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The use of measured water flows in furrow irrigation management – a case study in Swaziland

BRUCE ALISTAIR LANKFORD
Private Consultant, 16 Tangier Lane, Eton, Windsor, Berkshire SL4 6AZ, UK

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Abstract. The use of measured water in controlling flows for the irrigation of sugarcane was found to be vital for the rehabilitation and management of surface irrigation on a 5000 ha sugarcane project. Methods of water delivery, measurement and control at Inyoni Yami Swaziland Irrigation Scheme (IYSIS) are described. Improvements to the irrigation, using existing methods of water measurement, were carried out over a period of four years. The lessons gained in this programme of improvements confirmed the benefits of using modulus gates which allow a constant, measured, discharge of water.

Introduction

The use of measured water flows in irrigation projects is recognised as one of many important precursors to successful irrigation management (Zimbelman 1987). The problems of measuring water in large schemes are considerable (Abernathy 1988) though there is more opportunity of achieving control on smaller schemes. This paper is concerned with water control on smaller, possibly commercially-run estates where canal control structures can be installed and managed with effect.

The type of gates used at IYSIS are constant discharge on/off gates. (These are also described as modulus gates, nerypic or neyrtec gates.) They are opened manually, are extremely robust and give a pre-determined flow for a range of upstream levels within the hydraulic constraints of the gate design. The water issuing from such gates is measured not by a trained worker reading a graduated staff but by the nature of the gate design; the flow is constant and the flow is known. Hence is this paper, the phrase 'measured water' rather than 'water measurement' is used since it implies the use of on-off modulus gates rather

The article is based on the author's own work at IYSIS (Inyoni Yami Swaziland Irrigation Scheme) during the period 1985 to 1989.

than the use of variable flow measuring devices such as flumes.

The lack of measured water on a project may be due to two reasons; design and management. The absence of gates that measure water or the presence of complicated gates that discourage good management is a design fault. Where suitable gates are present their lack of proper use is a management fault. In fact their presence may only serve to "trick" managers into believing that measured flows are being correctly used and that benefits are occurring. This is a subtle weakness in irrigation management and is an example of where "normal professionalism" acts (Chambers 1988). In this example the use of measured water lies between the normal professionalism of project management and irrigation engineering. To achieve real beneficial uses of measured water a project needs both the physical structures and the willingness to investigate the uses of them. The correct use of measured water gives irrigation managers a yardstick by which it is possible to determine water management problems at all levels of the irrigation project.

Without water control and measurement, it is very difficult to know where the problems of water management occur. This leads to many problems which culminate in poor water supply schedules at the field level and in an ever compensating and therefore lower-producing farmer. The experience at IYSIS showed that measured water allows the monitoring and evaluation of a water supply system and the identification of in-field irrigation and people management problems.

Location

The Inyoni Yami Swaziland Irrigation Scheme is a commercial agricultural project which consists of estates of sugar, citrus and livestock situated in the North Eastern Lowveld of Swaziland. The irrigated sugarcane area is divided into two estates; the western, called Ricelands with a total area of 2505 ha and the eastern called Vuvulane with an area of 1815 ha. On both estates, sugarcane is irrigated by both sprinkler and gravity-fed furrow methods. It is the water measurement for the furrow-irrigated sugarcane on Ricelands estate that is the main subject of this discussion (Fig. 1).

