TESTING OPERATIONAL PERFORMANCE OF A PRIMARY CANAL USING HYDRODYNAMIC FLOW MODEL DURING DESIGN STAGE

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ABSTRACT

The Shafarud Irrigation Project is located in the North Western part of Iran by the Caspian Sea. At present, traditional water courses are irrigating about 7,150 ha of paddy fields. Even though there are water shortages during low river runoff and peak growing season, it was decided to extend the area under paddy to about 12,300 ha in net. This is not possible without taking full advantage of the river runoff, and preventing the flow of a large volume of water to the Caspian Sea annually. Therefore, it was foreseen to construct a storage dam on one of the four rivers existing in the area, and three diversion dams on the other rivers. By taking full advantage of the river runoff through the diversion dams and provision of irrigation water during deficiency period from the storage dam, the goal can be achieved.

The objective of this paper is to describe the design methodology adopted for the Shafarud primary canal by taking into account the operational performance of the system by using the MODIS hydrodynamic flow model. In the design of new primary canal, it was decided to investigate the effect of manual operation of secondary offtakes and impact of river runoff variation in two alternatives of automatic upstream and self-regulating downstream control systems during deficiency and sufficiency river runoff periods.

The results of the simulation show that the unsteady flow phenomena has an important effect on the water delivery and operational efficiency of the system, specially in the case of alternative using an automatic upstream control.

It was noticed that management by automatic upstream control is difficult, and during sufficient river runoff relatively more flow should be released from the storage dam as compared with its variant alternative of self-regulating downstream control system but due to topographical condition of the canal alignment with a few modifications it was considered to be a better design option.

The idea of taking into account the operational performance of a new irrigation system at the time of design is becoming increasingly important every day,

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especially when it is realized that many old irrigation schemes do not function properly. One of the main reasons is that water distribution and unsteady flow conditions were hardly considered in their design.

THE PROJECT DESCRIPTION

The present devices for distribution of irrigation water in the area are primitive and the water distribution method is more dependent on the visual inspection. In spite of great attention given for equitable distribution of water among the traditional irrigation ditches, in practice the method for distributing irrigation water is the least accurate.

Due to non-existence of permanent distributors, a large number of man-hours are required to carry out an accurate distribution of irrigation water.

Although the soil and water resources are reasonably rich to increase the area under paddy fields, irrigation water shortage and scarcity is a normal occurrence even for the present area under irrigation in the months of peak crop water requirement because the overall irrigation efficiency is very low. So it is envisaged to put a new modern and efficient irrigation network in place in the project area.

Objective

The objective of this study is to design Shafarud primary canal, taking into account the operational performance of the system, using MODIS hydrodynamic flow model.

Water delivery schedule

A fixed and rotational water delivery schedule to tertiary offtakes, resulted in variable (from 50 to 100%) and continuous water delivery to secondary offtakes. Two important occasions from paddy growing season were picked out, one during high river runoff (in the month of May) called it sufficiency period, and the other during low river runoff (in the month of July) which is called deficiency period.

In the following figure (Fig. 1) of water delivery schedule to secondary offtakes, states 1 and 2 occurred in sufficiency period, while states 3 and 4 take place during deficiency period.

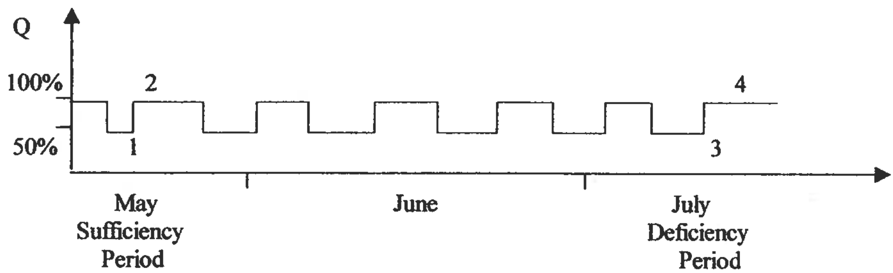

Fig 1. Water Delivery Schedule to Secondary Offtakes

SELECTED PRIMARY CANAL (SR)

The right primary canal (SR) of the Shafarud which is connected to the storage dam (SD) and two diversion dams (DM1 & DM2) was selected for investigation. Fig. 2 & Fig. 3 are present flow direction during sufficiency and deficiency periods respectively.

