

OPERATING SYSTEM FOR RETARDING BASIN SLUICE WAYS USING REAL-TIME STAGE PREDICTION

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SYNOPSIS

A system for operating many sluice ways located along retarding basins using a real-time runoff prediction scheme is developed. In the Ueno Retarding Basins (area : 250 ha, pondage : 9.0 Mm^3) in Japan, there are 36 sluice ways and during a flood at least 72 operators must stand by to operate the sluice ways. But it has been very difficult to arrange such many people. In this system, to operate many sluice ways one after another with as few people as possible, the stage of the river at each sluice way is predicted on a real-time basis and the time when the stage rises up to the operation stage at each sluice way is given. This system is made up of a real-time runoff prediction system and a flood routing system. For the flood data from 19–20 September 1990, this system is simulated and the time when the stage of the river rises up to the operation stage of each sluice ways is predicted, and the time is compared to the actual operation time.

INTRODUCTION

To prevent and reduce flood damages in an urban area, it is very important to predict a river stage on a real-time basis. Up to this time real-time flood runoff prediction methods have been developed mainly to forecast a river discharge in a mountainous region. But for a flood alert system or an operation of a sluice way in an urban area, it is important to forecast not only a river discharge but also a river stage.

In this study, to predict a river stage in an urban area where a channel reach is subject to backwater effect, a real-time stage prediction system which is made up of a real-time runoff prediction system based on the filtering and prediction theory developed by Kalman and others and a flood routing system based on the full one dimensional equations of unsteady flow is developed. The system is applied to the Ueno Retarding basin.

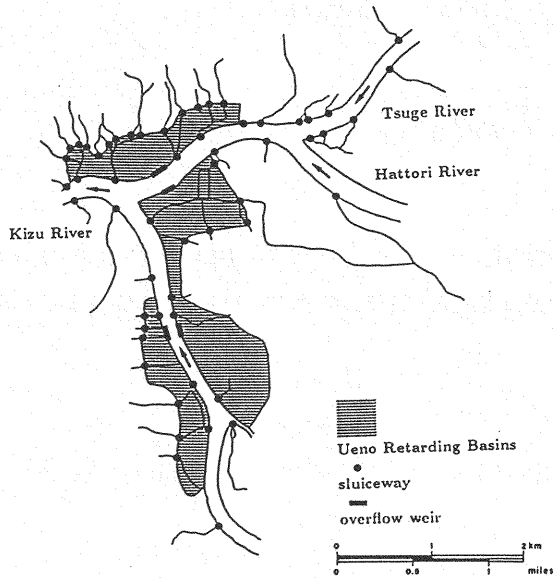


Fig. 1 The Ueno Retarding Basins

IMPORTANCE OF REAL-TIME STAGE PREDICTION FOR OPERATION OF UENO RETARDING BASIN SLUICE WAY

The role of the Ueno Retarding Basins is to control the discharges of the Kizu, Hattori and Tsuge River for flood protection of downstream area and to prevent and reduce flood damages which have long affected the area around the retarding basins. The Ueno Retarding Basins are made up of four retarding basins. Each retarding basin is surrounded by embankment and has an overflow weir. At the locations where the brooks flow across the embankment, sluice ways are constructed. Rainfall to the residential area behind the retarding basins is drained to the rivers through these brooks. The Ueno Retarding Basins are shown in Fig. 1.

These retarding basins are dry ponds and a large part of them are usually utilized as rice fields. Only during storms, flood water is detained and released by the following steps:

- (1) At each sluice way, when the stage of the river is lower than the stage of the brook, the gate of the sluice way is open to drain the flow in the brook.
- (2) When the stage of the river rises up and the flood water in the river begins to flow to the brook, the gate of the sluice way is closed.
- (3) When the stage of the river becomes much higher and rises to the level of the overflow weir, flood water of the river naturally flows into the retarding basin.
- (4) When the stage of the river becomes lower than the water level in the retarding basin, the gate is opened to drain water from the retarding basin to the river through the sluice way.

Now there are 36 sluice ways. When all the embankment are completed, the number of sluice ways will become 56. To operate one sluice way, at least two people are needed. This means now 72 people, and in the future more than 100 people must stand by during a flood. But recently it has been very difficult to arrange so many people.

