Operational Behaviour of Hydraulic Structures in Irrigation Canals in Sri Lanka

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Abstract: The Hydraulic performance of structures provided for regulation in irrigation canals is influenced by many parameters such as type of flow control, type and frequency of adjustments, and topographical features of sub-systems that they are installed. The irrigation systems in Sri Lanka mostly designed for up-stream discharge control operation, with manually/mechanically adjusted gated structures, under steady state flow conditions. Further, topographical features of many gravity irrigation systems are varying at sub-system level due to presence of single and double bank reaches, inclusion of in-lined storage tanks. However, irrigation systems are operated under varying flow regime due to scheduled or unscheduled flows in water delivery. The adjustments of gates in structures in such situations are done by manually/mechanically by operators at different frequencies.
Therefore these situations are analyzed by hydraulic simulations using SIC hydraulic model for three different topographical sub-systems under different frequency of adjustments. The actual performance in water delivery is evaluated by effective volume of water delivered, timeliness in water delivery, at the final delivery location while maintaining on-line water adequacy through delivery points along the canal. The results will provide guidance for operation of regulation structures for effective conveyance of water under varying flow conditions.

Keywords: Canal Irrigation, Canal Operation, Canal Regulation

1. Introduction

The operational behaviour of hydraulic structures in irrigation canals in conveyance, regulation and delivering water is a very important aspect in operation of canals for irrigation water management. In the management of irrigation systems in Sri Lanka this aspect receives low priority due to lack of knowledge. In the implementation of more complex irrigation schedules, high operational efficiency could be achieved by use of canal operation techniques. As such in-depth study of technology used in system level and individual structures will provide the basis for study the operational behaviour of hydraulic structures mainly use for regulation. Generic typology has been developed (Renault and Godaliyadda, 1999) to improve Canal Operation techniques and applied selected Major Irrigation systems in Sri Lanka to study the canal operation.

2. Typology for irrigation systems in Sri Lanka

Major and Medium irrigation systems in Sri Lanka can be considered as homogeneous in technology at the system level. They are all designed for discharge control operations except where intermediate reservoirs can be used as volume control devices. They are all upstream controlled and consist of fully operated structures.

They are also mostly homogeneous at the sub-level of structures. A similar type of structures, i.e. undershot gated regulators with side weirs and under short gated offtakes is found in all the systems. All these structures are gradually adjustable, manually operated and in-situ controlled.

In conclusion, at the level of system and structures, only the storage criterion brings a partition of irrigation systems:

Low storage – Distributed Storage – Localized storage (see Table 1)

Table 1: Typology Matrix Application to Sri Lankan irrigation systems with partitioned classes.

<table>
<tr><th>Level of typology</th><th>Criterion of characterization</th><th colspan="6">Identified Classes</th></tr>
<tr><td rowspan="11">System & Structures</td><td>Controlled variable</td><td colspan="6">Discharge</td></tr>
<tr><td>Type of control</td><td colspan="6">Upstream</td></tr>
<tr><td>Degree of operation</td><td colspan="6">Fully Manual</td></tr>
<tr><td>Adjustment(structure)</td><td colspan="6">Gradual</td></tr>
<tr><td>Manipulation</td><td colspan="6">Manual</td></tr>
<tr><td>Control</td><td colspan="6">In situ controlled</td></tr>
<tr><td>Sensitivity</td><td colspan="6">No information</td></tr>
<tr><td>Physical condition</td><td colspan="6">Medium</td></tr>
<tr><td>Storage</td><td colspan="2">Low Storage (DBK)</td><td colspan="2">Distributed Storage (SBK)</td><td colspan="2">Localized Storage (Intermediate Reservoir)</td></tr>
<tr><td>Control</td><td colspan="6">Variable</td></tr>
<tr><td>Bed material</td><td colspan="6">Unlined</td></tr>
<tr><td rowspan="4">Hydraulic Network</td><td>Type of supply(*)</td><td colspan="3">Reservoir</td><td colspan="3">River Diversion</td></tr>
<tr><td rowspan="3">Layout of lateral flows</td><td colspan="3">Return Flow (RF)</td><td colspan="3">Non Return Flow (NRF)</td></tr>
<tr><td colspan="3">Single Bank Canal (SBK) With run-off</td><td colspan="3">Double Bank Canal (DBK) without run-off</td></tr>
<tr><td colspan="6">No run-off ditches</td></tr>
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2.1 Reservoir and diversion

