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Performance of Canal Delivery Strategies and Control Systems

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Abstract
Performance analysis studies of irrigation systems are required to improve low efficiency, unequitable water distribution and low productivity which many irrigation systems are suffering from. The performance of a canal conveyance system under the impact of delivery strategies, control systems, and unsteady flow behaviour is investigated for the main Kushtia canal of the Ganges-Kobadak irrigation project in Bangladesh. The canal and two control systems(manual upstream control, and automatic upstream control) were modelled and three delivery strategies(rotational delivery, continuous delivery with big steps, and continuous delivery with small steps) were simulated using a hydrodynamic modelling package. Performance indicators were formulated and investigated. With regard to the results of the study, continuous delivery with big steps for manual upstream control and continuous delivery with small steps for automatic upstream control system were selected as optimal alternatives.

1 Introduction

Rapidly growing global population requires at least a 2% increase in agricultural products per annum which should mostly come from improving agricultural production of irrigated lands. Low performance of irrigation systems in terms of efficiency, equity, and productivity causes the recent studies to pay more attention to improving water management in irrigation systems. With regard to limited water resources and highly competitive uses of water, better control and distribution policy should be incorporated to improve the performance of irrigation systems.

The objective of this study was to quantify and investigate the performance of a canal conveyance system for alternative delivery policies and control systems, considering unsteady behaviour of the flow. Results of the study provide required knowledge to select the most appropriate delivery strategy and control system for the canal system.

The Ganges-Kobadak irrigation project is a large irrigation project in Bangladesh which covers about 142000 ha. The area is divided to 7 regions. Kushtia unit is one of the regions with 3 main canals from which the Kushtia canal is selected for this study (Fig.1). Kushtia canal is 63 km

long and serves about 4700 ha. The canal has a capacity of 1.2 lit/s/ha. There are 6 water level control structures and 22 secondary offtakes along the canal. The canal is designed to supply water for supplementary irrigation for paddy fields from July until November. There is no straight guidelines for operation the structures. The only official operation is execution of a rotational schedule among the main canal in dry season. For this rotation the main canal is divided in three sections, each section

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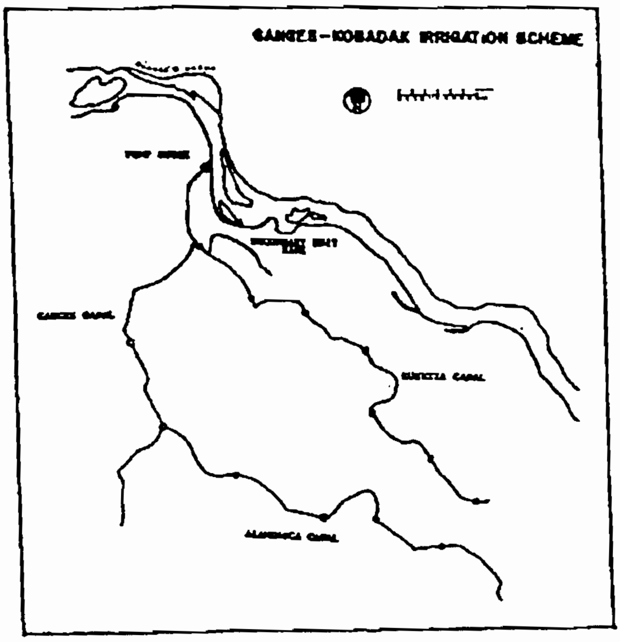

Fig. 1. The Kushtia unit of the Ganges_ Kobadak irrigation project.

Fig. 2. Three delivery schedules for the main Kushtia canal.
(a) Rotational delivery with fixed discharge.
(b) Continuous flow with big steps.
(c) Continuous flow with small steps.

(3)

receives water for three days followed by six days off.

