HYDRODYNAMIC BEHAVIOR OF A CANAL NETWORK UNDER SIMULTANEOUS SUPPLY AND DEMAND BASED OPERATIONS

Sarfraz Munir[1]
Bart Schultz[2]
Abdul Hakeem Khan[3]
F.X. Suryadi[4]
Francis Gichuki[5]

ABSTRACT

The irrigation network of this study consists of three branch canals (the Machai Branch Canal, the Pehure High Level Canal (PHLC) and the Maira Branch Canal) connected to each other in such a way that the Machai Branch and the PHLC feed the Maira Branch Canal for providing a reliable irrigation service. The Machai Branch Canal has limited and erratic discharges and can not fulfill the peak water requirements of the Maira Branch Canal and therefore any deficiency in the supplies to the Maira Branch Canal is automatically compensated by the PHLC. PHLC is an automatic canal and has been equipped with Proportional Integral Derivative (PID) discharge controllers at its head whereas the Machai Branch Canal has fixed supply based operations. The Maira Branch Canal is also an automatically downstream controlled irrigation canal, which is operated according to crop water requirements using Crop Based Irrigation Operations (CBIO) model. Under this scheme of operations the flows remain changing most of the time following the crop water requirements curve. The frequent changes in discharges keep the canal in unsteady state conditions, which affect the functioning of automatic discharge and water level regulation structures. Efficient system operation is a prerequisite for getting better water productivity and the precise understanding of the behavior of the structures and canal's hydrodynamics against such changes is a key for getting effective system operations. In this paper the canal's hydrodynamic behavior and the automatic structures' functioning have been assessed and suggestions have been provided to fine tune the automatic discharge controllers in order to avoid the oscillatory and abrupt hydrodynamic behavior in the canal. The guidelines have been provided for the operation of the secondary system for achieving smooth and sustainable operations of the canals. In addition to this the effects of any discharge variation in the Machai Branch Canal on the automatic discharge controller's behavior also has been assessed.

---

[1] PhD Student, Water Engineering – Land and Water Development, UNESCO-IHE, Westvest 7, 2601 DA, Delft, the Netherlands, Phone: +31 15 2152 374, Fax: +31 15 2122 921, e-mail. s.munir@cgiar.org

[2] Professor of Land and Water Development, UNESCO-IHE, Delft, the Netherlands, Top advisor, Rijkswaterstaat, Utrecht, the Netherlands, e-mail. b.schultz@unesco-ihe.org

[3] Head IWMI-Pakistan, International Water Management Institute, Lahore, Pakistan, Phone: +92 42 5410050, e-mail: a.khan@cgiar.org

[4] Senior Lecturer, Land and Water Development, UNESCO-IHE, Delft, the Netherlands

[5] Principal Researcher, IWMI-Colombo, Sir Lanka. E-mail: f.gichuki@cgiar.org

INTRODUCTION

The irrigation system of Pakistan was designed about a century ago with the philosophy of protective irrigation, for spreading less water to vast agricultural lands for producing food to avoid the risk of famine. But with the passage of time parts of the irrigation system deteriorated because of inadequate operation and maintenance conditions, which resulted in low water productivity. On the other hand the region's population escalated so high that the population, which was only thirty million in 1947, touched the figure of 160 million in 2005. The food and fiber requirements soared so high that the granary of the old times became unable to feed such a large number of people.

Irrigation plays a crucial role in the agricultural sector of the country as seventy percent of the agricultural produce is from irrigated agriculture. The Indus Basin Irrigation System of the Pakistan is one the world's largest contiguous river flow irrigation system, consisting of most of the canal commands based on the protective irrigation philosophy. In the early nineties the government enhanced the water allowance of some of some of the canal commands in North-Western Frontier Province (NWFP) and increased it to 0.7 l/s/ha from the conventional 0.28 l/s/ha for getting higher cropping intensity and productivity. Now in Pakistan there are four canals having higher water allowance and are considered to be designed under productive irrigation concept (Helsima, 2002).

High water allowances improve water availability and cause agronomic benefits but also cause some ill effects like waterlogging and wastage of water, if used injudiciously. High water availability typically leads the irrigator to apply more and more water, which results in waterlogging. This problem has been tackled by adopting CBIO under which the supplies to canal command area are made compatible with the crop water requirements. As crop water requirements vary throughout the growing season, as a result the supplies also vary accordingly under CBIO. Judicious system operations are the perquisite for getting maximum benefits from any irrigation scheme and the assessment of hydrodynamic behavior of the irrigation canals provides a tool for getting efficient system operations.

Rationale of the Study

This irrigation system is a combination of fixed supply based and flexible demand based operations. The supply-based system is fully manually controlled whereas the flexible demand based system is automatically controlled at main canal level and manually controlled at the secondary level. The question arises here is how the operation of the manually controlled irrigation system affects the hydrodynamics of the automatically controlled system. For example how the automatic discharge controllers respond to any change in the flow, how the amount of discharge variation (water used or refused) and the location of this change along the canal affect the stability and response times in the automatically controlled irrigation canal? The time elapsed in reaching the effect downstream and gaining new steady state conditions are important to know in a manually upstream controlled irrigation canal whereas the reaction from the automatic discharge controllers and the stability of the hydrodynamics of the automatically downstream controlled irrigation canals are important to know for attaining equitable, reliable and stable canal operations.

Objectives

The overall objective of the study is to develop guidelines on how the canal network can be operated to improve the performance of the water delivery and distribution system. To produce these guidelines we need to:

- fine tune the (Proportional Integral, PI) controller for achieving smooth, stable and quick behavior of the automatic discharge controller at the PHLC head;
- assess the effects of various options of Crop Based Irrigation Operations on the automatic hydraulic behavior and stability of the canal;
- assess the effects of changes in water supply from the Machai Branch Canal on the response of discharge controllers at the PHLC head.