In the case of a reservoir, freedom in selecting the input and stability, are generally high because, at least in the short term, water availability is not limited and the depth of water in the reservoir is steady. For river diversion, the freedom can be lower, because discharge to be diverted depends on instantaneous water availability. Furthermore, short-term changes in river level can lead to high variations in the discharge entering the system unless self- regulating structure equips the intake.

2.2 Single bank

The Single Bank Canal (SBK) has an increased free surface area compared to double bank canal. This reduces the speed of wave propagation. As a consequence, without operation the system, time-lags between the main sluice and targeted offtakes are greater.

A Single Bank Canal can also store more water per variation of water depth, in the typology it is considered as a “distributed storage”. Therefore proper management of its storage capacity can in some cases significantly reduce the time-lag between operation and delivery. Furthermore for unscheduled fluctuation, this additional storage capacity can be used to retain temporally surplus and to implement a reaction procedure.

2.3 Double bank

The double bank canal systems as a whole are not very common in Sri Lanka. However, there are numerous double bank canal subsystems as component of irrigation systems. The main characteristic of a double bank canal is that no flow enters the system during rains. Double bank canal has a limited distributed storage capacity. It is more dynamic than a single bank, i.e. fluctuations are generally propagated faster.

2.4 Intermediate reservoir

There is no clear criteria with respect to capacity allowing to declare whether or not a reservoir falls into this category. It is left to the concerned manager to categorize this feature.

Intermediate reservoir presents three important characteristics in relation to the operation. The first is the attenuation of upstream fluctuation which protects the downstream subsystem. The second is the possibility of issuing water in advance (before time leg). The third is the possibility of storing any positive unscheduled fluctuation occurring in the upstream subsystem. Therefore water savings can be achieved by controlling main supply through a feed-back volume control technique. Intermediate reservoirs are often called as regulating reservoirs.

3 . Flow fluctuation causes and their magnitudes

Fluctuations can be classified according to their causes and magnitude, and the degree of information available at management level.

A distinction is first made between scheduled and unscheduled fluctuations. Scheduled fluctuations concerns planned changes in the delivery and are assumed to be known by operation staff. Unscheduled fluctuations are the discharge variations that may occur along a canal and which cannot be predicted in advance. Unscheduled fluctuations can become known after a certain period of time if proper assessment of the canal flow status is carried out.

The second distinction is related to the magnitude of the change and leads to distinguish low and high fluctuation. At this point, only site specific considerations can decide where to place the threshold between low and high fluctuation. Low and High fluctuations may be distinguished on the basis of their cause or of their frequency of occurrence. They may be also distinguished with reference to conveyance and/or storage capacity to accommodate them. For example, a manager can classify any fluctuation that may lead to overtopping as HIGH and LOW otherwise.

3.1 Types of operation

In Sri Lanka the frequency of routine operation of gates is often twice per day. One operation takes place between 7 a.m. to 9 a.m. in the morning and the second between 4 p.m. to 6 p.m. in the evening. This pattern corresponds more or less to a 12 hours frequency operation- type. To investigate the relation between performance and operation, other types of operation are also considered in the study. The first one is the no-operation type (No). It corresponds to an "infinite" frequency and means that the system is left without changing the setting of the cross-regulator gates. Other alternatives are fixed frequency (FF) of 3 hours, 6 hours, and 12 hours during daytime. It must be pointed out that whatever the schedule, night- time is being kept without operation. A specific type of operation is studied for the purpose of scheduled delivery. It is the time-lag operation (TLO). The time-lag is the delay of the fluctuation propagation between the main sluice and the cross regulator gate. Operation is made approximately when the wave begins to pass through the regulator gates.