In this paper the three delivery strategies and two control systems are presented first. Then the hydrodynamic model and performance parameters used for simulation and evaluation of the performance of the canal system are explained. Thereafter modelling and simulation of the canal system is briefly introduced and the results of the simulation are discussed. Finally, conclusions and recommendations of the study are presented.

2 Water Delivery Strategies

A delivery system is a method of water distribution by which three delivery components (flow rate, frequency, and duration) are determined and can have different flexibility, ranging from the most flexible delivery (no limitation in delivery components and user controlled system), to the most rigid delivery (fixed delivery components and supplier controlled system). In between by manipulating the level of decision making and method of performing the delivery components, several flexibility levels and delivery systems can be defined (Replogel & Merriam 1980). Among the three general delivery systems (rotational, arranged, and on demand methods), the arranged method, in which the water delivery is determined by irrigation authority in advance of irrigation season, is selected for this project. Three delivery schedules were derived for the main Kushtia canal (Fig.2).

2.1 Rotational Delivery With Fixed Discharge.

In this delivery system a fixed discharge is determined in the main canal and variable water requirements are satisfied by manipulating the delivery frequency. Therefore no discharge regulation is needed and operation would be only on and off. Due to frequent filling of the canal the expected losses are high. This delivery schedule is the present water distribution system in the project.

2.2 Continuous Delivery With Big But Infrequent Steps.

In this delivery system the variable water requirements are scheduled in such a way as to have continuous flow with three big steps of discharge adjustment in the main canal offtake. Some losses due to scheduling will be introduced amounting to 1.6%. Since three different discharges should be regulated the operation is rather difficult compared to rotational delivery with fixed discharge. But because of continuous flow in the canal the overall operational losses are expected to be lower.

2.3 Continuous Delivery With Small But Frequent Steps.

In this delivery system the variable water requirements are followed more closely. The requirements are scheduled in such a way that produces continuous delivery with several small steps of discharge adjustments in the main canal offtake. The scheduling losses are about 0.6%. Because several discharges should be regulated the operation is much more complex and frequent, therefore higher operational losses could be expected.

3 Control Systems.

A control system as an arrangement of several components (monitor, regulator, controller,...) is required in a canal system to control the hydraulic process for implementation of the desired delivery policy. The action of a control system can be performed manually or automatically. Two types of control system were considered for this study:

1- Manual upstream control(present control system)
2- Automatic upstream control system.

After defining three delivery strategies and two control systems (six alternatives), the canal and control system are modelled and delivery schedules are simulated using a hydro dynamic flow model. Later on, performance indicators of the canal system are determined and investigated.

4 Hydrodynamic Flow Model.

One of the reasons which might have contributed to poor performance of canal systems is lack of considering the unsteady behaviour of the flow for alternative delivery strategies and control systems, and their impact on real water distribution and performance of the system.

Development of hydrodynamic models makes it possible to model canal and control systems and to simulate alternative delivery schedules and operation scenarios in an unsteady flow condition, and to investigate the results and select the optimal solution.

The MODIS hydrodynamic model was used to define a model of the studied canal and to simulate the delivery strategies and operation scenarios. The calculation of unsteady flow is based on numerical solution of the Saint venant equations written in the following form using finite difference method, four point implicit scheme (Preissmann's scheme):

$$\frac{\partial Q}{\partial x} + b_s \frac{\partial h}{\partial t} = q \qquad [1]$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\frac{\beta Q^2}{A}\right)}{\partial x} + \frac{\partial h}{\partial x} + \frac{g n^2 |Q| Q}{A (R)^{\frac{4}{3}}} = 0 \qquad [2]$$

Where:

Q = Discharge in m^3/sec.
x = Distance in m.
b_s = Cross sectional water surface width in m.
h = Water level in m.
t = Time in sec.
q = Lateral flow in m^3/sec.
β = Boussinesq's coefficient.
A = Cross sectional area in m^2.
g = Gravitational constant in m/sec^2.
n = Manning's roughness coefficient.
R = Hydraulic radius in m.