METHODS AND MATERIALS

Description of the Study Area

The study area lies in the North West Frontier Province (NWFP) of Pakistan between longitude 72^o to 72.8^o East and 33.9^o to 34.1^o North with a cultivable command area (CCA) of 89,300 ha. It gets water from two water resources, the Swat River and the Indus River. There is no reservoir at the headworks at the Swat River whereas at the Indus River there is the Tarbela Reservoir. The water availability in the rivers depends upon the snow melting on the mountains and rainfall in the catchments therefore they have maximum discharges in summer, especially in the monsoon and minimum in winter. The overall climate of the area is semi-arid with an average annual rainfall of 600-920 mm, of which 60 % occurs in the monsoon. The mean minimum and maximum temperatures vary between $3.5\text{-}42.2^o$ C. The average relative humidity is 40-72%, and pan evaporation is 77-428 mm/month (WAPDA, 2002). Schematic layout of the area is shown in Figure 1.

Irrigation Infrastructure

The irrigation system consists of three branch canals Machai, Maira and PHLC (Pehure High Level Canal). The Machai Branch canal is located at the upstream end and gets water from the Swat River through Upper Swat Canal and the PHLC gets water from Indus River through the Tarbela Reservoir. PHLC falls into Machai Branch Canal at a confluence downstream of RD 242 at an abscissa of 74000 m at Machai Branch Canal. These canals feed their own secondary system and also supply water to the Maira Branch Canal. The design contributions to Maira Branch Canal are from Machai 14 m^3/sec and from PHLC 24 m^3/sec. These supplies are variable as the system has demand-based operations and maximum discharge capacity of the canal at the confluence is 32 m^3/s. Salient features of the irrigation canals are given in Table 1.

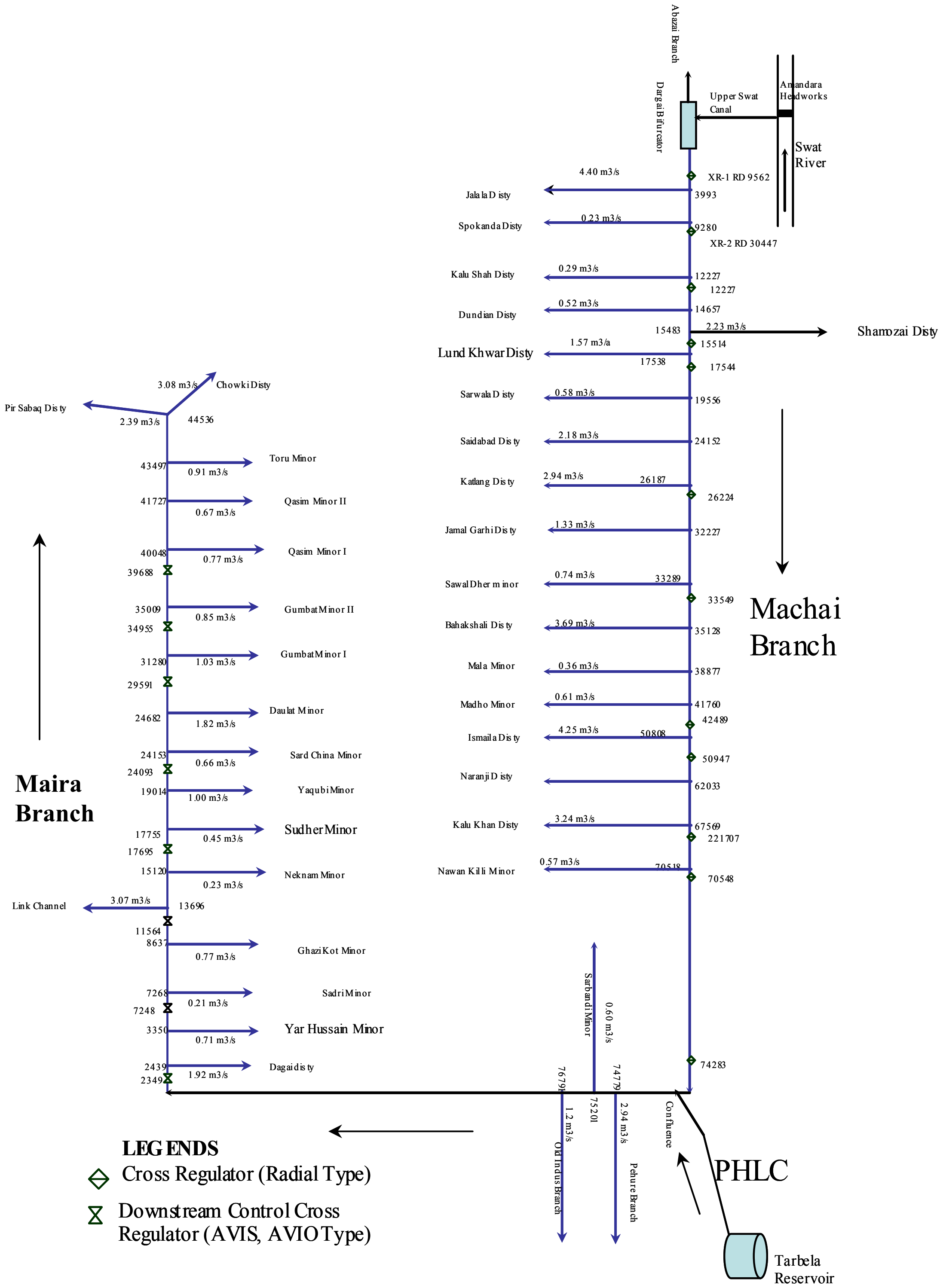

Figure 1. Schematic Map of the Study Area

Table 1. Salient Features of the Study Canals

S. No.	Description	Machai Branch Canal	Pehure High Level Canal	Lower Machai (d/s RD 242)	Maira Branch Canal
1	Discharge (m^3/s)	66.7	28.3	31.9	27.0
2	CCA (ha)	48,556	5,100	6,728	29,000
3	Length (km)	73.80	25.46	3.74	44.77
4	Cross regulators	12 No. Radial gates	03 No. AVIO, 02 No. AVIS		08 No. AVIS gates
5	Water level regulation	Manual	Automatic	Automatic	Automatic
6	Discharge control	Manual	Automatic	Automatic	Automatic
7	Secondary offtakes	21	5	3	17

System Operations

Operation Modes. The system has two modes of operations, fixed supply based operations (SBO) in the Machai Branch Canal and flexible demand based in the Maira Branch Canal and the PHLC.

