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in

Lamaddalena N. (ed.), Bogliotti C. (ed.), Todorovic M. (ed.), Scardigno A. (ed.).
Water saving in Mediterranean agriculture and future research needs [Vol. 1]

Bari : CIHEAM

Options Méditerranéennes : Série B. Etudes et Recherches; n. 56 Vol.I

2007

pages 341-352

Article available on line / Article disponible en ligne à l'adresse :

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To cite this article / Pour citer cet article

El Kassar G.M., Kutija V., O'Connell P.E. **Design of real-time control algorithm for on-demand operation of irrigation channels.** In : Lamaddalena N. (ed.), Bogliotti C. (ed.), Todorovic M. (ed.), Scardigno A. (ed.). *Water saving in Mediterranean agriculture and future research needs [Vol. 1]*. Bari : CIHEAM, 2007. p. 341-352 (Options Méditerranéennes : Série B. Etudes et Recherches; n. 56 Vd.I)



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DESIGN OF REAL-TIME CONTROL ALGORITHM FOR ON-DEMAND OPERATION OF IRRIGATION CHANNELS

G. M. El-Kassar *, V. Kutija ** and P. E. O'Connell ***

* Dr., Senior Researcher, Water management Research Institute WMRI,
National Water Research Center, NWRC, Cairo, Egypt.

** Dr., Lecturer in Computational Hydraulics, University of Newcastle upon Tyne, UK.

*** Prof., Water Resources Engineering, Civil Engineering Dep., University of Newcastle upon Tyne, UK.

SUMMARY-It is well known that, over the past decades water problems has risen to the top of the global development agenda, so reviewing its uses to be under control and reduce its losses is a must. Monitoring of water levels/discharges is considered one of the most important challenges that facing the design/implementation of anew irrigation schemes. A new methodology technique for a downstream control algorithm for on-demand operation of irrigation systems is proposed. The concept within this method is achieved by maintaining the downstream end water level of the channel at a target set point by manipulating the upstream end structure in **real-time**. The effectiveness of the method is tested using a simulation model that is based on the de St.-Venant equations and the implicit Preissmann scheme. The control model is presented using the MATLAB- Simulink programming to facilitate the use of the designed Proportional Integral Differential PID controller for feedback and real-time adjustment of the upstream end structure. The results of the simulations show that the proposed control algorithm is able to provide an effective control of the flow and cope with rapid variations of water demands and unknown disturbances and guide us to the best water-supply hydrograph from the main water source.

INTRODUCTION

The main function of irrigation canal is to deliver water in an accurate and flexible way (Burt, 1987). The delivery is said to be accurate if the actual supply matches the intended supply, and it is said to be flexible if the delivery meets the changing water requirements of the users. This main function can be translated into a water level control problem consisting of two parts: First, the water levels in the system located just upstream of the off takes and control structures need to be controlled within a sufficiently small range. Second, adjusting the control structure located at the upstream end of the canal to control the preferably water levels.

This requirements guarantees that the delivery matches the demands, one of the most useful control strategies that satisfy this requirement is the downstream end of pool water level control in real-time. The control algorithm should be mathematically simple in order to require small computing effort. Various control algorithms have been proposed in order to reduce the height of dikes in downstream controlled systems. A number of control methods have been proposed for maintaining a constant water level at the downstream end of each pool. For the application/calibration purposes for the presented model in this research; an existing irrigation project channel's data has been used. For this case, the principle in building the model is to internalise as many variables as possible so that the model is nearly closed.

PROTOTYPE CONTROL PROBLEM

Drive control algorithm to run irrigation channel on-demand delivery by controlling the upstream gate openings to maintain the downstream end pool water level. The main benefit of using this control method is minimising the required height of bank's dikes for the system. As a result of the control model, and to ensure maintaining the target water level, the model should give the new adjustment of the upstream end gates. The proposed control algorithm is applied to a controlled channel pool that takes water from a main source (upstream gate) and bounded by gates at the downstream end, as illustrated in Fig. 1. Since the river works as a source of water, it is considered that the discharge on

the main river is much greater than the one in the controlled channel and that the water depth in the river is not affected by discharge deviation to the controlled reach.

