RESEARCH PROJECT R6259
IRRIGATION CANAL CONTROL
FINAL REPORT OF STUDIES

VOLUME 2

THE GUIDELINES

CONTENTS

1 INTRODUCTION

Volume 1 of the Final Report (the Manual) presents the detailed background to the Guidelines described in this document.

The Manual describes the principal causes of water loss and inefficient water use in irrigation distribution systems, and suggests measures which can be adopted to reduce such losses and improve performance through better canal control. The format of the Manual reflects the methodology which has been developed to evaluate the performance of irrigation schemes. The methodology consists of a series of steps which seek to define the existing environment, conditions and constraints under which a scheme operates, and to identify measures to improve canal control and hence water use efficiency. The steps in the proposed methodology comprise:

1. The assessment of the current method of canal control; in the case of an existing scheme.

2. The identification of the constraints and deficiencies in the performance of the existing scheme and the causes of water wastage and poor performance based on the results of field investigations and the use of questionnaires.

3. The definition of appropriate performance measures and indicators against which evaluation of current performance is to be measured.

4. Identification of possible improvements from adoption of alternative control methods given that additional costs such as training and infrastructure would be incurred in achieving this.

5. The evaluation of the current performance of the scheme and the performance predicted under alternative control strategies using hydraulic modelling techniques.

6. The selection of the most attactive strategy.

Figure 1.1 presents the above methodology in the form of a flow chart.

The cost of implementation of alternative strategies including operation, maintenance and replacement costs together with the corresponding benefits to be gained would be evaluated in the selection of the preferred alternative. Implicit in this would be the selection of appropriate targets for performance, that is whether at the national, regional or scheme level.

2 THE GUIDELINES

The Guidelines have been formulated based on the methodology described above as an aid to improving the operational control of irrigation distribution canals. They have been prepared as a series of Tables which are presented either:

- As Guidelines for good practice when planning or designing new or extended schemes, or when considering the rehabilitation or modification of existing schemes; or

- As Guidelines about important factors to be borne in mind when evaluating the performance of existing schemes, or when considering the possibility of changing the type of operational control of a scheme in order to improve operational performance.

The format of the Guideline given in the following Tables reflects the process described above and comprises:

Table G1:	Characteristics, advantages and disadvantages of different canal control systems.
Table G2:	Major causes of water losses from distribution systems and Guidelines about possible remedial measures.
Table G3:	A step-by-step assessment of the performance of existing irrigation schemes.
Table G4:	The Compatibility Matrix approach to assessment of the suitability of different canal control methods based on factors that influence the operating environment of an irrigation scheme.
Table G5:	Principles and practices to be adopted in order to improve operational performance with focus on the physical and technical aspects of control of an irrigation distribution system.
Table G6:	Advantages and disadvantages of hydraulic and electrically operated control systems and hence Guidelines for selection of the most suitable system.
Table G7:	The use of mathematical models:

- To enable alternative design concepts or operational routines to be evaluated for new schemes.

- To develop operational procedures for existing schemes where performance can be enhanced through more efficient use of existing control structures.

- To evaluate the effect of modification or rehabilitation during the life of a project for example the construction of major extensions.

THE GUIDELINES

Tables G1 – G7

G1 SUMMARY OF THE CHARACTERISTICS OF VARIOUS CANAL CONTROL METHODS

Commentary:

The various methods of canal control each have advantages and disadvantages which influence the suitability of each method for use in a given operating environment. The Guidelines given below highlight the characteristics of each method. The methods are presented in ascending order of complexity beginning with Fixed Upstream Control using Proportional Dividers to Pressurised Systems. This Guideline should be read in conjunction with G4 and G6.

CONTROL METHOD		GUIDELINES	
G1.1 Fixed Upstream Control			
Water Control	Upstream water level	Advantages	Disadvantages
Water Delivery[1]	Continuous	• Easy to operate/ operational requirements are low	• Does not respond to changes in demand
Automation	--	• Operational costs low	• Requires regular adjustment to achieve high efficiency
Hardware	Proportional dividers (weirs)	• Tends towards equity of distribution	• Difficult to arrange correct proportional division of flow for all flows • Range of flows may lead to damage to canal linings • Siltation can cause variations in behaviour of control structures • Difficult to respond to emergency events
G1.2 Manual Upstream Control			
Water Control	Upstream water level	Advantages	Disadvantages
Water Delivery[1]	C, R, A	• Can be used for a range of delivery schedules (except on-demand)	• Can have long response times with difficulty in matching supply to demand
Automation	Manual	• Can be responsive to farmer demands and is best suited to arranged delivery	• Errors in control structure settings will be magnified at tail-end
Hardware	Manual or motorised sluice and/or radial gates or weirs	• Tends towards equity of distribution	• Requires high level of communication between farmers and irrigation agency • Requires large number of dedicated and trained operation staff • Expensive to operate

CONTROL METHOD		GUIDELINES	
G1.3	**Auto-Electrical Upstream Control**		
Water Control	Upstream water level	Advantages	Disadvantages
Water Delivery[1]	C, R, A	• Less costly to operate than manual systems	• Expensive to install requires high degree of maintenance
Automation	Auto-electrical	• Can be adjusted to achieve reasonable match between supply and demand	• Requires trained staff
Hardware	Undershot or overshot gates with electrical controllers such as Littleman (upstream) and Colvin		• Requires reliable power supply (if electrical)
G1.4	**Auto-Hydraulic Upstream Control**		
Water Control	Upstream water level	Advantages	Disadvantages
Water Delivery[1]	C,R,A	• less costly to operate than manual system	• expensive to install requires high degree of maintenance
Automation	Auto-hydraulic	• can be adjusted to achieve reasonable match between supply and demand	• requires trained staff
Hardware	AMIL gates and DACL controllers		• requires reliable power supply (if electrical)
G1.5	**Centralised Arranged Upstream Control**		
Water Control	Upstream water level or flow	Advantages	Disadvantages
Water Delivery[1]	Arranged	• less costly to operate than manual system	• expensive to install requires high degree of maintenance
Automation	Auto-electrical	• can be adjusted to achieve reasonable match between supply and demand	• requires trained staff
Hardware	Electrically controlled gates operated by central computer program		• requires reliable power supply (if electrical)
G1.6	**Downstream Control with Level-Top Canals**		
Water Control	Downstream water level	Advantages	Disadvantages
Water Delivery[1]	Demand	• more flexible than upstream control systems	• automation is essential
Automation	Auto-hydraulic	• responsive to farmer demands; can be efficient in water use	• experience in areas with slopes greater than 0.25m/km
Hardware	Level-top canals with AVIO & AVIS gates and DACL controllers		• requires stringent safety facilities to prevent overtopping