Discharge and Water Level Controls. The supplies at the Machai Branch Canal head and water levels in the canal are manually controlled. In PHLC, the supplies at the head are controlled automatically at Gandaf Tunnel Outlet (GO) by automatic discharge controllers and water levels in the canal are controlled by automatically downstream controlled AVIS and AVIO cross regulators. The Gandaf Tunnel Outlet has been provided with a SCADA (Supervisory Control And Data Acquisition) system for automatic discharge control and monitoring, having PID based discharge controllers. Water levels in the main canal are controlled by AVIS and AVIO type cross regulators.

Secondary Offtakes Operations. The operation of the secondary system is manual in both the Machai and Maira Branch Canals and is automatic in PHLC except for one secondary offtake. In the Machai Branch Canal, the secondary offtakes are operated according to the water availability in the canal. In the Maira Branch Canal, the secondary offtakes are operated according the crop water requirements. The water use and refusal in the Machai Branch Canal depends upon water availability whereas in the Maira Branch Canal and the PHLC it depends upon crop water demands.

Crop Based Irrigation Operations (CBIO). It is a canal operations strategy in which the irrigation water supplies are made compatible with the command area crop water requirements (CWR). As the CWR are low in the beginning and end of the crop season and high in the middle, CBIO follows the same trend for supplying water. Less water is supplied during low requirements and maximum water is supplied during peak requirements. Lower Machai (downstream RD 242) and Maira Branch canal systems are operated according to CBIO. When the supplies fall below 80 % of the full supply discharge, a rotation system is introduced among the secondary offtakes. During very low crop water requirement periods the supplies are not reduced beyond a minimum of 50 % of the full supply discharge. These are the operational rules[6] of CBIO, which were envisaged during system design (Wisansawat & Pongput, 2000).

SCADA System. Supervisory Control And Data Acquisition (SCADA) is a real time discharge monitoring and control system, which collects the data on actual water levels and automatically controls the discharge supplies. A setpoint is established in the canal and any deficiency/excess to this setpoint is automatically adjusted, based on the choice of automatic discharge controller. In this system the setpoint is an absolute water level of 382.15 m above the mean sea level. A sensor has been installed one kilometer downstream and is connected electronically to the Master Control Panel (MCP), from where the control actions are taken according to the difference between target and actual water levels. The MCP is supported by a Hydraulic Power Pack to operate regulation valves. The discharge controllers in the SCADA system are the PID (Proportional Integral Derivative) controllers. A Human Machine Interface (HMI) has been provided to exchange information with the operator and to enter new desired values.

PID Controller. PID is an automatic discharge control algorithm, which compares the actual water level in the canal with the target water level and instructs the regulator (in this case the SCADA system) about the difference and action. The PID is a combination of P, PD or PI controllers. To understand the PID the definition of P, PD and PI controller is required which has been elaborated here. The P controller is the simplest continuous controller. Any deviation $\in$ at moment t actuates the regulator and is proportional to the difference $\in$ between measured water level and the setpoint (the target water level). The intensity of the controller reaction is given by the proportional gain factor, Kp. A low absolute value of Kp leads to damped gate reaction and a high value leads to a strong reaction of the regulator and may cause instability (Ankum, undated). The reaction from the P controller can be supported by applying a damping effect to the gate movement by D controller. The D-controller (Derivative controller) is added to the P-controller, to create a PD-controller. Its function is to anticipate the future behavior of the controlled variable (water level) by considering the rate of change. The D-controller avoids any rapid increase or decrease in the water levels caused by extra opening or closing of the gate. An I-controller always forces the water levels back to the setpoints. The integral gain factor, Ki, inserts a memory of deviations $\in$ of the past, by taking the sum of the all deviations up to the present time. Finally the PID is the combination of these three controllers for giving smooth and stable reactions to the deviations. It became available commercially in the 1930s. The first computer control applications in the process industries entered into the market in the early 1960s (Seborg et al. 1989).

Modeling Canal Operations

The assessment of hydrodynamic behavior of an irrigation canal network under varying flow conditions is a prerequisite for attaining efficient system operations. A computer model SIC (Simulation of Irrigation Canals) has been used to assess the hydrodynamics of the study canals. This is a 1-D hydrodynamic model which allows the simulation of irrigation canals under steady

---

[6] Operation Rule: The secondary offtakes can not be operated below 80% of design discharge and can not be kept closed for more than one week under CBIO in order to maintain equitable distribution of water and to avoid sedimentation in the secondary canals.

and unsteady state flow conditions (Cemagref, 2003). In steady state simulations it solves the differential equation of the water surface profile by numerical discretization. In unsteady state simulations it computes water surface profile in the canal by using Saint-Venant equations. These equations are solved by implicit finite difference discretization using Preissmann's scheme. In addition, the simulation model needs upstream and downstream boundary conditions as upstream discharge and downstream depth-discharge relationship.

Calibration of the Model. The model was calibrated by measuring water levels and discharges in the Maira Branch Canal. The canal was kept running for two to three days to obtain steady state conditions. Then the canal divided into three parts for the discharge and corresponding water level measurements and all of the inflows and outflows to and from these parts were measured. The resulting water levels were measured at the upstream and downstream of every cross regulator. The measured values were then compared with the simulated values of the discharges and water levels.

