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Study on Optimal Gate Operation Method in a Long Open Channel

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Abstract

It is very important to achieve optimal water management in irrigation canal systems. The authors studied optimal water management in terms of water traveling time. First, the authors developed a computer simulation program for varied flow to estimate the water traveling time at any given point for the operation of cross-regulators and offtake regulators. Next, the authors also developed a computer program for unsteady flow in order to quantitatively evaluate the method based on the foregoing. These programs were applied to a long open channel in Thailand. The authors concluded that this method was suitable in terms of water saving and stability in the canal.

Discipline: Agricultural engineering
Additional keywords: water arrival time, caried flow, unsteady flow

Introduction

Recently long and large open channels for irrigation have been constructed all over the world. They should be optimally and effectively managed in terms of water resources as well as maintenance.

The authors consider that in terms of water resources there are various conditions for achieving optimal water management in irrigation canal systems, for instance, the development or improvement of calibration curves, proper estimation of water requirement, etc. The authors consider that the very slow temporal response in an open channel is one of the reasons why effective water use is difficult but not impossible.

In this paper the authors will discuss the optimal operation methods for cross-regulators and offtake regulators along a long and large open channel in terms of effective water use. For this study, the Chainat-Pasak canal in Thailand which is approximately 130 km long and has a flow capacity of about 200 m^3/s at its head was selected. The operation methods were determined based on a computer program designated as "Nuflow" which was newly developed to calculate the steady varied flow. However, since this program does not enable to estimate the degree of improvement for any operation method, a computer program designated as "Unste" was also developed for quantitative evaluation and for the analysis of unsteady flow. The authors consider that optimal operations or effective water management with reduced waste of water can be attained by the use of these 2 computer programs.

Description of irrigation canal for the case study

The Chainat-Pasak canal system was selected for the case study. It is located at the Chao Phraya delta formed by the (Mae Nam) Chao Phraya river

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(Mae means mother, Nam means water and Mae Nam means a river in Thai).

For irrigating 730,000 ha of farm lands, this system withdraws water in the left bank just upstream of the Chao Phraya dam which is located at about 250 km from the mouth. This system is approximately 130 km long with an unlined trapezoidal cross-section and average bed slope of 1 : 17,000. The downstream end is connected to the Pasak river and the Rama Six Barrage constructed in this river at about 0.5 km downstream from the connection point. There are 4 cross-regulators, called Manorom, Chong-Khae, Koke-Kathiem and Reong-Rang from upstream (Fig. 1). They consist of radial gates for which the dimensions and discharge formula are shown in Table 1. The canal has also 31 offtake regulators (including 4 pump stations) of the single gate type, several small farm turnouts and drainage inlets.

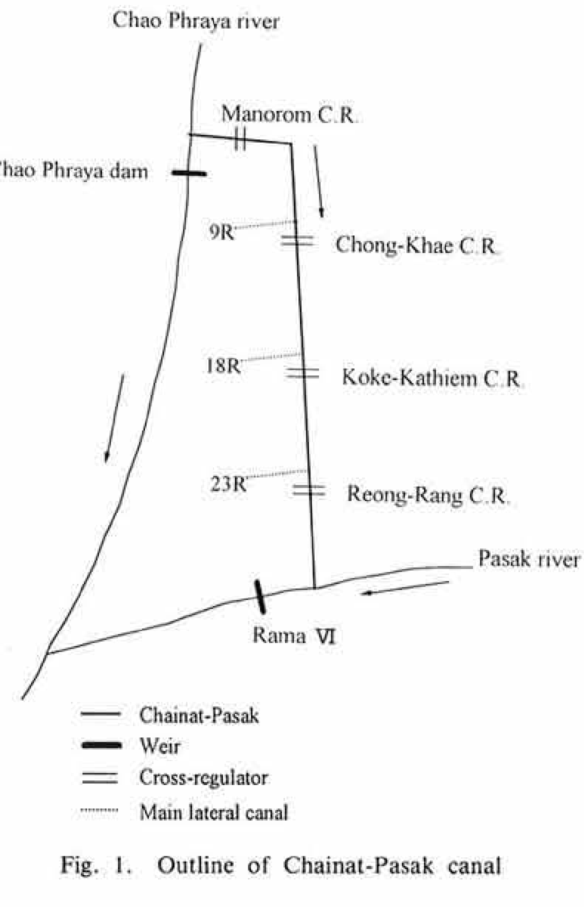


Fig. 1. Outline of Chainat-Pasak canal

Present operation method and problems

The Chainat-Pasak canal is managed by the Regional Office 8 under the Royal Irrigation Department, Ministry of Agriculture and Cooperatives, Government of Thailand. Regional Office notifies the flow to be distributed to the 4 Project Offices once a day, each of which controls one cross-regulator and some offtake regulators located between the cross-regulators based on the notified flow, actual water level and calibration curves.

