TESTING P+PR CONTROL SYSTEM FOR PARTICIPATION OF WATER USERS IN DELIVERY MANAGEMENT

Mohammad Javad Monem[1], Mohammad Sadegh kiapasha[2]

ABSTRACT

Facing water shortage and increasing water demand, it is necessary to consume limited water resource in an optimal fashion. In agricultural sector as the biggest consumer of water, due to low performance of irrigation networks improving, water delivery systems and its performance with participation of water users and applying improved control system is a must. For this purpose in recent decades several automatic control Systems including P+PR system, for flow management in irrigation networks are introduced. Applications of these techniques provide a situation that water users play a direct role in water delivery with high flexibility. After introducing any automatic control system, their application in irrigation canals, requires testing of their performance in relation with other structures. Considering unsteady behavior of the flow in irrigation canals, using hydrodynamic models is a regular approach for testing performance of control systems. For this purpose international test cases including two types of canals, with specific operational instructions are introduced by American Society of Civil Engineering (ASCE). In this paper ICSS hydrodynamic model is applied on ASCE standard canal no. two to test the global performance of P+PR downstream automatic control system. After calibration of numerical coefficients of control system, the operational scenarios are applied, and performance indicators such as MAE and IAE which represent maximum and average depth deviation respectively and SRT which indicates response time of control system are determined. In addition to the performance indicators, depth, Flow and gate adjustments variations are depicted and analyzed. The results show that average depth deviations are in the range of 0.001 to 0.014 % and maximum depth deviations are in the range of 0.111 to 0.211 %. The response time of control system shows that the depth is stabilized in the allowable range at the first time step. Depth variation graph shows appropriate response of control system to flow variations. Performance indicators and depth variations shows appropriate functioning of the control system. Relying on the results of this study, application of this control system in irrigation canal which provide higher flexibility and direct participation of water users in management of water delivery could be suggested.

1- Assistant Professor, Tarbiat Modarres University, Tehran, Iran. Po.Box: monem_mj@modares.ac.ir
Tel: 44196523-5, Fax: 44196524.
2- M.Sc. Student Tarbiat Modarres University, Tehran, Iran.

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INTRODUCTION

Most of Irrigation systems due to poor management are performing below expectation. Poor management in irrigation networks results to inadequate and unjust water delivery which contributes to unsatisfaction of water users. Management of water delivery and corresponding control systems has a great impact on performance of irrigation networks. Considering limited water resources and necessity of optimal con consumption of water, requires participatory management and increasing the level of contribution of water users in water delivery. In order to reach to this goal it is necessary to increase the level of flexibility of water delivery which in turn leads to low water losses and higher productivity at farm level. Higher flexibility requires implementation of advanced automatic control system such as regular and specific downstream control systems. Automatic downstream control systems provide opportunity for water users to participate in management of water delivery directly and receive the required amount of water at proper time. P+PR control system is one of control systems applied in irrigation canal to provide higher flexibility.

In this research the Global performance of P+PR[1] control system which provide direct farmers participation in management of water delivery is evaluated.

INTRODUCING P+PR CONTROL SYSTEM

Several control systems with different characteristics are developed for irrigation canals. P+PR control system which can be use in both upstream and down stream control system is introduced by USBR[2]. In this control system the gate adjustment is calculated using a proportional and integral relation and is applied by an electromotor installed on the gate. It is possible to use four different filters such as depth dead band, gate adjustment tolerance, electromotor speed, and hydraulic filter. Depth dead band is a depth tolerance around target depth. If water depth remains in this range no action will be done. Gate adjustment tolerance is minimum limit of gate adjustment. If the calculated gate adjustment is less than this limit no action will be done. Electromotor speed filter controls the speed of gate adjustment to be less than allowable range. Hydraulic filter diminishes gate adjustment due to minor depth variations. Hydraulic filter is calculated using equation 1 and 2.

(1) $$Y_{fn} = \frac{C_{sf}(Y_{wn} + Y_{wp}) + Y_{fp}(1 - C_{sf})}{1 + C_{sf}}$$

(2) $$C_{sf} = \frac{\Delta t}{2T_f}$$

1- Proportional Plus Reset
2- United States Bureau of Reclamation

Where y_f is filtered depth, y_w and y_t are observed and target depth respectively, C_{sf} is simulated filters constant, Δt time step, and T_f is time filter constant. The combined actions of all the filters lead to stable operation of gate.