RESULTS AND DISCUSSIONS

CBIO Schedules

Figure 2 presents the crop water requirements of the area and the CBIO schedule for supplying irrigation water. In the CBIO schedule the crop water demands and supplies have been tried to match closely in order to control groundwater recharge and to minimize the water losses. The minimum flows have been provided fifty percent of the full supply discharge, when fifty percent of the offtakes remain closed for one week and the other fifty percent remain open. This rotation continues until the water requirements go higher than fifty percent. Then sixty seven percent offtakes are opened and if further demand increases then seventy five percent of the offtake are kept open. This rotation remains applicable until the crop water requirements go higher than the eighty percent of the design discharge. Then the system remains fully open until the crop water requirements fall below eighty percent again.

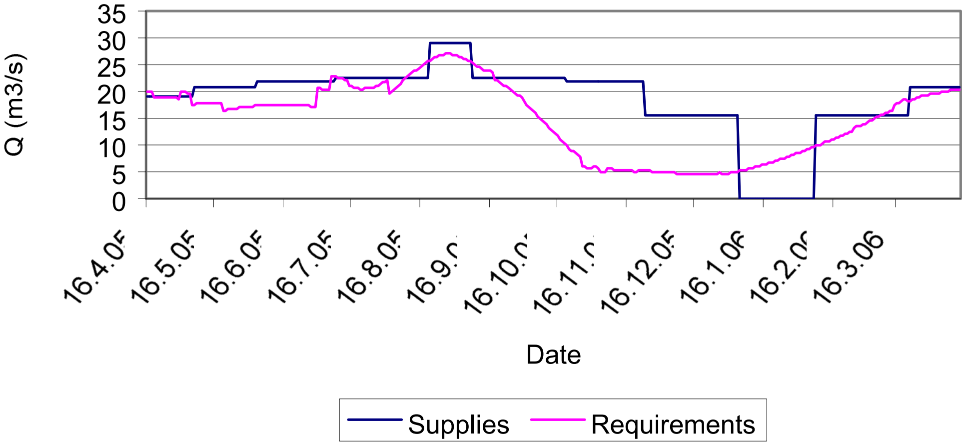

Figure 2. CBIO Schedule for the Year 2005-06

Calibration Results

The model was run according to the field conditions. The discharge withdrawn by the offtakes was imposed on these offtakes in the simulation, which resulted in good match even by having the design Manning roughness values. Figure 3 presents the measured and simulated water levels along the canal. The measured and simulated water levels are pretty close to each other.

The measured and simulated discharges were also compared along the canal. The discharge measurement took place at head, middle, and tail of the canal. This comparison shows that the measured and simulated values are fairly close to each other. The simulated and measured downstream water levels are almost same and the simulated upstream water levels are on average 0.12 m higher than the measured ones. The discharge comparison results are shown in Table 2.

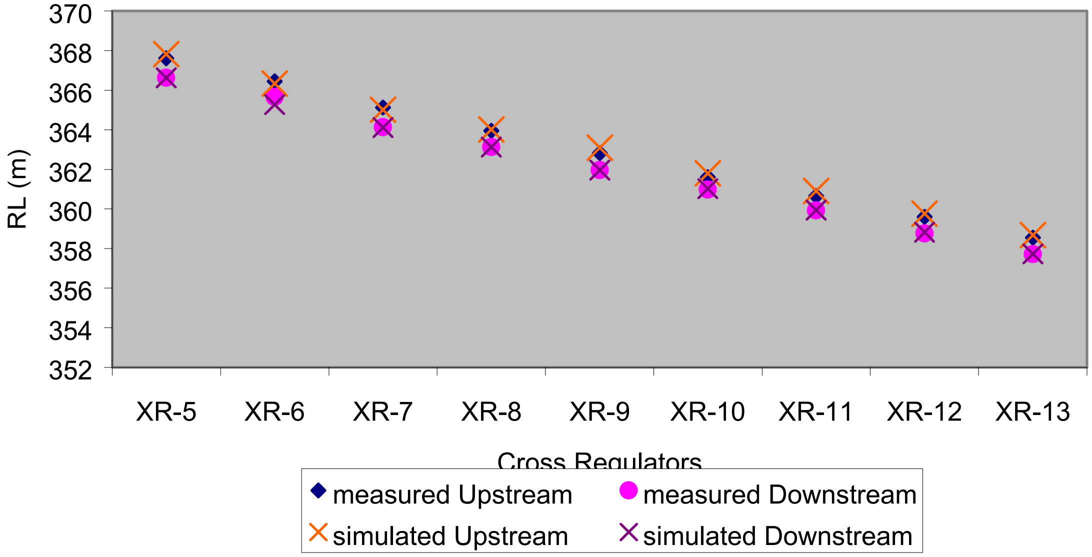

Figure 3. Water Levels (Simulated and Measured)

Table 2. Measured and Simulated Discharges along the Canal

S. No.	Location	Distance from Head Gate (m)	Q Measured (cumec)	Q Simulated (cumec)	% Difference
1	Head	500	18.01	17.56	2.50
2	Middle	16570	11.91	11.56	2.94
3	Tail	43220	6.55	5.99	8.55

Fine Tuning of PID Factors

The PID coefficients play a key role in water regulation in the continuous automatic flow control systems. The selection of correct values of the proportional, integral, and derivative gain factors leads to a safe and stable operations of the canal and prevents any oscillatory behavior of the automatically regulated hydromechanical gates. The quick response of the discharge regulator to the deviations from the setpoint (proportional property), the damping effect to these responses (derivative property), and finally meeting the setpoint (the integral property) are the characteristics of PID controllers. Various values of PI factors have been tested in order to find some optimum values for improving the hydrodynamic performance of the system in case of frequent changes in flow demand and supply.

Kp (Proportional Gain Factor) Values. Three different values of proportional gain factors have been tested as given in Table 3 along with other information on the refusal of the discharge and their location.

Table 3. Different Values of Kp and Other Parameters

S. No.	Kp value	Q from Machai	Q at PHLC Head	Q at Confluence	Q refused (% of Q @ confluence)	Location of closed offtakes
		m^3/s	m^3/s	m^3/s		
1	1.30	8.00	17.50	25.5	24%	Head
2	2.00	8.00	17.50	25.5	24%	Head
3	2.50	8.00	17.50	25.5	24%	Head

In Figure 4 the results of the simulations have been presented where the target water level is 382.15 m. An amount of 6.06 m^3/sec discharge was refused at the head of the Maria Branch Canal by closing five secondary offtakes. The discharge released under three different values of the Kp factor, as given in the Table 3, was tested and the effect was observed on the reactions from the Gandaf Tunnel Outlet (GO) and the results are shown in Figure 4.

