UNDERSTANDING WATER SUPPLY CONTROL IN CANAL IRRIGATION SYSTEMS

Analysis of irrigation water control

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Abstract
Water management on the extensive canal irrigation systems that supply the major parts of the world's irrigated acreage is difficult. This difficulty and the poor water-use efficiency arising from it can be shown to be caused by poor design practice. A method is presented which is intended to allow designers to evaluate the manageability of water supply stemming from their designs. Alternatively the method can be used by managers as part of a process of action research aimed at improving water control. Case studies on two irrigation systems in Swaziland are used to demonstrate the method of analysis.
Keywords: canal irrigation, design, operation, rehabilitation, water control.

1 Introduction

This paper is concerned with water supply control as a critical aspect of irrigation design. Water supply control is defined as the designed-in ability to regulate the supply of water over time over a canal or rotation command unit so that the irrigation need of the command unit at peak crop demand is met without excessive wastage. The term "designed-in" implies that the system is operated with an ease of management concomitant with performance aims and level of operator activity. Design architecture and operation is examined; a concept that embodies a combination of irrigation system infrastructure (gate/head control technology), system configuration (layouts, areas and groupings of fields into rotational units) and design operational procedures (e.g. allocation of supply within or between rotational units).

Interest in interactions between irrigation design and management has been growing since the mid 1980's when this topic was adopted by IIMI as one of its core

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research themes [1][2]. During that time various researchers have highlighted the need and support for the diagnosis and action research of systems [3][4][5]. In the last few years the International Program for Technology Research in Irrigation and Drainage (IPTRID) [6] has been set up to promote such research. Other recent work has identified water control as being central to general irrigation performance [7][8]. Nevertheless, these initiatives have not gained the momentum that other reforms in irrigation practice have achieved, such as irrigation management transfer. The failure to pursue technological reform alongside management reform may be attributed to:

- An acceptance by operators of the "as-built" design as complete and unchangeable together with restricted knowledge about options for irrigation design stemming from a lack of suitable training or forum for exchange of "working" experience.
- The lack of funding/procedures/support for on-going diagnosis and action research of operation and water control design.
- A low number of suitable studies and/or publication of results and methods.
- A lack of experience in operating schemes by irrigation engineers involved in design feeding through to improved innovation of design.
- An institutional reliance on one particular school of design.
- The lack of inclusion of design criteria in bid/proposal and contract evaluation.
- Complex interference of other factors affecting performance such as field design.
- Difficulty of comparison between schemes by clients (farmers and operators).
- Conflicts within the irrigation profession regarding appropriate design.

2 Method of analysis of water supply control

Work on two irrigation schemes in Swaziland indicated that water supply control in rotational supply systems could be characterised on the basis of seven interrelated factors or categories. These are presented in Table 1. The first two, discharge-supply match (DSM) and gate discharge (GD) are measures of design sizing and may be used to investigate design approximations [2][9]. The next four head control (HC), discharge measurement (DM), discharge adjustment (DA) and feeder compatibility (FC), reflect technology choice, the type of design, the amount of manual operation and to some degree robustness of design. The last, rotation integrity (RI), is a reflection of both system design and design operational procedure. The characterisation method is applied to individual rotational units - termed here "leadstream groups" - at the tertiary level. A leadstream (or main d'eau) is the supply of water which cycles around the fields belonging to the rotational unit.

The proposed characterisation method does not attempt to quantify the design or its effect on performance. Neither does the method recommend that any one design is optimal. Rather, it allows operators to review water supply control and reflect on whether their activities and performance may be influenced by its design. It also should be noted that this method represents a conceptual framework for an extended research project, and that it is subject to further refinement.

2.1 Specific demand - supply match (DSM)

The demand-supply match (DSM) measures two aspects of design; a) the gate size which gives a discharge at its maximum setting and b) whether the canal is the correct

Table 1. Characterisation of irrigation water supply control for rotated flow in tertiary canals.