CONTROL METHOD		GUIDELINES	
G1.7 Downstream Control with Sloping Canals			
Water Control	Water level, flow or volume in downstream pool	Advantages	Disadvantages
Water Delivery[1]	Demand	• more flexible than upstream control systems • responsive to farmer demands; can be efficient in water use	• requires sophisticated water level monitoring and automated control facilities • expensive to install
Automation	Auto-electrical		
Hardware	Sloping canals with electrical controllers such as Littleman (down-stream), BIVAL, EL FLO, and CARDD		
G1.8 Combined Upstream and Downstream Control			
Water Control	Combined upstream & downstream control	Advantages	Disadvantages
Water Delivery[1]	Arranged	• allows combined use of upstream and downstream control • activities good match between demand and supply	• requires land to be for storage reservoirs • automation essential in upstream control areas • may require pumping and associated costs if topography not suitable
Automation	Automatic		
Hardware	Any combination of the above arrangements for automatic control (usually hydraulic)		
G1.9 Centralised Dynamic Regulation			
Water Control	Flow and water volume	Advantages	Disadvantages
Water Delivery[1]	Demand	• minimises human intervention • size of canals can be smaller in comparison with downstream control options • may be possible to eliminate need for storage reservoirs	• highly sophisticated equipment required, significant maintenance requirements • costly to install • requires highly trained staff to manage
Automation	Auto-electrical		
Hardware	Almost all system is electrically controlled by central computer(s)		

CONTROL METHOD		GUIDELINES	
G1.10 Pressurised Systems			
Water Control	Flow	Advantages	Disadvantages
Water Delivery[1]	A,D	• suitable to most terrains	• investment costs usually high
Automation	Automatic	• highly efficient use of water, especially if metered and charged	• requires high value crops; high operating costs
Hardware	Pipelines and pumps. Gravity pressure possible in some circumstances.		

C = Continuous

R = Rotation

A = Arranged

D = Demand

G2 GUIDELINES RELATING TO THE CAUSES OF WATER LOSSES AND POSSIBLE REMEDIAL MEASURES

Commentary:

Water losses in the distribution of irrigation supplies in open channels may be caused by any one of the mechanisms described below or a combination of several of these mechanisms. In any given irrigation scheme, the causes of water wastage and/or low efficiency will in general be found among those described below although the degree to which any given mechanisms contribute to the overall water loss will vary according to circumstances. Field investigations will enable the most important of these to be evaluated and appropriate strategies to reduce water loss to be formulated.

COMMENT	GUIDELINES	
G2.1 Environmental		
Evaporation from free water surfaces, especially reservoirs and aquatic weeds resulting in loss of water diverted for irrigation.	G2.1.1	In new schemes, adopt cross-section design having minimum practicable top width, if possible.
Seepage from canals resulting in loss of water diverted for irrigation	G2.1.2	Provide suitable impermeable lining system to reduce seepage losses from canals.
	G2.1.3	Consider practising rotational flow if possible.
G2.2 Operation		
System designed to deliver irrigation water for 24 hours while farmers irrigate during daytime hours only (no night irrigation). Water diverted for irrigation is discharged during non-irrigation periods (at night) to drains. Ditto, to fields (in the absence of adequate escape structures).	G2.2.1	Implement and operate in-scheme storage.
	G2.2.2	Construction of escape structures and adequate drainage system.
Inappropriate design of rotations leading to Inequitable supply to tertiary offtakes.	G2.2.3	Review design of rotations to improve equitable supply between offtakes.
	G2.2.4	Adopt shorter canal reaches if possible to reduce travel time or canal filling time.

COMMENT	GUIDELINES	
Inadequate communication between gate operators and scheme managers leading to errors in gate operation and inequitable supply and wastage of water.	G2.2.5	Improve methods/means of communication such as radio or permanent telephone links.
Inaccurate calculation/updating of crop water requirement calculations leading to errors in calculation of canal discharge and inability to supply correct discharge to tertiary offtakes.	G2.2.6	Review basic crop data and calculation of crop and scheme water requirements.
	G2.2.7	Improve data collection quantity and quality and consider office automation.
Insufficient numbers and/or training of gate operators leading to errors in gate operation leading to inequitable supply and wastage of water.	G2.2.8	Review operator requirements and alternative canal control options, recruit and train operators.
	G2.2.9	Introduce incentives which are based on performance.
Unacceptable variation in upstream water levels and discharge to tertiary offtakes resulting in failure to satisfy criteria of equity, adequacy, timeliness and efficiency of supply.	G2.2.10	Review gate operation procedures and operator training.
Incorrect use or calibration of flow measurement facilities inability of field staff to obtain data to adequately manage the distribution of water supplies, errors in gate operation and water application to cultivated areas.	G2.2.11	Review calibration of flow measuring structures.
	G2.2.12	Train operators in the use of flow measurement installations.
Failure to operate water control gates correctly leading to errors in flow regulation on main and secondary canals, in application of water to fields and in farmers' ability to adjust discharge of tertiary offtakes during irrigation periods according to crop requirements.	G2.2.13	Review gate operating procedures and gate operator training.

