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# Early Release Reservoir Operation Simulation Model of Multi Reservoir

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**Abstract** This research intends to investigate the effectiveness of reservoir operation pattern for flood control in the parallel reservoirs of Tugu and Bagong reservoirs. These parallel reservoirs meet in the same junction before the town house of Trenggalek Regency. The Tugu reservoir supplies water requirement in 1,250 ha irrigation area, 12 l/s raw water supply, and 0.40 MW mini hydro electrical power. However, Bagong reservoir supplies water requirement in 857 ha irrigation area and 465 l/s raw water supply. The beneficiary from the two reservoirs do not overlap with each other except as the function of flood control. The methodology consists of simulation of reservoir operation based on the irrigation and raw water supplies, simulation of reservoir operation for flood control, and assessment of reservoir reliability. The reservoir operation pattern for flood control focuses on the decreasing of reservoir water level during the flood period so there is an empty space that can be utilized as flood control storage by regulating the outflow structure because the spillway structures of both reservoirs are not completed by regulator gates. The research result is hoped can obtain the most optimum flood storage by considering the maximum capacity in the river downstream of each reservoirs so it can minimize the flood risk due to 25 years return period.

**Keywords** Bagong Reservoir, Flood Control, Multi Reservoir, Reservoir Operation, Tugu Reservoir

## 1. Introduction

The aim of reservoir operation is to distribute the water resources, minimize the drought and flood risk, and maximize the water utilization based on the operation pattern rules [1]. To minimize the flood risk that is usually expressed as flood control in the benefits of reservoirs [2], however, reservoir that is not completed with gated spillway often only gives the benefit of flood reduction. It is due to the inflow that enters to reservoir [3] towards the reduction because there is a free spillway structure which is expressed in spillway outflow through the flood routing that the initial condition is started on the normal water level elevation of reservoir. If it is reviewed from reservoir operation pattern, there is a potency of flood control by regulating the reservoir operation pattern [4]; so there is an empty storage in the certain period and the flood routing through the spillway structure has the initial condition that is started from certain elevation under the normal water level elevation of reservoir. However, to minimize the drought risk usually is expressed in the benefits of reservoirs like irrigation water supply and raw water supply. Therefore, it is necessary to optimize the reservoir operation pattern [5] in accordance with the benefits of reservoirs mainly for multi-purpose reservoirs in a river system.

Optimization of multi-objectives due to the multi-purpose' reservoir refers to a problem that involves several objectives to be optimized simultaneously [6] like flood control, raw water supply, and hydro-power generation. However, the objective is often in conflict with one another and there is analysis with the different unit [7].

The Tugu and Bagong reservoirs are in Trenggalek Regency, East Java Province-Indonesia. Both reservoirs are parallel in the Ngasinan River system and both reservoirs downstream meet in river meeting section/ junction as utilization intersection of flood control in the townhouse of Trenggalek Regency. Based on the same utilization intersection, it is needed to review the ability of both reservoirs for maximizing the same utilization [8] by paying attention the other utilization of each reservoir.

## 2. Materials and Methods

### 2.1. Study Location and Methodology

Tugu Reservoir is in the Tugu District, Trenggalek Regency, East Java province-Indonesia. The Tugu Reservoir has 89,85 m main dam height, 41,47 hectare water surface area, and 11,17 MCM total reservoir storage which is utilized for: 1) Irrigation water supply of 1,250 ha; 2) Raw water supply of 12l/s; 3) Flood control; and 4) Micro Hydro Electrical Generation of 0.40 MW. However, Bagong Reservoir is in the Bendungan District, Trenggalek Regency, East Java Province-Indonesia. The Bagong Reservoir has 82 m main dam height, 81 hectares water surface area, and 20,49 MCM total reservoir storage which is utilized for: 1) Irrigation water supply of 857 ha; 2) Raw water supply of 465 l/s; and 3) Flood control.

Location map of Tugu and Bagong Reservoirs is presented in Figure 1. However, the research method is as follows: 1) simulation of reservoir operation based on the irrigation and raw water supplies; 2) simulation of reservoir operation for flood control; and 3) assessment of reservoir reliability.

### 2.2. Method of Flood Routing

Flood routing of reservoir is carried out by hydrologic routing that is based on the continuity equation as follows [2]:

$$I - Q = ds/dt \quad (1)$$

With:
I = inflow to reservoir ($m^3$/s),
Q = outflow through spillway ($m^3$/s),
ds = storage change ($m^3$),
dt = routing period (s).