3.2 Evaluation of performance

For the purpose of evaluation and comparison, different performance indicators are used in relation to the water management targets.

3.2.1 On-line delivery adequacy

This indicator evaluates the deviation between actual and expected total volume delivered at the offtakes which are located between the main sluice and the tail delivery point.

3.2.2 Tail delivery adequacy

This indicator assesses the effectiveness in conveying the hydrogram to the delivery point. Specifically it represents the ratio between the effective volume reaching the tail-end of the subsystems and the targeted volume.

3.2.3 Timeliness at tail

This indicator evaluates the time deviation at tail, between actual and expected delivery.

4. Hydraulic simulations

In this section, hydraulic simulations carried out to analyze irrigation systems behavior as presented in Table 2.

Table 2: Matrix of the hydraulic simulation

Operation Mode	Simulated Fluctuation	Status of Delivery	Internal characteristics	Type of Operation
FSD (level and discharge control)	Low Increase (24hr)	Scheduled (Change in Delivery)	DB K	T.L.O 3hr 6hr
	High Increase (24hr)	Unscheduled (Return Flow, Run-off, Diversion Change)	SBK STO (Localized Tail Storage)	12 hr No Operation

4.1 Presentation of the studied subsystems.

To study the behavior of the main irrigation system types, hydraulic simulations have been performed in three different subsystems. The topography of these subsystems is derived from a real canal of Sri Lanka, the Kirindi Oya irrigation system. The DBK system considered in the study is the real (existing) main canal. The SBK canal has a twice bed width of DBK canal. The third system STO corresponds to a localized storage located at the tail-end of the DBK canal. The reservoir has a capacity of 600,000m^3.

4.2 Presentation of the hydraulic simulation model

The hydraulic software used in these simulations is SIC (Beaume et al., 1993), which has been recently equipped with additional regulation module. SIC, "Simulation of Irrigation Canals", is a mathematical flow simulation model developed by Cemagref,

France, to study the hydraulic behavior of irrigation canals under steady and unsteady flow conditions. Basically the model numerically solves the Saint-Venants equations of continuity and momentum for a given set of boundary conditions. The model comprised of three modules.

Topography module (Unit I):
This is designed to generate the topographic data of canals used by the computation programs of Units II and III. This module allows the user to input and verify the data obtained from a topographical survey of the canal

Steady flow module (Unit II):
This is designed to perform the steady flow computation. It allows to study the water surface profile for any given combination of offtake discharges and cross regulator gate openings. Unit II also allows to determine offtake gate openings and adjustable regulator gate settings required to satisfy a given water distribution plan whilst simultaneously maintaining a set of target water levels.

Unsteady flow module (Unit III):
This is designed to carry out the unsteady flow computation. It allows the user to test various scenarios of water demand schedules and operations at the head works and control structures. Starting from an initial steady flow regime, it will help the user to look for the best way to attain a new water distribution plan. The efficiency of the operational strategy may be evaluated via a set of water delivery indicators computed at the offtakes.

The regulation module attached to this module allows to select different operational options at cross regulators, when unsteady flow simulations are carried out.

Originally model has been calibrated under steady flow condition for main supply discharge of 8.21 m^3/sec and targeted offtake discharges in a real canal in Kirindi Oya irrigation system in Sri Lanka.

4.3 Fluctuation (Inputs) simulated

Fluctuations are of two types. The LOW positive fluctuation is an increase of 1 m^3/s occurring in the upstream part of the subsystem while the main supply is 8.21m^3/s. The HIGH positive fluctuation is an increase of 3 m^3/s at the same location with the same basic discharge of 8.21m^3/s.

The duration of the fluctuation is taken as 24 hours. This duration has been chosen as it is reasonable to assume that after 24 hours any unscheduled fluctuation can be detected and later on could be treated as a scheduled fluctuation if it continues.

