in their own right, use of a systems simulation model to translate MIL data/information into associated impacts on crop yields and water use and then relative profit margins, increases the value of a MIL evaluation considerably. The role of a MIL in a more complete systems evaluation which uses a systems simulation model to translate MIL information and data into predicted impacts on crop yields, water use and thereby profitability, is illustrated diagrammatically in Figure 1.

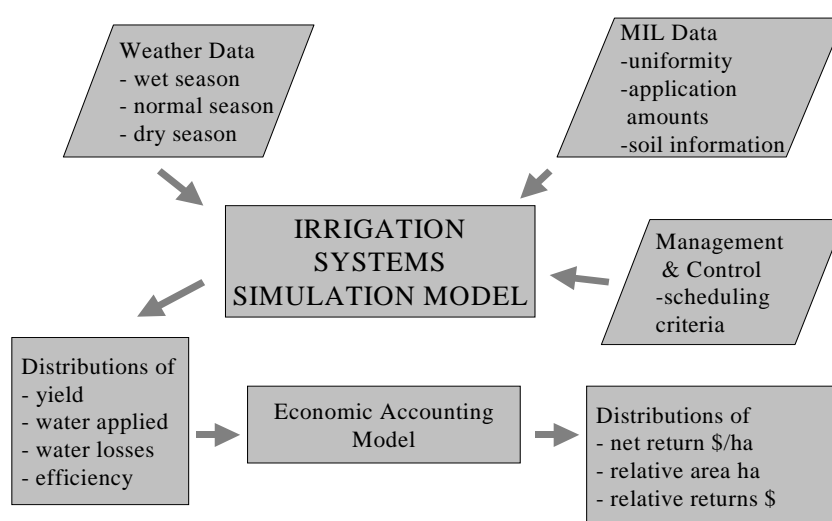


Figure 1. Diagrammatic depiction of the methodology used for the evaluation of irrigation hardware and water management systems. MIL stands for Mobile Irrigation Performance Evaluation Laboratory (after Lecler, 2003)

In a study of the performance of irrigation systems in the sugar industry in the Zimbabwe Lowveld, infield measurement of key irrigation system characteristics undertaken by a MIL, combined with a systems modelling approach (cf. Figure 1), was used to evaluate various water management and irrigation systems, and provide recommendations for improvement. The studies showed many areas in which the design, maintenance and operation of the system hardware could be improved. For example, a common design fault resulted in many drip irrigation systems having inadequate flushing velocities. This in-turn, resulted in an increased number of emitters which were blocked or semi-blocked, and poor irrigation application uniformities. Using the systems simulation model to assess the impact of the uneven water applications, showed that with the uneven water applications, yield reductions of up to 12 % could be expected together with substantial increases in deep percolation losses and reduced efficiencies (Griffiths and Lecler, 2000; Lecler and Griffiths 2003).

The water management guidelines which were in place on the various sugar estates were also shown to be sub-optimal. Use of *ZIMSched* (Lecler, 2000), a spreadsheet-based irrigation scheduling tool, was shown to have potential to facilitate up to 20 % savings in annual irrigation water requirements in many cases (Lecler and Griffiths, 2003). Interest in the MIL and the *ZIMSched* scheduling tool was greatest amongst a relatively small number of growers, in particular, those who had access to additional irrigable land relative to their water quota. These growers had a relatively large incentive to make water savings, as the saved water could be used to grow additional crops. Growers who did not have additional land relative to their water quota, were less interested in irrigation systems performance. These growers paid for water whether they used it or not. Any water savings they made were left in the system or storage works for re-allocation in a subsequent season. In addition, their potential

water savings, would, very possibly, be re-allocated in a subsequent season to other less efficient users who were higher up in the allocation priority scale!

The Zimbabwe study showed examples of tools and methods which were developed and adopted for use in facilitating improved WCDM in irrigated sugarcane. However, adoption of these and/or similar water management tools and best practices, was very dependent on associated institutional arrangements and policies for water allocation and management. Therefore, rather than focus on refining field-level water management tools and lamenting their poor adoption, more attention should be focused on reasons for the poor adoption of WCDM guidelines and tools.

Institutional Arrangements for Water Allocation and Management

Institutional arrangements which provide positive incentives to use water more effectively are likely to be key to the successful uptake and implementation of best water management practices which, in turn, will lead to higher productivity, increased and sustained profits, and a healthy environment both now and in the future. Since the irrigated agricultural sector often uses the major portion of the available water resources, facilitating gains in efficiency in this sector is a vital strategic issue. There are at least two contrasting options by which water allocations can be instituted by Water Management Authorities (WMA), namely:

- volume per unit time water allocations, issued at an estimated level of assurance, or
- fractional water allocations and capacity sharing (FWACS).