As can be observed from these figures, during sufficiency period there should be almost zero discharge in reaches AB and CD, because the rivers' runoff is high enough to satisfy the irrigation water requirements of the related secondary offtakes.

On the other hand during deficiency period more water should be released from the storage dam (SD) in order to compensate the deficiency of river runoff for secondary offtakes no. 3, 4, 5, 6, and 7.

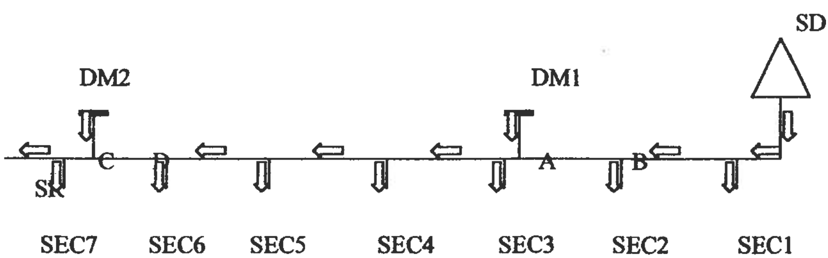

Fig. 2. Flow Direction During Sufficiency Period

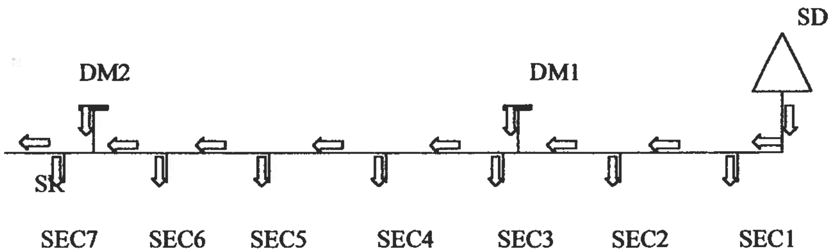

Fig. 3. Flow Direction During Deficiency Period

Flow control system

Two different alternatives for flow control system were considered for SR primary canal. The first one was an automatic upstream control, and the second one was self-regulating downstream control.

Water supply strategy and operation

In the case of first alternative of upstream control system in the main, primary and secondary canals, the water supply method to the secondary offtake is on a semi-demand basis.

A large Water Operation Centre (W.O.C.) [3] is required to instruct and supervise every regulation and adjustment to be carried out by gatekeepers on offtakes at diversion dams, secondary, and tertiary offtakes throughout the whole irrigation network. The tasks to be performed by the Water Operation Centre are as follows:

- Data collection on crop stage;
- Collection of meteorological data;
- Determination of water need for tertiary units;
- Assessment of water availability;
- Calculation of flow through each reach; and
- Determination of gate setting;
- Information to ditch riders;

In second alternative of self-regulating downstream control in the main (coming from storage dam) and primary canals, the system is decentralised and the water supply method to secondary offtake is on demand basis.

It means that the numbers of water operation centres are equal with the number of seconday canals (each secondary canal has its own water operation centre) but it is obvious that their staff requirements are much less than the first alternative.

In the first alternative of automatic upstream control, a Duckbill check structure was selected as the water level regulator just downstream of each secondary offtake.

Design of SR primary canal

A Duckbill check structure was considered appropriate as water level regulator in first alternative of automatic upstream control. In order to minimize the water level variation in front of offtake, appropriate length of the Duckbill check structure was selected but on the basis of economic justification [4].

For managing a constant flow delivery to secondary canals during either maximum or minimum flow through the primary canal, double baffle Neyrpic modules was selected as secondary offtakes. In automatic upstream control, the sill level of the Neyrpic module was fixed at a certain depth (0.51 and 0.28 metre for "L2" and "XX2" types respectively) lower than halfway between maximum and minimum water levels in front of the offtakes.

In the second alternative of self-regulating downstream control system just (or in vicinity) upstream of offtake, an Avio gate was selected as water level regulator.