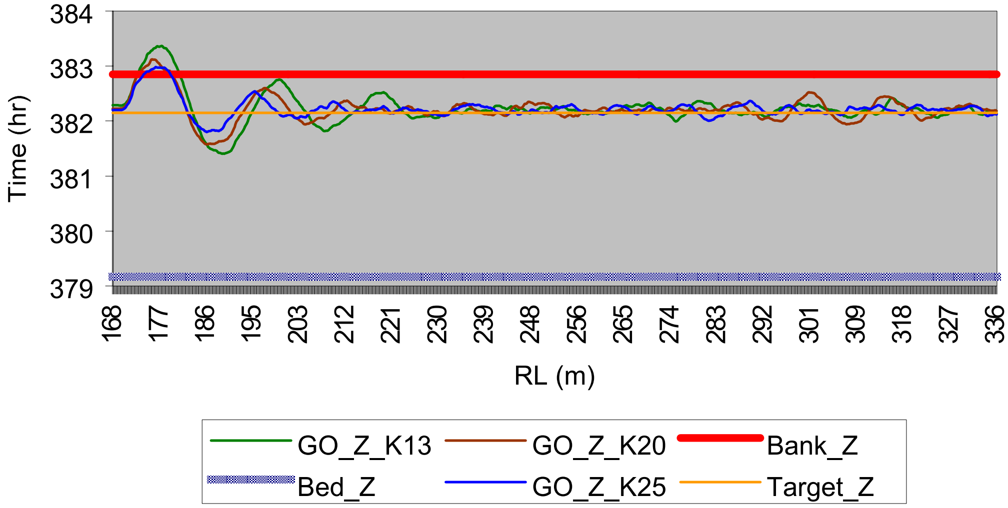

Figure 4. Water Level Oscillations Under Different Kp Values

Figure 4 shows that the Kp = 1.30, which is basically the same value used at the Gandaf Tunnel Outlet, gives oscillatory behavior and requires a long time to comeback into steady state conditions, whereas the Kp values 2.00 and 2.50 give comparatively less oscillations and the discharge gets stable earlier. The discharge released against these Kp values is shown in Figure 5, which also shows almost the same behavior. The discharge released under Kp = 1.30 becomes stable after about 64 hours, whereas it becomes stable under Kp = 2.00 and Kp = 2.50 after 46 hours. The maximum and minimum discharge released under all these Kp values is almost the same.

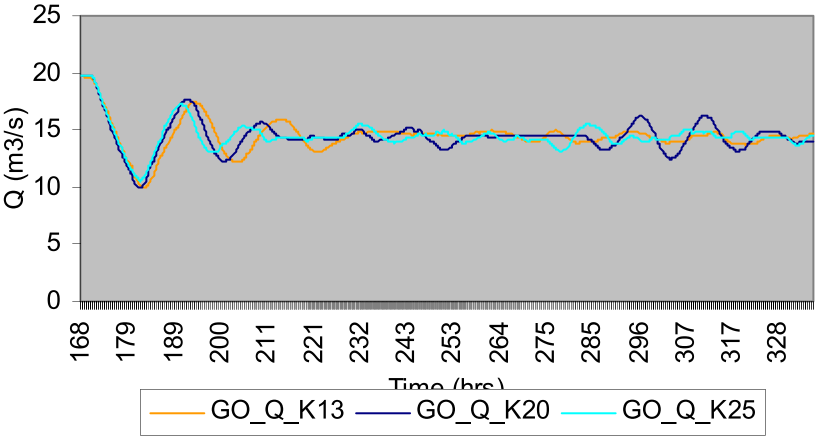

Figure 5. Discharge Released Under Different Kp Values

Testing the Integral Time (Ti) Values . The integral time, Ti, is another important parameter which affects the response of the PI controller. The integral property reduces the decrement and brings the deviations to zero. Two different values of integral time, Ti = 3000 seconds and 1200 seconds were simulated with the same amount of discharge. It has been tested that, which value brings the stability earlier in the system and reduces the oscillatory behavior. The results have been presented in the Figure 6. The flow parameters during this test were the same as given in the Table 3. Figure 6 shows that the Ti = 1200 s led smoothly but slowly to the new discharge conditions as compared to Ti = 3000 s, which though achieved new conditions earlier but did not get stability even after 250 hours after the downstream change in flow. The system was fully stable after 230 hours in case of the Ti = 12000. So Ti = 1200 s seems better option for smooth and stable canal operations.

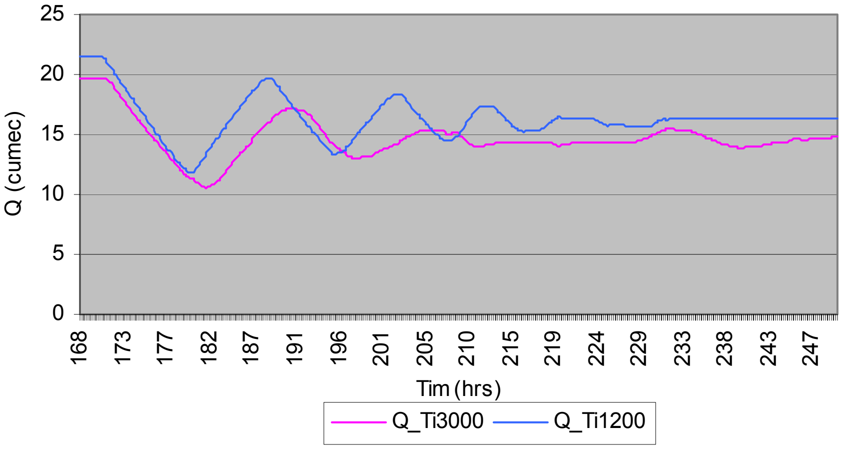

Figure 6. Discharge Variations Under Ti = 3000 s and 1200 s

Effect of Amount and Location of Discharge Refusal

Effect of Location of Discharge Refusal. In this scenario the effect of discharge refusal from different locations along the canal has been simulated to assess the response times and system stability against these water refusals. It has been observed after how long the system gets new steady state position. Basically the effect of distance on the response times has been assessed. The effect of the location of offtakes closed on the system stability has been compared and results have been presented in Figure 7. The offtakes were grouped with almost the same amount of discharge at the head portion, tail portion, and along the canal (composite) and their effects were simulated on the system behavior. Table 4 gives the information about the offtakes grouping, their location and their total discharge.