Several standard structures are incorporated in the model and non standard structures can be defined as fortran subroutines. The operation of the structures can be defined either manually by defining the structure parameters as a function of time or automatically in which the structure's parameters are constantly adjusted as a predefined function of other variables to maintain the flow parameter at its predetermined value.

5 Evaluation the Performance of Canal System.

In order to evaluate the performance of water delivery to each individual offtake two performance indicators were defined. One is delivery performance ratio (DPR) which determines to what extent the intended supply to an offtake has been satisfied and the second is operation efficiency (e_o) which shows how much water is lost due to inappropriate delivery to an offtake. The indicators read as:

$$DPR = \frac{V_e}{V_i} * 100 \qquad [3]$$

$$e_o = \frac{V_e}{V_a} * 100 \qquad [4]$$

Where: DPR = Delivery Performance Ratio in %.
e_o = Operation Efficiency in %.
V_i = Volume of water intended to be delivered to an offtake in m^3.
V_a = Volume of water actually delivered to an offtake in m^3.
V_e = Volume of water effectively delivered to an offtake in m^3.

The intended volume is specified by defining the intended discharge and desired delivery period. The actual volume is determined by model computation of integrated actual delivered discharge during delivery period. And the effective discharge is defined as that portion of actual volume which is delivered within the acceptable discharge range during desired delivery period (Fig.3). The acceptable maximum and minimum discharges are defined by the user.

To evaluate the performance of the whole canal system, the weighted average of delivery performance ratio (DPR) of all offtakes is used as overall delivery performance ratio, and the overall operation efficiency is defined as the ratio of total effective volume delivered to all offtakes to the actual volume of water released from the head work in the canal. Therefore in addition to operation losses of each individual offtake, the volume of water used for filling the canal is also considered in performance evaluation. The parameters read as:

$$DPR_{overall} = \frac{\sum_{n=1}^{n=k} (DPR_n) * V_{i,n}}{\sum_{n=1}^{n=k} V_{i,n}} \qquad [5]$$

$$e_{o,overall} = \frac{\sum_{n=1}^{n=k} V_{e,n}}{V_{a,overall}} \qquad [6]$$

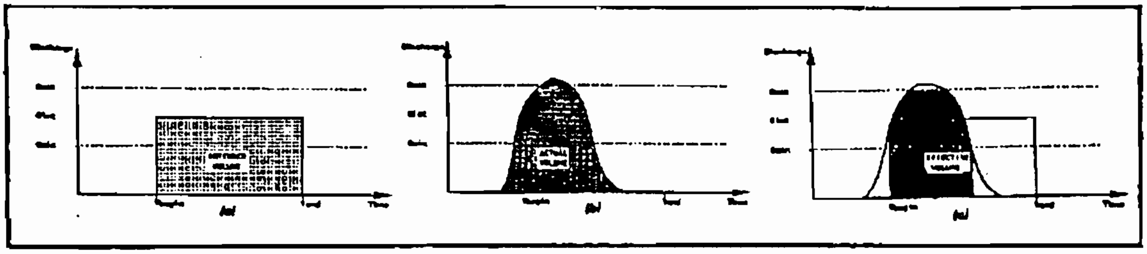

Fig. 3. (a)Intended,(b)Actual, and (c)Effective volumes.