For comparison with the first alternative, the same type of double baffle Neyrpic modules was selected as secondary offtake. Sill level of the offtakes are positioned at a two different depths (0.51 and 0.28 metre for "L2" and "XX2" types respectively) lower than design head (target level) of Avio gates. After structures for both alternatives of automatic upstream control, and self-regulating downstream control system for the SR primary canal were finalized, now it was possible to draw the longitudinal profiles of the canal for both alternatives. The following steps were carried out in order to calculate the water line (FSL) and preparing the longitudinal profiles of main and primary canals:

The longitudinal profile of SR primary canal (16.19 km long) was prepared with horizontal and vertical scale of 1:25000 and 1:100 respectively;

Locations of all secondary offtakes were shown on the longitudinal profile;

Taking into account number of tertiary units located downstream of each secondary offtake, and considering 90 % conveyance efficiency from tertiary offtake up to the headwork, capacities of canals were calculated;

The minimum water levels were established to command the land for irrigation;

All canals were envisaged to be concrete lined in the Shafarud project area;

With adopted design criteria and by using the Manning Formula, parameters of the canals cross-sections were calculated for each reach;

Bottom width, side slope, manning coefficient used in design of primary canal were 1.5 metre, 1.5 (H:V), and 0.014 respectively. Bottom slope of the primary canal is 0.5 metre per one kilometre (1/2000);

Taking into account the calculated head losses due to regulating structure (Duckbill for automatic upstream control and Avio for self-regulating downstream control), normal depth of water, length of selected reach (especially in second alternative) and full supply line are drawn;

Natural ground surface is about 1.0 metre above bottom slope of SR primary canal and very much parallel to it.

Following completion of the designs, the effect of manual operation of secondary offtakes and changes of river runoff in two alternatives of automatic upstream and self-regulating downstream control systems during deficiency and sufficiency periods was investigated.

In both alternatives, offtake setting were changed from 50 to 100% position manually according to time schedule.

Four alternative situations of automatic upstream control during sufficiency and deficiency periods, and self-regulating downstream control system for the same periods of sufficiency and deficiency by using MODIS hydrodynamic flow model [7] were simulated. Operation performance parameters have been formulated. The two performance parameters of delivery performance ratio (DPR), and operation efficiency are defined as follows:

$$DPR = (Ve/Vi) * 100\% ,$$

$$Eo = (Ve/Va) * 100\%$$

where

DPR = Delivery Performance Ratio;

Ve = Volume effectively delivered;

Vi = Volume intended to be delivered;

Eo = Operation efficiency; and

Va = Volume actual delivered.

RESULTS OF SIMULATION

The results of the simulation showed that the unsteady flow phenomena had an important effect on the water delivery and operation efficiency of the system, especially in the alternative of automatic upstream control. In Fig.-4, the delivery performance ratio to individual offtakes for automatic upstream control during deficiency period is presented.

The period of unsteady flow lasted about 7 hours in automatic upstream control. The time interval between two flows delivery adjustment to secondary offtake (from 50 to 100% and vice versa) was every 5 or 6 days. Within 6 days the effect of unsteady flow would be decreased appreciably, but it was not ignorable

Delivery performance ratio to individual offtake for both flows control systems during steady state condition, and sufficiency period are presented in Fig. 5 & Fig. 6. Water supplied was more than targeted, in the case of automatic upstream control, and the overall operation efficiency declined to 85.6% which is low when compared to 99.5 % overall efficiency in self-regulating downstream control system.