Table 4. Information on the Offtake Groupings

Group No.	Location	Total Discharge cumec	Percentage of Flow at Confluence	Offtakes names
1	Head	6.1	24	Pehur, Sarbandi, Old Indus, Dagi, Yar Hussain
2	Tail	6.1	24	Gumbat 2, Qasim 1 & 2, Toru, PirSabaq
3	Mixed	5.2	21	Pehur, Dagi, Yaqubi, Gumbat 2

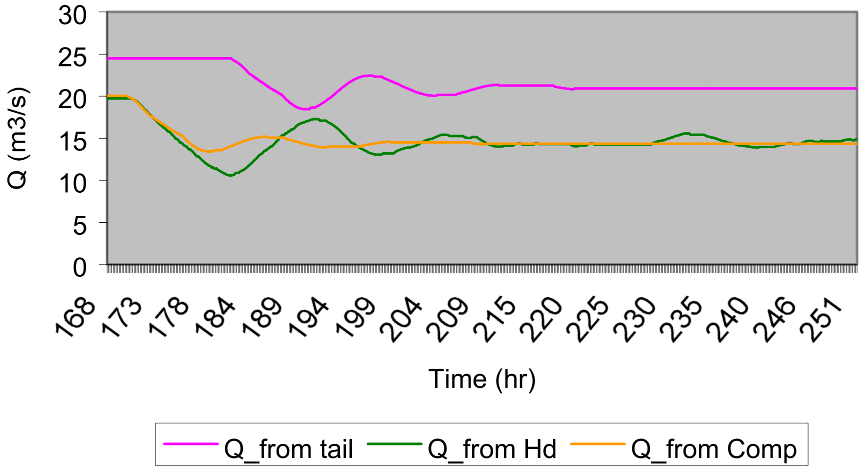

Figure 7. Flow Stability and Response Times of Offtake Closures at Different Locations

Figure 7 shows that the composite grouping of offtakes gives early stability and less oscillations as compared to the discharge refusal at head and tail. The discharge controller responds to discharge variations at the tail after 14 hours and becomes stable after 51 hours. Whereas the discharge controller at GO responds after 3 hours to discharge refusal at head and becomes stable after 51 hours. The discharge controller reacts after 3 hours to the discharge refusal along the canal (composite) and becomes stable after 29 hours. These results show that the mixed offtakes closing is a better option for stable system operations.

Effect of Amount of Discharge Refusal. The amount of discharge refusal also affects the stability of the system and response times. The effects of two different amounts of discharges were compared and the results have been presented in Figure 8, which shows that a high number of discharge refusal takes more time for system stability, whereas in limited discharge refusal situations the system stabilizes comparatively earlier. For the 50 percent discharge refusal the system took 48 hours to become stable whereas in case of discharge refusal of 24 percent the system became stable in 28 hours.

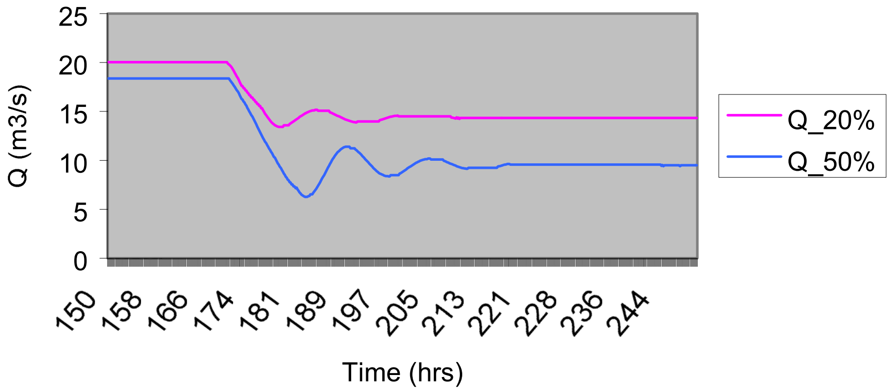

Figure 8. Response Times of Eighty Percent and Fifty Percent Offtake Closures along the Canal

Testing of the CBIO Schedules

The overall purpose of this paper is to describe the hydrodynamic behavior of the automatically downstream controlled system under the CBIO. To assess the hydrodynamic behavior of the canals and the system stability under these operations is very important from the point of view of efficient and reliable system operations. Hence four different options of CBIO were simulated and the results are presented in the Figure 9. The CBIO options tested were running the system on 100, 80, 67, and 50 percent of the design supply and then again on 100 percent.

Figure 9 shows that the gradual increase or decrease in flow conditions gets stability earlier and takes less response time, whereas the big changes in discharge refusal or discharge opening result in prolonged instability and longer response times as given in Table 5. It is clear from the Table 5 that as the amount of discharge variation increases or decreases the response increases and decreases accordingly.