COMMENT	GUIDELINES	
Inadequate supervision of night irrigation resulting in inaccuracy in quantity of water applied to fields and loss of water from canals via tail escapes and from fields (overflow/runoff into drains)	G2.1.14	Review night security arrangements and communications.
	G2.1.15	Irrigate large fields.
	G2.1.16	Provide for storage of water at night.
G2.3 Maintenance Causes		
Inadequate maintenance of canal embankments and design freeboard resulting in overtopping of canal bunds and wastage to drains or fields when high water levels occur in canals.	G2.3.1	Review inspection and maintenance schedules and availability of mechanical equipment.
	G2.3.2	Secure sufficient funds to cover all maintenance activities required.
	G2.3.3	Introduce asset management procedures
Inadequate silt clearance and/or weed control resulting in reduction in canal capacity and accompanying occurrence of high water levels in canal reaches affected.	G2.3.4	Review inspection and maintenance schedules and availability of mechanical equipment.
Failure of tertiary offtake gates to seal correctly resulting in reduced supply to downstream offtakes and wastage of water during off phase where rotations are practised.	G2.5.5	Inspect and maintain gate seals.
G2.4 Infrastructure Design		
Too great a distance between offtakes and commanding cross-regulators results in unacceptable variations in water level upstream from distant offtakes, particularly at times of reduced canal flow.	G2.4.1	Review performance under reduced flow in supply canal and either install additional cross-regulator(s) or modify design of offtakes affected.

COMMENT	GUIDELINES	
Incorrect choice control structures and/or use of incompatible components for main canal control and control of main canal offtakes resulting in unmanageable variation in flow diverted to secondary canals and offtakes.	G2.4.2	Review design of main canal structures and compatibility of regulators and offtakes.
Insufficient provision of flow measurement facilities resulting in gate operators not being able to correctly monitor flows and operate gates on main and secondary canals, and for farmers to apply the correct quantity of water to fields.	G2.4.3	Review minimum flow measurement facilities required and install measurement facilities to maximise distribution efficiency.

G3 GUIDELINES FOR ASSESSING THE PERFORMANCE OF IRRIGATION SCHEMES

Commentary:

Performance assessment is essential for any management activity, including the management of irrigation systems. The utilization of water and other resources for irrigation require that the efficiency of their use is evaluated periodically.

The use of performance assessment techniques and methodologies is described in detail in the Manual. The main components of such techniques are summarised below as a set of step-by-step Guidelines.

COMMENT	GUIDELINES	
G3.1 Clearly establish the purpose of the assessment		
Before an assessment of the performance of an irrigation scheme can be carried out the purpose of the performance assessment must first be established. This could include operational, accountability, intervention or sustainability assessment.	G3.1.1	Operational assessment would be selected if there is a need to provide scheme managers with information to enable them to manage the scheme and operate the system to meet service delivery standards.
	G3.1.2	Accountability assessment would provide information to assess the performance of those responsible for the scheme's performance.
	G3.1.3	Intervention assessment would be undertaken to determine how to improve some aspects of the scheme's performance.
	G3.1.4	Sustainability assessment would enable planners to assess the long term viability of a scheme.

COMMENT	GUIDELINES	
G3.2 Clearly establish the objectives of the assessment		
Performance cannot be assessed unless there are objectives against which assessment may be made. Objectives must be clearly defined and may vary depending upon the level and emphasis and targets set.	G3.2.1	Objectives can be at different levels and with different emphases and can be complementary or conflicting. The appropriate level of objectives to be met should be established, for example: • National • Regional • Scheme • Water User Association / Village Water Management • Farmer level
	G3.2.2	The emphasis of objectives to be met should be defined and could include: • Technical • Institutional including legal • Economic • Social • Environmental
	G3.2.3	In order for objectives to be assessed specific targets should be set against which performance can be measured. Such targets could include: • Internal targets set within the organisation which reflect the management's standards for operation of the system. • External targets derived from various sources including technical, political, economic and ethical sources principally based on an irrigation agency's accountability to outside organisations.

COMMENT	GUIDELINES
	• Relative targets derived from the performance of other similar schemes or systems.
G3.3 Clearly establish the extent or boundary of the assessment.	
The extent or boundary of assessment must be clearly defined in order to clearly assess the inputs, outputs and impacts of the scheme.	G3.3.1 Boundaries shoud be established and could include: • Geographical and emographic physical boundaries which will be partly defined by the system under consideration. • Time boundaries which can be short term (within the cropping cycle) or longer term, (relating to the lifetime of the project). • Social boundaries which are difficult to define since performance assessment may address a farmer's broad concerns only part of which may be directly related to irrigation activities.
G3.4 Select performance measures for assessment	
Appropriate performance measures must be chosen in order that the assessment of the scheme validly addresses the defined purposes and objectives. Such measures should be quantifiable so as to allow the use of indicators many of which will be ratios. (e.g. relative water supply is the ratio of supply to demand).	G3.4.1 Adequacy is a measure of the performance of the system in meeting the demand either for water or for other resources. The assessment of performance would come from measurements of how well demand is satisfied at different locations in the system.
	G3.4.2 Equity as a measure would compare water distribution performance at different points in the system. Some indicators that do not directly measure equity could be used to assess equity by comparing data collected from different points in the system.