For instance, the Manorom Project Office controls the Manorom cross-regulator and offtake regulators between this regulator and the Chong-Khae cross-regulator. Since the regulators are independently operated by each Project Office and the bed slope is very gentle, the effect of one cross-regulator operation reaches another regulator at the upper reaches and the flow through the cross-regulator changes with time. Accordingly, the regulators must be frequently operated in order to adjust the flow notified by the Regional Office.

Concept of optimal operation method

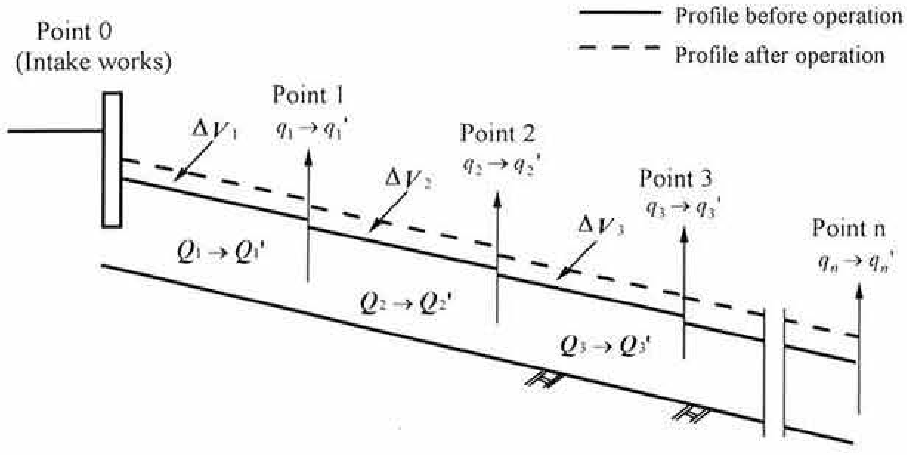
Flow arrival time is known to be very important for optimal operation method based on the previous study[3]. In this paper, flow arrival time is defined as $\Delta V/\Delta Q$, where ΔV is the change in the volume from one point to another point for steady conditions before and after operations, and ΔQ is the change in flow before and after operations (Fig. 2).

A usual flow arrival pattern at a downstream point is represented with a line (g, a, c, e) in Fig. 3 when

Table 1. Discharge formula and specification of cross-regulators

Name	Formula of discharge[a)]	Height of sill (m)	Total length of gate (m)	Number of gates
Manorom	$Q=1.01\cdot L\cdot G_o^{1.092}\cdot h_s^{-0.092}\cdot\sqrt{2g\cdot\Delta H}$	12.910	36.0	6
Chong-Khae	$Q=1.03\cdot L\cdot G_o^{1.414}\cdot h_s^{-0.414}\cdot\sqrt{2g\cdot\Delta H}$	9.390	30.0	5
Koke-Kathiem	$Q=1.00\cdot L\cdot G_o^{1.159}\cdot h_s^{-0.159}\cdot\sqrt{2g\cdot\Delta H}$	6.290	24.0	4
Reong-Rang	$Q=1.00\cdot L\cdot G_o^{1.509}\cdot h_s^{-0.509}\cdot\sqrt{2g\cdot\Delta H}$	3.970	18.0	3

a): L; Length (m), G_o; Opening (m), h_s; Water depth at downstream end of gates (datum line corresponds to sill), ΔH; Water depth difference between upstream and downstream ends.



$$T_m = \sum_{i=1}^{m} (\Delta V_i / \Delta Q_i) = \sum_{i=1}^{m} \{\Delta V_i / (Q_i' - Q_i)\}$$

$$Q_m = \sum_{i=m}^{n} q_i$$

T_m : Flow arrival time (s)

ΔV_i : Change in storage volume between point (i-1) and point (i)(m^3)

Q_i : Flow rate between point (i-1) and point (i) before operation or under the present conditions (m^3/s)