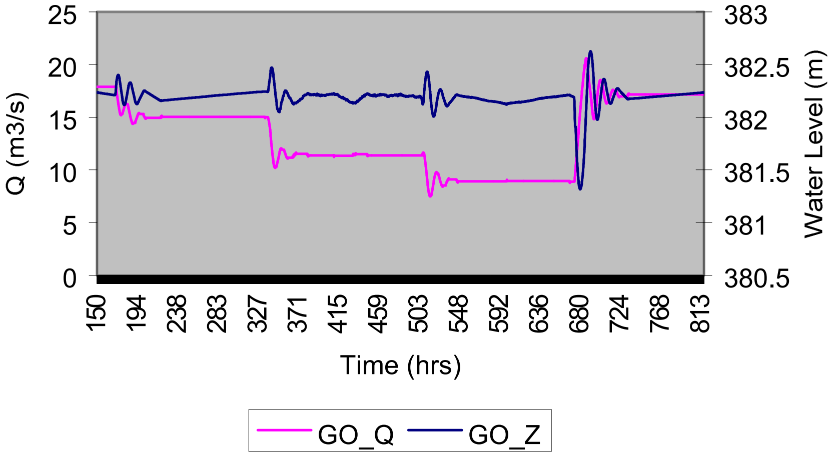

Figure 9. Testing of CBIO Schedule at 100, 80, 67, 50 and 100 % of Full Supply Discharge

Table 5. Response Times of Different Flow Changes

S. No	Flow variations (percentage)	Amount of Flow supplies at Confluence (m^3/s)	Response Time (hrs)
1	100 → 80	2.9	32.83
2	80 → 67	3.6	44.33
3	67 → 50	2.5	38.67
4	50 → 100	8.2	64.17

Gate Responses

Gate response to discharge variations is a very crucial factor for smooth and sustainable irrigation system operations. It needs to be assured that the frequent opening and closing of secondary offtakes due to changes in water demands in the canal may not lead to abrupt opening/closing or oscillations in the automatic water level control AVIO/AVIS gates of the cross regulators. Hence the AVIO/AVIS gates behavior under some discharge refusals have been tested and the results are presented in Figure 10. A discharge of 6 m^3/s was refused at the tail portion of the Maira Branch Canal. The discharge refusing point was selected at the tail portion so that the behavior of all the automatic cross regulators could be assessed. Figure 10 shows that the gates settled smoothly to the new positions within 3-6 hours.

Together with the smooth settling and opening of the gates, their reaction time is also important in order to estimate the time elapsed in traveling of the effect of change in the system to the controller. Table 6 gives the reaction times of the cross regulators from cross regulator No. 13 (XR-13) at Maira Branch Tail to cross regulator No. 1 (XR-1) at PHLC head, which finally conveys the messages of change to sensor and discharge control system. The total time elapsed in conveying the message of change from XR-13 to XR-1 is 10.67 hours and the final settlement takes place after 16.67 hours. Every next cross regulator took about 0.89 hours to respond and finally it settles on new position after 5.58 hours, on average, under the given conditions.

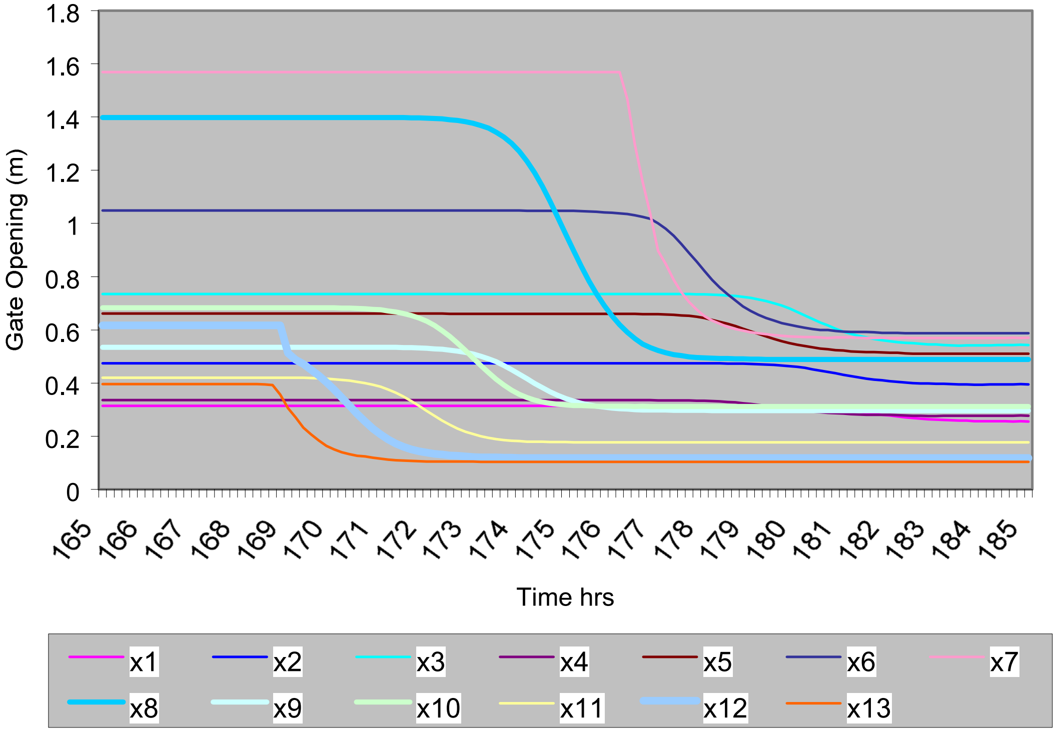

Figure 10. Gate Responses to Some Offtake Closures at the Tail of the Maira Branch Canal

Table 6**.** Gate Openings and Time Elapsed in Response of Discharge Refusal at Maira Tail

Cross Regulator	Distance from from PHLC Head	Start Time	End Time	Initial Opening	Final Opening
	M	hrs	Hrs	m	m
XR-13	67,124	168.33	171.83	0.396	0.106
XR-12	62,374	168.83	173.67	0.671	0.119
XR-11	57,024	169.33	175.00	0.420	0.178
XR-10	51,524	170.33	175.67	0.682	0.313
XR-9	45,124	171.33	177.17	0.543	0.312
XR-8	38,794	172.00	178.50	1.396	0.492
XR-7	34,674	176.17	180.50	1.596	0.572
XR-6	29,774	174.83	183.00	1.048	0.588
XR-5	24,254	176.50	182.33	0.660	0.512
XR-4	21,312	176.83	182.33	0.336	0.296
XR-3	15,032	177.67	183.67	0.734	0.542
XR-2	11,485	178.33	183.33	0.474	0.396
XR-1	4,487	179.00	185.00	0.322	0.255

