INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

A Study on New Technique of dam Sluice Operation for Flood Control

Chaochao Qian & Tadashi Yamada
Chuo University, Tokyo, Japan

Yusei Kitada
Tohoku Electric Power Co., Inc, Sendai, Japan

Hideo Kikkawa
Foundation of River & Watershed Environment Management, Tokyo, Japan

ABSTRACT:
Dam gate operation plays a prominent role in comprehensive water resources management of river basins. An increase of rainfall frequency and strength recently and in near future was reported by current IPCC reports. Existing dam operating rules cannot deal with this alteration by using the existing rules which are only depends on the flood-control capacity of dams. Therefore, it is needed to enhance the efficiency of dam gate operation method to improve the flood-control capacity of existing dams without obstructing irrigation, municipal supply and generation of electricity. In this paper, authors propose a new sluice rule called “anticipatory sluice” for dam operation. Authors propose the “Yamada’s method” for calculating the discharge from dams by estimating the income water without using analytical solution. In this paper, the verified dam reservoir and rainfall data that authors intended for is Kusaki dam reservoir (catchment area is 254km^2) and accumulated value of the short-term precipitation forecast respectively in Watarase River basin in Japan. Yamada’s method is still effective in the status quo that it takes three hours to prepare the gate operation because it is possible to provide six hours at earliest before flood peaks arrival. Therefore, this is a realistic and practicable method.

Keywords: prior flow, runoff, flood control capacity, short-term precipitation forecast

1. INTRODUCTION

Dam gate operation in Japan plays one of the prominent roles in comprehensive flood control and water resources management of river basins. In terms of river improvement when a flood or a deluge is surely predicted, it maintains flood-control capacity as much as possible. Meanwhile, in term of irrigation, the operation principle of a multipurpose dam is to maintain the water level as high as possible. Recently an increase frequency and strength in floods due to an increase of a deluge reported by IPCC the 4th evaluation report. Existing dam operating rules cannot deal with this alteration because the existing rules are only based on the flood-control capacity. Therefor, it is important to enhance the efficiency of dam gate operation method to improve the flood-control capacity of existing dams without obstructing irrigation, municipal supply and generation of electricity.

In this paper, the dam reservoir that authors intended for is Kusaki Dam Reservoir with a 254km^2 catchment area. This dam is the only reservoir in Watarase River catchment area. The river is the longest branch of upper stream of Tone River (the second longest river in Japan) system. **Figure-1** shows the location of the Tone River system and the Kusaki Dam Reservoir.

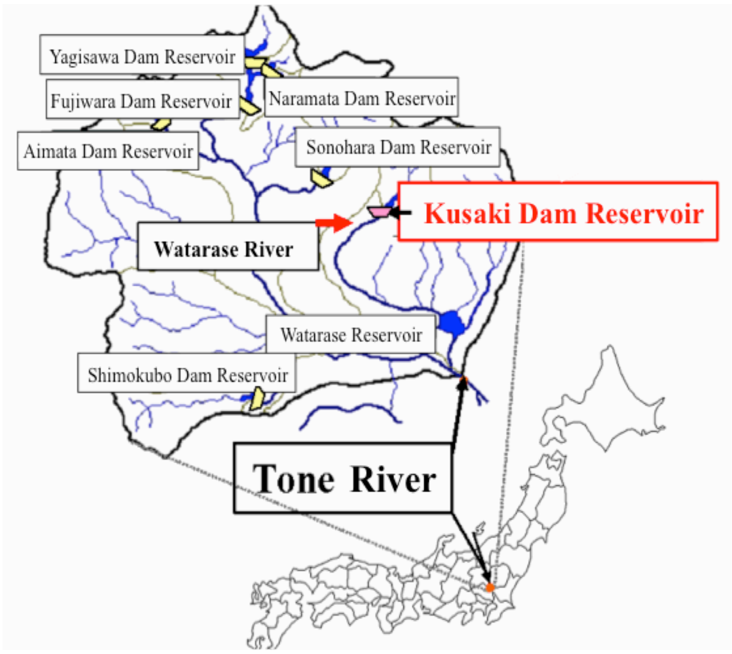

Figure 1. Tone River System and the Target Dam Reservoir

2. DAM RESERVOIR DISCHARGE DETERMINATION METHOD

A calculation method of dam reservoir discharge is described in this study below. Inflow and outflow of continuity equation (1) is obtained in any dam reservoir. Where, V [m^3]: total surely inflow into the dam reservoir from present time is described as