COMMENT	GUIDELINES	
	G3.4.3	Reliability is a measure of how closely actual performance matches expected performance. This expectation can be real or perceived. Real (technical) reliability measures focus on the frequency with which target levels are achieved. Perceived reliability measures focus on people perceptions, and are thus more difficult to quantify.
	G3.4.4	Variability is a measure of reliability although it is usual to measure deviations from a mean rather than from a target value.
	G3.4.5	Efficiency is a measure comparing the actual performance of a system to its potential performance in terms of the efficiency of resource use. Measures can be applied to the whole system or of parts of the system.
	G3.4.6	Accuracy is a measure of the extent to which supply is able to respond to demand.
	G3.4.7	Command is a measure used for comparison of design with actual command levels within a system.
	G3.4.8	Productivity is a measure used to assess the absolute performance of a project. Certain productivity measures can be compared the level of resources used compared with productivity to give efficiency.
G3.5 Identify performance indicators		
Performance indicators are variables for which data can be collected to enable quantification of performance. They are often quoted as ratios. Different indicators may be required to quantify in detail one performance measure. Conversely, one indicator may be useful for two or more measures. A performance indicator should have attributes that make it practical and reliable for measuring performance.	G3.5.1	An indicator should be scientificaly based, that it should be empirically quantifiable for the part of the irrigation process that it describes.
	G3.5.2	The data needed to quantify the indicator must be available or obtainable (measurable) with available technology. The measurement must be reproducible.

COMMENT	GUIDELINES	
	G3.5.3	Ideally, performance indicators should not be formulated from narrow ethical, cultural, religious or physical perspective. This, in reality, is difficult to achieve so it is necessary to be aware of what bias may be inherent in an indicator.
	G3.5.4	For routine management, performance indicators should be technically feasible and easily used by agency staff given their level of skill and motivation. Further, the cost of collecting, processing and analysing data for indicators in terms of finances, equipment, and commitment of human resources, should be well within an agency's resources.
	G3.5.5	Performance indicators tend by their nature refer to a target value, though this is always a necessity. Those that do refer to a target imply a relevance and appropriateness of that target and that tolerances can be established for the indicator.

G4 GUIDELINES FOR CHANGING THE METHOD OF CANAL CONTROL

Commentary:

A change of canal control method is only necessary if the current method is not achieving satisfactory performance. The control of a system includes the *procedures* used to *operate structures* and therefore the *people* and *processes* involved in irrigation. When assessing canal control therefore account must be taken not only of *technical* and *economic* issues, but also what *operational methods* are in use and where and how the *water users* are involved in planning and operation. If an improvement or change is to be made then the method proposed used must be technically and non-technically appropriate for the environment, into which it will fit.

The C*ompatibility Matrix* approach is described in detail in the Manual and has been developed in order to assist in assessing whether a particular canal control method will fit into a certain environment or not. The Matrix is shown in the Table at the end of these Guidelines. A qualitative assessment of the requirements of the operating environment for each canal control method is denoted by a code number between 0 and 5. A value of 5 indicates that the particular feature of the environment is of major importance for that particular canal control method. A value of 0 indicates that the feature is not sensitive or relatively less important. It should be noted that the level of sophistication and complexity of control for the methods shown in the Table increases from left to right.

When a canal control method is not fully compatible with the environment within which it should work two options are available. One is to try to close the gap between the actual capabilities and features of the environment and the ideal situation. The second is to select another control method which more closely matches the already existing features in the environment. The decision of which option to choose is dependent how wide the gap is between the actual environment and the ideal situation. Wide gaps indicate that the control method investigated will not easily fit in the environment unless radical changes are made. A more feasible option in this case will be to choose another control method which is more compatible with the existing environment without the need for major changes.

The Guidelines given below have been summarised from the Matrix and the detailed discussion in the Manual. They are presented in the form either of suggestions for good practice, or as important information to be borne in mind when selecting a canal operational control system.

COMMENT	GUIDELINES	
G4.1 Strategic considerations regarding changes to canal control methods		
Effect on performance criteria	G4.1.1	Simple, fixed proportional distribution control systems primarily satisfy equity performance criteria and should be considered if this is important.
	G4.1.2	Automated downstream distribution control systems mainly satisfy adequacy, reliability and accuracy performance criteria usually at the expense of equity, and should be considered if these criteria are important.
Flexibility and freedom from constraint	G4.1.3	With the exception of the need for trained staff and access to spare parts pressurised distribution systems offer a control system with the minimum of constraint.
	G4.1.4	Manual upstream control schemes are subject to the greatest number of operational constraints.
Organisational requirements	G4.1.5	Upstream control schemes require efficient organisation and strong community organisations to achieve good levels of operational control.
G4.2 Physical/Technical Considerations regarding changes to canal control methods		
Water supply reliability	G4.2.1	Downstream control is a demand-oriented system. A highly variable water supply with downstream control should be avoided since this will increase the frequency of system failure in satisfying farmers' requirements and result in inequitable water distribution and inefficient water use.
	G4.2.2	Upstream control systems can enforce delivery schedules which ensure equitable distribution when the supply is short, thus better tolerating variable water supply situations.
Silt loads	G4.2.3	Care should be exercised if high silt loads are present. Pipeline systems are sensitive to silt loads because cleaning silt which deposits in pipes is not an easy maintenance activity. Downstream control is prone to the same problem because with this control method water can stand still in canal reaches when the demand diminishes giving opportunity for silt to deposit in the canal network.

COMMENT	GUIDELINES	
Climate	G4.2.4	Responsive systems such as downstream control and centralized automated upstream control can respond swiftly and efficiently to changes in the demands when heavy rainfalls occur. The quick response of such systems saves irrigation water by reducing the supply. Manually controlled upstream systems may not be able to respond quickly enough, and hence will result in large quantities of water being wasted. Responsive systems are therefore more efficient in more humid climates.
Topography	G4.2.5	Topography is an important factor to consider in two types of irrigation control methods: downstream control with level-top canals and pressurised distribution control systems. Downstream control with level-top canals requires relatively flat terrain for the system to be economical. Pipelines, on the other hand, have the advantage that they cope well with undulating terrain and do not require extensive earth works to adjust the land to the canal slope.
Scheme size and extension	G4.2.6	An important factor that favours the use of centralized control is when distribution schemes are large. Centralized control is more efficient in such cases because it saves the cost of the large number of staff that would be required if the system were manually operated. It also speeds up the communication and data collection processes, thus enabling faster and more efficient control.
	G4.2.7	When a scheme is to be enlarged it will require in most cases the modification of the physical system to give it larger capacity. Some control systems will be able to accommodate the required modifications better than others. Manual upstream control can be modified by enlarging its cross-sections and adding extra bays to existing control structures if required. Modification will be much more expensive for canals under downstream control with level banks because more earth work will be required and fixed-target control structures (such as AVIO and AVIS gates) may have to be re-positioned.
Power supply	G4.2.8	Automated systems with electrical controllers must have a good and reliable power supply to minimise system failure.
Spare parts	G4.2.9	Control methods dependent on highly sophisticated electronic equipment should have spare parts for such equipment readily available.