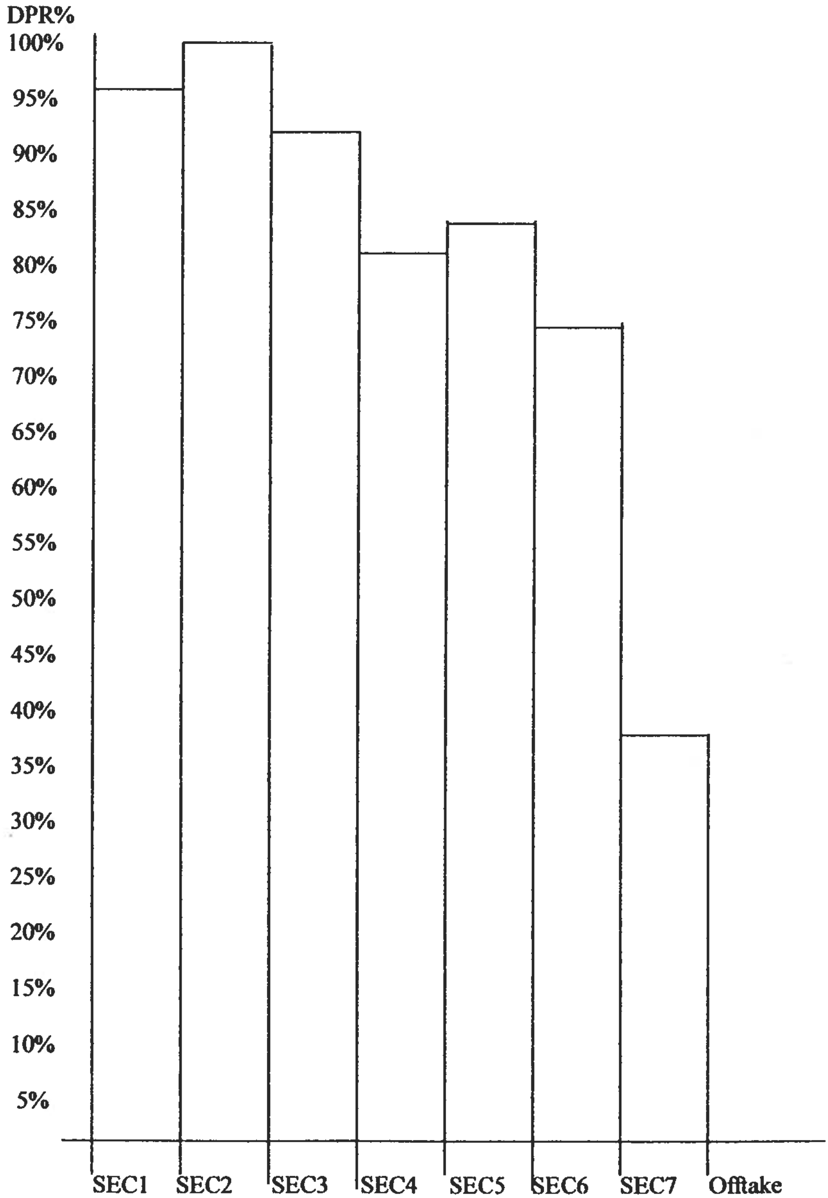

Fig. 4. DPR to Offtakes in Automatic Upstream Control During Deficiency Period

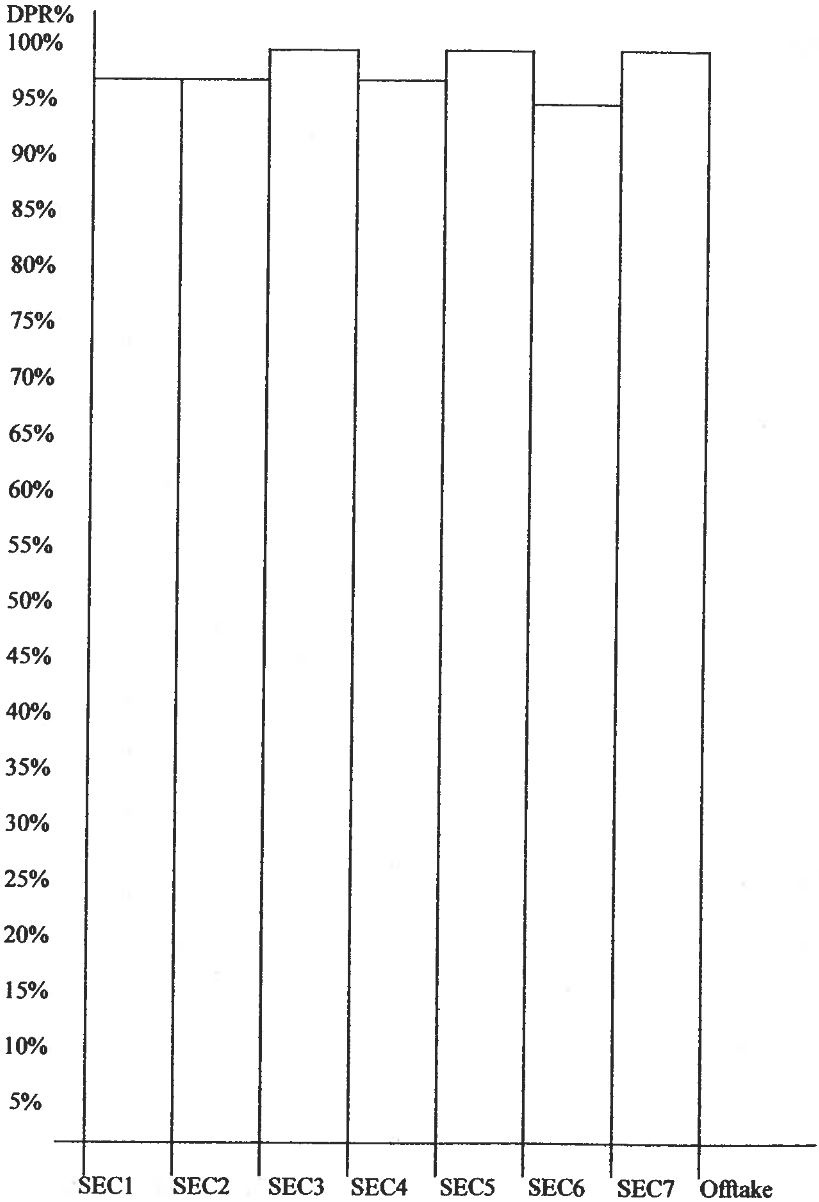

Fig. 5. DPR to Offtakes in Self-regulating Downstream Control During Sufficiency Period