$$-\int_0^t (Q_{IN} - Q_{OUT})dt = V \quad (1)$$

Generally, V can be calculated by an analytical solution. However, in this method, it is difficult to apply to the real time scale cases because it is complex and take a lot of time to analysis. Authors proposed the technique for calculating outflow to calculate the inlet flow without using an analytical solution, and it is called the "Yamada's method" in this study. There are two steps in the method as follow.

1. The method to express the function $Q_{IN}(t)$ of momentary inflow: $V(Q_{IN}(t))$

$$-\int_0^t (Q_{IN}(t) - Q_{OUT}(t))dt = V(Q_{IN}(t)) \quad (2)$$

2. The method to express in function $R(t)$ of the momentary accumulated rainfall: $V(R(t))$

$$-\int_0^t (Q_{IN}(t) - Q_{OUT}(t))dt = V(R(t)) \quad (3)$$

In this study, step 1 and step 2 are defined as "recession characteristics step" and "accumulated rainfall step" respectively. Equation (4) is obtained by differentiating equation (2) respect to time:

$$Q_{OUT}(t) = Q_{IN}(t) = \frac{dV(t)}{dQ_{IN}(t)} \cdot \frac{dQ_{IN}(t)}{dt} \quad (4)$$

We can get the relation between peak inflow discharge (Q_{IN}) and Total discharge from decreasing (V) by using the equation (4) as shown in **Figure 2**:

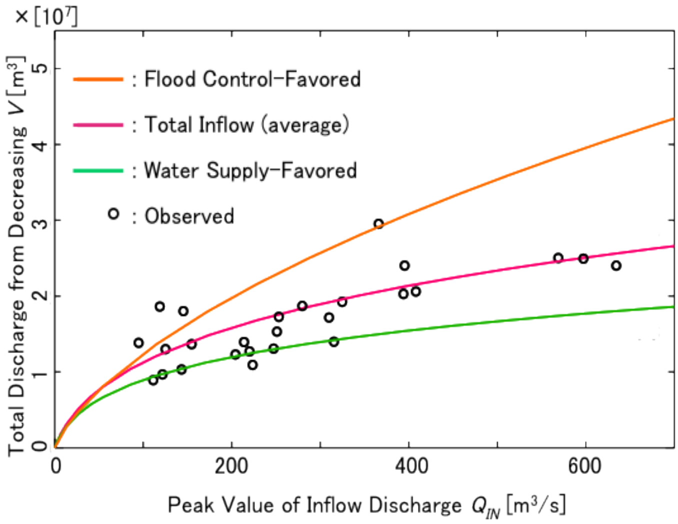

Figure 2. Relation between Peak Inflow Discharge (Q_{IN}) and Total Discharge from decreasing (V)

Equation (6) is obtained by differentiating equation (3) respect to time:

$$R(t) = \int_0^t r(t)dt \quad (5)$$

$$Q_{OUT}(t) = Q_{IN}(t) + \frac{dV(t)}{dR(t)} \cdot \frac{dR(t)}{dt} = Q_{IN}(t) + \frac{dV(t)}{dR(t)} \cdot r(t) \quad (6)$$

$R(t)$ [mm]: total rainfall from rain event started to present in a dam reservoir basin, $r(t)$ [mm/h]: observed rainfall density. The water level of a dam reservoir is calculated by equation (7). Thus, the safety of service water capacity is verified. $A(h)$ [m^2]: reservoir area, h[m]: water lever of reservoir.

$$A(h)\frac{dh(t)}{dt} = Q_{IN}(t) - Q_{OUT}(t) \quad (7)$$

Additionally, there are two methods shown below depend on substantiality condition (rainfall and inflow quantity data) of the dam basin for calculating V.
a). There is substantial hydrological past data of the basin: get the relation between V and Q_{IN} from the data.
b). Hydrological past data of the basin is not enough: get the relation between V and Q_{IN} from an analytical curve.
Figure 3 shows that in the case of Kusaki Dam basin, dV/dR is determined and the discharge of sluice can be calculated by using existing hydrology data.