In P+PR control system the controlled out put which is gate adjustment is calculated using equations 3, 4 and 5.

$$\Delta G_p = K_p.(Y_{fn} - Y_t) \qquad (3)$$

$$\Delta G_i = K_i \int_0^k \left[(Y_t - Y_{fn}) \pm 0.5.Z_{db} \right] dt \qquad (4)$$

$$\Delta G_T = \Delta G_p + \Delta G_i \qquad (5)$$

Where: K_p and k_i are proportional and integral coefficient respectively. ΔG_T, ΔG_i, ΔG_p are proportional, integral and total gate adjustment respectively, Z_{db} is allowable dead band and n and p subscripts refer to present and past computational time steps.

In automatic operation the downstream depth is observed by sensor. The observed depth is filtered by equation 1. The filtered depth is compared with target depth and proportional gate adjustment is calculated by equation 3. The filtered depth is compared with dead band, if it is out of dead band the integral gate adjustment is calculated by equation 4. In equation 4 the plus sign for 0.5 Z_{db} is for the time when filtered depth is above dead band and minus is for the time when filtered depth is be below dead band. Finally the total gate adjustment is calculated by equation 5. The total gate adjustment is compared to gate filter, if it is less than that the gate adjustment is set to zero. Considering total gate adjustment the required gate speed in operational time step is calculated and compared to motor speed. If calculated speed is greater than allowable speed, the gate adjustment is set to the multiple of allowable motor speed and operational time step.

INTRODUCING THE ICSS[1] MODEL

ICSS hydrodynamic model is developed by Manz to simulate hydraulic, hydrology, and operation of irrigation conveyance system (Monem, 1990). The model is able to simulate one dimensional, gradually varied steady and unsteady flow under different operational conditions and control structures in canal with any cross sections. In ICSS model, hydraulic structures are considered as a boundary condition. For performing the hydraulic simulation the relations of boundary conditions are computed in four step such as computation of steady flow (BC[2]#D), operation (BC#C), unsteady flow computation (BC#A), and updating the parameters of boundary condition (BC#B).

1- Irrigation Conveyance System Simulation

2- Boundary Condition

MATHEMATICAL MODEL OF P+PR CONTROL SYSTEM

This control system is developed for controlling a rectangular flat slide gate as a boundary condition no.12 (BC12) and combined with ICSS model by Massah (Massah, 1380). Here short introduction of four step of this model is presented.

STEADY FLOW SIMULATION

Steady flow computation is started from the most downstream structure with a specific discharge which is determined in input data file. At P+PR boundary condition considering the specified discharge and hydraulic equation of flat sliding gate, the initial gate opening is calculated.

SIMULATION OF OPERATION

In flat sliding gate manual and automatic operation is considered which could be specified in input data file. In automatic operation the options of upstream control or downstream control is provided. The switches of four filters explained earlier could be set to on or off. In automatic operation the subprogram type c (BC12C) is called in each time step and gate opening is calculated using equations 1 to 5.

UNSTEADY FLOW SIMULATION

In order to compute unsteady flow the continuity equation for upstream boundary condition (G_o) and momentum equation for downstream boundary condition (F_N) and their partial derivations with respect to depth and velocity are required. The automatic flat slide gate With P+PR downstream control system works under submerged condition and G_o and F_N equations are derived as equation 6 and 7.

(6) $$G_0 \; : \; A_1.V_1 - A_N.V_N \; = \; 0$$

(7) $$F_N \; : \; A_1.V_1 - C_d.b.GO \; .\sqrt{2g(Y_N - Y_1)} \; = \; 0$$

In which, A is flow cross sectional area, V is flow velocity, C_d is flat slide gate discharge coefficient, b is gate width, GO is gate opening, y is flow depth, the subscript 1 and N refer to first node of downstream reach and last node of upstream reaches respectively. In unsteady flow computation at each time step the A subprogram is called, the equation 6 and 7 and their partial derivations with respect to depth and velocity are calculated and unsteady flow equations for whole canal reaches are solved for one time step. After calculating depth and velocity at all nodes along the canal, the B subprogram is called and flow depth and discharge are updated in boundary condition matrices.

CONTROL SYSTEM PERFORMANCE INDICATORS

For performance evaluation of P+PR control system, 3 indicators introduced by ASCE[1] (Clemens et al., 1998) and Monem (Monem et al., 1382) are used. The indicators are as follows:

Maximum absolute error (MAE**).** This indicator shows the maximum deviation between observed and target depth during operational period and is calculated by equation 8.