5. Results and discussion

Results derived from the simulations are regrouped and displayed in the following manner: Performance indicators are plotted for types of subsystem under low magnitude fluctuation in Figure 1, for high magnitude fluctuation similar results are plotted in Figure2. The analysis will be carried out considering first the physical criteria of the typology, i.e. DBK, SBK and STO. The operation types tested here are: TLO, and NO, and FF (3 hr, 6hr, and 12 hr) during daytime (there is no night-time operation).

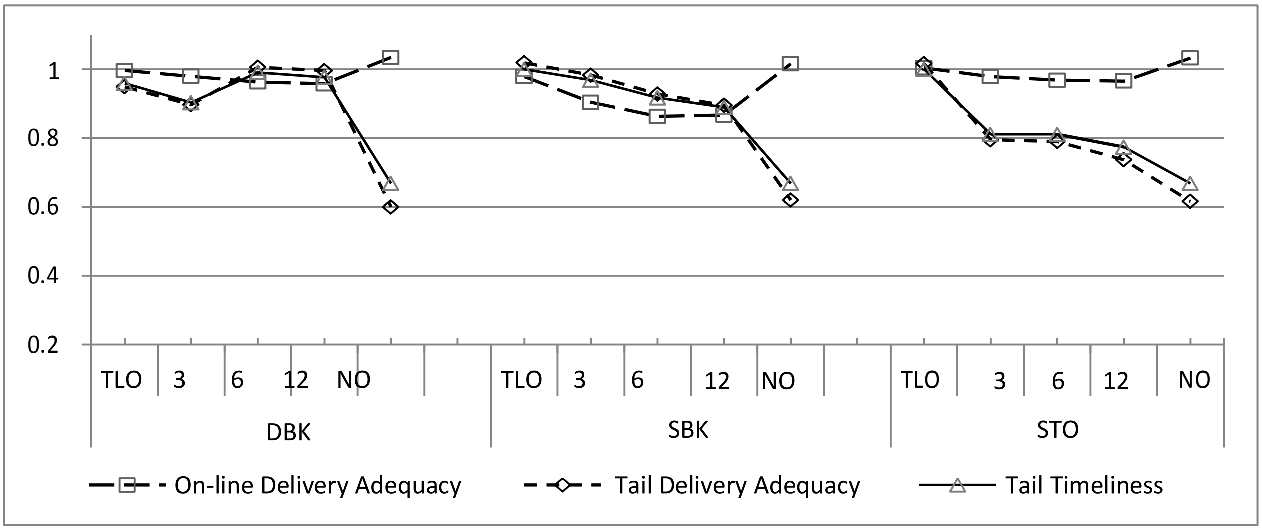

Figure 1. Performance *vs* type of operation for LOW positive fluctuation

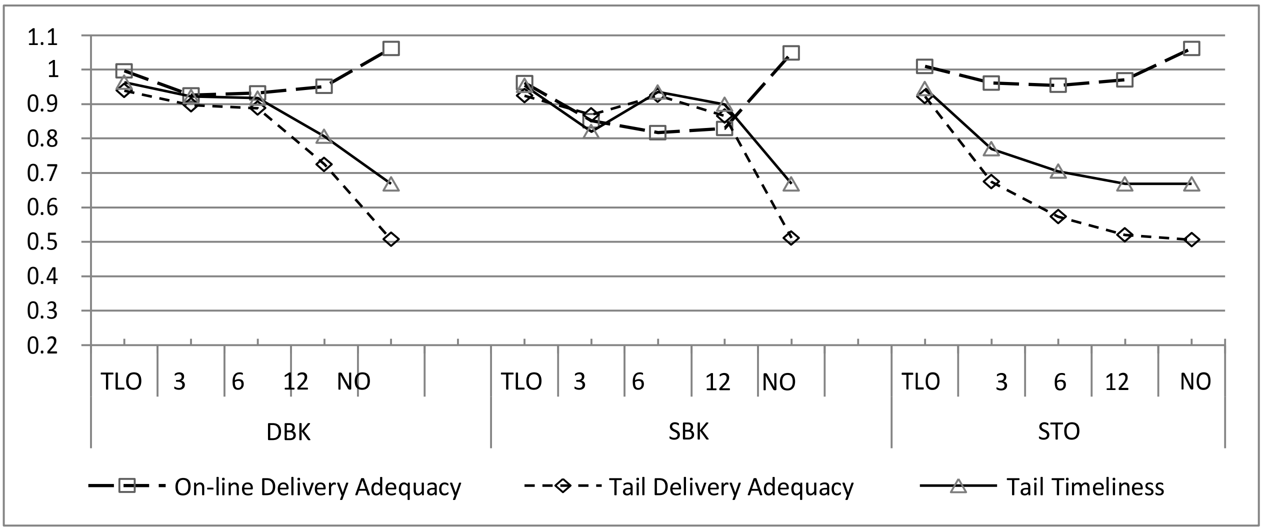

Figure 2. Performance *vs* type of operation for HIGH positive fluctuation

5.1 DBK Subsystem

Time-Lag Operation (TLO) appears to be the more effective operation type, as computed value of all indicators are very close to 1.

For scheduled change, in any case, the best solution is TLO. For fixed frequency type, 12hr is sufficient for low changes but 6hr is recommended for high changes. Furthermore, if the manager seeks a unique rule for operation, then 6hr operation during daytime period is recommended.

For unscheduled fluctuation same conclusion can be drawn except for TLO which is not relevant. In case of DBK system with Return Flow, where low magnitude fluctuations are expected, 12hr operation is recommended. In case of DBK with River Diversion, 6hr is recommended as the probability of having high fluctuations cannot be neglected.

5.2 SBK Subsystem

Similarly, for the SBK it is observed that Time Lag Operation (TLO) is the more effective type of operation, as all indicators are very close to 1. For fixed frequency operation, 3hr is better than 6hr and 12hr for low fluctuation. For high fluctuation, 6hr is the best option, whereas 3hr and 12 hr perform equally low.