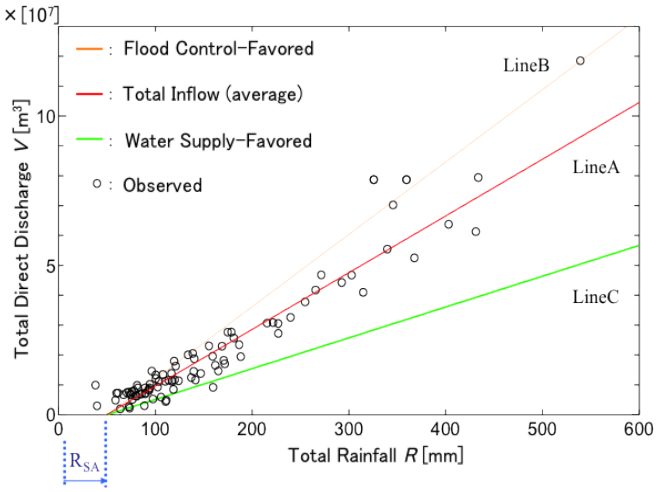

Figure 3. Relation between Total Rainfall (R) and Total Direct Discharge (V)

The threshold of outflow according to rainfall is defined as R_{SA} in this study. Since the total rainfall reaches R_{SA}, the time is set as t=0. R_{SA} in Kusaki Dam basin is 46mm.

3. ANTICIPATORY SLUICE BY ACCUMULATING SHORT-TERM PRECIPITATION FORECAST RAINFALL DATA

Nowadays, before the discharging from the dam, about three hours are needed for preliminary work, for example: (1). Ensuring sufficient numbers of personnel. (2). Serving sluice notices to the local municipalities. (3) Making decision to discharge. (4). Inspecting equipment, etc. In this study, we propose to determine earlier initial discharge time using the accumulation value of short-term precipitation forecast (Six-hour forecast announced every 30 minutes and forecast the value of rainfall per hour) but not the observed. Anticipatory sluice volume is determined by accumulated rainfall method using short-term precipitation forecast. The volume at time t is determined using assumed discharge of inflow to the reservoir from the n-hour forecast rainfall data. In this method, the Accumulated rainfall $R(t)$ is accumulation of n-hour forecast rainfall. Anticipatory release volume using forecast rainfall can be calculated by equation (8).

$$Q_{OUT}(t) = Q_{IN}(t) + \frac{dV(t')}{dR(t')} \cdot r(t') \qquad (8)$$

t' is the time assumed to be rain from the n-hour forecast at time t. $t'=t+n$ (n: n=1,2,…,6[hour]). **Figure 4** shows the conceptual diagram.

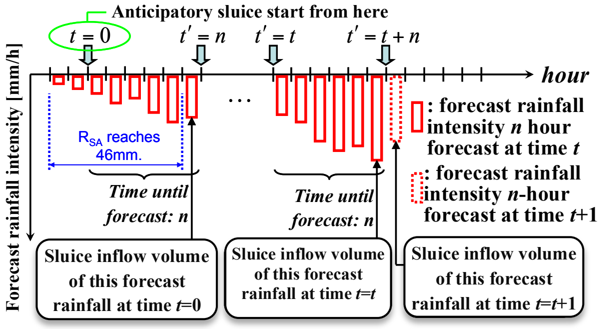

Figure 4 Conceptual Diagram of n-hour Forecast for Anticipatory Sluice

4. CORRECTING FORECAST RAINFALL DATA FOR ANTICIPATORY SLUICE

The forecast rainfall doesn't necessarily consist with the observed rainfall as shown in this study. If the forecasted overestimates the observed, the reservoir level might be difficult to recover after anticipatory sluice. Meanwhile, if the forecasted underestimates the observed, anticipatory sluice will difficult to be executed. Therefore, it is needed to improve the accuracy of anticipatory sluice by using equation (9) to correct the forecast rainfall data.