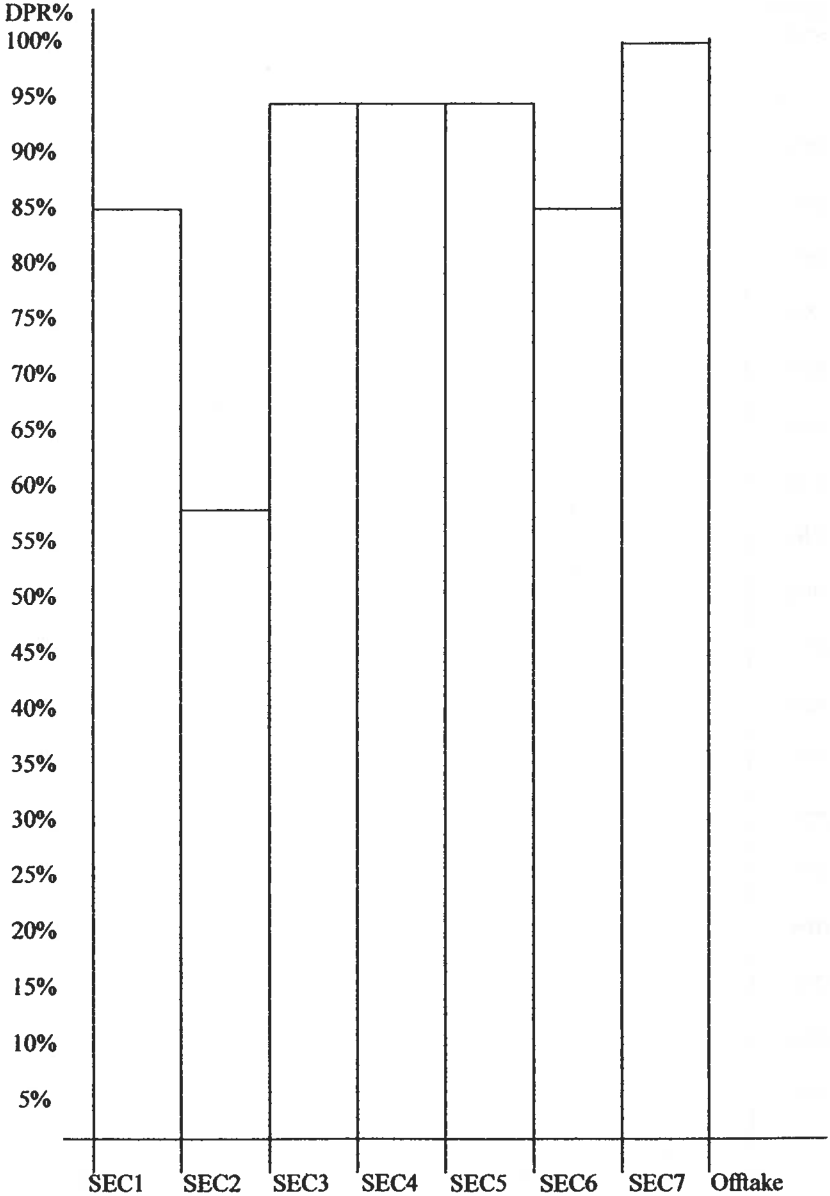

Fig. 6. DPR to Offtakes in Automatic Upstream Control During Suficiency Period

Target delivery discharge to different secondary offtakes during maximum (MAX. REQ.) and minimum (MIN. REQ.) requirement were collected in Table-1.