Q_i' : Flow rate between point (i-1) and point (i) after operation or under the target conditions (m^3/s)

q_i : Distribution flow rate at point (i) before operation

q_i' : Distribution flow rate at point (i) after operation

Fig. 2. Calculation method of flow arrival time

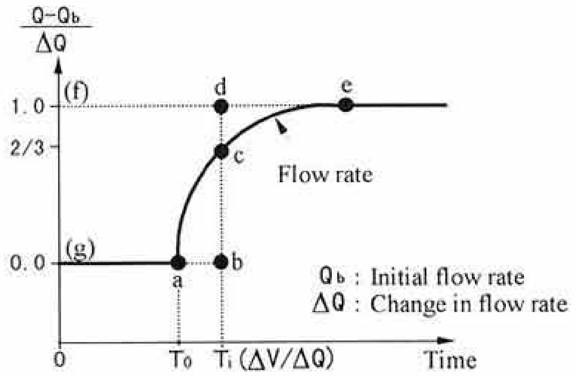


Fig. 3. Flow arrival pattern

withdrawn flow at an upstream point increases at time 0. That is, point (a) represents the time when the initial flow begins to increase and point (e) the time when the flow corresponds to the change in flow.

It was reported in a previous study[1] that about two-thirds of ΔQ occur at time $\Delta V/\Delta Q$ and that the water volume (a, b, c) which corresponds to the water volume (c, d, e) had been reached at a downstream point by the time $\Delta V/\Delta Q$ (Fig. 3). Therefore, it is assumed that operations at this time do not affect appreciably the flow conditions, if at all.

Steady conditions before and after operations can be estimated using the equations of varied flow which can be represented by ordinary differential equations. First of all, a computer program designated as Nuflow was developed for the simulation of the arrival time.

Based on this program, since we can predict the flow arrival time at any given point, we can determine when and how extensively cross-regulators and offtake regulators should be operated. The data that must be inputted into the Nuflow program are basically as follows:

1. Canal structure data, that is, canal cross-sections, bed elevations at slope changing points, roughness coefficients of Manning, regulator dimensions and calibration curves, etc.
2. Actual upstream water levels of cross-regulators. If a cross-regulator has not been installed at the downstream end, data on downstream water level are required.
3. Target upstream water levels of cross-regulators. If there are no cross-regulators at the downstream end, data on downstream water level are also necessary.
4. Actual flow rate at offtake regulators and flow

rate at downstream end of the model.

5. Target flow rate at offtake regulators and flow rate at downstream end of the model.

Canal structure data, however, do not need to be changed for each calculation, whereas items 2 to 5 must be changed if necessary. Examples of the required data and results are shown in Tables 2 and 3. Once the canal structure data are inputted, it takes a very short time to calculate them and it is very easy to input other data. Therefore, this procedure can be easily used for daily operations. The Nuflow program, however, cannot evaluate the degree of improvement of a new operation method. For solving this problem, the authors therefore developed a computer program for unsteady flow simulation designated as Unste. The program Unste is less easy to handle than the program Nuflow because the time element must be inputted. Accordingly, the program Unste is not used for daily operations but for the evaluation of the method of operation recommended by the program Nuflow. The relationship is shown in Fig. 4.

In the program Unste, partial differential equations, that is, dynamic equation and continuity equation, are numerically integrated using a kind of central difference method[2]. The necessary data for the program Unste include, in addition to the data for the program Nuflow, the operation time and the opening of cross-regulators and offtake regulators, which are given by Nuflow. As we can eventually predict the change in the flow conditions with time at any point, we can quantitatively evaluate the degree of improvement of the operation methods.

Evaluation of improvement of operation methods

1) Assumptions on distribution patterns

The improvement of operation methods for cross-regulators and offtake regulators through changes in the distribution pattern will be evaluated. Therefore, 2 distribution patterns must be assumed, that is, the distribution pattern before the operation and that after the operation. The former is designated as Pattern A, which is determined based on the actual distribution pattern recorded on November 14, 1992. The latter is designated as Pattern P, which is determined based on the actual pattern recorded on November 16, 1992 (Table 4).