Water is supplied to the estates by the Mhlume Water System whose main features are a weir-offtake on the Komati River, a 65 km main canal and a 44 million cubic metre off-river storage dam. Water is supplied up to a maximum hydromodule of 0.946 l/sec/ha to the estates according to their daily water order. The water is then delivered from the main canal 24 h later. As furrow irrigation takes place only during the day, double the duty is supplied, i.e.; 1.89 l/sec/ha. At the tertiary unit this is rounded up to 2.0 l/sec/ha to give an easily measurable delivery flow rate from modulus discharge gates. Water is

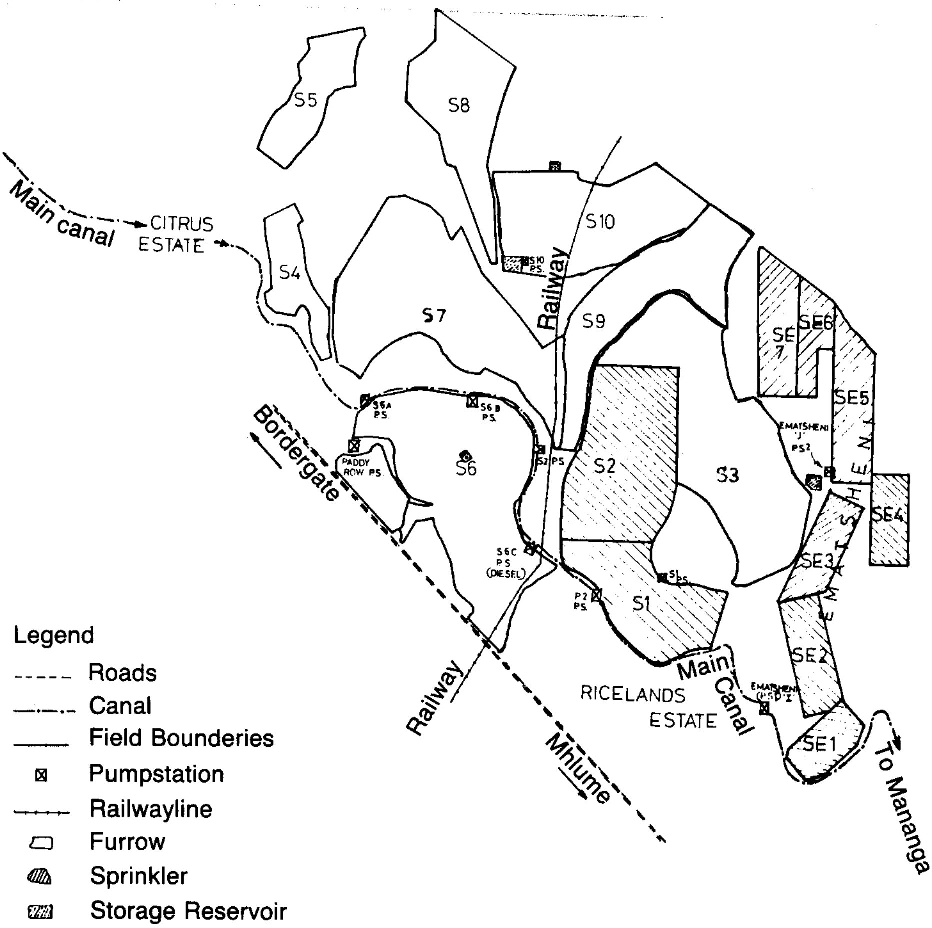

Fig. 1. Ricelands Estate, Inyoni Yami Swaziland Irrigation Scheme.

supplied to Ricelands Estate from the main canal through five outlets each with a water measuring structure. This is usually a parshall flume and head-controlling weir, though for smaller outlets constant flow structures are used.

Ricelands is divided into four furrow sections each about 300–500 ha for which a Section Manager has responsibility of the crop husbandry. In each section there are three to four blocks of fields, e.g. S4 and S5 in Fig.1, in which there may be 7–25 fields. Table 1 gives the water supply and distribution information for the blocks on Ricelands estate. Each block has a main water supply from the main canal which gives the flow at maximum demand (MD). This flow is then divided at bifurcation points using the constant discharge struc-

Table 1. Water supply and distribution for each block on Ricelands, IYSIS.

