



## Sinus Optimization Method for Multi Reservoir Operation by Using Multipurpose Simulation Model

Yudha T. Ahmadi <sup>1\*</sup>, Moh. Sholichin <sup>1</sup>, Lily M. Limantara <sup>1</sup>, Runi Asmaranto <sup>1\*</sup>

<sup>1</sup> Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia.

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### Abstract

This research intends to apply the multiplication sinus method to optimize two parallel reservoirs, namely the Tugu and Bagong reservoirs, in order to increase the efficiency of multipurpose water resource utilization for irrigation, raw water supply, micro-hydro electrical power (PLTMH), and flood control. The methodology consists of optimizing water allocation during low-flow conditions for the two parallel reservoirs with multiple purposes. For irrigation, the multiplication sinus method is used, while the other purposes are optimized using a simulation model with the objective function of maximizing the net benefit. Meanwhile, flood control under high-flow conditions is addressed through simulation by optimizing gate openings. The results show that the strategy of valve opening at the initial stage of a flood event significantly reduces the volume of flood storage required. This makes it possible to increase the reservoir water level, thereby directly increasing the potential of water energy without exceeding the river channel capacity downstream. Specifically, in the Tugu reservoir, flood storage is reduced from 1.8 million m<sup>3</sup> to 1.3 million m<sup>3</sup>, with a peak discharge of 124.5 m<sup>3</sup>/s, which remains below the downstream river capacity (approximately 125 m<sup>3</sup>/s). Meanwhile, in the Bagong reservoir, flood storage can be reduced from 5.2 million m<sup>3</sup> to 4.3 million m<sup>3</sup>, with a peak discharge of 41.9 m<sup>3</sup>/s, which is still safe and below the river capacity (approximately 44 m<sup>3</sup>/s). This efficiency proves that coordinated flood management between two parallel reservoirs can be carried out without sacrificing other interests. From the economic benefit perspective, the annual total value generated by the Tugu reservoir reaches a maximum of Rp. 136 milliard and a minimum of Rp. 117 milliards, with the main contribution coming from irrigation water supply. Likewise, the Bagong reservoir produces the highest annual benefit of Rp. 93.5 milliard and the lowest of Rp. 83.7 milliard, which comes entirely from irrigation.

*Keywords:* Tugu Reservoir; Bagong Reservoir; Reservoir Operation; Flood Control; Multi Reservoir.

### 1. Introduction

The human impact on ecosystems has long been recognized. However, nowadays the evidence supporting the hypothesis that we have entered the Anthropogenic era has increased [1]. Human activities have been identified as one of the main driving forces behind simultaneous changes in natural environments [2]. In addition, they influence the availability of ecosystem goods and services [3, 4], landscape spatial patterns [5], and increase the vulnerability of regional biomes and human well-being to climate change [6]. Meanwhile, inundation and flooding problems have become more crucial [7] due to climate change in general and changes in rainfall intensity patterns in particular. From June to September, during the monsoon months, most rivers in Indonesia are in spate with bank-full discharges, which cause inundation and flooding in several areas [3, 8].

Significant landscape modifications are caused by rapid urban sprawl. However, the transformation of natural land into impervious surfaces must be considered as one of the most pervasive hallmarks [9, 10]. This alteration leads to

\* Corresponding author: [yudhatantra84@gmail.com](mailto:yudhatantra84@gmail.com); [runi\\_asmaranto@ub.ac.id](mailto:runi_asmaranto@ub.ac.id)

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negative hydrological impacts by increasing hydraulic efficiency, which consequently raises discharge rates and runoff volumes [11], shortens flow time in urban catchments, and increases peak discharge [12, 13]. Meanwhile, predictions of future changes in precipitation patterns appear fairly robust [14], although climate change projections themselves are inherently uncertain [15-20].

Every year, many people are exposed to catastrophic flooding, as more than 50% of water-related disasters worldwide are floods. Floods are natural disasters that cause functional damage to transportation, communication, and especially infrastructure. In addition, floods damage various facilities and properties [21]. Compared with other disasters such as landslides, droughts, forest fires, and volcanic eruptions, floods have the greatest destructive potential and affect people throughout the world [22]. Several factors contribute to flooding, including topography, climate, engineering structures, and drainage systems; however, most floods are caused by storms in which large amounts of precipitation fall within a short period of time [23]. The intensity and duration of rainfall are the most influential factors for flood hazards. Moreover, human activities such as uncontrolled building construction, rapid and unplanned settlement development, and major land-use changes [20] can influence both the spatial and temporal patterns of hazards.