(8) $$MAE = \frac{\max\left| y_t - y_{target} \right|}{y_{target}}$$

In which: Y_t is observed depth at time t and Y_{target} is target depth.

Integral of absolute magnitude of error (IAE). This indicator shows the average deviation between observed and target depth during the operational period and is calculated by equation 9.

(9) $$IAE = \frac{\frac{\Delta t}{T}\sum_{t=0}^{T}\left| y_t - y_{target} \right|}{y_{target}}$$

In which: Δt is computational time step, T is operational period, and other terms are defined earlier.

System response time (SRT). System Response time is a time duration from when the observed depth is getting out of allowable range until when it get back and stabilized in the allowable range. The allowable rang is a tolerance around target depth as a percentage of target depth $((1\pm0.5\%\ X)\times Y_{target})$ value of X is determind by user (Monem et al., 1382). The smaller SRT shows the faster system response.

ASCE CANAL NO.2 AND OPERATIONAL SCENARIO

Different control Algorithms are tested and evaluated in different canals with different specifications. Canals specifications have a significant impact on performance of control algorithms. Therefore performance evaluation, comparison, and judgment of proposed control algorithms under this situation is not an easy job. To overcome these short comings ASCE working group has suggested two standard canals for testing new control algorithms (Clemmens et al, 1998). In this research ASCE canal no.2 is selected to test and evaluate the performance of P+PR downstream control system for participation of water user in water delivery management in irrigation canals. In this study the numerical coefficient of P+PR control system are also calibrated. The canal has a trapezoidal cross section with 1.5H: 1V side slope, and manning roughness coefficient of 0.02. Canal specifications are given in table 1.

1- American Society Civil Engineers

Table1. Specifications of ASCE standard canal no. 2

Reach	Length (m)	Upstream Elva. (m)	Downstream Elva. (m)	Bed slop	Bed width	Upstream Structure	Downstream Structures
1	7000	400.0	399.3	0.0001	7	Reservoir	1- turnout 1 2 – slide gate 1
2	3000	399.1	398.8	0.0001	7	Slide gate 1	1- turnout 2 2 – slide gate 2
3	3000	398.6	398.3	0.0001	7	Slide gate 2	1- turnout 3 2 – slide gate 3
4	4000	398.1	397.5	0.0001	7	Slide gate 3	1- turnout 4 2 – slide gate 4
5	4000	397.5	397.1	0.0001	7	Slide gate 4	1- turnout 5 2 – slide gate 5
6	3000	396.9	396.6	0.0001	7	Slide gate 5	1- turnout 6 2 – slide gate 6
7	2000	396.4	396.2	0.0001	7	Slide gate 6	1- turnout 7 2 – slide gate 7
8	2000	396.0	395.8	0.0001	7	Slide gate 7	1- turnout 8 2 – slide gate 8

In mathematical model all physical and hydraulic specifications of the canal and boundary conditions are defined in form of input data file for ICSS model. The flat slide gate between canal reaches is equipped with P+PR automatic downstream control system. At the canal inlet, a reservoir with automatic outlet is considered to satisfy the downstream requirements automatically. At the end of canal a stop log weir with fix height is considered. The numerical coefficients of the control system are calibrated under wide rang of discharge variation. In order to evaluate the performance of the developed P+PR control system for participatory management and operational scenario with large flow diversion from canal is simulated. In this operational scenario simulatenious and large flow diversion by water user at turnout no 1, 2, 3, 4 and 6 is taken into account. The response of control system and mutual impacts of check structures are studied and performance of control system is evaluated. For this study the dead band and gate tolerance are taken as 1 and 3 millimeters respectively. Target depth for check structures no. 1, 2 and 3 are 2, 1.9 and 1.8 meter respectively and for check structures no. 4, 5 and 6 are 1.7 meter. For this study the steady flow of 3 CMS and simultaneous flow diversion of 0.3 CMS by all turnouts is considered as initial condition for the first 12 hours. Total operational duration is taken as 36 hours. During this time the flow diversion of turnout no. 1, 2, 3, 4 and 6 have been increased and decrease by about 200% in two steps. Table 2 shows turnout flow diversion variations during operational period.