Block	Area (ha)	Supply from main canal	MD flow (l/sec)	Secondary and tertiary distributors	Rotation units
S3	305.1	1 parshall flume	660	14 modulus gates	5
S4	55.4	2 modulus gates	115	Direct to rotation units	2
S5	77.6	1 parshall flume	160	3 modulus gates	2
S6	343.4	3 pumping stations 1 parshall flume at NSR outlet	720	3 modulus gates 4 variable flow valve gates	6
S7	313.3	1 parshall flume and 1 modulus gate	720	15 modulus gates	6
S8	146.9	1 parshall flume to S8 NSR, released via 3 modulus gates	300	6 modulus gates	3
S9	159.1	3 modulus gates	360	5 modulus gates	3
S10	194.9	From parshall flume to S8 NSR, pumped to S10 NSR	420	6 modulus gates	4

Note: NSR = Night storage reservoir.
The number of rotation units includes those using less than 120 l/sec.

tures. These flows, termed leadstreams (main d'eau), are used for rotating around the tertiary units and are usually 120 l/sec for a 60 ha unit. This highly developed system of water delivery was designed and installed when the estates were originally developed.

Irrigation improvements

In 1985 a programme of irrigation improvements was begun by IYSIS management. At that time irrigation scheduling during the peak summer months was unfavourable, resulting in intervals of 10–20 days between irrigations. An analysis of the soil water availability, meteorological conditions and crop water use suggested that irrigation should be occuring every 5–7 days. The moisture stresses experienced by the sugarcane had to be reduced by changing to quicker cycles and lighter applications. It proved very difficult to bring this about; extension advice and new scheduling targets were not effective. The irrigation system seemed to be too entrenched in slow cycling and heavy irrigation applications. It was during the next four years that the importance of water flow measurement was recognized as the central means by which the changes in furrow irrigation scheduling and management could be carried out. These changes are described under the following headings:

- Scheduling, monitoring and summarising irrigation

- Division of estate water
- Formation of suitably designed rotation units
- Identification of supply problems
- Identification of in-field problems
- Identification of management/people problems

Scheduling, monitoring and summarising irrigation

Record keeping

The initial changes in irrigation began with improving the quality of information used in the irrigation scheduling. This was relatively quickly achieved because the modulus gates were already in place. Estate staff were trained to set the gates correctly and flow rates were painted on the gates to enable staff to collect flow data. The time and duration of water flows was also collected. Tables were made up for each field so that estate staff could determine the gross depth of application in millimetres of each irrigation. Runoff experiments were carried out which led to the use of a factor of 0.85 to arrive at a field efficiency factor and a net irrigation application. Rainfall was measured by rain gauges and was recalculated as effective rainfall. Crop water use was estimated by using Class A evaporation pans and crop factors (Thompson 1976; Ellis & Lankford 1990). This data was then used in the Soil Moisture Profit and Loss balance sheet that was operated for each field.

The steps in improving water measurements, scheduling and soil moisture records are listed in Table 2. These changes allowed accurate monitoring of the daily changes in irrigation on both estates. Clear summaries could be drawn up on a monthly and seasonal basis to show which fields, blocks and sections were suffering from the most stress. At the end of the year, total stress was calculated and correlated with yields. A desktop computer allowed very rapid calculation of summaries.

The implementation of accurate records had a tangible effect on irrigation management. Discussions on irrigation were held regularly using the records and summaries. It became possible to place much greater emphasis on crop stress and the need to minimise it. The higher standards showed the importance of irrigation to the estate staff from field irrigators, who collected data, to Section Managers who responded to it. Furthermore, the records were used as a means of gauging performance; using the summaries of the average stress of the sections, project staff could compare the performance of Section Managers in attaining irrigation objectives.

Perhaps the most important development was the identification of problems that were leading to unacceptable delays in irrigation; observations showed

Table 2. Improvements to irrigation measurement, scheduling and records.