COMMENT	GUIDELINES	
G4.3 Organisational considerations regarding changes to canal control methods		
Organisational structure	G4.3.1	Manually operated systems require well defined, efficient, and well managed organisations.
Scheduling	G4.3.2	The matching of supply with demand in supply-oriented systems is essential to achieve high water use efficiency and prevent water shortage and wastage. Matching supply with demand requires precise estimation of the demands (irrigation scheduling) or collection of requests for water from the farmers in systems with arranged-delivery schedules. This is not required for demand-oriented systems to operate efficiently.
Technology	G4.3.3	Manually operated systems can benefit from the introduction of some office automation (computers) to help organize and process the large quantities of data that need to be collected in such cases.
Operational plans	G4.3.4	Poor performance of manually operated systems is usually directly linked to the lack of clear and workable operational plans and manuals that clearly state the responsibilities of every staff member. Automated systems are relatively less dependent on the need for detailed manuals.
Monitoring and evaluation	G4.3.5	Monitoring and evaluation programmes are more important in manually operated systems to ensure that planned allocations/control settings are implemented in practice.
Communication	G4.3.6	Responsive or demand systems have their own means (usually hydraulic) of communication to transmit changes from downstream to upstream. Supply-oriented systems lack such built-in communication and must therefore have other means of communication between operation staff. Automated systems with centralized control require very efficient communication systems to link the central control location with control equipment and sensors in the field.
Staffing and operation	G4.3.7	Manually operated systems require a larger number of operation staff than automated ones. Highly skilled operation staff are required for automated systems, especially those with electrical automation. Efficient operation of manual systems can only be realised if staff are highly motivated and willing to improve the performance of the system they run.
Maintenance	G4.3.8	Operation and maintenance requirements for a system become more critical as the level of technology and computerisation increases.

COMMENT	GUIDELINES	
Water user associations	G4.3.9	For manually operated smallholder systems Water User Associations and farmer participation in management, operation, and maintenance are essential for good system performance.
G4.4	**Socio-Economic considerations regarding changes to canal control methods**	
Water rights	G4.4.1	Downstream control methods do not make allowance for water rights whereas upstream control methods can be adjusted to accommodate them.
Labour costs and availability	G4.4.2	Manually operated systems may be more appropriate and economic where labour is available and relatively cheap. As cost of labour becomes higher the transition to automated systems becomes more viable. Where water is available on-demand, farmers can schedule the farming activities which need additional labour to best match with labour availability. Rigid water delivery schedules on the other hand do not give such freedom to the farmers to decide upon the optimum timing for farming activities.
Farmer experience	G4.4.3	Supply-oriented systems are more rigid than on-demand ones thus requiring more experienced farmers to adapt to them. Arranged-delivery schedules also require that farmers know when and how much water they need to order. On-demand systems adapt to farmers needs, but can be wasteful if farmers misjudge crop water requirements.
Education	G4.4.4	The level of education and technology awareness of the community are important factors to consider when deciding upon the proper control method to implement.
Water Charges	G4.4.5	In demand-oriented systems some form of water use control needs to be imposed on farmers. This can either be in the form of charges per unit of water used, or the allocation of a limited volumetric water right for each season. If the value of the crop relative to the price of water is high charging for water will not be as effective as limiting the water right.
Environment	G4.4.6	Under supply-oriented delivery systems it is not always guaranteed that delivered water will be required or optimally used. Excess water flowing to drains or causing spills from canals may lead to water logging and salinity problems.