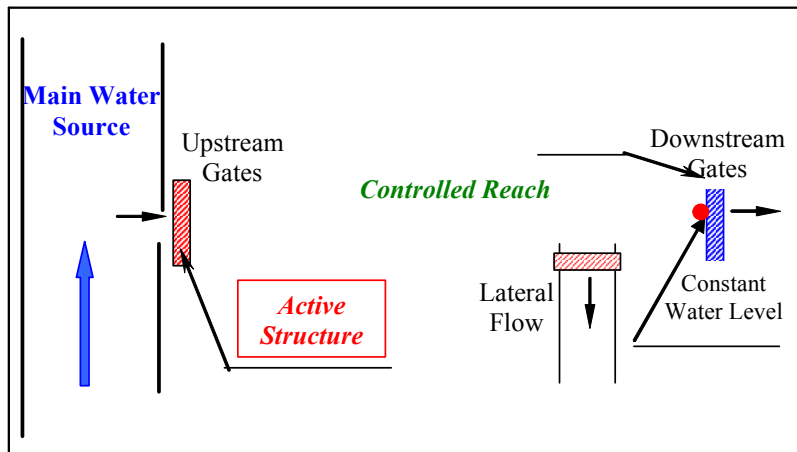


Fig. 1. Controlled Reach Scheme

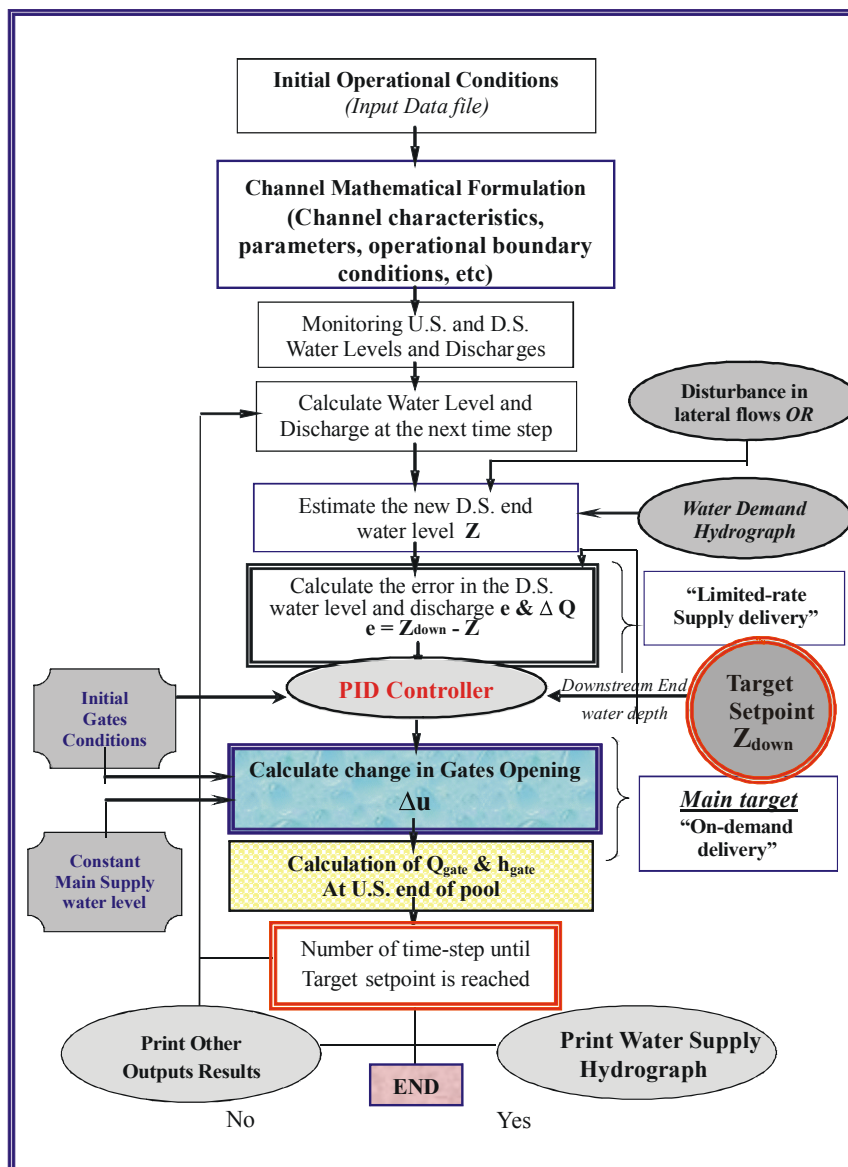


Fig. 2. Control Algorithm Flow Chart

The input to the algorithm is the water surfaces and discharges upstream the control structure, with the set point to be maintained. The output from the algorithm is an adjustment in the controlled gate openings, with response to some disturbance happened in the lateral flows from the system.

A simple algorithm of the proposed control model could be illustrated as in Fig. 2. The method will be tested for the control of an irrigation channel as illustrated in Fig. 3.