The 2 operation methods are described as follows: The first based on Nuflow is referred to as Case 1. The time and extent of operations which are estimated by Nuflow are shown in Tables 2

Table 2. Inputted data and results (1)

Chainat

	Case 1*	Case 1	Case 1	Case 1	Case 2*	Case 2	Case 2	Case 2	Time delay
	Hup EL. m	Hdown EL.	Q m^3/s	Open m	Hup EL. m	Hdown EL.	Q m^3/s	Open m	h : m
Manorom	16.310	16.267	191.484	5.469	16.310	15.871	159.498	1.577	0 : 0
Chong-Khae	13.930	13.640	172.240	2.777	14.010	12.966	121.278	1.309	5 : 52
Koke-Kathiem	11.050	10.516	128.830	1.878	11.060	10.025	98.690	1.103	10 : 7
Reong-Rang	8.530	7.804	99.250	2.017	8.470	7.419	67.800	1.337	15 : 6

Where, Case 1 refers to the condition before operation and corresponds to Pattern A in the paper. Case 2 refers to the condition after operation and corresponds to Pattern P.

* Inputted data.

Table 3. Inputted data and results (2)

Chainat

	Case 1	Case 1*	Case 1		Case 2	Case 2*	Case 2		Time delay
	H EL. m	Q m^3/s	Open m	%	H EL. m	Q m^3/s	Open m	%	h : m
Division : 1R (MESH.6)	16.232	1.010	Pump		15.837	2.270	Pump		0 : 11
Division : 2R (MESH.26)	15.985	1.070	Pump		15.604	2.600	Pump		1 : 14
Division : 3R-1 (MESH.66)	15.400	0.210	0.163	20	15.076	0.200	0.178	22	3 : 20
Division : 3R-2 (MESH.70)	15.357	0.430	Pump		15.039	0.950	Pump		3 : 29
Division : 3R (MESH.80)	15.220	2.110	0.202	16	14.922	2.930	0.318	25	3 : 55
Division : 4R (MESH.94)	15.039	0.670	0.202	25	14.773	0.730	0.230	29	4 : 26
Division : 5R (MESH.114)	14.767	1.050	0.183	12	14.559	2.050	0.390	26	5 : 07
Division : 6R (MESH.126)	14.624	1.150	0.192	13	14.453	3.030	0.550	37	5 : 24
Division : 7R (MESH.146)	14.384	0.974	0.244	24	14.288	1.820	0.402	40	5 : 42
Division : 8R (MESH.178)	14.024	1.630	0.342	34	14.063	3.460	0.629	63	5 : 49
Division : 9R (MESH.184)	13.931	8.940	0.493	25	14.010	18.180	1.038	52	5 : 52
Division : 10R (MESH.216)	12.652	1.100	0.800	>100	12.154	0.000	0.004	0	7 : 21
Division : 1L (MESH.224)	12.495	0.450	0.244	41	12.030	0.000	0.002	0	7 : 43
Division : 11R (MESH.236)	12.299	3.050	1.000	>100	11.882	1.460	0.701	70	8 : 08
Division : 2L (MESH.248)	12.081	2.730	0.834	83	11.723	1.610	0.543	54	8 : 34
Division : 12R (MESH.256)	11.948	2.470	1.000	>100	11.630	1.460	0.807	81	8 : 48
Division : 13R (MESH.270)	11.765	3.520	0.800	>100	11.507	0.780	0.263	33	9 : 12
Division : 1D	11.683	0.000	Pump		11.453	0.000	Pump		9 : 22
Division : 14R (MESH.278)	11.672	1.580	0.375	37	11.445	1.350	0.360	36	9 : 24
Division : 3L (MESH.284)	11.608	0.810	0.379	47	11.405	0.350	0.210	26	9 : 31
Division : 15R (MESH.286)	11.578	0.790	0.397	40	11.386	0.560	0.329	33	9 : 34
Division : 16R (MESH.296)	11.463	13.240	0.899	45	11.305	5.180	0.340	17	9 : 44
Division : 17R (MESH.312)	11.304	5.150	0.885	88	11.213	3.558	0.609	61	9 : 58
Division : 2D	11.211	0.000	Pump		11.155	0.000	Pump		10 : 04
Division : 18R (MESH.342)	11.050	8.520	1.003	50	11.060	6.280	0.717	36	10 : 07
Division : 19R (MESH.350)	10.373	0.000	0.000	0	9.896	0.000	0.000	0	10 : 31
Division : 20R (MESH.378)	9.649	0.300	0.195	24	9.247	0.270	0.206	26	12 : 05
Division : 21R (MESH.396)	9.408	15.400	2.000	>100	9.039	15.080	2.000	>100	12 : 57
Division : 22R (MESH.418)	9.165	4.470	0.572	38	8.854	6.070	1.500	>100	13 : 47
Division : 23R (MESH.482)	8.530	9.410	0.631	36	8.470	9.470	0.643	37	15 : 06
Division : 24R (MESH.514)	7.510	9.370	0.611	31	7.230	7.250	0.501	25	15 : 58

Case 1 refers to the condition before operation and corresponds to Pattern A in the paper. Case 2 refers to the condition after operation and corresponds to Pattern P.