Features of the Operating Environment			Fixed upstream control (1)	Manual upstream control (2)	Auto-electrical upstream control (3)	Auto-hydraulic upstream control (4)	Auto-hydraulic downstream control with level to (5)	Auto-electrical downstream control with level-to (6)	Downstream control with sloping canals (7)	Combined upstream and downstream control (8)	Centralised arranged upstream control (9)	Centralised dynamic regulation (10)	Pressurised systems (11)	Studied scheme ( ) (S)
			Canal Control Method											
Physical/Technical	1	Water supply reliability	0	2	2	2	3	3	4	3	4	5	3	
	2	Permissible silt load (water quality)	4	5	4	4	2	2	2	2	2	2	1	
	3	Climate (humid region)	1	1	1	1	5	5	5	3	4	5	5	
	4	Topography	0	0	0	0	s	s	0	s	0	0	L	
	5	Scheme size	0	0	0	0	0	0	0	4	5	5	0	
	6	Possible scheme extension	5	5	3	3	2	2	2	2	4	4	1	
	7	Access roads condition	1	5	3	3	2	2	2	2	1	1	2	
	8	Power availability (Electrification)	0	0	4	0	0	4	4	0	5	5	2	
	9	Spare parts	0	0	4	3	3	4	5	3	5	5	3	
	10	Durability	5	5	3	4	4	3	2	4	2	2	3	
Irrigation Agency	11	Organisational structure	0	5	4	4	2	2	2	2	3	3	2	
	12	Strength & influence within society	0	5	5	5	3	3	3	3	3	0	0	
	13	Scheduling preparation	0	5	5	5	0	0	0	2	2	0	0	
	14	Data collection (quantity & quality)	0	3	3	3	1	1	1	2	4	5	1	
	15	Office automation & technology	0	2	2	2	0	0	1	1	4	5	0	
	16	Operational plan & manual	0	4	3	3	1	1	1	3	5	5	2	
	17	Monitoring & evaluation	1	4	3	2	1	2	2	2	1	1	2	
	18	Communication	0	4	3	3	1	1	1	1	5	5	1	
	19	Staff numbers	1	5	3	3	2	2	2	2	1	1	2	
	20	Staff skill (in operation)	1	3	2	2	1	1	5	1	5	5	3	
	21	Staff motivation	0	5	3	3	0	0	0	0	0	0	0	
	22	Maintenance level	1	2	4	3	3	4	5	3	5	5	3	
	23	Training facilities	0	4	3	3	2	2	2	3	5	5	3	
Organisational	24	WUA & farmer participation	0	3	3	4	5	5	5	5	3	0	5	
	25	Legislation	1	2	4	5	5	4	3	5	3	3	3	
Social/Community	26	Water rights	5	5	2	2	0	0	0	0	5	0	0	
	27	Labour availability & cost	0	5	5	5	2	2	2	2	3	2	2	
	28	Farmer experience & traditions	3	5	5	5	2	2	2	2	4	2	3	
	29	Education & technology	0	0	2	1	1	2	3	1	3	4	3	
Environmental	30	Water logging and salinity problems	5	4	3	3	1	1	1	1	1	1	1	
	31	Spills from canals	5	4	4	4	1	1	1	2	2	1	1	
Economic	32	Water charges and water accounting	0	1	1	1	5	5	5	3	1	4	5	
Operational Objectives														
Performance Criteria	33	Equity	5	4	3	3	1	1	1	2	4	2	2	
	34	Adequacy	0	2	3	3	5	5	5	4	4	5	5	
	35	Reliability	3	2	3	3	5	5	5	4	5	5	5	
	36	Accuracy	4	2	3	3	4	4	4	4	5	5	5	
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(S)

G5 GUIDELINES FOR PHYSICAL MEASURES TO REDUCE WATER LOSSES AND INCREASE WATER USE EFFICIENCY

Commentary:

The causes of water losses and the low efficiency of irrigation distribution systems are due to a variety of physical, institutional and socio-economic constraints. The Guidelines given below focus on appropriate measures to address physical constraints upon the effective operational control of irrigation distribution systems.

COMMENT	GUIDELINES	
G5.1 Selection of the appropriate type of control structure		
The type and location of control structure has a significant impact on the performance of the irrigation system. Control structures are usually of two main types that is weirs (fixed) or orifices with gates. The selection of the proper type of structure is important for the proper and efficient operation of the system.	G5.1.1	Use weirs as upstream water level control structures (cross-regulators) since they are less sensitive to discharge variation, require less operation effort and are much easier to maintain. However see G5.16.
	G5.1.2	Use undershot gates for discharge regulation (canal head-regulators, offtake structures, etc.) since they are less sensitive to water level changes
	G5.1.3	Where canal dimensions allow and where the range of discharge variation is wide, use long crested weirs. These are advantageous over short ones for upstream water level control (cross-regulators) because of their lower sensitivity to variations in flow.

COMMENT	GUIDELINES	
	G5.1.4	Weir cross-regulators should be provided with emergency gates to allow flexibility to close canals for rotation and maintenance purposes.
Flow travel and response times are highly dependant on the type of control structure and the operational procedures used to operate them, particularly if they are manually operated. Highly responsive systems tend to be more efficient provided water is usefully abstracted by farmers.	G5.1.5	A canal with weir cross-regulators has shorter travel and response times than a similar canal with gated cross-regulators. This feature supports the preference for weirs to regulate water levels in long canals in order to improve the response of the system.
	G5.1.6	A canal with weir cross-regulators has much less in-line storage capacity than a similar canal with gated cross-regulators. Therefore any increase in the supply at the head of a canal with weir cross-regulators will quickly travel down the canal and if not abstracted usefully will be lost through the tail escape. Thus operational losses from a canal with weir-type cross-regulators can be potentially higher than those that may occur if the canal has gated cross-regulators. In general, avoid weir cross-regulators if large uncontrolled variations in flows are likely to occur.
G5.2 Location and spacing of control structures		
Interference between control structures is undesirable in systems operating under upstream water level control since it complicates system operation. [Note that interference between control structures in systems which operate under downstream control is an essential feature of such systems].	G5.2.1	Provide sufficient spacing between control structures to avoid interference. However the potential conflict must be resolved between this requirement, and the need to ensure that offtakes to minor canals are not located at too great a distance upstream from cross-regulators since command at such offtakes during low flows.

COMMENT	GUIDELINES	
	G5.2.2	Where possible increase canal slope though the selection of appropriate canal alignments in relation to topography.
	G5.2.3	Provide critical flow sections between controls by installing critical-depth flow-measurement structures such as broad crested weirs and flumes downstream of gated regulators. The structures must be designed to maintain critical flow at all times. The advantage of this is that it allows flow measurement as well as control.
	G5.2.4	Seek to minimise interference at a canal head reach as this will be the most critical location. The interference between canal head-regulator and any subsequent control structure is more likely to affect the flow into the canal and therefore cause negative impact on the performance of the whole system.
	G5.2.5	Consider the use of computer based hydraulic modelling as an essential tool for assessing the interference that might occur under unsteady flow conditions and the subsequent impact upon different parts of the system.
G5.3 Automation of control structures		
Control structure automation improves system performance by achieving fast and continuous response to changes flows and demands in the system without the need for large numbers of operators.	G5.3.1	Automation is particularly appropriate where frequent adjustments to regulators are required caused by variable water supply or demand patterns. This is particulary so at lower levels in distribution systems where combined upstream and ownstream control should be considered.
	G5.3.2	The cost of automating large control structures can be reduced by automating only one third of the gates in a structure. This type of partial automation can handle flow variations of up to 20%.
G5.4 Rotational flow supply		
Rotational flow is an effective operational procedure to practice in systems under upstream control during periods of water shortage	G5.4.1	Consider rotational supply under conditions of water shortage where flows are 50% of peak design flows or lower.
	G5.4.2	It can be advantageous to evaluate the benefits of introducing rotational flow at all levels throughout a distribution system, primary, secondary or tertiary.