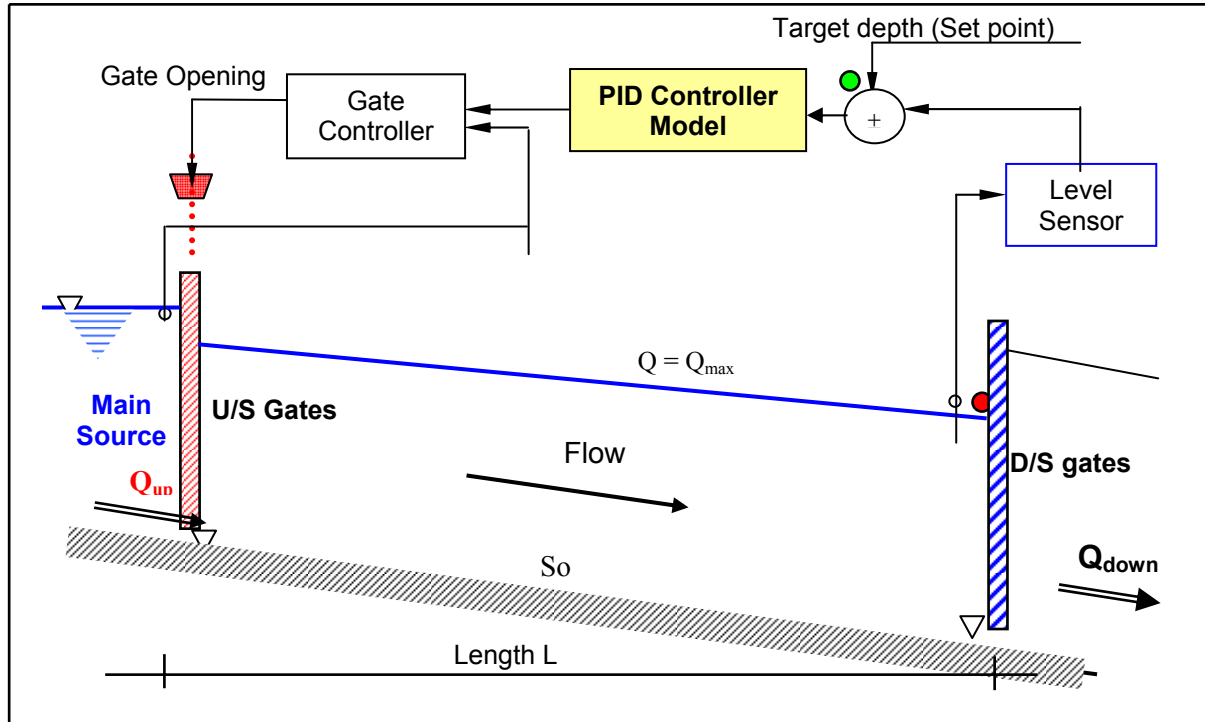


Fig. 3. Prototype of the controlled channel

WATER SYSTEM OPERATIONAL STRATEGIES

The disturbance in any irrigation systems may be caused by any increase or decrease in water withdrawal from the system or an incorrect setting of the control gates. In the case where the water level at the downstream end differs from the target level, some effort is needed to return it to the target setpoint. The value of the required adjustment is:

$$\Delta z = z_t - z \quad (1)$$

Where:

- Δz = change of water depth at downstream end of the pool;
- z_t = target water depth (setpoint);
- z = current water depth.

For Limited-rate Supply Delivery

In order to achieve a constant water level at the downstream of the pool, without more water supplies, in case of limited water resources, some changes for the downstream discharges are required; these changes will ensure a fast return to the target setpoint:

$$\Delta q = Q_{z_t} - Q_z \quad (2)$$

where:

- Q_{z_t} = the discharge related to target water depth;
- Q_z = the discharge related to current water depth.

This operational strategy might be the case in many irrigation channels; where a shortage of water resources from the main source may be expected.

For Downstream On-demand Delivery

In case of enough water resource in the main source; some effort is needed to adjust the flow of the upstream gates, to alter the water level in the downstream end, by the amount of Δz in equation (1). This will be the task of the controller provided to the designed control model.