Discharge Variations in Machai Branch Canal and Responses from PHLC (Gandaf Outlet)

According to the design concept of the combined USC (Upper Swat Canal)-PHLC system, PHLC is supposed to supplement the flows to the Machai Branch Canal for reliable irrigation water supply to the Maira Branch Canal. The water availability in the Machai Branch Canal depends upon the flow availability in the Swat River. As there is no storage reservoir at the headworks, the flow availability in the Machai Branch Canal is quite variable. Therefore, it becomes very important to assess the effect of different scenarios of water availability in the Machai Branch Canal on the automatic operation of the PHLC. Two scenarios have been tested with maximum and minimum supplies from the Machai Branch Canal. It has been tested how the automatic discharge controllers respond to any variation in Machai Branch Canal discharges. The lag times in the Machai Branch Canal also have been estimated and the time required by the PHLC to respond to these changes also has been assessed. The results of these simulations are presented in the Figure 11. A discharge of 10 m^3/s was increased at the Machai Branch head and in response of this the automatic flow adjustment started to take place at the Gandaf Outlet after 13.33 hours and finally it reached a new equilibrium after 98.67 hours.

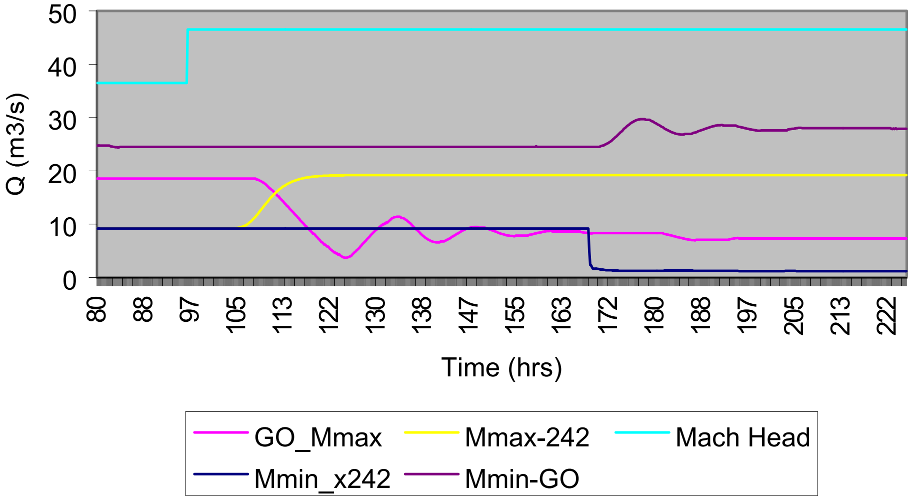

Figure 11**.** Gandaf Outlet's Behavior Against Variation in Machai Branch Canal

The time elapsed in reaching the effect of this change at the RD 242 (74 km), the last cross-regulator of the Machai Branch Canal, was 9.5 hours which reached a new steady state after 16 hours. Similarly the other scenario was tested by reducing the contribution from the Machai Branch Canal to the Maira Branch Canal. The automatic discharge controllers responded according to this deficiency in the flows and the same amount of discharge was increased automatically at Gandaf Outlet as shown in Figure 11.

CONCLUSIONS

A good proximity was found in the simulated and measured water levels and discharges in the Maira Branch Canal. The proportional gain and integral time of PI, Kp = 2.5 and Ki = 1200 seconds led to comparatively smooth and stable system operations. The composite closing of the offtakes resulted in less response times than the offtakes closed at the tail of the canal and in this case the canal achieved early stability. The amount of discharges refusal also affected the response time, in case of small amounts of discharge refusal by the secondary system, the main canal achieved new equilibrium conditions earlier and vice versa. Four different cycles of CBIO schedules were tested and found that the gradual increase or decrease in the discharge withdrawals favored smooth system operations and achieved new equilibrium conditions earlier as compared to the large variations in discharge. The hydro-mechanical cross regulators reacted to the water level changes and settled at new positions without any oscillations at the given amounts of discharges under the CBIO. On a refusal of 6 m^3/s discharge at the tail end of the Maira Branch Canal every consecutive cross regulator responded to these changes after 0.85 hours and the final settlement was made after 16.67 hours at the last cross regulator at the head portion of the PHLC. The Gandaf Outlet responded efficiently to the changes in contribution from the Machai Branch Canal. Any deficiency or addition of the discharges from the Machai Branch Canal to Lower Machai and Maira Branch Canal was accordingly adjusted by the Gandaf Outlet automatically. These simulations of various parameters show a stable hydrodynamic behavior of the canals and automatic discharge regulators. Following these parameters the operations of the system can be improved for having reliable irrigation water supplies.

REFERENCES

[1] Ankum. P. (Undated). Lecture notes on “Flow Control in Irrigation Systems”. UNESCO-IHE, the Netherlands

[2] Cemagref., (2003). SIC (Simulation of Irrigation Canals) User’s Gudie. The French institute of agricultural and environmental engineering research. Montpellier Cedex 1, France.

[3] Helsema, G. E. van. (2002). Trial & Re-Trial; The evolution of irrigation modernization in NWFP, Pakistan. PhD Thesis. Wageningen University, the Netherlands.

[4] Seborg E. E., T.F. Edgar and D. A. Mellicham. 1989. Process dynamics and control. Wiley series in chemical engineering. New York.

[5] WAPDA. 2002. “Operation and Maintenance Manual for USC - PHLC” Tarbela.

[6] Wisansawat, K., K. Pongput. 2000. “CBIO, Scheduling Model for Crop Based Irrigation Operations. User Manual and Technical Guide”.