Category number	Category of irrigation control	Category code	Classification of subtype	Subtype Code	Number Code
1	Specific demand - supply match (For whole group)	DSM	No subtypes. Demand hydromodule and specific supply are calculated. Specific supply is expressed as a fraction of demand hydromodule		
2	Gate discharge (Each gate is described)	GD	No subtypes. Gate discharges are expressed as a fraction of the maximum discharge found Max discharge = 1.0		
3	Head control (Each gate is described)	HC	Omitted	O	1
			Irregular	I	2
			Manual - active	MA	3
			Manual - passive	MP	4
			Automatic	A	5
4	Discharge measurement (Each gate is described)	DM	Omitted	O	1
			Irregular	I	2
			Manual - active	MA	3
			Manual - passive	MP	4
			Automatic	A	5
5	Discharge adjustment (Each gate is described)	DA	Irregular	I	1
			Manual - active	MA	2
			Manual - passive	MP	3
			Fixed	F	4
			Automatic	A	5
6	Feeder compatibility (For whole group)	FC	No subtypes. See separate method for scoring between 1 and 5 (Table 2)		
7	Rotation integrity (For whole group)	RI	Rotation integrity poor	P	1
			Rotation integrity medium	M	2
			Rotation integrity good	G	3

size to carry the required discharge. The terms specific demand and specific supply are used because crop water demand and canal supply can be more accurately compared when both are expressed in litres/second/hectare (l/sec/ha). Volume-based supply should be recalculated to a flow over time. DSM is calculated in three steps:

Step 1. Specific demand (which is also known as the hydromodule) is the irrigation need of the command area at peak demand expressed in l/sec/ha. The specific demand can be seen as the inverse of the water duty. A weighted average demand can be calculated if fields within the rotation unit have very different water requirements.

Step 2. Specific supply is calculated in l/sec/ha by dividing the maximum flow supplying the tertiary command unit in litres/second by its area in hectares. The flow is at the crop level by adjusting for tertiary canal and field losses. If the flow is not currently measured then flow measurement is necessary. If tertiary canal flows within a leadstream group are different, a weighted specific supply should be calculated.

Step 3. The demand-supply match is calculated by dividing the specific supply by the specific demand. If the specific supply matches the demand, the match is equal to or close to 1.0. An over- or under-supply gives a DSM greater or less than 1.0.

2.2 Gate discharge (GD)

This is a measure of the uniformity of flows in the canals supplying fields. Operators may wish to have uniform flows so as to not create bottlenecks, or to enhance visible equity of supply between leadstream groups. Gate discharge is expressed as a fraction of the maximum flow supplying fields in the group.

2.3 Head control (HC)

This is an expression of the **local** control of the level of water which regulates the discharge through the irrigation gate. Head control provides for a head difference between upstream and downstream water levels at the gate which gives stable flows. No distinction is made here between upstream and downstream level control in the conveyance canal (see feeder compatibility). Five main types have been identified:

1. Omitted (O, 1). Head control is effectively remote or absent in design.
2. Irregular (I, 2). The structure is faulty or broken, or water in the offtaking canal backs up and interferes with the upstream water level.
3. Manual-active (MA, 3). Manual adjustment is used. An example is the constant head orifice (CHO) gate which includes a head-controlling gate that needs frequent adjustment and is difficult to operate accurately [7].
4. Manual-passive (MP, 4). No manual input is required within certain flow limits otherwise input is minimal. Examples are composite-weir cross regulators [7].
5. Automatic (A, 5). No manual input is required over a wide range of flows. Two examples are optimally designed long-cilled weirs and electrically operated gates.

2.4 Discharge measurement (DM)

This is a measure with which the ease and accuracy of discharge measurement takes place. It can be characterised in one of the five following ways:

1. Omitted (O, 1). Absent in design.
2. Irregular (I, 2). Structure is broken, missing, incorrectly constructed or inaccurate.
3. Manual-active (MA, 3). Measurement requires manual recording. Examples include stick-gauged flumes, weirs and orifice gates.
4. Manual-passive (MP, 4). Measurement is designed-in and hidden from gate operator as in module gates (e.g. of the neyrpic or neyrtec design).
5. Automatic (A, 5). Flow measurement is recorded automatically (e.g. via float and sensor flow gauging and radio-telemetry).

2.5 Discharge adjustment (DA)

Discharge adjustment may not be necessary in all schemes depending on intended operation. Five classes have been identified. Note that there is no "absent or omitted" class since this would fall into the fixed class which requires no manual input.

1. Irregular (I, 2). The gate is broken, missing or incorrectly constructed.
2. Manual-active (MA, 2). Gates are adjusted manually but can be set at continuously variable openings. Examples are sluice gates and adjustable flow dividers.
3. Manual-passive (MP, 3). Gates are adjusted manually but have easily discernible settings such as on-off or two or three settings giving stepped flow rates. Examples are neyrpic gates with one or two shutters that are either on or off.

4. Fixed (F,4). Here manual input is reduced further as gates do not need opening at all. Examples are fixed flow dividers.
5. Automatic (A, 5). The gates are adjusted by automatic, hydraulic/electrical, or possibly computer controlled means.