MATHEMATICAL CONTROL MODEL AND BASIC EQUATIONS

Channel Equations and Simulation Method

The general forms of the simulation for the de St.-Venant equations are:

$$A_1 q_j + B_1 z_j + C_1 q_{j+1} + D_1 z_{j+1} = E_1 \quad (3)$$

$$A_2 q_j + B_2 z_j + C_2 q_{j+1} + D_2 z_{j+1} = E_2 \quad (4)$$

Where:

- $q_j, q_{j+1}, z_j, z_{j+1}$ are discharge and water level increments from time step n to $(n+1)$ at grid point j to $(j+1)$ respectively.
- $A, B, C, D,$ and E are coefficients computed at time step n .
- $\Delta x =$ distance interval; $\Delta t =$ time interval; $\theta =$ time-weighting coefficient;
- and $\Psi =$ distance-weighting coefficient

Solution by Double sweep Method:

$$q_{j+1} = F_j z_{j+1} + G_j \quad (5)$$

$$z_j = H_j q_{j+1} + I_j z_{j+1} + J_j \quad (6)$$

For the first upstream end node, this equation is:

$$A_{1_0} q_g + B_{1_0} z_g + C_{1_0} q_1 + D_{1_0} z_1 = E_{1_0} \quad (7)$$

So the values of (Z_g) is:

$$Z_g = \frac{E_{1_0} - (A_{1_0} Q_g + C_{1_0} Q_1 + D_{1_0} Z_1)}{B_{1_0}} \quad (8)$$

From the double-sweep method:

$$Z_1 = \frac{Q_1 - G_0}{F_0} \quad (9)$$

By substituting this value in the previous equation to obtain the value of the middle point(s) discharge Q_1 as a function of Q_g and Z_g , the following equation is estimated:

$$Q_1 = \frac{E_{1_0} + \frac{D_{1_0} G_0}{F_0} - A_{1_0} Q_g - Z_g B_{1_0}}{C_{1_0} + \frac{D_{1_0}}{F_0}} \quad (10)$$

From the implicit Preissmann finite difference scheme, it is known that:

$$Z_j = H_j Q_{j+1} + I_j Z_{j+1} + J_j \quad (11)$$

and

$$Z_{j+1} = \frac{Q_{j+1} - G_j}{F_j} \quad (12)$$

By substituting this equation to get the values of the downstream nodes discharge Q_{j+1} as a function of Z_j . The next relation is estimated.

$$Q_{j+1} = \frac{\left(Z_j - J_j + \frac{I_j G_j}{F_j} \right)}{\left(H_j + \frac{I_j}{F_j} \right)} \quad (13)$$

Gate Equation

The flow through a rectangular gate under submerged flow condition can be described as:

$$Q = C_d b u \sqrt{2g(z_{up} - z_{down})} \quad (14)$$

Where:

C_d = discharge coefficient; b = gate width; u = gate opening; and z_{up} , z_{down} = U.S. and D.S water depth. This equation can be rearranged as:

$$u = \frac{Q}{C_d b [2g(z_{up} - z_{down})]^{1/2}} \quad (15)$$

Once the values of water depth and discharges at the most upstream end are estimated, the required change of upstream gates opening (Δu) is computed at each time step.

DESIGN OF THE PID CONTROL ALGORITHM

The PID controller can be used to operate a structure in such a way that a specific hydraulic parameter (e.g. water level or discharge) is maintained (Schuurmans et al., 1995). The basic algorithm for a PID controller is given as:

$$v_s(t) = v_0 + K_p e(t) + K_i \sum_{t=0}^t e(t) + K_d (e(t) - e(t-1)) \quad (16)$$

where:

- K_p = Proportional gain factor.
- K_i = Integral gain factor.
- K_d = Differential gain factor.
- t = Sampling interval time
- $e(t)$ = error signal
- v_0 = Initial value of controlled input.
- $v_s(t)$ = Controlled output.

DESIGN OF THE REAL-TIME CONTROL MODEL

Fig. 4 shows simple sequences for the process of the designed control model.