If the routing period is changed into Δt, $I_1$ and $I_2$, it can be known the hydrograph of inflow to reservoir, but S is reservoir storage at the beginning of routing period that is measured from datum of outflow facility (outlet), so the flood routing method is as follows [9]:

$$\frac{I_1 + I_2}{2} + \left(\frac{S_1}{\Delta t} - \frac{Q_1}{2}\right) = \frac{S_2}{\Delta t} + \frac{Q_2}{2} \quad (2)$$

If

$$\frac{S_1}{\Delta t} - \frac{Q_1}{2} = \psi_1 \;\; and \;\; \frac{S_2}{\Delta t} + \frac{Q_2}{2} = \varphi_2 \quad (3)$$

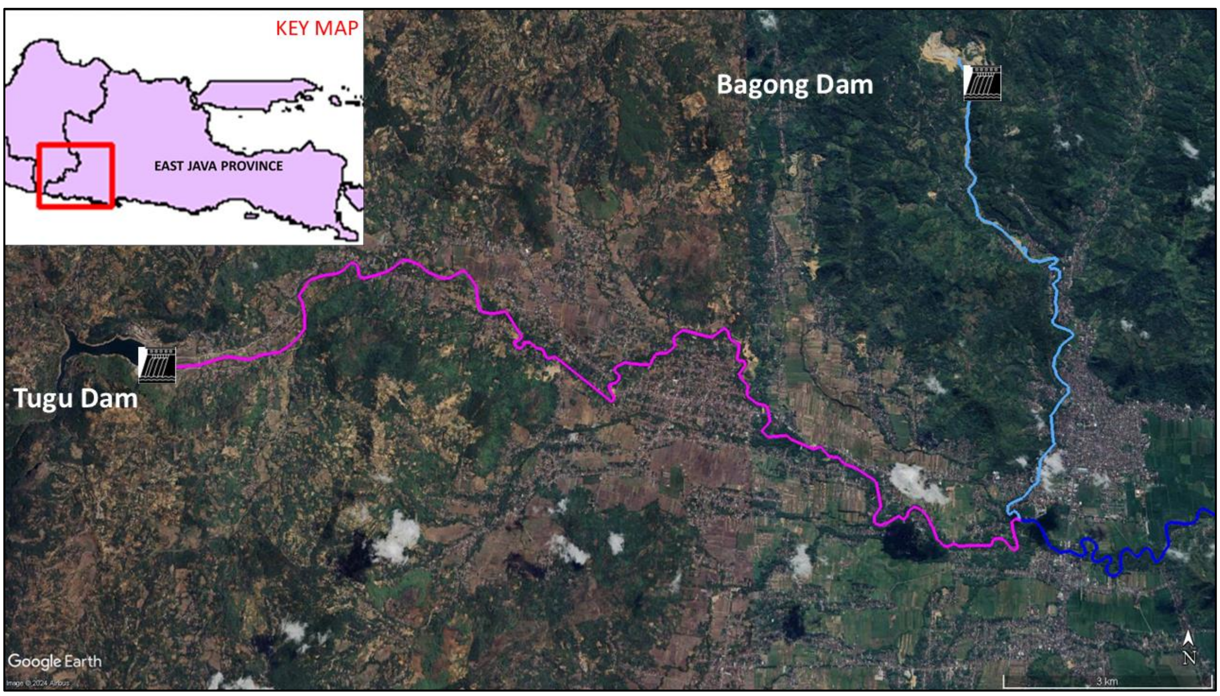


**Figure 1.** Location Map of Tugu and Bagong Reservoirs-Trenggalek Regency Source: Google Maps and sda.pu.go.id, to be accessed on 2-10-2024

So, the equation (2) can be written as follows:

$$\frac{I_1 + I_2}{2} + \psi_1 = \varphi_2 \quad (4)$$

With:
I1 = inflow more than discharge that is found ($m^3/s$),
I2 = inflow that is found ($m^3/s$),
Q = outflow from reservoir ($m^3/s$),
$\psi 1$ = condition at the beginning of routing,
φ2 = condition at the end of routing,
Δt = period of routing (second, hour, or day),
S = volume of reservoir storage ($m^3$),
Q is outflow at the beginning of routing period. If the output is spillway, so:

$$Q = C.B.H^{3/2} \quad (5)$$

With:
C = discharge coefficient of spillway (1.7–2.2 $m^{1/2}/s$),
B = width of spillway threshold (m),
H = energy head over the spillway threshold (m).

### 2.3. Simulation of Reservoir Operation for Irrigation, Raw Water, and Micro-Hydro Power Generation Water Supply

Tugu Reservoir is utilized for irrigation water supply in Tugu irrigation area of 1,250 ha that has the cropping pattern as paddy-paddy-second crop. The other utilization is raw water supply of 12 l/s for 5 villages in Tugu District-Trenggalek Regency. However, the utilization of Micro-hydro Power Generation follows the outflow through outflow structure in every period. The three utilizations do not insect with Bagong Reservoir, so the simulation of reservoir operation in Tugu Reservoir is not dependent on the other reservoir.