*Inputted data.

Table 4. Simulation conditions (assumed water distribution, m^3/s)

Cross-regulator, offtake regulator	Pattern A (Nov. 14, 1992)	Pattern P (Nov. 16, 1992)
Manorom	191.60	159.49
1R	1.01	2.27
2R	1.27	2.60
3R	2.11	2.93
3R-1	0.21	0.20
3R-2	0.43	0.95
4R	0.67	0.73
5R	1.05	2.05
6R	1.15	3.03
7R	0.94	1.82
8R	1.63	3.46
9R	8.94	18.18
Chong-Khae	172.24	121.27
10R	1.10	0.0
1L	0.45	0.0
11R	3.05	1.46
2L	2.73	1.61
12R	2.47	1.46
13R	3.52	0.78
14R	1.58	1.35
3L	0.81	0.35
15R	0.79	0.56
16R	13.24	5.18
17R	5.15	3.55
18R	8.52	6.28
Koke-Kathiem	128.83	98.69
19R	0.0	0.0
20R	0.30	0.27
21R	15.40	15.08
22R	4.47	6.07
23R	9.41	9.47
Reong-Rang	99.25	67.80
24R	9.37	7.25
Rama 6	89.88	60.55

and 3. The other method is the simultaneous operation method in which cross-regulators and offtake regulators are simultaneously operated and the extent of operation is determined based on the flow rate of Pattern P, the current water levels at regulators, and calibration curves. This case is referred to as Case 2 and is defined in order to evaluate Case 1.

Evaluation is carried out by numerical analysis of unsteady flow in open channels. Unsteady flow needs to be simulated under steady conditions for a certain period of time in order to eliminate the effect of initial conditions. Therefore, we assume that every regulator is operated at 24.00 h in Case 2, and at $(24 + T)$ h in Case 1, where T is the water arrival time derived from Nuflow at every regulator. The results are shown in Table 5 and Figs. 5–10. Table 5 shows insufficient or excessive water volume at each regulator based on target flow rate for 24 h after the operation of each regulator. Table 5 and the Figs. show that the volume of water through each cross-regulator is almost equal to the target volume in Case 1, whereas unused and wasted water or excessive water passing through each cross-regulator accounts for more than 20% compared with the target volume in Case 2.

Also at each offtake regulator the water volume is almost equal to the target water volume in Case 1, whereas the water volume through offtake regulators located in the lower reaches (16R, 17R, 18R, 23R) far exceeds the target volume in Case 2.

The reasons for the above phenomena are described below.

In Case 2, the opening of the Manorom cross-regulator is determined based on the current water levels downstream and upstream and on the target flow rate. The value for the opening is 4.66 m, if

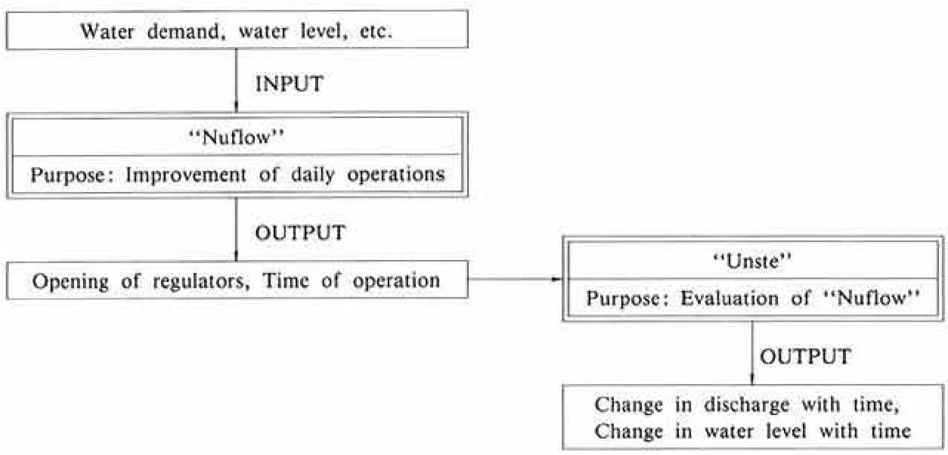


Fig. 4. Relationship between "Nuflow" and "Unste"