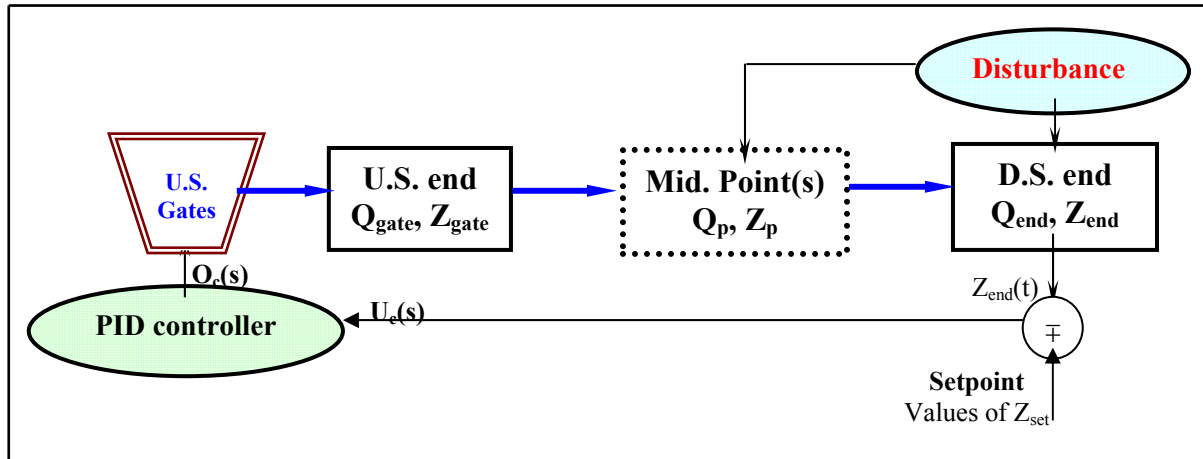


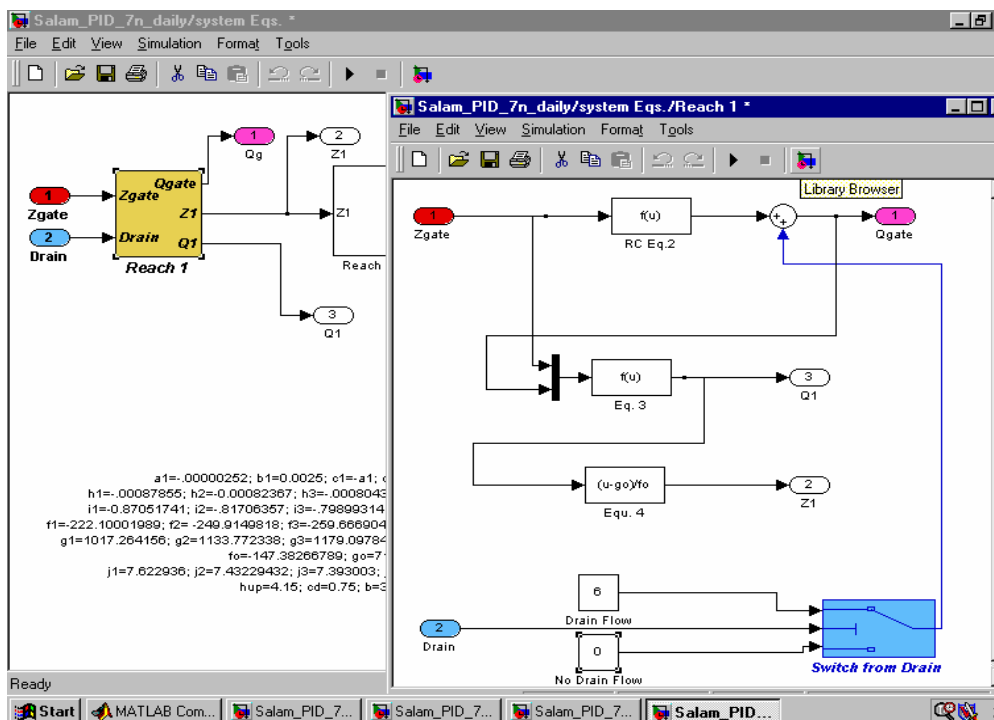
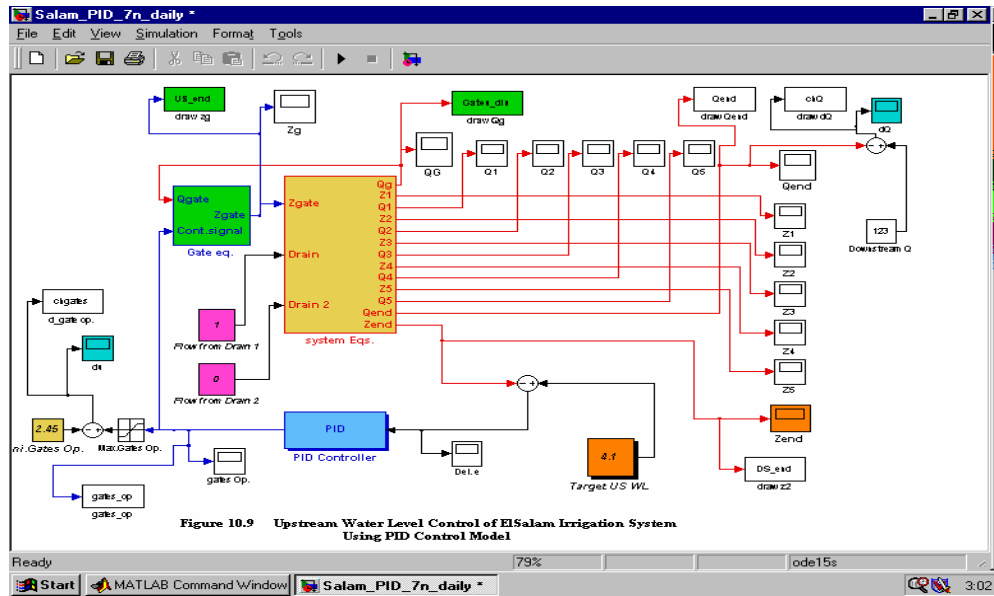
Fig. 4. Process of the designed control model