Volumetric water allocations and priority-based reservoir and river operating rules (VWA-PRROR)

Most of the water planning and allocation decision support tools procedures which have been developed, and traditionally used in southern Africa, have been based on VWA-PRROR. For example, an irrigation water allocation of 10000m³ ha⁻¹ annum⁻¹ may be issued and expected to be available, say, eight years out of ten. If VWA-PRROR are instituted and the flow in a given river or the level of a dam is low, certain users have their access refused or limited relative to other users, according to a penalty or priority structure. Because licenses are based on a volume entitlement, upstream users may, on occasion, pump a river dry in low flow periods even although the amount pumped may be less than their license entitlements thereby causing serious conflicts and problems for downstream users and the WMA. Apart from the potential for recurrent conflicts, the major problem with VWA-PRROR, is that there is little, if any, incentive for individual water use sectors to implement effective water conservation and demand management strategies. This is because with VWA-PRROR individual users have very limited or no control as to when in the future their water abstractions may be curtailed. Therefore, whilst water is available, the motivation is for users to abstract it. Also, if a user's water is stored in a shared multi-purpose reservoir, there is the risk that any water savings made by an individual and 'left' (stored) in the storage reservoir, may, at a later stage, be ceded to another user deemed to have a higher priority of use, even if this previously saved or unused water had been paid for. The outcome of the 'use it or lose it' mindset which becomes inherent in such a system is that with the diminished incentive to save water, the number and duration of water shortage periods is likely to increase and overall water use productivity is likely to decrease.

An example of the potentially catastrophic results such an allocation and licensing option has had, happened in the Runde River catchment in Zimbabwe. Between 1980 and 1992 the available water reserves in the Runde catchment were severely depleted culminating, *inter alia*, in the near collapse of the country's sugar industry. The VWA-PRROR institutional arrangements and water allocation system which, during the 12 years preceding 1992, led many users to take as much water as they could, when it was available, played a major role in this catastrophe (in the authors opinion and based on personal communication with stakeholders in the catchment).

Fractional water allocations and capacity sharing (FWACS)

Under a FWACS allocation and water management system, water allocations/licenses do not reflect a volume, but rather entitlement to a percentage or fraction of the total available river flow. The rate at which water can be extracted for use or storage by any given user, is then dependent on the flow in a defined river section at any given time multiplied by the licensed allocation fraction. The weekly or monthly volumes available for potential abstraction will vary significantly with the climate of the season. If there are storage works, the total potential storage capacity is divided and portions of the total available storage made available for rental or purchase by individual stakeholders. Over time, stakeholders may decide to purchase or rent smaller or larger capacities, dependent on individual risk aversions and the willingness of other users to trade storage space.

The practical challenge of measuring and monitoring flows, water abstractions, and successfully implementing FWACS was achieved in practice, in the Mazowe catchment in Zimbabwe (Darby Doertenbach, 1998). In 1984, eleven commercial farmers formed Zimbabwe's first "Combined Irrigation Scheme" (CIS). Each of the CIS members subscribed to a defined percentage of the cost of construction of a dam and its related infrastructure and members further agreed that each of them would be entitled to the same defined percentage or "fraction" of the annual new storage capacity of the dam to which the CIS was entitled. This practice allowed members to manage their own percentage share of the stored water and manage their own risk (of failure of supply) independently. However, a management system was needed to ensure its success.

"The solution turned out to be much simpler than believed possible," said Darby Doertenbach (1998). "The water in the reservoir was treated like money in a bank. Each of the participants was given a separate 'account', with a facility for both 'deposits' and 'withdrawals'. The new water to which the parent Water Right was entitled each month was quantified, separated into the appropriate percentages or 'fractions' and 'deposited' into each individual account."

Darby Doertenbach (1998) explained that the "normal river flow" coming into the reservoir was also quantified and "deposited" into the account of the river itself, or "the system" as it was called. Flow measuring devices were installed at each pump and canal offtake so that "withdrawals" could be accurately measured and debited to each account. Monthly evaporation losses were calculated and debited to each account in proportion to the account holder's percentage of total storage in the reservoir that month. At the end of each month, the reservoir's "assets" were reconciled in the same manner as the accounts in a bank, to confirm that the total of all accounts matched the amount of water in the reservoir. "Bank statements" were produced monthly for each account, showing deposits, withdrawals and a month-end balance. These calculations, while difficult to manage manually, were easy, quick and accurate to make when computers and spreadsheets became readily available.

The same management methods were applied to water that was released from the reservoir. This water was a mixture of natural river flow (which belonged to "the system" account) and stored water released for transmission to account holders downstream. The amount of water released (deposited) into the river was measured, as was the amount abstracted (withdrawn) by all those abstracting water downstream of the reservoir. Darby Doertenbach (1998) noted, "Not all downstream abstractors were members of the CIS and both members and non-members also had Rights to river flow (or system water) which was 'passed through' the reservoir." At a point downstream of the last CIS participant, the amount of water flowing downstream was also measured. The section of river between the dam and the downstream measuring weir was then "reconciled" in the same manner as the reservoir.

Each month, the reconciliation of the river section between the dam and the downstream measuring weir produced a significant "surplus" or a small "loss". The surplus in the downstream river section was assumed to be a combination of irrigation return flow and natural river accretions, and was called "generation". "Gains" and "losses" in the reservoir itself were assumed to be due to normal inconsistencies in the "smoothed" surface area/capacity curves for the reservoir and/or natural "generation" from the section of the river submerged by the reservoir. In order to prevent the possibility of prejudice to other Right holders, the "generation" in both the reservoir and the section of river below the reservoir was quantified and deposited into the account of the "system" so it could be "withdrawn" by those with Rights to river flow.