$$R_c(t) = R_f(t) + (R_0(t-1) - R_f(t-n)) \qquad (9)$$

The corrected value is the sum of n-hour forecast rainfall at time t and the difference between observed at time t-1 and n-hour forecasted at time t-n-1. This correction method does not correct the forecasted in the next n hours, but the difference between the observed and the forecasted up until now time.

5. FLOOD CONTROL BY ANTICIPATORY SLUICE

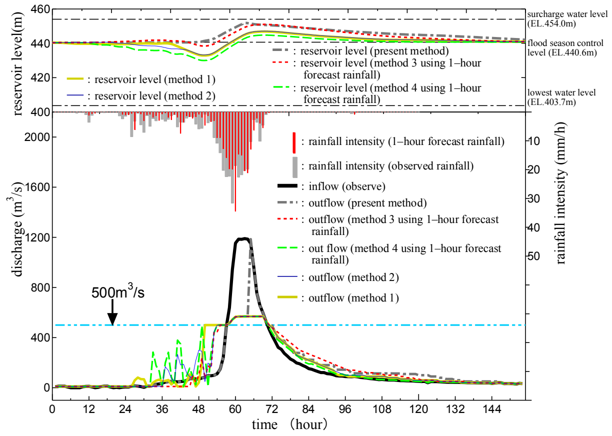

Figure 5 Time Series of Outflow and Reservoir Level in Kusaki Dam for Anticipatory Sluice Using 1-hour Forecast Rainfall

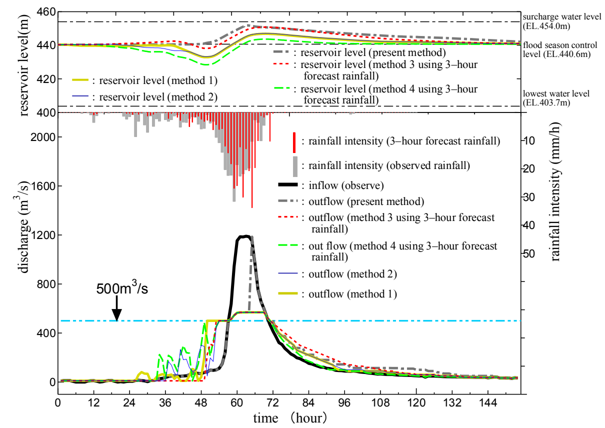

Figure 6 Time Series of Outflow and Reservoir Level in Kusaki Dam for Anticipatory Sluice Using 3-hour Forecast Rainfall

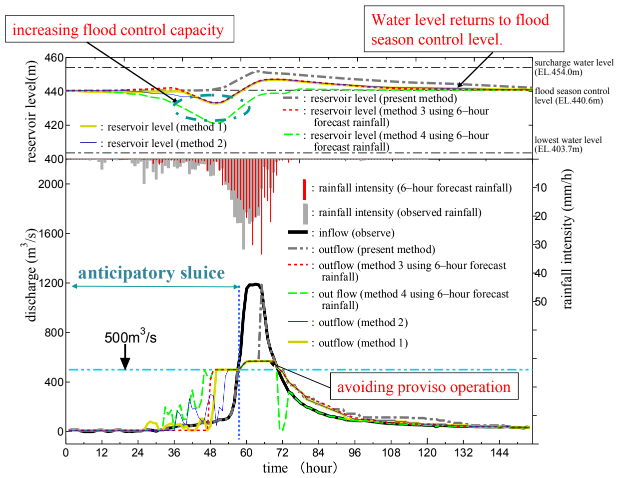

Figure 7 Time Series of Outflow and Reservoir Level in Kusaki Dam for Anticipatory Sluice Using 6-hour Forecast Rainfall

Authors applied the anticipatory sluice based on the proposed method. The flood used in the applied case was typhoon9 (recorded greatest outflow 1190m^3/s) in the Kusaki dam reservoir from September 4th to 8th, 2007.