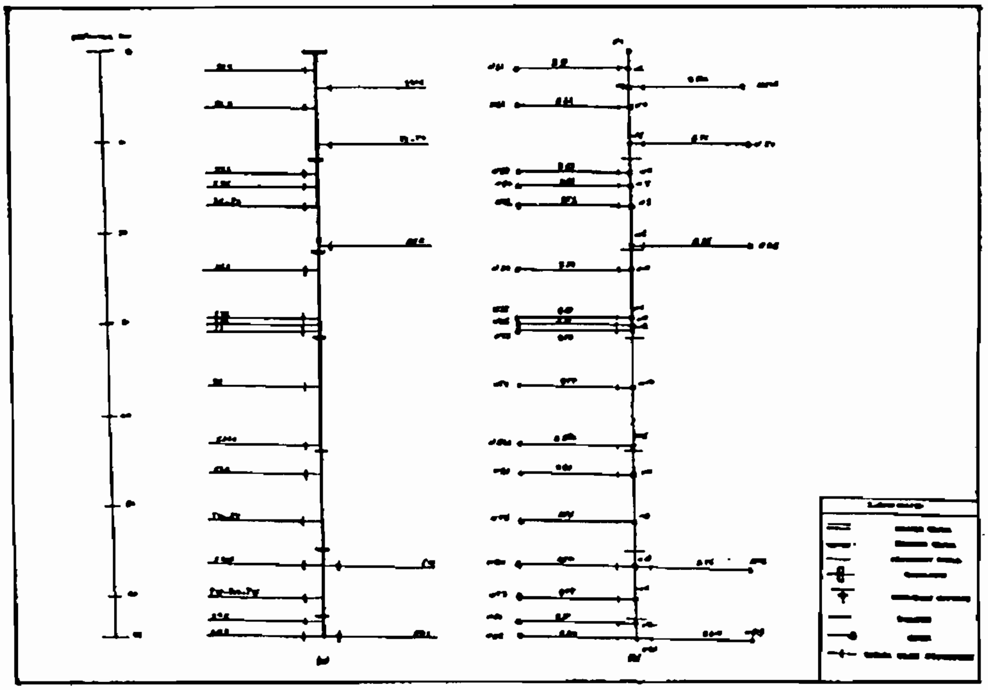

Fig. 4. (a)Schematized and (b)Modelled Kushtia canal.

(8)

Where: DPR_n = Delivery performance ratio of each individual offtake in %.

$V_{i,n}$ = Intended volume of each individual offtake in m^3.

$V_{e,n}$ = Effective volume of each individual offtake in m^3.

$DPR_{overall}$ = Overall delivery performance ratio in %.

$e_{o,overall}$ = Overall operation efficiency in %.

$V_{a,overall}$ = Actual volume of water released from head work in the canal, m^3.

k = Number of offtak s along the canal.

6 Modelling and Simulation the Canal System.

Two models were built for two control systems. The Kushtia canal, with six control structures and twenty two offtakes, was modelled (Fig.4). The models were built by defining detail configurations of the canals and detail specifications of the structures. Three delivery schedules were simulated for each control system by defining the inflow at the headwork as a function of time. Ideally the performance of the canal system should be investigated for the whole irrigation season. However this requires a long time, and since the steps of discharge adjustments for each delivery schedule were almost equal, the difference of simulation results for every step are expected to be small. Therefore for each alternative one step of discharge adjustment was simulated.

The time period for each simulation was taken as the response time from the already existing steady state at the moment of discharge adjustment until the new steady state condition is established in the whole canal system (unsteady flow period). This interval is considered as the short term period. After steady state has been achieved the performance is considered to be perfect and performance indicators (DPR and e_o) would be 100%. Hence the intended, actual, and effective volumes will remain equal during steady state condition and performance indicators can be extended for a long term period. The short term period was taken as 48 hr and long term period was taken as five weeks. Simulation time step was taken as 10 minutes, and the distance increment was 100 m.

7 Results of Simulation.

After modelling the canal and control system, each delivery schedule was simulated. The performance indicators for individual offtakes and the whole canal system were derived for short term and long term periods. The results were investigated and presented for each control system as follows:

7.1 Manual Upstream Control System.

Results of simulation show that the performance differs for each individual offtake, and water distribution among the offtakes is not uniform. The nonuniformity is the highest for rotational delivery due to long response time (48 hr). The delivery performance ratio varies from 90% to 41%, and operation efficiency varies from 97% to 82% between upstream and downstream offtakes. The other two continuous deliveries have lower degrees of nonuniformity. The overall performance indicators are shown in Table 1. The short term results show that the rotational delivery results in low performance. Application of continuous delivery with big steps has contributed to significant performance improvement due to shorter response time (16 hr). Continuous delivery with small steps has resulted in marginal performance improvement. Long term evaluation (5 weeks),has resulted in higher performance parameters for rotational delivery. That is because the dominant effect of unsteady flow in the short term period has diminished for the long term period. The long term results didn't show significant difference in performance between delivery strategies.