Bagong Reservoir is utilized for irrigation water supply in Bagong irrigation of 857 ha that has the cropping pattern as paddy-paddy-second crop. The other utilization is raw water supply of 465 l/s for 3 districts in Trenggalek Regency. Both utilizations are not intercepted, so the simulation of reservoir operation is not dependent on the other reservoir except for flood control.

Based on the reservoir utilization above, the simulation analysis of reservoir operation is carried out for obtaining the reservoir operation pattern by using water balance as follows [10]:

$$I = O \pm \Delta S \quad (6)$$

With
I : inflow ($m^3/s$)
O : outflow ($m^3/s$)
ΔS : storage change ($m^3$)

### 2.4. Simulation of Reservoir Operation Pattern for Flood Control

Downstream meeting junction of Tugu and Bagong Reservoirs is appropriate before the general facility area and national road, and densely population settlements in Trenggalek Regency with the distance about 20 km from Tugu Reservoir and 10 km from Bagong Reservoir. The simulation of reservoir operation pattern for flood control is focused during flood period [11] by allocating the empty storage in reservoir and maintaining the reservoir release in accordance with the maximum river capacity in the reservoir downstream. The Tugu Reservoir downstream has the river capacity for a 25-year return period that is 125 $m^3/s$ and in Bagong Reservoir downstream is 44 $m^3/s$.

The last event of flood overflow in Ngasinan River with the significant impact happened in October 2022. Rainfall in Bendungan is 140 mm in 24 hours. Meanwhile, the rainfall in Tugu District is recorded at 184 mm in the same period. Due to the high rainfall [12], some affluents like Tugu, Keser, and Prambon affluents produce high surface run-off. Therefore, Ngasinan River is not able to store water [13] that flow from the affluents. This event caused flooding in some areas in Trenggalek Regency that are 21 villages in 5 districts (Dinas Kominfo Provinsi Jawa Timur, 2022).

The reservoir operation pattern for flood control is obtained by modifying reservoir operation pattern in flood period by using the boundary of certain water level that is obtained from the analysis result of flood routing through spillway. The method is level pool routing which is defined as the procedure for analysing the outflow hydrograph from reservoir with plain water level by entering the inflow hydrograph data and the characteristic of storage-outflow as follows [14]:

$$\left(\frac{2S_{j+1}}{\Delta t} + Q_{j+1}\right) = \left(I_j + I_{j+1}\right) - \left(\frac{2S_j}{\Delta t} - Q_j\right) \quad (7)$$

With
$S_j$ : storage on period -j ($m^3$)
$S_{j+1}$ : storage on period-j+*1*($m^3$)
$I_j$ : inflow on period-j ($m^3/s$)
$I_{j+1}$ : inflow on period-j ($m^3/s$)
$Q_j$ : outflow on period-j ($m^3/s$)
$Q_{j+1}$ : outflow on period-j ($m^3/s$)
Δt : duration (hour)

## 3. Results and Discussion

### 3.1. Simulation of Reservoir Operation for Irrigation, Raw Water, and Micro-Hydro Power Generation Water Supplies

The simulation result of reservoir operation in Tugu Reservoir for irrigation and raw water, and water supplies is presented in Figures 2 and 3, in Bagong Reservoir is in Figures 4 and 5. Figure 2 and Figure 4 show the simulation result is the area between BON A (upper reservoir operation boundary) and BON B (lower reservoir operation boundary) and the reservoir water level operation not below LWL (Low Water Level) and also not exceed NWL (Normal Water Level). However, for micro-hydro power generation flows the outflow from outlet.