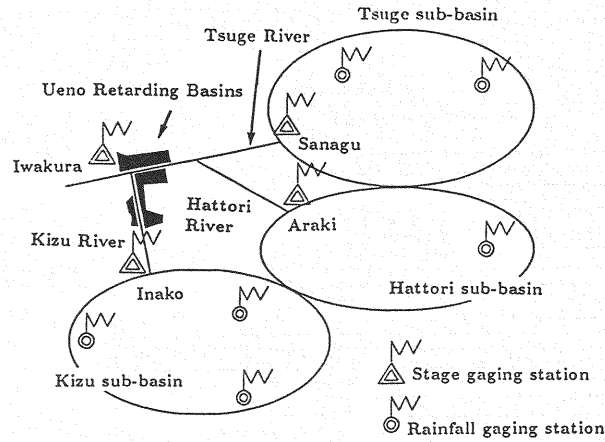


Fig. 2 Schematic drawing of the forecasting system for the Ueno Retarding Basins

To operate many sluice ways one after another by as few people as possible, our real-time stage prediction system is used to give the time when the stage of the river rises up to the operation stage of each sluice way. Here, the operation stage is assumed to be the same as the ground level where each sluice way is located.

REAL-TIME STAGE PREDICTION METHOD

The system is made up of a real-time runoff prediction system and a flood routing system. The schematic drawing of this system for the Ueno Retarding Basins is shown in Fig. 2. The flow chart of this system is shown in Fig. 3.

A real-time runoff prediction system based on the filtering and prediction theory developed by Kalman and others has been developed and improved by Shiiba *et al.* (5), Takara *et al.* (6), and Takasao *et al.* (7). Using this system, the discharges of the Tsuge sub-basin (152.8 km²), the Hattori sub-basin (94.0 km²), and the Kizu sub-basin (148.9 km²) which flow into the upstream ends of the channel reach are predicted.

In the flood routing system, the flow of the channel reach between the upstream ends of the Sanagu, Araki and Inako stage gaging station, and the downstream end of the Iwakura stage gaging station is modeled using the one-dimensional equations of unsteady flow. These equations are solved with the four-point implicit method (Amain & Fang (1), and Kanda & Tsuji(3)). The upstream boundary conditions are given by the predicted discharges and the downstream boundary condition is given by the stage-discharge relationship provided by the rating curve at the Iwakura stage gaging station.

Real-time runoff prediction system

The rainfall-runoff model for each sub-basin based on Kimura's storage function model (Kimura (4)) is represented as a stochastic continuous-discrete state-space model:

$$\frac{dx}{dt} = fr(t - T_L) - \xi x^{1/p} + w(t) \quad (1)$$

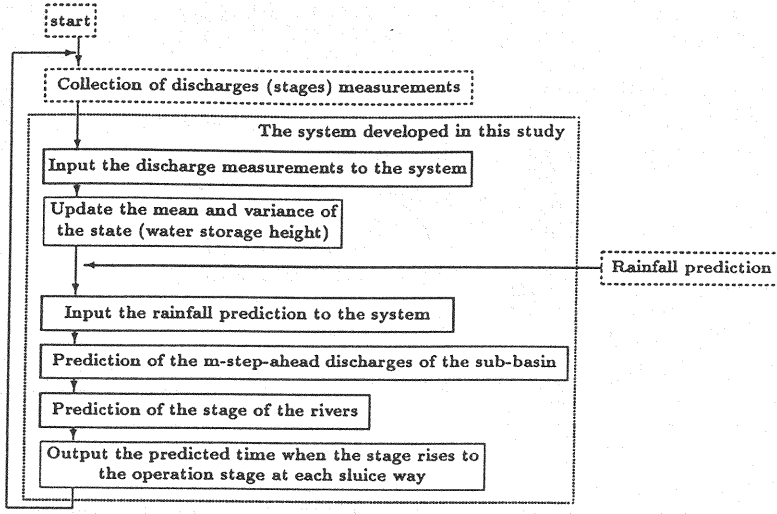


Fig. 3 Flow chart of the forecasting system for the Ueno Retarding Basins

$$y_k = \xi x_k^{1/p} + v_k \quad (2)$$

where t = time; x = state (water storage height); $r(t)$ = input (rainfall intensity); y_k = output (runoff height at time t_k); $\xi = (1/K)^{1/p}$; f , K , p and T_L = constant model parameters; $w(t)$ = continuous system noise; v_k = discrete observation noise, and

$$E[w(t)] = 0, \quad E[w(t)w(\tau)] = Q\delta(t - \tau) \quad (3)$$

$$E[v_k] = 0, \quad E[v_k v_l] = R\delta_{k,l} \quad (4)$$

where $\delta_{i,j}$ is the Kronecker delta function.

It is impossible to get strictly the transition of the stochastic distribution of the state x , therefore x is supposed to be Gaussian and the stochastic differential equation of Eq. 1 is approximately solved by an iterative difference method with the aid of a statistical linearization technique (Gelb (2)).