2.6 Feeder compatibility (FC)

Feeder compatibility describes how well the upstream canal delivery system is designed so as to complement the tertiary turnout design and requirements. The objective of feeder compatibility is the accurate delivery of flow for the turnouts which is congruent with the cumulative and changing demands of the leadstream groups. Table 2 shows the scoring system based on four main aspects of feeder compatibility:

1. Measured flow may enhance the accuracy of supply of water in the secondary system for tertiary turnouts. There are three main subtypes; absent or broken; manually measured (e.g. a flume); or automatically measured (e.g. a modular gate).
2. Flow fluctuations at the head of secondary canals may lead to flow variations in offtaking turnouts. The degree to which these variations are dampened is scored accordingly; absent or broken technology; technology that gives non-steady flows (e.g. manually-operated sluice gates); and technology that gives steady flow such as long-cilled weirs in the main canal.
3. Responsiveness of supply refers to the design of the secondary canal gate to adjust to changing downstream demand. The three main types are absent, manual or automatic (e.g. hydraulically-operated gates sensitive to downstream water levels).
4. Accuracy of supply. Having investigated the flow or range of flows, it is then possible to check whether the supplying canal delivers the correct flow for the combined demand of the leadstream groups. This should be done at peak demand.

Table 2. Scoring system for feeder compatibility (starting score = 1)

Aspect of feeder compatibility	Classification of subtype	Score
Measured flow	Absent or broken	Add 0
	Manually measured	Add 0.5
	Automatically measured	Add 1.0
Flow fluctuation	Absent or broken	Add 0
	Non-steady	Add 0.5
	Steady	Add 1.0
Responsiveness of supply	Absent or broken	Add 0
	Manual	Add 0.5
	Automatic	Add 1.0
Accuracy of supply	>25% difference in required supply	Add 0
	10-25% difference in required supply	Add 0.5
	<10% difference in required supply	Add 1.0

2.7 Rotation integrity (RI)

This reflects the manner in which the cycling of the leadstream around the group's fields are adhered to. As it is not easy to calculate an accurate measure of the rotation integrity, three broad classes are suggested:

1. Poor (P, 1). Within the secondary command unit, fields are not aligned to individual tertiary leadstream groups. Water is cycled in no discernible pattern, frequently to fields on a driest-basis first. This type of operation makes the area and specific supply of the leadstream group extremely difficult to determine.
2. Medium (M, 2). Water often circulates in a discernible pattern but occasionally leadstreams are transferred between groups (due to driest-first irrigation) leading to a broken rotation. The area and thus specific supply are not known with certainty.
3. Good (G, 3). Leadstreams are circulated only within their respective groups. Irrigation is scheduled to fields within the leadstream group on driest-first basis, and a clear rotation of delivery is discernible. This allows the specific supply to be easily calculated since the area of the leadstream group is known.

Scoring of water supply control may be difficult in some schemes, and in cases may have to be omitted. Furthermore, scores could be estimated between whole numbers for systems that do not fall easily into the above named classes.

3 Characterisation of two irrigation systems - case studies from Swaziland

Two tertiary systems from neighbouring irrigation systems (MSCo and IYSIS) in Swaziland were analysed with the method. Table 3 gives the results of analysis and Figures 1 and 2 are the characterisation diagrams for MSCo and IYSIS respectively. The supply for the MSCo command area closely matches the irrigation demand (DSM = 96%) whereas the IYSIS rotation unit is oversupplied (135%). There is variability in gate discharge for MSCo (GD = 1 and 0.86) but uniformity for the IYSIS group. The score for all head control structures at IYSIS is 4 (all are long-cilled weirs) but broken and irregularly constructed weirs at MSCo scored 2. At MSCo, DM scored 3 in one canal (a cut-throat flume was present) but zero for the other. For IYSIS, DM = 4, reflecting the use of neyrpic modular gates. Discharge adjustment for MSCo scored 2, reflecting orifice gates, but DA = 3 at IYSIS since flows are chosen in three steps; 0, 60 and 120 l/sec. For both IYSIS and MSCo, feeder compatibility scored 4.25 which originated from a starting score of 1.0, + 1.0 for automatically measured flow at the head of the secondary canal (neyrpic gates and flow recorders), + 0.75 for flow fluctuation (corrections to gates on main canal required about three times a day), +0.5 for manual adjustment of neyrpic gates/orifice gate at head of secondary canal, and +1.0 for accuracy of supply since in both cases the secondary canal turnout was accurately sized within 10% of the maximum demand flow. For both systems, rotation integrity scored 2 because leadstreams were sometimes mixed between rotation units.