"The new management system received broad approval from both the CIS members and non-member Right holders," says Darby Doertenbach (1998). "It was simple to calculate, easy to understand, mathematically verifiable, and transparent. Released storage could be mixed with natural river flow and safely transported downstream without suspicion or prejudice. Natural river flow was quantified more accurately than ever before and readily available to those with Rights to river flow." The management system also satisfied the original requirements of the CIS participants, all of whom were free to manage their own stored water and risk of failure as their individual financial circumstances required, just as if they were owners of individual private reservoirs.

Apart from being implemented in practice successfully, FWACS has also been:

- assessed in terms of equity and efficiency by Natsa *et al.* (2000),
- assessed in terms of environmental water releases by Symphorian *et al.*, (2002), and
- the principles underlying FWACS have been reported on in an Australian context by Dudley and Musgrave (1988) and Dudley (1990).

The main advantages of FWACS include:

- it is relatively easy to audit and regulate water use because the rate (and hence weekly / monthly / annual volume) which individual users are allowed to abstract at any given time can be determined from actual flow measurements and reconciliation. Whilst presenting some practical implementation challenges, flow measurement and monitoring is a non-negotiable requirement if water is to be managed equitably - under any system;
- the license conditions allow upstream and downstream users to be managed in an integrated fashion, as opposed to a license based on a volume entitlement which may result in upstream users pumping a river dry in low flow periods, even though the amount pumped may be less than their license entitlements, thereby causing serious conflicts and problems for downstream users and the WMA;
- it is a more equitable option. Periods of high or low flows affect all users in a predictable, equal fashion;
- most importantly, users are empowered to manage their water supply status/security, and can receive direct benefits from any water savings they make. There is, therefore, a positive incentive to institute WCDM strategies. There is also a framework to facilitate 'win-win' water trades. The associated transfer of water to more productive users, can therefore, take place transparently and with minimal administrative complications. In addition, optimizing strategies, such as deficit irrigation (English, 1990; Lecler, 1999) will be facilitated. The overall result should be a significant improvement in the productive use of water and few conflicts. Individual stakeholders will be confident that water savings resulting from investments can be stored and saved for use (or trade) at a later stage, for example, during droughts, rather than taken and possibly wasted in high rainfall seasons. This is a key aspect of FWACS, the significance of which should not be underestimated (Lecler, 2003a).

Discussion and Conclusions

Mobile Irrigation Laboratories (MIL) facilitate the collation and analysis of critical in-field irrigation systems performance data and information. Apart from the valuable data and information gathered by MILs, a major benefit has been that irrigation farmers are sensitised to improved standards for irrigation systems design, installation and operation. Significant value can, however, be added to the data and information gathered by MILs if these can be translated into associated impacts on crop yields and water budgets. In order to achieve this a computer simulation modelling tool, was developed. In a case study application in Zimbabwe, the model was used to predict how MIL information/data, such as the distribution uniformity of applied water, DU, impacted crop yields and water budgets, assuming various prevailing water management recommendations. These comparisons were done for different soils and seasons, relatively cheaply, efficiently and objectively. Experiments to do this would not have been practically feasible. One of the key findings was that if the irrigation scheduling tool, *ZIMsched*, was adopted on a wide scale, there was potential for more than 20% of the water presently used on an annual basis when there are no water restrictions, to be saved. However, because of recurring droughts, the simulated potential water savings should be stored, and used to support the industry through the drought years. If water savings are not made, or a portion of the sugar industry's allocated water was re-allocated to another user, or a significant portion of the water savings could not be stored, there is every chance that another disaster, such as that which occurred after the 1991 to 1993 drought, when the industry nearly collapsed due to severe water shortages, could recur. Therefore, appropriate institutional arrangements to facilitate 'water banking' should also be developed.

Availability of appropriate methods and tools for field level WCDM such as MILs and irrigation scheduling tools, is, therefore, only part of the solution. Appropriate institutional arrangements must be developed and implemented to provide the incentives needed to encourage adoption and implementation of these WCDM methods and tools, and ensure that individual farmers can benefit from such adoption. Arrangements which provide positive incentives to use water more effectively are key to the successful uptake and implementation of Best Irrigation Management Practices. In this regard, it was shown that traditional volumetric per unit time water allocations, issued at some estimated level of assurance and managed using priority-based reservoir and river operating rules have significant disadvantages in terms of: ease of management, equitability, and potential for fomenting conflicts. Critically, they also provide little opportunity for stakeholders to manage their water supply status and so have a positive incentive to use water efficiently. In contrast, fractional water allocation and capacity sharing (FWACS), which was successfully implemented in the Mazowe catchment in Zimbabwe (prior to the present chaos and turmoil in the farming sector there), was presented and shown to enable more efficient, equitable and productive water use and management.

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