Prediction scheme At time t_k , to obtain the one-step-ahead prediction of state estimate $\tilde{x}_{k+1} = \tilde{x}(t_{k+1})$ and error variance $\tilde{P}_{k+1} = \tilde{P}(t_{k+1})$, ($t_{k+1} = t_k + \Delta T$ and ΔT = discharge observation time increment), following procedures are carried out. First, by linearizing the right-hand side in Eq. 1 at time s ($t_k \leq s < t_{k+1}$),

$$\frac{dx}{dt} = Ax + b + w(t) \quad (5)$$

is obtained. Discretizing Eq. 5 yields

$$x(s + \Delta t) = \Phi x(s) + \Gamma b + \Gamma w_s \quad (6)$$

where Δt = computation time increment, $E[w_s] = 0$, and $E[w_s^2] = Q_s = Q/\Delta t$. From Eq. 6,

$$\tilde{x}(s + \Delta t) = \Phi \tilde{x}(s) + \Gamma b \quad (7)$$

$$\tilde{P}(s + \Delta t) = \Phi^2 \tilde{P}(s) + \Gamma^2 Q_s \quad (8)$$

is derived. Iterating these procedures until time t_{k+1} , we get the one-step-ahead prediction of state estimate \tilde{x}_{k+1} and error variance \tilde{P}_{k+1} . Finally, to get the stochastic distribution of y , by linearizing Eq. 2 at time t_{k+1} ,

$$y_{k+1} = Hx_{k+1} + d + v_{k+1} \quad (9)$$

is obtained, and the estimate of output \tilde{y}_{k+1} and error variance \tilde{Y}_{k+1} are computed from

$$\tilde{y}_{k+1} = H\tilde{x}_{k+1} + d \quad (10)$$

$$\tilde{Y}_{k+1} = H^2 \tilde{P}_{k+1} + R \quad (11)$$

Filtering scheme At time t_{k+1} , when y_{k+1} is observed, \tilde{x}_{k+1} and \tilde{P}_{k+1} are updated, and filtered state estimate \hat{x}_{k+1} and error variance \hat{P}_{k+1} are obtained using the Kalman filter:

$$\hat{x}_{k+1} = \tilde{x}_{k+1} + K(y_{k+1} - \tilde{y}_{k+1}) \quad (12)$$

$$\hat{P}_{k+1} = (1 - KH)\tilde{P}_{k+1} \quad (13)$$

where $K = \tilde{P}_{k+1}H(H^2\tilde{P}_{k+1} + R)^{-1}$

Flood routing system

The channel reach for this study is subject to backwater effect, so that the full one dimensional equations of unsteady flow are used:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (14)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) + gA \frac{\partial h}{\partial x} + gA(I_f - i) = 0 \quad (15)$$

where t = time; x = distance along the channel axis; A = cross-sectional area of flow; Q = average discharge across a section; h = water surface elevation; I_f = friction slope; i = bed slope; and g = acceleration due to gravity. These equations are solved using the four-point implicit numerical scheme with the Newton iteration technique.

APPLICATIONS AND RESULTS

For the flood data from 19-20 September 1990, the time when the stage of the river rose up to the operation stage at each sluice way was predicted by computer simulation.

The values of the runoff model parameters are shown in Table 1. The variances of $w(t)$ and v_k were set to be $5.0 \text{ mm}^2 \text{ h}^{-2}$ and $10.0 \text{ mm}^2 \text{ h}^{-2}$, respectively. In this simulation, rainfall was treated as a deterministic value and the 1-, 2-, 3-hour-ahead prediction of the discharges

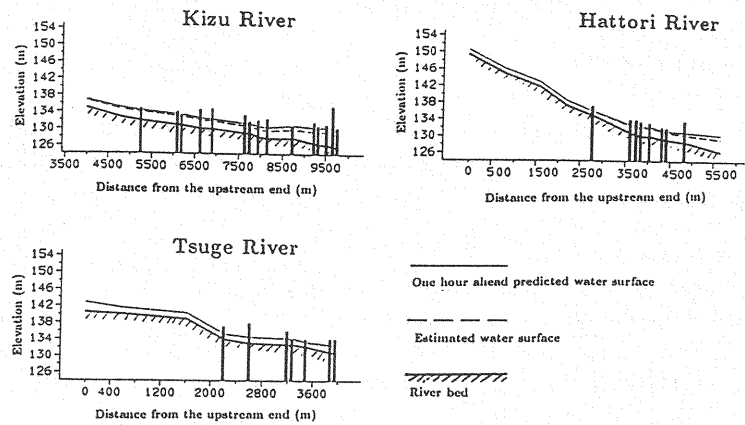


Fig. 4 Current estimation and one-hour-ahead prediction of the stage at 21 h on 19th

Table 1 Parameters of the runoff prediction model

Sub-basin	Catchment area (km^2)	f	K	p	t_L (h)
Tsuge	152.76	0.474	17.34	0.536	1
Hattori	94.03	0.769	27.35	0.554	0
Kizu	148.88	0.631	18.73	0.489	1

were calculated every hour. The observation time-increment ΔT and the computation time-increment Δt were set to be 1.0 h and 0.1 h, respectively.