PID controller

This part includes the control parameters of the channel; (K_p , K_i , and K_d), they are estimated from the characteristics of the channel system (Van Overloop, 2000).

MODEL INTERFACE

Layout of the Control



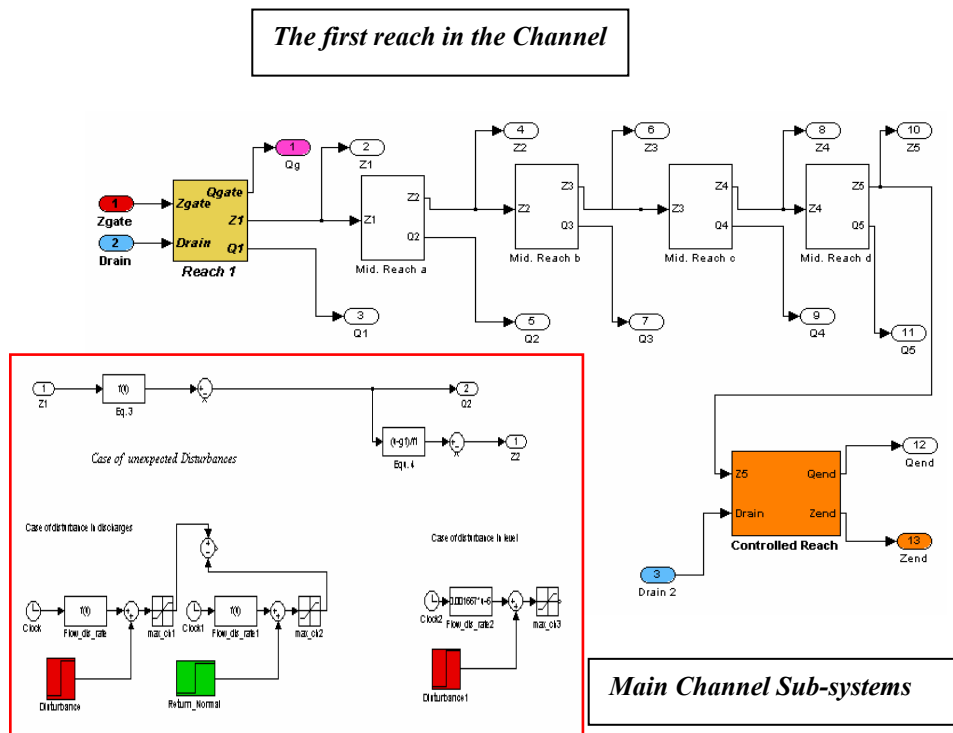
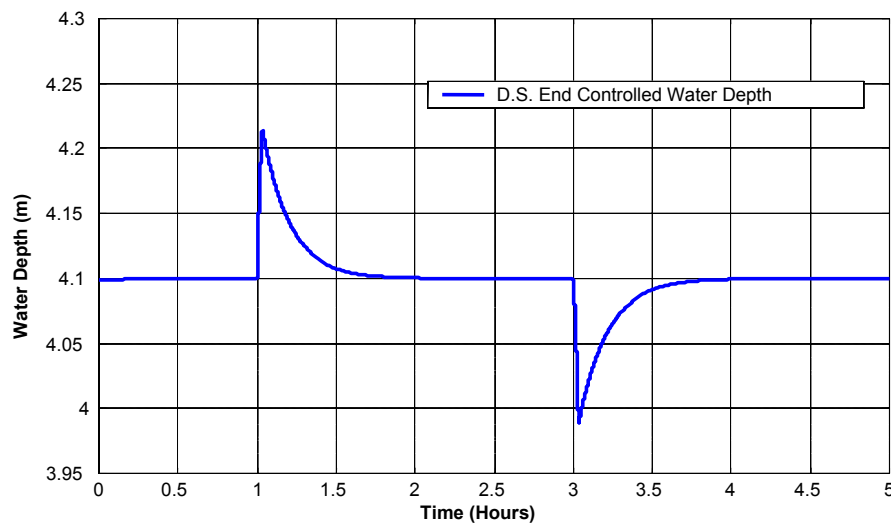