For scheduled change, the best solution is TLO. For fixed frequency type, 3hr is performing little better than 6hr in case of low changes. However 6hr is better for high changes as stated for DBK. The manager will have to decide whether it is worthwhile to go for 3hr for low change instead of having a unique rule of operation. The 6hr operation during daytime period is recommended.

5.3 Storage Subsystem

The Time-Lag Operation (TLO) is the most effective operation type. Conversely to previous, poor performance is observed for fixed frequency type operations (3hr, 6hr, and 12hr). The fixed frequency type of operation, when applied to all the cross-regulators including the one downstream of the storage, is not effective for this type of subsystem.

For scheduled low fluctuation (change in delivery), storage can be used to issue in advance as long as the storage capacity permits it. For scheduled HIGH fluctuation, the most effective type is TLO but its performance does not reach a value of 1 as for Low fluctuation.

6 Conclusion

Time-Lag Operation (TLO) appears to be the more effective operation type, as computed value of all indicators are very close to 1 in all three topographical situations. The operational efficiency in delivering water of DBK canals are high if operated at fixed frequencies such as 6 hr and 12 hr. In case of Single Bank canals due to distributed storage, delivery performance are comparatively low but inversely such systems will attenuate unscheduled fluctuations in compared to DBK systems. The presence of SBK systems in River diversions with fluctuating flows and surface runoff from highland areas will not propagate the flows to tail end areas unlike in DBK systems. Especially when intermediate reservoirs are located in the system, it suggested to operate the gates when wave reaches by deploying gate operator at the location to store or release water.

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References

[1]. Renault,D., Godaliyadda,G.G.A. 1999, Generic Typology for Irrigation System Operation, Research Report 29, Colombo, Sri Lanka: International Water Management Institute.