In the flood routing system, using the 1-, 2-, 3-hour-ahead prediction of the discharges for the upstream boundary conditions, the stages were computed every six minutes until three hours later, and the time when the stage of the river rose up to the operation stage at each sluice way was predicted. For the channel slope, the actual values of the channel geometry were used, and for the channel section, design values were used because from the actual channel geometry it was difficult to get the relationship between stage and cross-sectional area and the relationship between stage and wetted-perimeter. The value of Manning’s friction coefficient was set to be $0.035\text{ m}^{-1/3}\text{ s}$ for all the channel sections.

Fig. 4 shows the current estimated stage and one-hour-ahead prediction of stage at 21 h on 19th. In the figure, “elevation” represents the height above the mean sea level of the Osaka Bay, and vertical bars denote the locations and the ground levels of the sluice ways. The result of the predicted time and the actual operation time is shown in Table 2. The sluice ways which were actually operated corresponded with the sluice ways at which the stage of the river was predicted to rise up to the operation stage. But, the predicted times were later than the actual operation times. The reasons are considered as follows:

- (1) The predicted discharges from the sub-basins were underestimated.
- (2) The design cross-sectional area is larger than the actual cross-sectional area, so that the stage was underestimated.
- (3) In this system, the discharges from the brooks were not considered.

Table 2 Actual operation time and predicted time when the stages of the rivers rose up to the operation stages of the sluice ways

Sluice way	actual time	predicted time	Sluice way	actual time	predicted time
Iwakura	22:40	#* (23:00) [†]	Oothubo	21:30	—
Hiranokawa	22:00	— [‡]	Shirode	—	22:20 (22:00)
Ichiba	—	—	Nishide	—	—
Asaya	22:00	—	Asakogawa	—	—
Iwanekawa	20:00	# (22:00)	Nii	—	—
Sumikogawa	—	—	Ootani	—	—
Kiko	22:00	22:27 (22:00)	Hattori	—	—
Yawata	20:00	21:03 (21:00)	Mita1	—	—
Shimizu1	19:40	# (23:00)	Mita2	—	—
Shimizu2	—	—	Mita3	—	21:27 (21:00)
Otashinden	—	—	Ota	—	22:11 (22:00)

* “#” denotes that the stage had already rose to the operation stage at the time when the computation for forecast was executed.

[†] Numbers in parentheses denote the time when the computation for forecast was executed.

[‡] “—” denotes that the stage did not rise to the operation stage for this flood.

CONCLUSIONS

In this study, to operate many sluice ways one after another by as few people as possible, the system which predicted the stage of the river on a real-time basis and gave the time when the stage of the river rose up to the operation stage of each sluice way was developed.

This system has computational ability for real-time prediction, because computation time needed to obtain the 3-hour-ahead prediction of the stages was about three min on a workstation (SUN SPARCstation IPX).

In this simulation, the predicted discharges from the sub-basins were underestimated. To cope with this point seems to be most important to improve the accuracy of the prediction of the operation time of the sluice ways.

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APPENDIX - NOTATION

The following symbols are used in this paper:

f, K, p	=	constant model parameters of storage function method;
\tilde{P}_k	=	error variance of state estimate at time t_k ;
\hat{P}_k	=	filtered error variance of state estimate at time t_k ;
$r(t)$	=	input variable (rainfall intensity at time t);
t	=	time (continuous);
t_k	=	time (discrete), $k=1, 2, \dots$;
T_L	=	lag time parameter;
v_k	=	discrete observation noise;
$w(t)$	=	continuous system noise;
$x(t)$	=	state variable (water storage height at time t);
\tilde{x}_k	=	state estimate at time t_k ;
\hat{x}_k	=	filtered state estimate at time t_k ;
y_k	=	output variable (runoff height at time t_k);
Δt	=	computation time increment;
ΔT	=	discharge observation time increment;
$\delta(t)$	=	Dirac delta function; and
$\delta_{i,j}$	=	Kronecker delta function.

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