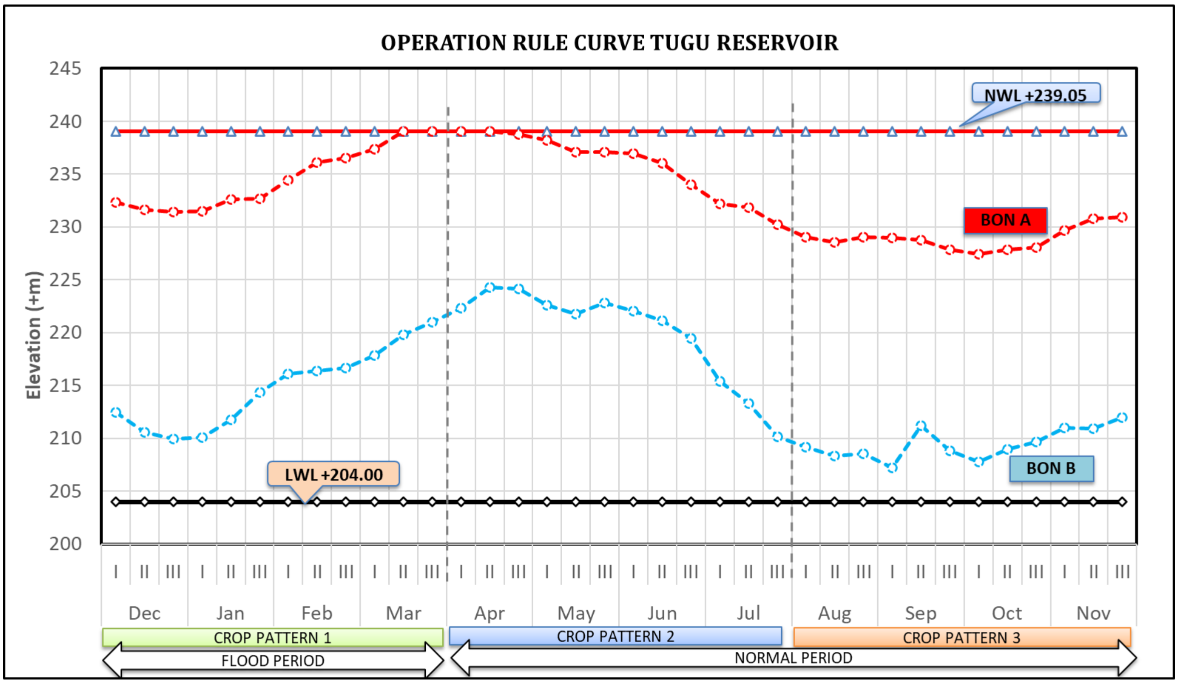


**Figure 2.** Reservoir Operation Pattern of Tugu without Flood Control

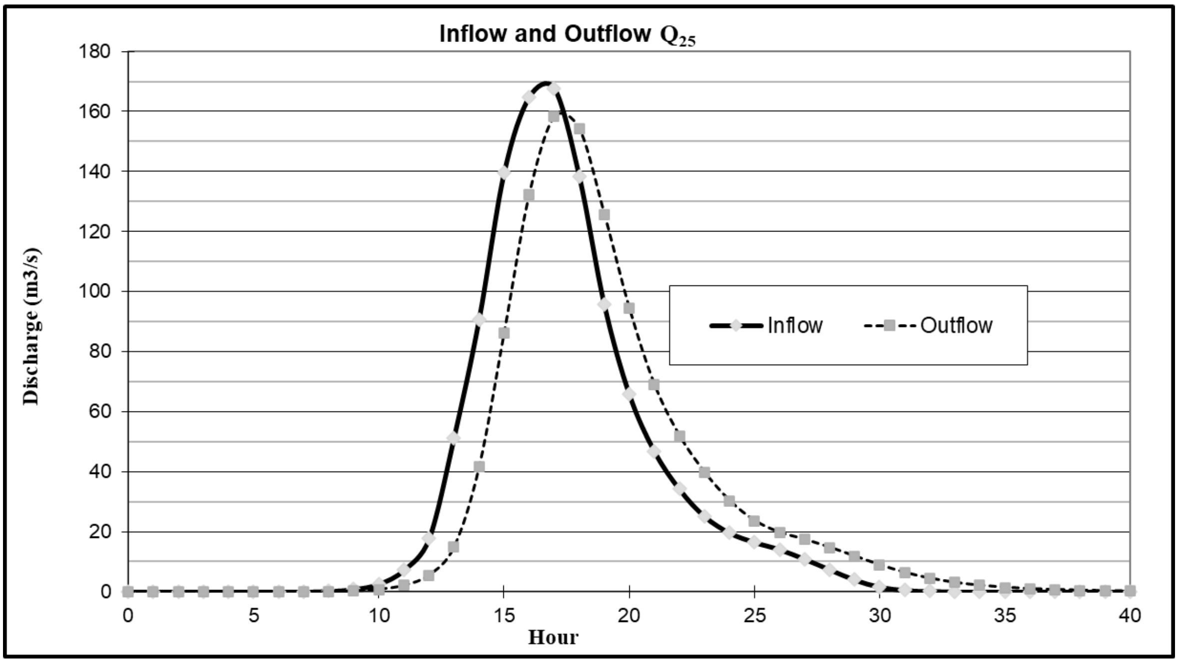


**Figure 3.** Flood Routing of Spillway in Tugu Reservoir without Flood Control

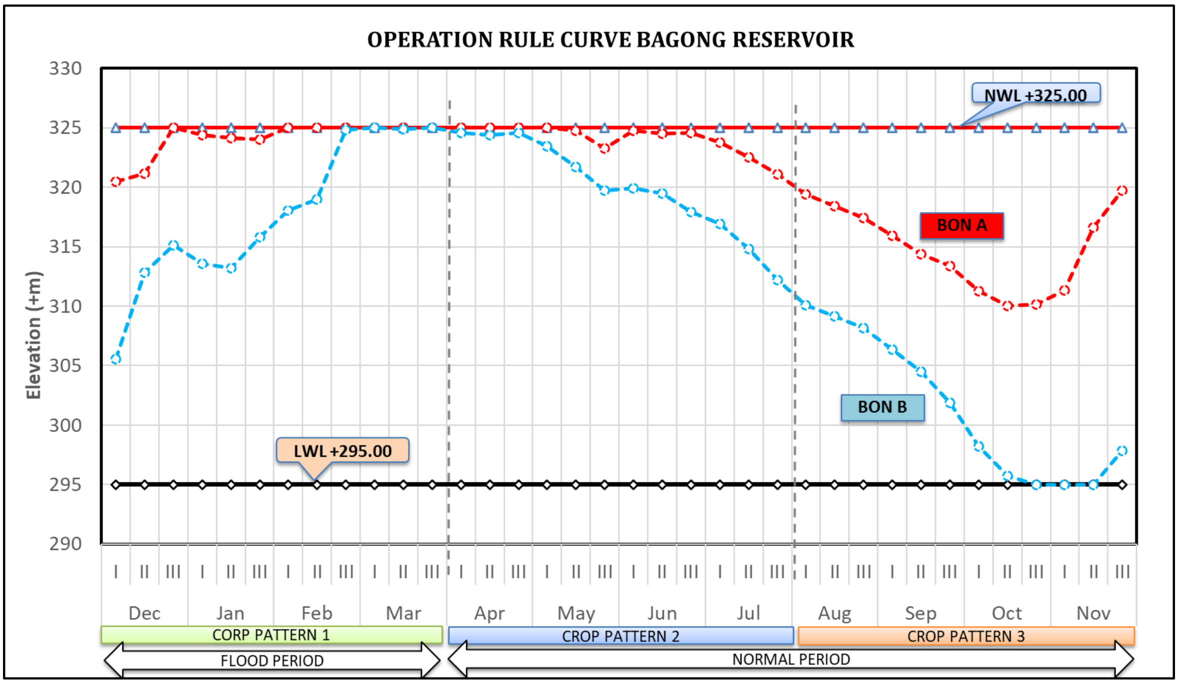


**Figure 4.** Reservoir Operation Pattern of Bagong without Flood Control

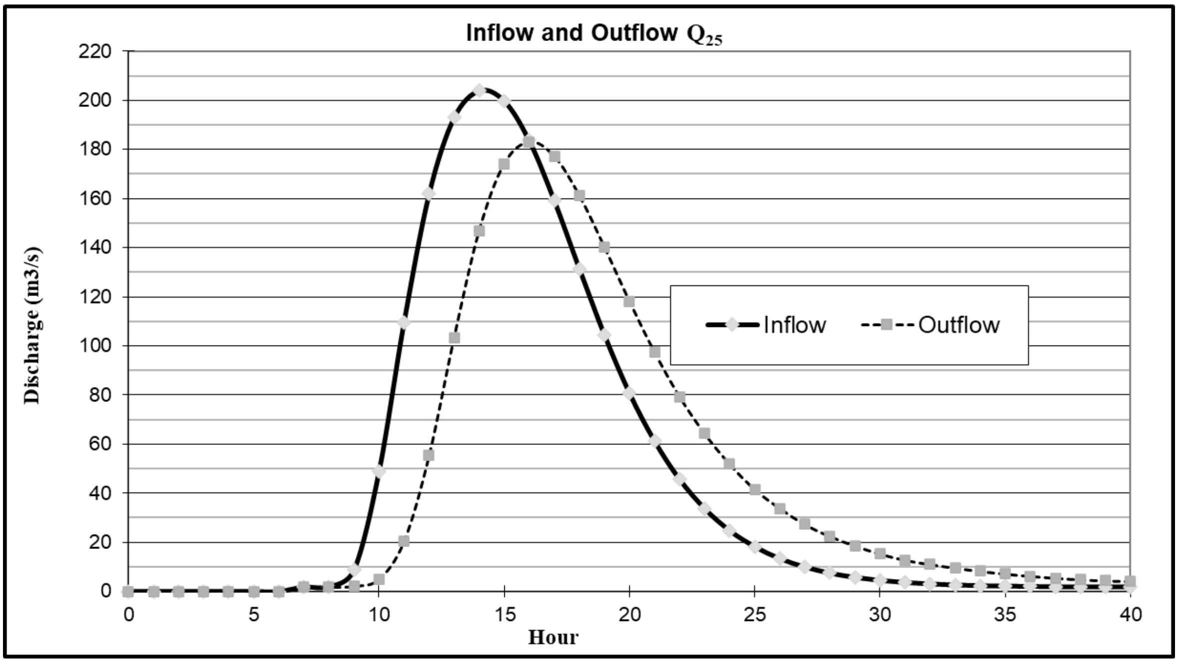


**Figure 5.** Flood Control of Spillway in Bagong Reservoir without Flood Control

Without the allocation of certain empty storage as the flood control, it is seen that the reduction of peak discharge is only about 12% and the outflow from spillway is more than the capacity of river downstream of Tugu Reservoir. It shows that when a flood with a return period of 25 years occurs, the downstream river water of Tugu Reservoir will overflow and cause flood inundation.