Table 2. Flow variation turn out no. 1, 2, 3, 4 and 6

Time (hour)	0-12	12-18	18-24	24-30	30-36
Discharge (CMS)	0.300	0.900	1.500	0.900	0.300

RESULTS AND DISCUSSIONS

For performance evaluation of P+PR control system for participatory management the explained operational scenario is simulated in ASCE standard canal no.2 and performance indicators are calculated for check structures which are give in table 3. Depth, discharge, and gate opening variations downstream of all check structures are depicted in figure 1 to 6.

The performance indicators given in table 3 shows that the maximum amounts of MAE and IAE for check structures are 0.211 and 0.014% respectively.

Table3. Performance indicators for P+PR control system

Check no.	MAE (%)	IAE (%)	SRT (1%)	Maximum deviation of depth from target level (cm)	Average deviation of depth from target level (cm)
1	0.200	0.010	0.000	0.400	0.019
2	0.211	0.014	0.000	0.400	0.026
3	0.111	0.007	0.000	0.200	0.012
4	0.118	0.003	0.000	0.200	0.006
5	0.177	0.004	0.000	0.300	0.007
6	0.119	0.001	0.000	0.200	0.002

The maximum depth deviation from target depth downstream of check structures is about 0.4 cm and the maximum average of depth deviation during delivery period is 0.026 cm. The value of SRT within %1 range for all check structures is zero. This states that depth was within the allowable range during delivery period. Considering practical accuracy required in irrigation networks for control structures the value of the indicators is completely acceptable.

Comparing the performance of check structures show that the value of indicators for mid-canal structures are in the same range, how ever for the upstream structures the indicators have higher values. This result shows that mid-canal structures have performed better than upstream structures. This result might be due to accumulative impact of diversion variations from downstream moving toward upstream. Since the control system is P+PR downstream control, moving toward upstream the amount of discharge delivery variation is accumulated. At the canal upstream the discharge variation is higher than in mid–canal which results to higher depth variation for upstream structures compared to mid-canal structures during operational period.

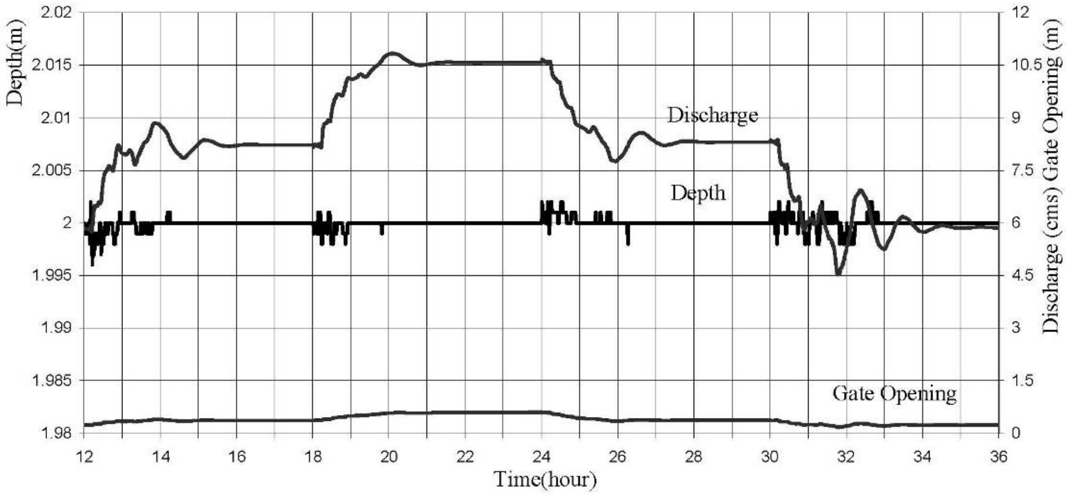

Figure 1. Depth and discharge variation downstream of check no. 1 and its gate opening