COMMENT	GUIDELINES	
	G5.4.3	Higher performance can be achieved by rotating supply between short rather than long canals.
	G5.4.4	There is a direct relationship between management input and the achieved levels of performance. When rotating flow between canals by operating their head regulators only, the performance of the system is relatively low especially when the canals are long. Performance levels can be significantly increased by operating all cross-regulator offtake gates on canals by closure to maintain water levels and volumes stored in the different reaches of the canals. This procedure increases the management input significantly. It also increases the potential for silt deposition in the canals.
	G5.4.5	Water user groups are essential to the effective implementation of rotational distribution of water.
G5.5 Design of offtake structures		
Offtake structures are very important and should be designed to ensure equitable distribution between offtakes for different levels of supply	G5.5.1	The offtakes should be located as close as possible to commanding cross-regulators in order to minimise inequity of distribution during periods of less than maximum supply..
	G5.5.2	Ensure that offtake hydraulic dimensions are sufficient for the whole range of design flows and needs especially during low flow and rotational supply conditions..
G5.6 Storage of irrigation water in surface reservoirs in order to increase efficiency of operation and water use		
Cessation of irrigation at night and the mismatch between supply and demand in source-oriented systems are major sources of water loss and inefficient water use.	G5.6.1	Ensure that sufficient water storage in surface reservoirs is provided for upstream and downstream control systems as this is a very effective water saving measure which can greatly increase the water use efficiency, flexibility and response of system operation.
	G5.6.2	Water can be stored in the irrigation canals themselves (in-line storage) or in separate reservoirs (off-line storage).
	G5.6.3	Off-line storage can in part relieve the dependency of downstream users on upstream users, but cannot totally isolate them.

COMMENT	GUIDELINES	
	G5.6.4	Implementing in-line storage with upstream water level control is not the optimum solution. Operating such a system will not be easy due to widely fluctuating water levels in the canals. Operational losses will still occur at the tail-end of the system which lowers its efficiency.
	G5.6.5	Downstream control is better suited for in-line storage.
	G5.6.6	Off-line storage is preferred to in-line storage because: • In-line storage has the disadvantage of storing water in canals with the additional possibility of siltation and excessive seepage. Siltation of off-line reservoirs should be accounted for in the design. • All canal flows have to pass through in-line reservoirs which means that the reservoir must be continuously operated whether there is a need for water storage or not. Achieving command at low water supplies will be problematic because of the large cross-sections of the canals at the locations of the in-line reservoirs. The response of the system to changes will be very slow unless the in-line reservoirs are distributed between different locations in the system.
	G5.6.7	Depending on topography and land use, off-line reservoirs should be located where drops exist in the canal bed. Water can then be allowed in and out of reservoirs by gravity.
	G5.6.8	Off-line reservoirs that can be discharged by gravity should be designed such that the depth of water to be stored is as small as possible by enlarging its surface area (see G5.6.9) to minimise the change in the head on the reservoir outlet structure and hence help release steady flow from the reservoir with minimum adjustments to the outlet structure.
	G5.6.9	If water is to be pumped the surface area of the off-line reservoir should be minimised to reduce water losses by evaporation and the area of agricultural land lost.
	G5.6.10	For optimum performance, off-line reservoirs should be located at the lowest level of the system possible, that is as on-farm reservoirs. Locating reservoirs close to the water users minimises the response time of the system and leaves higher canals with steady flows.

COMMENT	GUIDELINES	
	G5.6.11	Generally advantageous to locate one off-line reservoir at the top of a canal where water storage is to be provided instead of using intermediate reservoirs distributed along the canal. The advantage is in terms of ease of operation and minimising the number of control structures required for the reservoirs.
	G5.6.12	To achieve high performance levels for a system with night storage the optimal operational procedure will be to operate the gates of all cross-regulators and offtakes such that they are fully closed at night when no water is needed for irrigation provided siltation in canals is not a problem. In order to safeguard irrigation systems where storage is implemented, automation of reservoir control structures is highly recommended,. The potential consequences of a mismanaged storage system will most probably justify the cost of automation.
	G5.6.13	Facilities for rejecting excess water such as side weirs and canal tail escapes must be provided in any system where storage is used for rejected water. It is most likely that the downstream reaches of such irrigation systems will experience higher flows than anticipated in the design.
G5.7 Phased develoment of irrigation schemes		
Phased development of irrigation schemes over many years results in over-abundance of water in early years and hence the development of poor water management practices. These are subsequently difficult to overcome once schemes reach full development	G5.7.1	Ensure designs of head regulating structures allow them to be commissioned on a staged basis.
	G5.7.2	Ensure designs of cross-regulating control structures have built in facilities to allow progressive increase in discharge capacity (eg moveable weir sections).
	G5.7.3	Ensure in general that designs are appropriate not only for maximum flow/head conditions, but for other intermediate conditions also.
	G5.7.4	Ensure clear operational plans are prepared compatible with the planned, phased development.

G6	GUIDELINES ON THE ADVANTAGES AND DISADVANTAGES OF DIFFERENT AUTOMATIC CANAL CONTROL MECHANISMS

Commentary:

The type of input to the control of a gate is described as automatic where decisions and commands are made by hydraulic equipment, electronic circuits or computer software without the intervention of operators. The comparison between Hydraulic and Electrical Automation is described below for a number of different consideration.