Fig. 5. Interface of the control model with the MATLAB-Simulink programming

TEST THE MODEL FOR REAL-TIME DELIVERY SCHEME

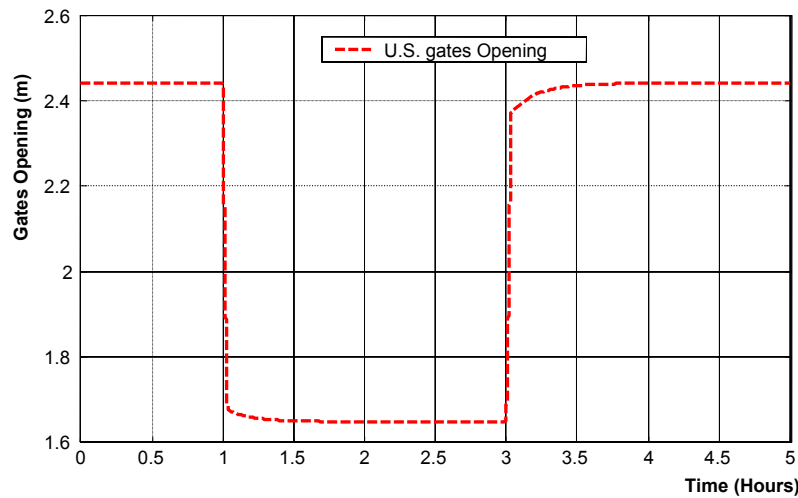
Case of Failure in Lateral Off takes Pumps

As an example to test the performance of the control model, the flow rate in the lateral channels decreased by 50 m³/sec. within 2 minutes. Graph 1 shows the behaviour of the control system to maintain the allocated set point.

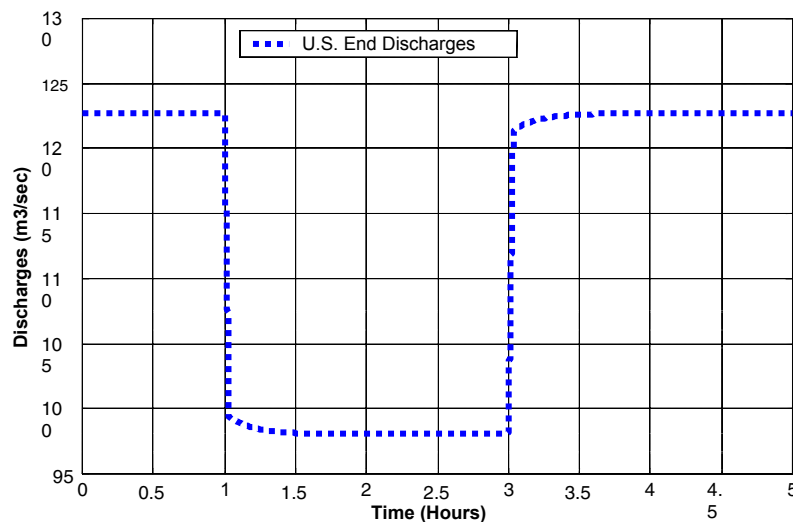


Graph 1. Controlled water depth at Set point

The performance of the control model at the U.S. end of the pool is given in Graphs 2 and 3. A self-tuning response of the upstream gates according to the disturbance is expected.