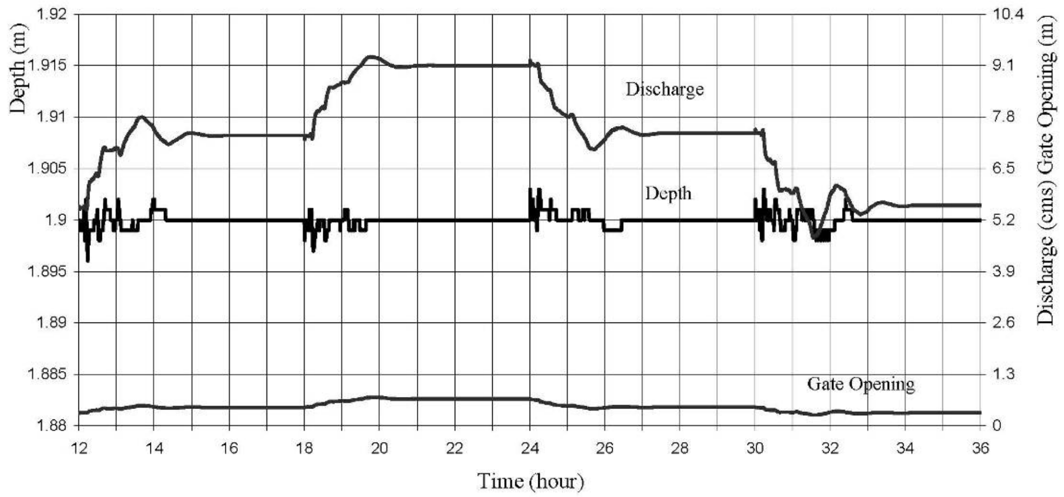

Figure 2. Depth and discharge variation downstream of check no. 2 and its gate opening

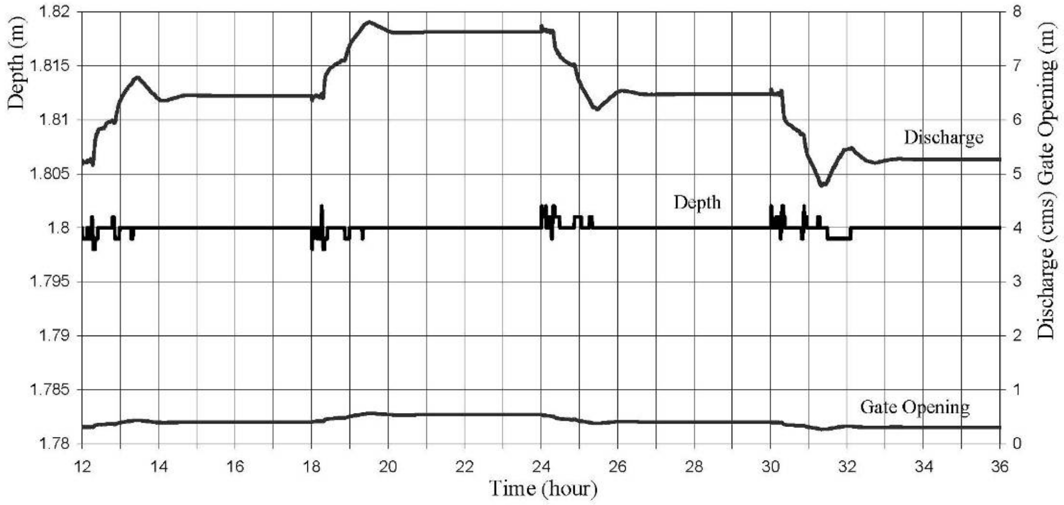

Figure 3. Depth and discharge variation downstream of check no. 3 and its gate opening

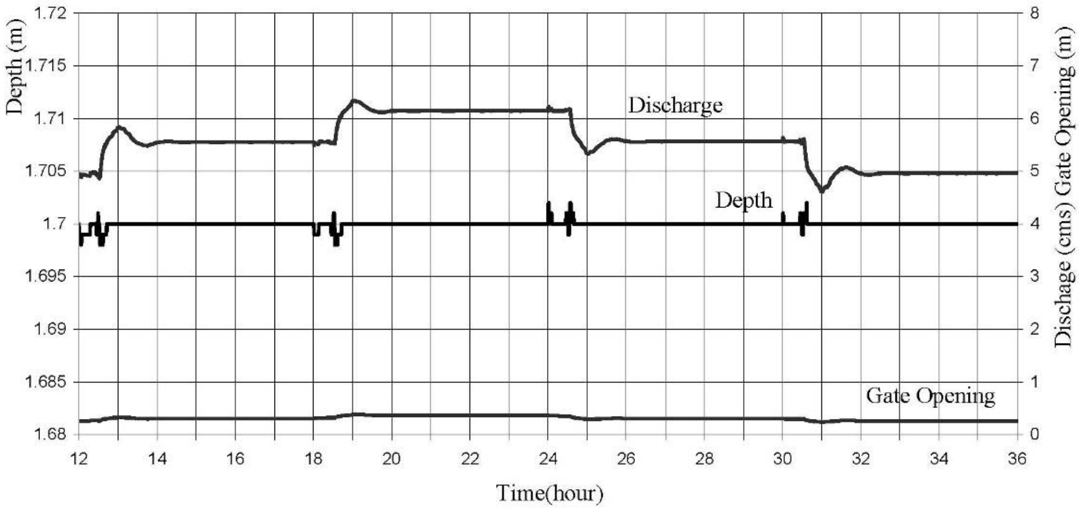

Figure 4. Depth and discharge variation downstream of check no. 4 and its gate opening