Improvements
Painting of litres/second on modulus gates
Records of irrigation duration; start/stop times
Records of l/sec used
Calculation of gross millimeter depth applied
Runoff experiments – assumption of 85% field efficiency
Calculation of net millimeter depth applied
Calculation of effective rainfall based on precipitation rate
Re-assessment of Readily Available Water in soil
Clearer Profit and Loss forms
Profit and Loss balance using US Class A pan evaporation readings
Alteration of water ordering forms from imperial to metric units
End of season accumulated stress
Graph of uniformity of irrigation application over season
Correlation of irrigation records with yield
Identification of fields with abnormal applications

that some fields were always more stressed than others. It was this lack of irrigation control that dominated the remaining rehabilitation work which began with an analysis of the canal delivery system.

Division of estate water

Good water control is defined as ensuring that the maximum water supply ratio available to the project of 2.0 l/sec/ha is applied to each section, block and field and by irrigator management to field subplot, furrow and cane set. This was achieved by the bifurcation of flows at primary, secondary and tertiary division levels.

Primary division

The first division involved ordering and abstracting the correct flow from the main canal for the area irrigated. Knowledge of the section areas and accurate operation of the main canal offtake structures was vital for this first step. Accurate division of water within the estate depended to a great extent on the initial accuracy of main system water supply. This was achieved through the use of measuring structures in the main canal and at the oulets; the control and "policing" of these flows was carried out frequently during the day by the

Mhlume Water Department. The flows are then sent down the secondary canal system for division at the second stage.

Secondary division

In some parts of the estate a secondary bifurcation of the water supply was required before reaching the level of the rotation unit leadstreams. In other places, leadstreams were abstracted directly from the main canal. In the former case, the divisions at the secondary level had to ensure that the total flow for the tertiary canals supplying each group was in keeping with the hydromodule ratio. Water was measured with the modulus gate structures and their operation was carried out by estate staff.

At this stage (and at the primary division) it was necessary to abstract flows that were in multiples of the flows for the gates on next level down. This facility was originally meant to have been engineered into the system, although this was not always the case particularly where changes in field area had occured due to land coming in or going out of production.

An example of the division to block level is given in Table 3. It shows the areas and flows of Section Four in Ricelands and its four blocks, S5, part of S7, S8, S10. Referring to Table 3, the total area of Section Four is 585.8 ha which is supplied by 1240 l/sec. An example of determining the flow for one block is given by S8, which has an area of 146.9 ha. In order that 2.5 lead-

Table 3. Division of Section 4 into blocks and rotations units.

Block	Area (ha)	Main supply (l/sec)	Rotation unit	Fields in rotation unit	Area (ha)	Rotation supply (l/sec)	l/sec/ha (12 hrs)
S5	77.6	160	1	1 to 4	28.7	60	2.24
			2	5 to 10	50.9	100	1.96
S7*	166.4	360	1	8,9,12,13,14	55.9	120	2.14
			2	10,15,E8b,19	55.5	120	2.16
			3	11,16,17,18	55.0	120	2.18
S8	146.9	300	1	2,4	29.1	60	2.06
			2	1,3,6,7	58.8	120	2.04
			3	5,8,9	59.0	120	2.03
S10	194.9	420	1	1,2	44.3	90	2.03
			2	3,4,5a	40.5	90	2.22
			3	5b,6,7	54.7	120	2.19
			4	8,9,10	53.5	120	2.24
Total area	585.8						

* Blocks 1 to 7 of S7 are part of Section 2.

streams of 120 l/sec could be used, which fits in with the type and size of modulus gates within S8, the block receives a flow of 300 l/sec.

Once these flows have been determined, it was important that they were adhered to. A flow destined for one block could not be moved to another except under certain circumstances such as irrigating newly planted fields. Prior to these changes flows were often moved between blocks to wherever stress was greatest and although this may seem to be an understandable step, it did not show up which blocks and fields had inherent irrigation problems. A common complaint was that some fields took a long time to irrigate, but closer analysis showed that the whole block was under-supplied whilst a neighbouring block was enjoying more ample supplies. The simple and logical division of the estate water to each section and block had never been re-checked since the initial construction of the sugarcane project and so it was felt to be a significant step.