7.2 Automatic Upstream Control System.

When automatic upstream control system is applied, in rotational delivery between delivery periods when the headwork is off, the water does not spilled off the canal and for the next delivery stage only the wedge storage of the canal should be filled. Therefore the response time would be much shorter (12 hr) compared to manual operation, therefor water distribution among the offtakes is more uniform. The delivery performance ratio (DPR) ranges from 100% to 45%, and operation efficiency (e_o) ranges from 100% to 89% between upstream and downstream offtakes. In short term periods automation has contributed to high performance improvements for rotational delivery, while it has insignificant effect for continuous delivery (Table 1). There is no significant difference in performance between different strategies both in short term and long term evaluation, because the response times for all delivery strategies are in the same order (10-12 hr).

Table 1: Performance Parameters of Different Alternatives in %.

	TIME PERIOD	SHORT TERM (48 hr)		LONG TERM (5 WEEKS)	
DELIVERY STRATEGY	MODE OF UPSTREAM CONTROL	MANUAL	AUTO	MANUAL	AUTO
ROTATIONAL DELIVERY WITH FIXED DISCHARGE	DPR	71	96	99	100
	Eo	72	87	92	99
CONTINUOUS DELIVERY WITH BIG BUT INFREQUENT STEPS	DPR	99	98	100	100
	Eo	89	84	98	98
CONTINUOUS DELIVERY WITH SMALL BUT FREQUENT STEPS	DPR	99.5	99.5	100	100
	Eo	89.5	89	99	99.3

8 Discussion of Results and Conclusions.

The ratio of minimum delivery period (time between two successive discharge adjustments) to the corresponding response time is in the order of 3.5, 72, and 4.8 for rotational delivery, continuous delivery with big steps, and continuous delivery with small steps respectively. This shows that for the minimum ratio the delivery period is 3.5 times the response time, implying the insignificant effect of transient flow on performance evaluation during the delivery period. When the delivery period is more frequent (only day time irrigation, or on-demand systems) and response time is larger the impact of transient flow becomes important. For the ratio of order 1 to 1.5 the unsteady flow plays the major role in performance evaluation.

The simulation results were achieved in a computer environment, where the operational instructions are exactly followed. However, usually in practice operation deviates from instruction and lower performance would be expected for a manually operated system. The more complex and frequent the operation the higher operational losses to be expected. As a result, for a system with manual upstream control, continuous delivery with big steps is selected as an optimal delivery strategy. For a system with automatic upstream control the operational losses could be reduced because of easy operation and less operator interference. Therefore more frequent delivery schedule could be easily handelled with low operational losses. As a result, for the automatic upstream control system the continuous delivery with small steps provides the highest performance and is selected as an optimal strategy.

9 Recommendations.

For performance investigation of irrigation systems the method of water distribution and control system can not be separated. Proposing any delivery strategy should be done in accordance to the appropriate control system.

In a manual control system several operational scenarios could be tested for each delivery strategy. With regard to the simulation results, the optimal operation which leads to best performance could be selected.

In a computer environment all the structural parameters are considered as having certain values which should be verified with real parameters in the field, for different discharge and water level ranges in free or submerged flow conditions.

The MODIS hydrodynamic package is able to determine the performance indicators for alternative delivery strategies, control systems, and operation schedules. Testing many different possible alternatives and selecting the optimal one could be laborious and require a long time. Therefore optimization techniques could be incorporated in the model to generate the optimal delivery strategy and operation schedules.

10 References

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