Figure 5, 6, 7 show the time series of observed inflow discharge, outflow discharge and the reservoir level by using: i) Accumulating forecast data method. ii) Corrected accumulating forecast data method. iii) Recession characteristics method. iv) Accumulating observed data method with each 1-hour, 3-hour, and 6-hour forecast data respectively.

According to the existing rules of the Kusaki dam reservoir, sluice should start with flood control base on the equation (8) when the inflow discharge reaches 500m^3/s.

$$Q_{OUT}(t) = (Q_{IN}(t) - 500) * 0.1 + 500 \quad (10)$$

The maximum value of the anticipatory sluice discharge is set to 500m^3/s defined by the Kusaki dam's operation rules. Since inflow exceeds 500m^3/s in discharge, the flood control will follow the existing procedure to perform 'proviso operation' that is outflow=inflow. In the typhoon9, 2007 flood, the reservoir level did not shift to the proviso operation because reservoir level was lower than flood season control level. Meanwhile, the result of the simulation of this study, present operation shifted to the operation because it set initial reservoir level to flood season control level. In any case, it may be said that anticipatory sluice is very effective which is based on the flood control technique to suggest in this study, as we did not have to practice the proviso operation. Corrected accumulating forecast rainfall method sluice the most discharge than any other methods to maximize the flood-control capacity. In addition, this study assumes that any anticipatory sluice method can save up the water level up to flood season control level.

5. CONCLUSION

In the verified flood, the methods that authors proposed can controlled the flood successfully to increase the flood-control capacity in each anticipatory sluice technique before inflow to the dam reservoir was superior. From this study it can be said that these methods can be applied to this basin. Yamada's method is effective in the current state that it takes only three hours to prepare the dam gate operation, it is possible to provide for the flood by six hours at earliest. Therefore, this is a realistic practical method.

AKNOWLEDGMENTS

This study was supported by Kusaki Dam Management Office of Japan Water Agency that provided valuable data for analysis, it is gratefully acknowledged.

REFERENCES

Contribution of Working Group I to the Fourth Assessment, Report of the Intergovernmental Panel on Climate Change. (2007): Intergovernmental Panel on Climate Change(IPCC) Climate Change 2007: The Physical Science Basis.

Kure, S., Koshizuka, Y., and Yamada, T. (2004) :Extraction of runoff characteristics from flow recession rharacteristics of hydrograph, Annual Journal of Hydraulic Engineering, JSCE, Vol.48, pp. 13-18.

Toya, H., Akiba, M., Miyamoto, M., Yamada, T., and Kikkawa, H. (2006) : Study on determination method of amount of dam discharge based on the runoff characteristics, Journal of Japan Society of Civil Engineering, JSCE, Division2, No.810, pp. 17-30.

Kikichi, K., T.Hideo., Yamada, T., Kikkawa, H. (2008): A study on reservoir operation based on runoff characteristics of a basin, the 4th Conference of the Asia Pacific Association of Hydrology and Water Resources, APHW, CDROM, Session 2-11.

Shimosaka, M., Kure, S., Yamada, T., and Kikkawa, H. (2009): A new flood control method by dam gate operation based on run-off characteristics of a basin for the improvement of flood mitigation effects of a dam , Journal of Japan society of Civil Engineering, JSCE, No. 65, pp. 106-122.

Kitada, Y., Kikichi, K., Okabe, M.,Yamada, T. (2010): A new technique of discharge release from dam reservoir for flood control base on the short-term precipitation forecast of Japan meteorological agency, 54th Conference on Hydraulic, JSCE, pp. 88-93