Formation of suitably designed rotation units

At this division level, the modulus gates were used in dividing a block's allocation of water into individual leadstreams for each rotation unit. Table 3 shows the combinations of fields in Section Four into rotation units. Since it was not possible to match flow to area exactly, some groups are slightly better supplied than others (refer to column 8, Table 3). Although this imbalance may be interpreted as being unfair, the ratios were found to be closer than those found in the original groupings. Prior to the changes, fields were grouped into tertiary units in a loose and *ad hoc* manner which led to inequitable supply-to-area ratios; some groups had supplies as low as 1.5 l/sec/ha resulting in lengthy delays between irrigations.

On both estates, Ricelands and Vuvulane, balancing areas to flows was a complicated and lengthy task, often requiring much discussion with Section Managers. A survey was carried out of the areas of fields and possible leadstream flows within each block so that fields could be combined into manageable groups which corresponded to the supplies as determined by the range of modulus gates. Therefore where flows of only 60 or 120 l/sec occurred (because of the modulus gate configuration) fields could only be combined into groups with areas of around 30 or 60 ha, respectively. If the range of selection of flows was greater, the area of the rotation unit could be more flexible. For example, gates that passed flows of 30, 45, 60, 90, 105 and 120 l/sec allowed the blocks to be divided more accurately. An example occurred in Block S10 where the modulus gates allowed only multiples of 60 l/sec, but two rotation units needed 90 l/sec, leaving them either oversupplied with 120 l/sec or undersupplied with 60 l/sec. The solution was to replace two of the modulus gates with two that discharged 45 l/sec. Without measured water such a discrepancy could not have been identified.

The fields in the rotation units had to have the correct supply and be grouped so that they were easy to manage. The criteria used to group fields that made up a rotation unit were:

- to form a unit supplied by approximately 2.0 l/sec/ha on a 12 h basis;
- to ensure that the fields which were grouped used the same gate type and capacities. This allowed the leadstream to stay at the same flow, regardless of which field within its rotation unit it was serving;
- to choose fields that were geographically as close as possible;
- to choose fields that were on the same secondary supply system, though this was not always possible;
- to ensure that two or more fields that shared a single tertiary canal were not split up. (This is where an in-field canal runs between two fields, with furrows leading off from both sides.);
- to ensure that two or more rotation units did not share the same secondary canal(s) without overflowing unless raising of walls could be carried out;
- to minimise the cost of new gates by swopping gates where possible.

Identification of supply problems

The attempts to arrive at a correct ratio of water supply to area at all division levels (down to the leadstream cycling unit) produced a wealth of information about the faults of the supply system and its inbuilt control and flexibility. A list of the types of supply problems and their remedies is given in Table 4. It was realised that almost all the 218 furrow fields at IYSIS had supply problems of some form or another. The most common problem was under-supply due to poor conveyance of design flows or incorrect grouping of fields in a rotation unit. A programme of rehabilitation was started which included raising canal walls and adding extra bifurcation points with modulus gates.

Correcting all the canal distribution and supply problems greatly increased the ability to schedule irrigation properly. However, these gains were not fully realised because delays occured due to the inefficient field irrigation methods. These were caused by a combination of in-field irrigation problems and a lack of suitably trained field workers.

Identification of in-field problems

The identification of in-field problems rested upon water application records. When the supply problems were solved, any continuing problems of under- or

Table 4. Faults in the water supply for furrow irrigation.