The analysis provides avenues of diagnosis of manageability of water supply, and of means by which water control may be improved. Thus, managers at IYSIS may wish to evaluate whether the medium-scored rotation integrity is a reflection of the large DSM in one group and the need to move water between leadstream groups on the S9 secondary canal due to a resulting imbalance of supply between the groups.
If necessary, it would be possible to re-size the nerypic gates to deliver the correct flow. Managers operating the example MSCo leadstream group may wish to

investigate whether discrepancies in gate discharge between the two gates involved and the need for manual measurement of flow are leading to an unacceptable loss of water control. From there, managers may decide to correct the problem either via changes to gate technology or via more stringent gate-operator management.

Table 3. Analysis of water supply control within leadstream groups MSCo and IYSIS

Category number			1		2	3	4	5	6	7
	Specific demand (l/s/ha)	Specific supply (l/s/ha)	DSM	Gate discharge (l/sec)	GD	HC	DM	DA	FC	RI
MSCo - Leadstream group, fields 201/2+3 & 201/4+5 (area = 30.3 ha)										
Gate 1	1.892	1.824	0.96	59	1.00	2	3	2	4.25	2
Gate 2	1.892	1.824	0.96	51	0.86	2	1	2	4.25	2
IYSIS - Leadstream group, fields S7/20-22 & S9/1+2 (area = 46.9 ha)										
Gate 1	1.892	2.558	1.35	120	1.00	4	4	3	4.25	2
Gate 2	1.892	2.558	1.35	120	1.00	4	4	3	4.25	2
Gate 3	1.892	2.558	1.35	120	1.00	4	4	3	4.25	2

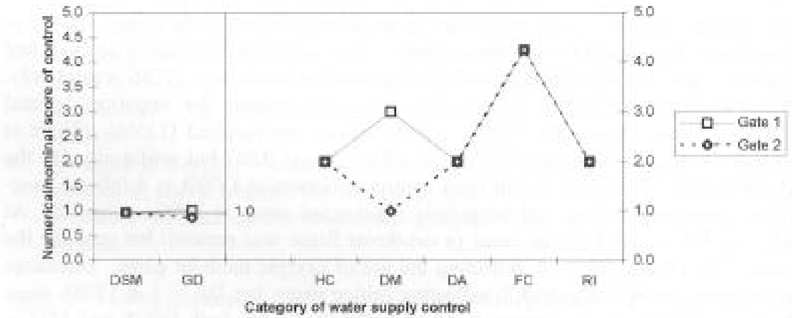

Fig. 1. Characterisation diagram of water supply control for MSCo leadstream group

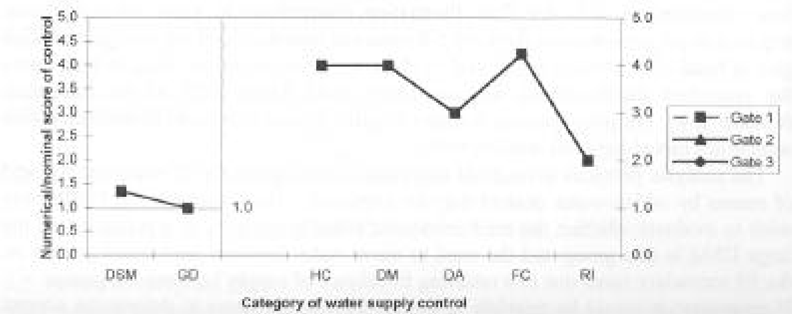

Fig. 2. Characterisation diagram of water supply control for IYSIS leadstream group

4 Conclusions - policy implications

Irrigated agriculture is the major category of demand for water in many countries and is widely criticised for its profligacy in water use. In any individual scheme therefore, the operational policy must be to deliver adequate supplies to all users at the highest attainable level of efficiency. However, irrigation managers are confronted by the trade-off that generally exists between equity and efficiency because of the inadequate level of control over water distribution that is designed into the system. Real progress with improving water control in irrigation will be achieved only if management reforms and technological reforms receive equal recognition and attention. Provision of manageable irrigation infrastructure requires a better understanding of the interactions between design and management. The policy of separating the process of "design" from the process of "operation" serves to exacerbate the problem. Objective methods of assessing both design and "manageability" of water supply control will contribute to closing the gap between policy and practice.

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