Table 5. Comparison between Case 1 and Case 2

Name	Mesh no.	Target flow rate (m^3/s)	Target volume (a) ($\times$ 1000 m^3)	Case 1 Excessive/Insufficient volume (b)($\times$ 1000 m^3)	Case 1 Rate (b/a) (%)	Case 2 Excessive/Insuficient volume (b)($\times$ 1000 m^3)	Case 2 Rate (c/a) (%)
Manorom	3	159.498	13780.6	− 276.6	− 2.0	2843.8	20.6
Chong-Khae	185	121.278	10478.4	− 161.0	− 1.5	2915.5	27.8
Koke-Kathiem	343	98.690	8526.8	− 132.4	− 1.6	2373.8	27.8
Reong-Rang	483	67.800	5857.9	− 187.4	− 3.2	1817.6	31.0
3R	80	2.930	253.2	− 0.6	− 0.2	− 2.3	− 0.9
5R	114	2.050	177.1	− 0.5	− 0.3	− 1.3	− 0.7
6R	126	3.030	261.8	− 0.9	− 0.3	− 1.7	− 0.6
8R	178	3.460	298.9	− 1.3	− 0.4	0.8	0.3
9R	184	18.180	1570.8	− 2.4	− 0.2	4.6	0.3
16R	296	5.180	447.6	− 1.9	− 0.4	25.3	5.7
17R	312	3.558	307.4	− 1.5	− 0.5	23.0	7.5
18R	342	6.280	542.6	− 1.7	− 0.4	34.9	6.4
23R	482	9.470	818.2	12.2	1.5	57.0	7.0
24R	514	7.250	626.4	16.3	2.6	− 10.6	− 1.7