Graph 2. Adjusted U.S gate openings



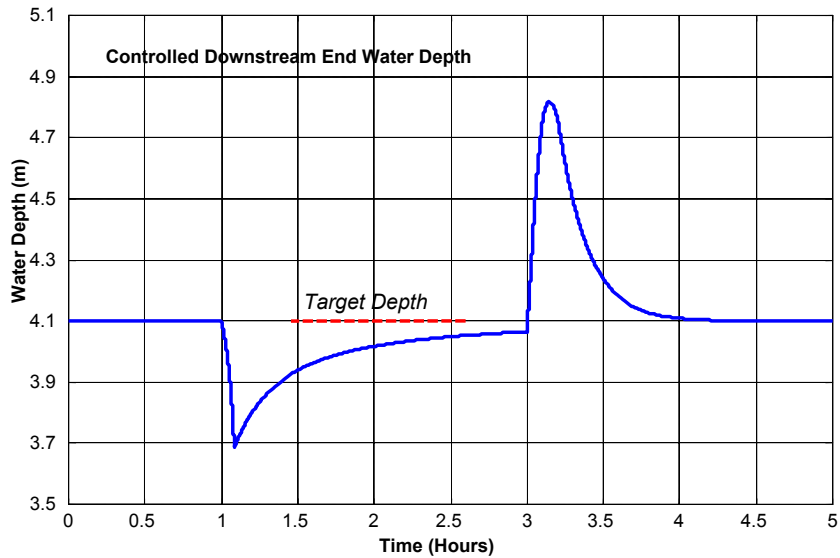
Graph 3. Estimated U.S water releases

THE CASE OF HIGH WATER WITHDRAWAL

This case of disturbance is to test the performance of the PID controlled in case of high withdrawal, which may be due to emergency water demands for a certain period.

To present this case an increase of water demand by 50 m³/sec. is assumed. The question here may be: *is the controller able to match any unexpected increase in water demands?* The answer is **no**. The restrictions on maintaining the target water depth as a result of any unexpected disturbances could be subjected by one of the following constraints:

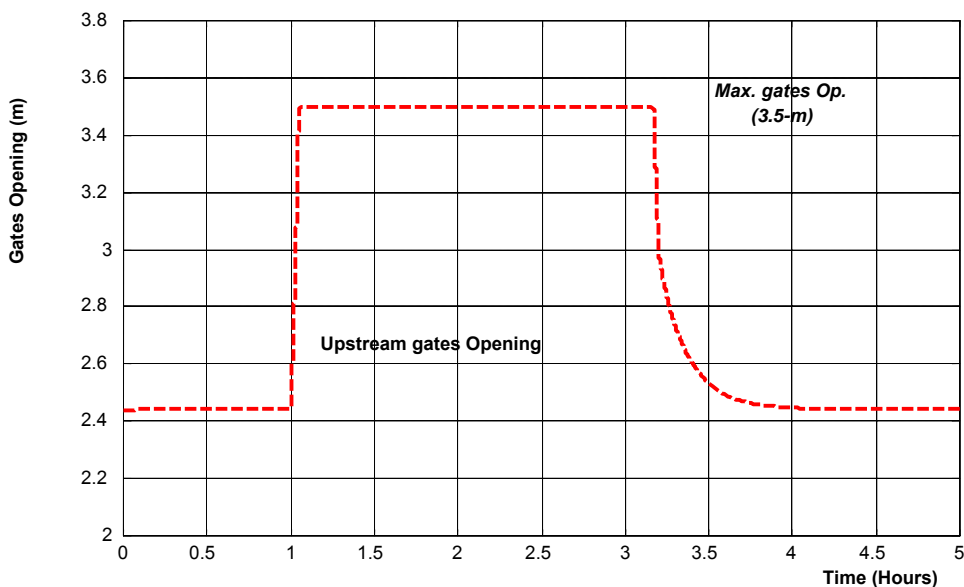
- a. The availability of water resources in the main water supply;
- b. The capacity of the intake.



Graph 4. Controlled D.S. end water depth (high demand)

Graph 4 shows the expected profile of the water level at the downstream end of the channel due to a high withdraws by lateral off takes. It is cleared that the target water depth is not maintained. Graph 5, shows the adjusted upstream gate openings; the gates reach maximum opening and the maximum water discharges is reached. When comparing the two graphs, however, when the maximum discharges is supplied to the system, the target water depth at the downstream end of the system is not maintained and the controller is not able to satisfy the constant water level target.

In the meantime the outputs from the previous cases indicate that the performance of the designed control model could cope with any unexpected disturbances and able to maintain the target water depth if the previous two constraints are satisfied.



Graph 10. Adjusted U.S. gate openings (high demand)

CONCLUSION

This research has proposed a downstream control algorithm for on-demand operation of irrigation channel system by maintaining the downstream end water level of a system by manipulating the upstream end structure in real-time.

The main difference between the presented control and the classical downstream water level control theory is to take the advantage of the upstream control theory mainly the low bank's dikes required. Also, the proposed control method is able to handle unknown disturbances in the system.

For comparison reasons, all testes presented are performed on the same proposed irrigation system. Similar tests could be carried out for canals of different sizes and hydraulic parameters. The performance of the controlled system was tested also for operating the system under given demand-patterns hydrograph, the performances of the model for self-tuning the supply gates opening and calculate the supply-patterns was rather good.

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