Supply fault	Remedy
Incorrect grouping of fields that share a leadstream	Rearrange fields
Block is difficult to divide into rotation units	Add new gates and canals where necessary
Secondary and tertiary canals unable to convey designed flow	Raise walls or rebuild canal
Modulus gate flows incorrect for area served	Replace with correct gate
Incorrect choice of modulus gate openings	Train staff accordingly
Main supply flow varies	Investigate main supply turnout and report
Variable flow gates present	If hydraulically possible replace with constant flow gate
Poorly designed inverted syphons	Raise walls or rebuild
Unmeasured bifurcation of two or more leadstreams	Re-design 2 and 3 way boxes and add modulus gates
Problems with pumps supplying furrow areas	Investigate and correct
Insufficient Night Storge Reservoir capacity	Investigate and correct
Unmeasured tail-end leadstream suspected to be too low	Improve measurement at initial supply point and subsequent offtake points

over-irrigation were signs of problems with methods of irrigation at the field level. It was felt that the in-field supply problems had to be dealt with before, or along side, improving the management of the irrigator teams. This was important since asking irrigators to meet targets with an ''unworkable'' field system was likely to lead to very poor motivation.

A list of in-field problems found at IYSIS is given in Table 5. The main cause of slow irrigation was found in ''top-of-furrow bottlenecks'' and field layout problems. Bottlenecks were commonly found at the point where the water was delivered from the tertiary canal to the top of the furrow. Apart from field layout changes, the remedies were normally quite cheap to effect. Field layout problems, particularly the gradient and furrow shape were more difficult to alter since sugarcane is a perennial crop which is ratooned. In this case the redesigning of the layouts was carried out during replant; about once every 3–6 years.

Once again it was found that the use of measured water flows in tertiary canals was vital in determining the location of in-field problems. Without it a true knowledge of the extent of under- or over-irrigation is impossible. Prior to these changes, Section Managers tended to compensate by irrigating longer or by taking more water from elsewhere which inevitably caused further shortages. These shortages were too often blamed on insufficient hydromodule flow rate or a lack of rainfall. There was a widespread belief in water shortages that were not in fact 'real'.

Identification of management/people problems

Good irrigator management is the next logical step in ensuring the correct division of the leadstream down each furrow and thus to each crop stand. When a correct water supply, to the field edge, was secured by improving canal supply and solving in-field problems, good irrigation became the responsibility of Section managers and their irrigation staff. Furthermore, excuses for poor irrigation performance could no longer be blamed on the system.

First principles on the motivation of labour were used at IYSIS. These stated that with any job there should be a sense of achievement and recognition for it. For this to occur a manager should be able to set measurable and attainable goals and then assess performance. In the furrow irrigation system at IYSIS, this was made possible by water measurement and record keeping. Some examples of irrigation-personnel management at IYSIS are given below:

- At the Section Manager level, performance was assessed from scheduling records, number of irrigations per month, average depth applied (other tasks such as the repair of canals were also used).
- The Field Supervisors' performance were assessed by rotation frequency and depth of water applied which depended on the performance of their teams of irrigators.
- Field Irrigators were tasked and assessed by the time they took to complete individual fields and portions of fields.

Since the first two were largely based on the efforts of the field irrigators, the latter are discussed in more detail.

Tasking field irrigators

It was possible to set time objectives for the completion of each field which the irrigator worked on. The duration comes from the equation that combines the millimeters depth applied, the hours of irrigation, the flow used, the area covered and the field efficiency factor. However, since fields have different areas this would result in a complicated array of varying duration objectives. It was therefore decided that fields should be divided into smaller but constant areas

Table 5. Indentification of in-field irrigation problems.