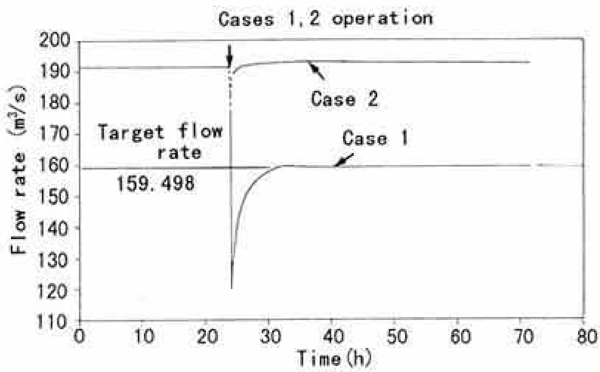


Fig. 5. Flow rate-time relationship at Manorom

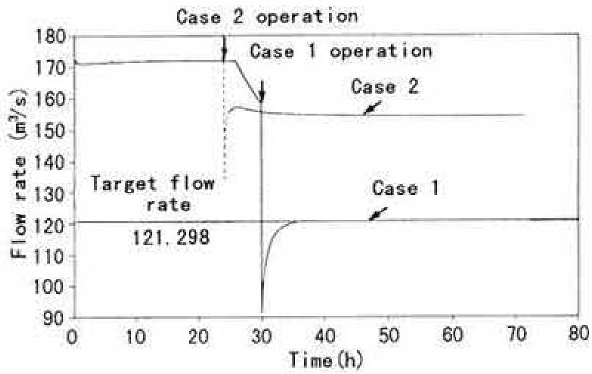


Fig. 6. Flow rate-time relationship at Chong-Khae

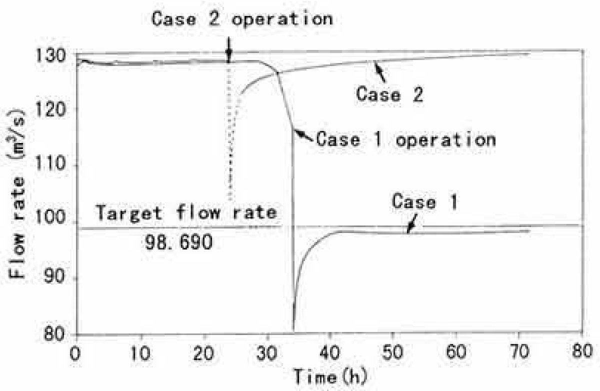


Fig. 7. Flow rate-time relationship at Koke-Kathiem

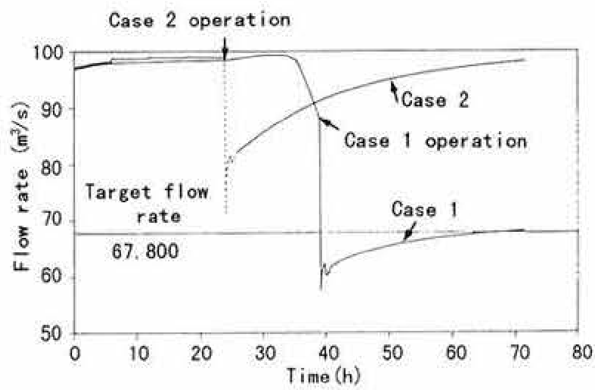


Fig. 8. Flow rate-time relationship at Reong-Rang

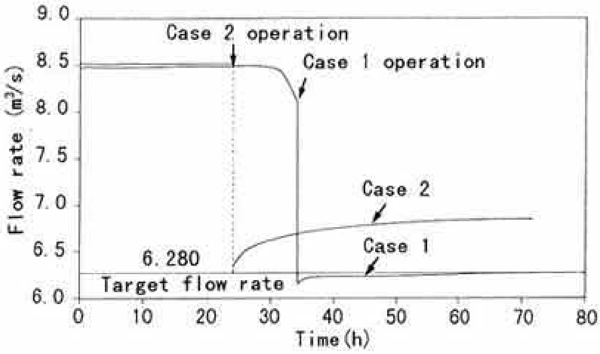


Fig. 9. Flow rate–time relationship at 18R

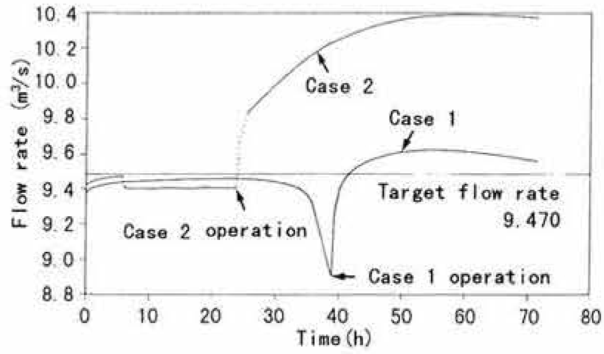


Fig. 10. Flow rate–time relationship at 23R

the upstream water level is 16.3100 m, downstream water level is 16.2674 m, and the target flow rate is 159.498 m^3/s while the height of the sill is 12.91 m, based on the formula for the Manorom cross-regulator,

$$Q = 1.01 \cdot L \cdot G_o^{1.092} \cdot h_s^{-0.092} \cdot \sqrt{2g \cdot \Delta H}$$

where, Q: flow rate (m^3/s), L: length (36 m), G_o: gate opening (m), h_s: water depth downstream (m), ΔH: difference between upstream and downstream water depth (m).

However, as the downstream water level decreases, the flow through the Manorom regulator increases. Eventually, the flow rate increases to about 192.0 m^3/s, suggesting that the amount of withdrawn flow does not actually decrease. Accordingly, the target flow can not be achieved in Case 2.

In Case 1, since the flow condition in future is predicted by Nuflow, the opening of the Manorom regulator and other regulators can be determined. In Case 1, however the downstream water level decreases quickly, for instance, 25.6 cm in 30 min at the Manorom regulator. Therefore the gate opening speed should be evaluated accurately in order to prevent sidewalls from collapsing. Incidentally, in this simulation we assumed that the gate opening can be changed in 1 min.

Conclusion

During this study, the authors developed 2 computer programs for improving the gate operation method based on the theories of steady varied flow and unsteady varied flow. Since one method Nuflow aims at daily operations, data can be easily inputted and calculation with personal computers can be rapidly performed. The other method Unste aims at the evaluation of various operation methods. With these programs, the gate operation methods can be remarkably improved in terms of flow arrival time. However, if the method is not satisfactory, based on Nuflow, the program Unste can be used in order to evaluate the new method.

It is also very important to accurately estimate or forecast the water requirement on-farm, and to draw or improve the gate calibration curves. Although these aspects are not taken up in this paper, the authors consider that the program reported could contribute to the optimal operation of long and large irrigation canal systems.

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