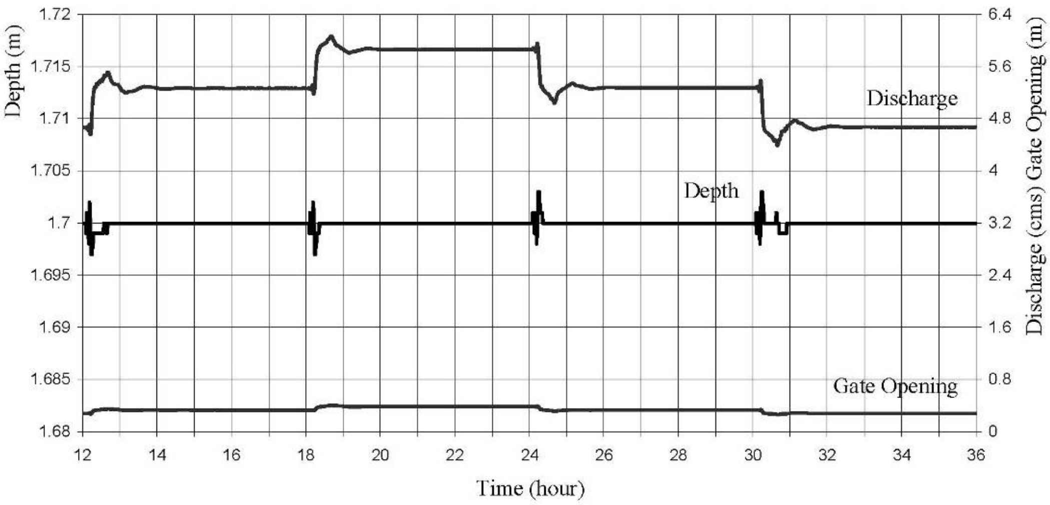

Figure 5. Depth and discharge variation downstream of check no. 5 and its gate opening

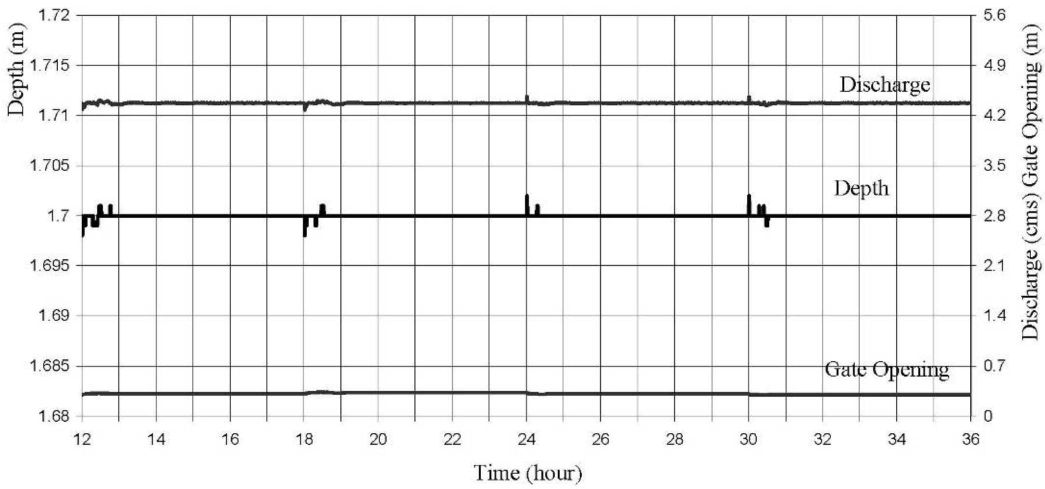

Figure 6. Depth and discharge variation downstream of check no. 6 and its gate opening

Figures of depth variation downstream of structures show that for each structure after controlling the initial variations due to diversion change, the depth is maintained at target depth and is stabilized in short time.

As a conclusion it could be states that the performance of developed P+PR automatic downstream control system for simultaneous and significant diversion variations of outlets is quite suitable and it could be used for direct participation of water users in management of water delivery.

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