Table-1 Intended Discharges to Secondary Offtakes in m^3/sec

OFFTAKES	MIN. REQ. STATE 1 & 3	MAX. REQ. STATE 2 & 4
SEC1	0.26	0.52
SEC2	0.20	0.40
SEC3	0.78	1.55
SEC4	0.22	0.22
SEC5	0.40	0.80
SEC6	0.17	0.33
SEC7	1.95	3.90
TOTAL	3.98	7.94

Also, an ideal situation for taking full advantage of different sources of water during deficiency and sufficient river runoff periods is presented in Table-2.

In this table states 1 and 2 relate to the water delivery schedule to secondary offtakes during sufficient river runoff, but states 3 and 4 are occurred during low river runoff.

Table-2 Flow From Different Sources of Water in m^3/sec

SOURCE OF IRRIGATION WATER	DEFICIENCY PERIOD STATE 3	STATE 4	SUFFICIENCY PERIOD STATE 1	STATE 2
DIVERSION DAM DM1	1.26	0.60	1.57	3.12
DIVERSION DAM DM2	1.41	0.00	1.91	3.91
STORAGE DAM	1.32	7.35	0.46	0.92
TOTAL	3.99	7.95	3.99	7.95

Simulation results of SR model for two different alternatives of automatic upstream and self-regulating downstream flow control systems during deficiency and sufficiency period are discussed in the following paragraphs respectively:

Automatic upstream control during deficiency periodupstream control during deficiency period" \l 1

During minimum flow from the storage dam, a discharge of 1.32 m^3/sec was considered to be delivered to the headwork of SR primary canal. Also, two inflows with the amount of 1.26 and 1.41 m^3/sec were considered to be delivered to the primary canal at the specified locations. To begin with, it was assumed that the need of secondary offtakes was at 50% of maximum flow delivery, so the relevant module were considered half open. After reaching steady state, the two inflows were changed to 0.60 and 0.00 m^3/sec respectively. Also, the offtakes were fully (100% or maximum flow delivery to secondary offtakes) opened. In order to study the downstream demand, it was investigated as to how much and at what time water from the storage dam should be released. It was found out that for satisfying the downstream demand, it was necessary to release 7.35 m^3/sec from the storage dam to the headwork of the primary canal at the time of manual operation on offtake. It is pertinent to mention that in reality the river runoff does not change all of a sudden, but for making simulation more interesting at time of manual operation on offtake, river runoff was also changed. These actions are better observed in the model function definition in Table-3 and Table-4.

Table-3 Inflow From Diversion Dams (DM1 & DM2) Into SR Primary Canal and Water Release from the Storage Dam for the Headwork (QIN) of the Canal

TIME	QIN.	DM1	DM2
00:00:00:00	1.32	1.26	1.26
01:12:45:00	=	=	=
01:13:00:00	7.35	0.60	0.60
06:00:00:00	=	=	=

Table-4 Manual Operation on Secondary Offtake

TIME	EFFECTIVE WIDTH OF SECONDARY OFFTAKES						
	SEC1	SEC2	SEC3	SEC4	SEC5	SEC6	SEC7
00:00:00:00	0.50	1.00	1.50	1.10	0.80	0.85	3.80
01:12:45:00	=	=	=	=	=	=	=
01:13:00:00	1.00	2.00	3.00	2.20	1.60	1.65	7.80
06:00:00:00	=	=	=	=	=	=	=

In the first trial, although the operation efficiencies during minimum flow was 100% (Table-5), it was realised that some of the secondary offtakes were not fully satisfied, because, the DPR parameter for offtakes no. 1, 2, 4, and 6 were 83, 58, 72, and 75% respectively. During maximum flow, operation efficiency for the same offtakes was slightly lower, but delivery performance ratios (Table-6) were much better.