In-field irrigation problem	Remedy
Incorrect furrow shape for soil type	Investigate and correct
Incorrect furrow gradient for soil type	Investigate and correct
Under-sized ridges leading to breakouts and poor water control	Re-draw furrows
Trash restricting advance rates	Correct
Poor layout; too complicated; uneven gradients; too many infield feeder furrows, short lines	Re-design layout with irrigators' work load in mind
Low capacity feeder furrows supplying too large an area	Re-build feeder furrows, ensure good supply from field-edge canal
Incorrectly sized spile or syphon pipes	Investigate and correct
Insufficient walk-ways through tall cane to allow irrigators to check runoff	Correct
Insufficient number of syphon pipes	Manufacture more
Poor head control at the field edge canal:	
– shooting flow in canal, lowers head, occurs below step with no stilling basin	Re-design canal and rebuild Design and install stilling structures
– poor stepcanal equipment; spile caps, syphons, checkboards	Correct
– cane too close to spile/syphon pipes, water backs up	Cut out cane (1–2 meters)
– trash and soil too high on field side, water backs up	Correct
– soil ridge insubstantial, causes break-outs	Correct

so that there was a uniform set time for completion. This was set at 4 hours, which divided neatly into 12, the duration of water flow each day. Depending on the leadstream flow used and the soil type (to correctly replenish the readily available moisture) the task area was found to be about 3.5 to 3.8 ha. The task-areas (called "Tindzima") were set out using the existing furrow layout and were demarcated by painted numbers on the side of the tertiary canal.

The time of completion (4 h) of the Tindzima became the goal of the irrigator and his/her supervising team so that at peak crop water demand, irrigators were asked to complete 3 Tindzima a day. Records of times were kept by supervisors and analyzed by estate staff. At no time were the results used to castigate slow irrigators mainly because of the innumerable problems that still had to be solved with layout, scheduling, and supply problems. Even so, good management should not punish slow workers as their work rate is usually a reflection of the management itself! The Tindzima deadlines were a rough guide-line; if the time to complete 3.8 ha was improved by only 10–20 percent then the

Table 6. Management problems causing delays in irrigation.

Management/irrigator problem
Failure to implement changes on water measurement, time keeping, record keeping, division of water and leadstream cycling groups
Failure to schedule correctly, soil too dry leading to slow advance rates, and greater burden on field irrigators to achieve correct duration time of irrigation
Failure of managers to meet their staff's needs; equipment and training:
Equipment
Spile caps, syphon pipes, checkboard gates, watches, etc May be lacking or in poor condition
Training
Meeting Tindzima targets Adjusting flows down furrows. Controlling runoff Using flush and cut-back irrigation Setting of gates Maintaining field area, feeder furrows, furrow necks
Insufficient encouragement of field irrigators to achieve the Tindzima targets
Lack of reward given to successful irrigator teams

cumulative effect over the whole estate (over 800 Tindzima) was of great benefit.

The delays in irrigation due to management, motivation and training are listed in Table 6. Training was given to all the irrigators on a continuing basis by field staff and the Sugar Department. The final aim of the management changes was to give the irrigator teams responsibility in all matters concerning irrigation with the possible exeption of scheduling and to eventually use sugarcane yield as an indicator of achievement.

Discussion

Control and flexibility

When the crop water demand at IYSIS exceeded supply, the use of measured water was the only means by which sufficient control could be obtained to maintain optimum production. Above all, this control is defined by the delivery of a set hydromodule (ratio of water flow to area) to the field edge.

Expanding this definition; control came through the use of measured water flows which were obtained by on-off modulus gates. The gates delivered measured, fixed water flows at all bifurcation points of the distribution system to the rotation unit level. Good management then ensured control was taken to the level of the field, tasking area and individual furrow. A good field layout helped increase uniformity of irrigation so that control was extented to individual cane setts.

When crop demand exceeded canal supply (set by the engineering capacity of the system, or low supplies) then flexibility was no longer possible except in the choice of how to select areas of *increased crop stress*. Statements such as "control and flexibility are desirable to achieve maximum crop production" were found to be meaningless as IYSIS when additional water supply was no longer available. In fact it was the flexibility which existed prior to the rehabilitation changes which gave greater opportunity for uneven distribution of water and exacerbated the supply shortages.