The same with the Tugu Reservoir, without the allocation of certain empty storage as the flood control, it is seen that the reduction of peak discharge is only about 10% and the outflow of spillway is more than the river downstream capacity of Bagong Reservoir. It shows that when the flood with a return period of 25 years occurs, the downstream river water of Bagong Reservoir will overflow and cause flood inundation.

### 3.2. Simulation of Reservoir Operation Pattern for Flood Control

The simulation result of reservoir operation pattern in Tugu Bagong Reservoir for irrigation and raw water supplies but the flood period of reservoir water level is reduced to the certain elevation is presented in Figures 6 and 7. However, micro-hydro power generation follows the outflow from outlet. It is seen that in the flood period, the water level (BON A) is maintained at the elevation of +234 m (5 m under spillway threshold) and at the end period of flood, the reservoir water level is full and ready as the control of drought risk in the next operation year

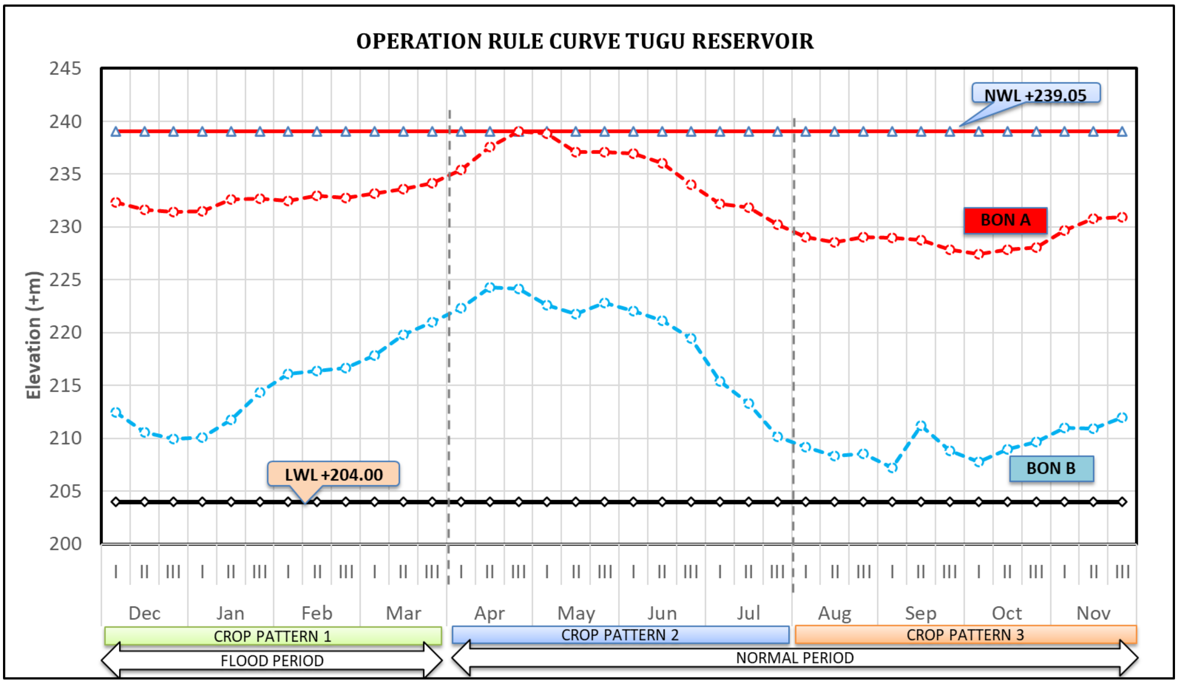


**Figure 6.** Reservoir Operation Pattern in Tugu Reservoir with Flood Control

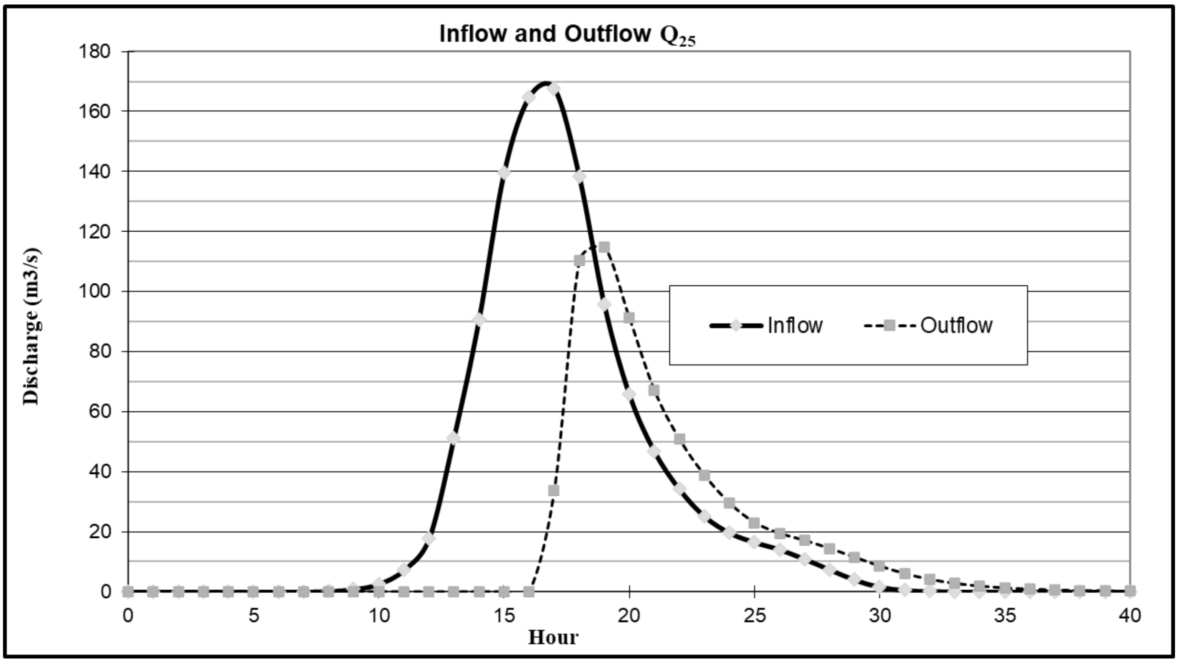


**Figure 7.** Flood Routing of Spillway in Tugu Reservoir with Flood Control

By the allocation of empty storage of about 2.8 million $m^3$ as the flood control, it is seen that the reduction of peak discharge is increasing to 31% and it is followed with the moving of flood peak time and the outflow of spillway is less than the river downstream capacity of Tugu Reservoir. It shows that when a flood with a return period of 25 years occurs, the downstream river water of Tugu Bagong Reservoir will not overflow, and cause flood inundation.

The simulation result of reservoir operation pattern in Bagong Reservoir for irrigation and raw water supplies but the flood period of reservoir water level is reduced to the certain elevation is presented in Figures 8 and 9. It is seen that in the flood period of water level (BON A) is maintained at the elevation of +317 m (9 m under spillway threshold) and at the end period of flood, the reservoir water level is full and ready as the drought risk in the next operation year. The reduction of reservoir water level that is high enough from spillway threshold is caused by the downstream river capacity of Bagong Reservoir is not big enough because the land use in downstream area of Bagong Reservoir is a densely populated settlement with the characteristic of river section being narrow.