Table-5 First Trial in AutomaticUpstream Control During Minimum Flow (Steady State Condition) and Deficiency Period

Point	Operation Performance Parameters							
	DPR %	Eo %	Qtarg	Qmean	Qmax	Qmin	Tbegin	Tend
SEC1	83	100	0.26	0.21	0.21	0.21	01:00	02:00
SEC2	58	100	0.20	0.12	0.12	0.12	01:00	02:00
SEC3	91	100	0.78	0.71	0.71	0.71	01:00	02:00
SEC4	72	100	0.22	0.16	0.16	0.16	01:00	02:00
SEC5	95	100	0.40	0.38	0.38	0.38	01:00	02:00
SEC6	75	100	0.17	0.13	0.13	0.13	01:00	02:00
SEC7	100	100	1.95	1.95	1.95	1.95	01:00	02:00

$DPR_{overall}$ =91.90% $Eo_{overall}$ =91.90%

Table-6 First Trial, During Maximum (Steady State) Flow and Deficiency Period in Automatic Upstream Control System

Point	Operation Performance Parameters							
	DPR %	Eo%	Qtarg	Qmean	Qmax	Qmin	Tbegin	Tend
SEC1	98	100	0.52	0.51	0.51	0.51	01:00	02:00
SEC2	100	94	0.40	0.42	0.42	0.42	01:00	02:00
SEC3	98	100	1.55	1.52	1.52	1.52	01:00	02:00
SEC4	100	96	0.44	0.46	0.46	0.46	01:00	02:00
SEC5	100	99	0.80	0.81	0.81	0.81	01:00	02:00
SEC6	100	96	0.33	0.34	0.34	0.34	01:00	02:00
SEC7	98	100	3.90	3.83	3.83	3.83	01:00	02:00

$DPR_{overall} = 98.50\%$ $Eo_{overall} = 98.50\%$

Therefore, there is some room for improvement in management during minimum flow. Releasing more water from storage dam is an option for increasing delivery performance ratio for offtakes that do not receive sufficient water. But this option is too costly, and management is always looking for a cheap solution.

DISCUSSION AND CONCLUSIONS

Since a Duckbill check structure was used as water level regulator in upstream control, during steady state and sufficiency periods relatively more flow (75% more) should be released from storage dam as compared with its variant alternative of self-regulating downstream control system. Most of the flow is lost at the end of SR canal to the drain, and could not be used by the secondary offtakes. It is felt that management in automatic upstream control is rather difficult, whereas for the self-regulating downstream control system management is relatively easy. In automatic upstream control during 50% delivery to secondary offtakes and steady condition of deficiency period, the offtakes were not satisfied (delivery performance ratio was low) accordingly. Therefore, step by step, more shutters of offtakes were considered to be opened, and the simulation was carried out in order to find out the best opening width (with maximum overall efficiency) for the secondary offtakes. Without a hydrodynamic model, if not impossible, it would be very difficult to establish the best opening width of the secondary offtakes during both periods of deficiency or sufficiency and steady state condition. In self-regulating downstream control system, instead of double baffle distributor for secondary offtake, single baffle could be used very effectively while it does not function properly in automatic upstream control. However, the high cost of top level embankments for the steep SR canal makes it very difficult to accept this alternative. Particularly if one pays attention to use of three relatively long syphons (SR canal is crossing one river, and two water courses), use of self-regulating downstream control could not be justified without economic analysis which is out of the scope of this report. An alternative of self-regulating system which would not need horizontal embankments is BIVAL or ELFLOW system. Since both of these systems are dependent on external power supply, they are not recommended for Shafarud Irrigation Project. Finally, the idea of taking into account the operational performance of new irrigation system at the time of design is becoming increasingly important every day, especially when it is realized that many old irrigation schemes do not function properly. One of the main reason is that water distribution and unsteady flow condition were hardly considered at the time of their design. After observing the results of simulation of unsteady and steady flow conditions in the primary canal of the Shafarud Irrigation Project, **automatic upstream control** with the following modifications and suggestions for upgrading the performance behavior of the system is considered to be better design option.

- Using an Amil gate for the water level regulator instead of Duckbill check structure;

- Change water delivery schedule to secondary offtakes and extend the time interval between two gate adjustments to at least one month in order to reduce the operational losses which are due to unsteady flow phenomena;

- Use hydrodynamic flow model for finding the best position for offtake opening during minimum flow delivery and steady state conditions.

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