When crop demand was less than supply the question of true flexibility arose. Section Managers could use a more relaxed schedule with more or less frequent irrigations. In this case measured, fixed supplies were not found to be a hindrance. The modulus gates were constructed to allow flows to be changed in set fractions of the maximum leadstream flow. If more water was required then irrigation could be carried on longer. If faster irrigation was necessary then the options suggested in Tables 4, 5 and 6 were relevant.

It can be argued that an irrigation system which is designed for peak crop use but has a lack of control will not be able to irrigate according to the normally strict requirements. Therefore strictness needs to be managed and built in as well. This has to be done on all levels: main supply, canal distribution, scheduling, management, in-field control and so on. The experience at IYSIS showed that measured water allows all these elements to be brought together in an effective manner. In fact it is hard to envisage how the changes could have been brought about without the use of measured water.

Conclusion

From the period 1896 to 1989 IYSIS implemented complete changes in the management of irrigation. The use of measured water flows proved vital to the successful outcome of these changes. In summary, the reasons for using controlled flows were the following:

- It enabled accurate data to be used for soil moisture profit and loss accounting and the scheduling, monitoring and summarizing of irrigation.
- It allowed the total estate allocation to be evenly divided at bifurcation points through the levels of section, block and field.
- It allowed a canal network analysis to be carried out on the supply of water to area served so that system improvements could be made.

- It allowed estate staff to implement a tasking system (Tindzima) which could then be used to highlight supply faults, in-field problems and management deficiencies.
- It shifted some responsibility to the lower levels of management, and to field staff for achieving irrigation targets with a guaranteed water supply.
- It allowed the estate to adapt to water shortages during drought by maintaining an equal division of the water supply.

The use of measured water in irrigation is recommended for all the above reasons, but particularly so as it is a practical measure that can be introduced. Experience at IYSIS showed that robust modulus gates were suitable for this. The potential of this type of gate can, however, be eroded by weak or technically poor management. Some authors have suggested how systems may be modernized using simple automatic flow regulators on the main canal and on secondary and tertiary canals (Rogier & Rousset 1987).

It is clear from this study that the presence of water measurement structures on an estate will not directly improve equity or accuracy of timeliness. These benefits have to be won in an indirect manner over a long period of time via a programme of evaluation, monitoring and implementation of improvements. In fact it is the belief of the author that the benefits of measuring structures are often not realised because it assumed that improvements in water delivery will automatically occur if they are present.

It is also believed that the decision to use measured flows should not be restricted to irrigations systems which have a water supply schedule that traditionally warrants this, e.g. in the case of on-demand systems. The use of measured flows should not be seen as merely a method of charging farmers, but in the context of improving all aspects of an irrigation system even those with rotational or continuous-flow supplies. In the end, economics, environmental constraints and the level of management ability should be the deciding criteria of introducing measured water supplies.

Finally, even though yield data is not yet proving conclusively that the systems changes are working (however IYSIS has had a record year in the 1990/91 season), staff felt at that time that the effort in making the changes was worthwhile. The time it took to correct the large number of improvements and to move away from the entrenched slow irrigation scheduling, despite a concerted team effort, was a surprise to all. Particulary since the irrigation infrastructure was already highly developed. Changing the management of a scheme so that it becomes easy to run *effectively* is more difficult than changing the scheme so that it just becomes easy to run. Using measured water, collecting data, checking flows, making summaries, and recording irrigation is one way to analyze what is going on in order to make improvements where necessary. After any possible changes have been made, there is no reason why the project managers should not drop many of these time-consuming (but still relevant) jobs and get on with the day to day running of the project. Hopefully the changes, both structural (raised canal walls, new gates, improved layouts, etc) and non-structural (improved groupings of fields, giving irrigators greater responsibility) will allow the scheme to run well without slowly reverting to "old habits". This is in keeping with the statement by Bos (1987): "Water management in future irrigation systems could be improved if systems were designed in such a way that their proper management would be as easy as the mismanagement of existing systems".

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