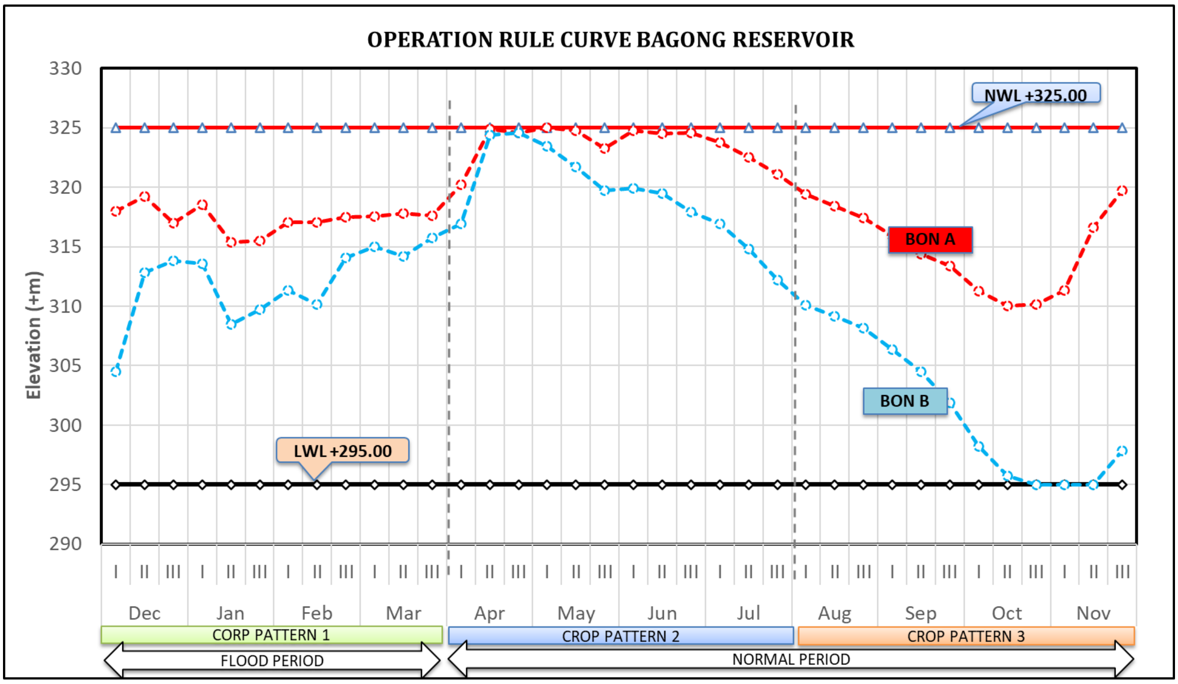


**Figure 8.** Reservoir operation Pattern of Bagong Reservoir with Flood Control

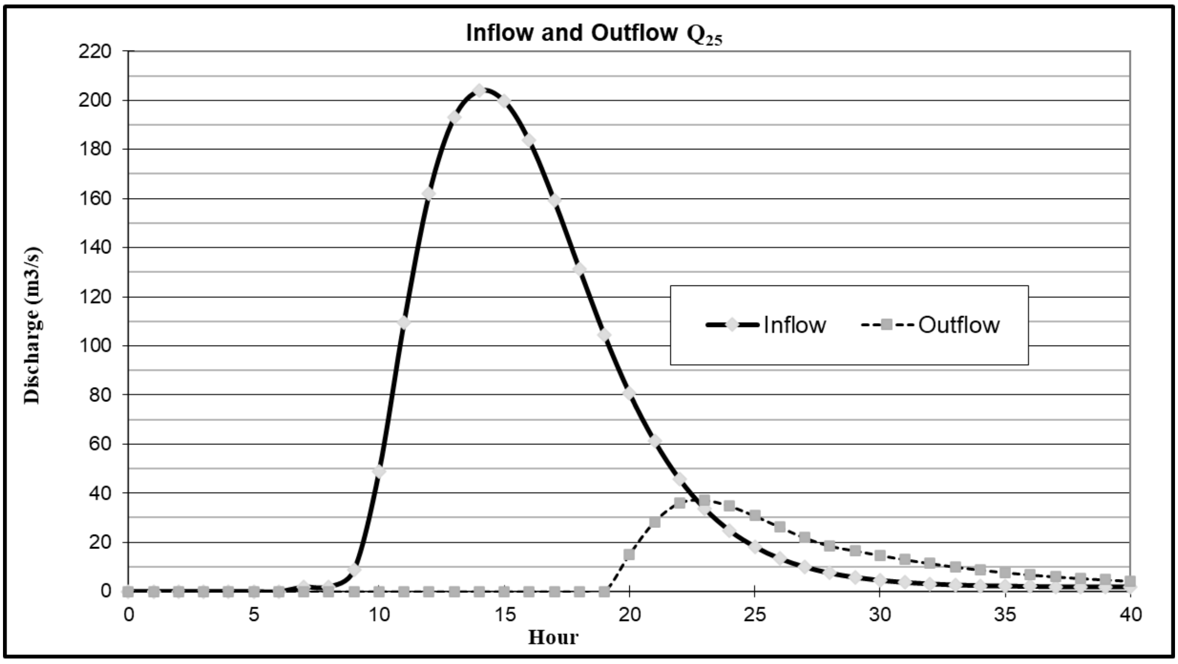


**Figure 9.** Flood Routing of Spillway in Bagong Reservoir with Flood Control

By the allocation of empty storage of about 5.2 million $m^3$ as the flood control, it is seen that the reduction of peak discharge is increasing to 81% and it is followed with the moving of flood peak time and the outflow of spillway is less than the river downstream capacity of Bagong Reservoir. It shows that when a flood with a return period of 25 years occurs, the river water level in Bagong Reservoir downstream will not overflow and cause flood inundation.

If the reservoir operation pattern of flood control from both reservoirs is applied, it will be effective in controlling the flood risk in Trenggalek Regency mainly in town house that is densely populated and has many general facilities.

# 4. Conclusions

In Tugu Reservoir, the allocation of empty storage is about 2.8 million $m^3$ as the flood control indicates that the reduction of peak discharge is increasing to 31% and it is followed by the moving of flood peak time and the outflow of spillway is less than the river downstream capacity of Tugu Reservoir. It indicates that when a flood with a 25-year return period occurs, the downstream river water of Tugu Reservoir will not overflow, and it cause flood inundation.

In Bagong Reservoir, the allocation of empty storage about 5.2 million $m^3$ as the flood control indicates that the reduction of peak discharge is increasing to 81% and it is followed by the moving of flood peak time and the outflow of spillway is less than the river downstream capacity of Bagong Reservoir. It indicates that when a flood with a 25-year return period occurs, the river water level in Bagong Reservoir downstream will not overflow and cause flood inundation.

Based on the simulation of reservoir operation that has been carried out, it can be concluded that flood control from Tugu and Bagong Reservoirs is increasing from the sides on the reduction of flood discharge peak and the moving of flood peak time by utilizing the early release as the effort in preparing the flood storage in reservoir.

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