HYDRAULIC AUTOMATION	ELECTRICAL AUTOMATION
G6.1 Durability Considerations	
• Not easily affected by severe weather conditions • Difficult to vandalise • Longer life	• Heavy rain, storms, or lightning can seriously damage equipment • Electronic equipment must be upgraded from time to time in order that spare parts will be available for the equipment when replacements are needed • Vulnerable to vandalism
G6.2 Robustness Considerations	
• Not dependant on external power supply • Structures can be easily tampered with if not properly guarded/locked	• Structures are not so difficult to tamper with • Require reliable power supply otherwise system may fail • Vulnerable to programming errors in control algorithms • Can cause highly unsteady flow due to frequent oscillation of structures (hunting) if controllers are not fine tuned
G6.3 Flexibility Considerations	
• Control set point can be changed in very limited range • Not easy (or even impossible) to change control to manual mode • Cannot be centrally controlled	• Easier to change control set point • Easy to change control to manual mode • If locally controlled, can easily be upgraded to centralised control

HYDRAULIC AUTOMATION	ELECTRICAL AUTOMATION
G6.4 Operation Considerations	
• Almost no operation input or cost	• Power consumed in operation
G6.5 Maintenance Considerations	
• Does not require frequent maintenance • Maintenance is relatively simple (mainly painting and lubricating parts)	• Must be frequently maintained (preventive maintenance) • Qualified technicians are required for maintenance

G7 GUIDELINES FOR THE USE OF COMPUTER BASED HYDRAULIC MODELLING OF CANAL CONTROL SYSTEMS

Commentary:

Rapid developments have been made in the application of computers in recent years. In the field of irrigation and drainage, commercial software is now available for a number of different aspects including planning, design, management and operation of projects. Most irrigation schemes have distribution networks consisting of open channels with a variety of different types of open channel flow including uniform, non-uniform, steady and unsteady flows.

As described in the Manual the use of modern software to simulate the hydro-dynamic operation of irrigation schemes is invaluable in the process of identifying improved canal control measures and procedures. The use of different software is evaluated in the Manual and conclusions are summarised below in the form of a series of Guidelines.

COMMENT	GUIDELINES	
G7.1 Application of Hydraulic Modelling at the distribution level		
Hydraulic modelling is a powerful tool and has a wide range of application for simulating the operation and control of irrigation distribution systems.	G7.1.1	To test the effectiveness and efficiency of different operational procedures and to correct those procedures if the resulting performance is not satisfactory or needs improvement.
	G7.1.2	To evaluate the characteristics of existing or planned irrigation systems including lag times, in-storage capacity, physical constraints, incompatible and interfering structures, storage reservoirs, and other features. A detailed understanding of these characteristics can greatly improve the design operation and performance of a project.
	G7.1.3	To analyse the impact of floods which may enter irrigation systems and to test the effectiveness of the available alternatives to route the flood waves through the system in order to prevent or minimise the damage.

COMMENT	GUIDELINES	
	G7.1.4	To develop and test canal control algorithms examples of which are CARDD, BIVAL, and EL-FLO. This application for hydraulic modelling is indispensable since testing canal control algorithms on real systems is in practice not possible. Testing algorithms using hydraulic modelling is essential before implementing them on real systems.
	G7.1.5	To assess the effect of inappropriate or the lack of maintenance such as weed growth and sedimentation, as well as malfunctioning or damaged structures on system operation and performance.
	G7.1.6	To design effective system rehabilitation and modernisation measures by assessing the improvement in system performance arising for example from modified canal alignments, sections and control structures.
G7.2 Limitations of Hydraulic Modelling		
Real Time Management is difficult to model	G7.2.1	The experience from this study supports the opinion that it is still very difficult to use hydraulic modelling for real-time management. Simulating unsteady flow in complicated and large irrigation networks is complex and almost all simulation models have built-in assumptions to simplify certain modelling problems.
Need for facility to model Physical Losses from system	G7.2.2	The review of hydraulic modelling software packages has shown that many cannot account for seepage or evaporation losses. In most of the others, seepage losses cannot be directly accounted for and must be approximated by other arrangements.
Simulation of Manual Operation Control	G7.2.3	Whilst hydraulic simulation models allow the user to control the settings of adjustable structures in a manual mode, this virtual manual mode does not allow exact simulation of the *real* manual operation in the field. The virual mode is usually achieved by means of a user-defined set of simulation run times and corresponding structure settings, that is a series of time-setting relationships. Real manual operation however rarely relates structure operation to time but to changes in the hydraulic conditions (such as water levels or flows) in the irrigation system.
G7.3 Data Requirements for Hydraulic Modelling		
General Requirements	G7.3.1	The data required for building hydraulic models of irrigation systems can generally be grouped as data regarding the irrigation canals and data of control and other structures in the network.

COMMENT	GUIDELINES	
Requirements for Canal Cross-Sections	G7.3.2	Design canal cross-sections may be used for modelling lined canals and newly constructed or rehabilitated earth canals. Surveyed cross-sections will be required for modelling earth canals which have been operating for some time in order to consider the deformation in actual cross-sections. Essentially, canal cross-sections will be required at locations where changes exist such as changes in cross-section dimensions and drops in bed level. Other cross-sections will be required at more or less regular spacing in order to improve the accuracy of simulation results. The spacing between the cross-sections in a model depends on factors such as the steepness of the canal and on the requirements of the specific hydraulic model used.
Roughness	G7.3.3	Information about every structure in the modelled canal network must be available to enter into the model. Required information varies from model to model but generally includes the structure type (weir, vertical gates, radial gates, etc.), its location (chainage), dimensions, design flow, discharge/friction coefficients, design head loss, and required operational schedule.
Roughness	G7.3.4	The actual roughness of the canals is not usually available. Common practice in this case is to assume values of roughness of canals based on experience or as recommended in standard texts and then refine the assumptions by model calibration.
Operation	G7.3.5	Information concerning the operational procedure of the system and structure operation schedules will be required in order to simulate and test the efficiency of those procedures