Water resources management is not an easy task, especially when the problem occurs on a national scale. If a region is considered unstable and the climate is unpredictable, the challenge becomes even greater [21]. Various technical aspects require regional decision-making, involving an interplay between the factual base of system information, the methods used to process the information, and the interpretation of the results [22, 23]. The management of water resources has the specific objective of balancing the demand–supply relationship of water in a given area while considering multiple dimensions such as time, space, environment, economy, politics, and other related aspects. In addition, water management includes water conservation and the management of related land resources, reconciliation among all users, and ensuring sufficient water availability for continuously expanding demands [24, 25].

Drought and flood prevention, as well as their management, are urgent functions of dams. These functions are further magnified by climate-change-induced disasters. This issue became particularly evident during the 2014–2015 drought and the 2020 flood events in South Korea [26, 27]. Although the assessment of dam operations is urgently needed to enhance improvement and ensure proper operation, existing dam assessment methods that consider operational manipulations such as gate operation or time delays are still limited.

Many methods and studies have been reviewed and discussed regarding dam and reservoir operations. These methods are generally referred to as Reservoir Operation Methods (ROM). Examples include scheduled release discharge of ROM, the linear decision rule, Stochastic Dynamic Programming, simulation models, the Standard Operation Policy, and the Nonlinear Decision Rule [28, 29]. In addition, other approaches such as Ev-ROM, which considers flood mitigation downstream of the dam [30], reservoir operation criteria used to stabilize water supplies in multipurpose dams [31], and reservoir operation methods that consider real-time prediction or operation [32, 33] have also been proposed. This research intends to optimize both low flow and high flow, which are two contradictory aspects; therefore, it uses a simulation model to solve this problem. The simulation model is accommodative for addressing these two conflicting interests.

Reservoir operation aims to redistribute water resources, minimize the risks of drought and flooding, and maximize water utilization through an appropriate operation pattern [34]. To minimize flood risk, the benefits of dams are generally expressed through flood control functions [35]. Dams without gated spillways often only provide flood reduction benefits by reducing the inflow that enters the reservoir [36]. Additional reduction occurs due to the presence of a free spillway structure, which is expressed through the spillway outflow discharge during flood routing [37], where the initial condition begins at the elevation of the reservoir's normal water level. When reviewed from the reservoir operation pattern, there is potential for flood control by regulating reservoir operations in such a way that empty storage is available during certain periods. Therefore, the initial condition of flood routing through the spillway structure can start from a specific elevation below the reservoir's normal water level. On the other hand, minimizing drought risk is generally expressed through dam benefits such as irrigation water supply and raw water supply. Consequently, optimization of the reservoir operation pattern [38, 39] is required in accordance with dam benefits, particularly for multipurpose reservoirs, especially in multi-reservoir systems within a river basin.

Optimization with a multi-objective function in a multipurpose reservoir system refers to a problem that involves several objectives being optimized simultaneously [40–42], such as flood control, raw water supply, and hydroelectric generation. However, these objectives are often conflicting with one another and are analyzed using different units [43].

The Tugu and Bagong reservoirs are two dams located in Trenggalek Regency, East Java Province, Indonesia, within the Ngasinan river system. These reservoirs are arranged in parallel, and the downstream flows from both dams meet at a river junction that functions as a flood control intersection for the urban area of Trenggalek Regency. In addition, the Bendo moving weir is located downstream of the Trenggalek urban area and functions as flood control infrastructure downstream of the moving weir before the river flows into the Indian Ocean (Samudera Hindia). This research aims to optimize water allocation during low-flow conditions for two parallel multipurpose reservoirs. For irrigation, the multiplication sinus method is applied, while the other purposes are optimized using a simulation model with the objective function of maximizing net benefit. Meanwhile, flood control during high-flow conditions is analyzed through simulation by optimizing gate openings.

## 2. Material and Methods

### 2.1. Study Location

The Tugu and Bagong reservoirs are located in Tugu and Bendungan Districts, Trenggalek Regency, East Java Province, Indonesia. The objectives of developing the Tugu Dam are as follows: 1) to fulfill the irrigation water requirement for an irrigation area of 1,250 ha; 2) to supply raw water in the amount of 12 l/s; 3) flood control; and 4) micro-hydro electrical power (PLTMH) generation with a potential capacity of 0.40 MW. Meanwhile, the objectives of developing the Bagong Dam are as follows: 1) to fulfill the irrigation water requirement for an irrigation area of 857 ha; 2) to supply raw water in the amount of 475 l/s; and 3) flood control.

The location map of the Tugu and Bagong dams is presented in Figure 1. The research methodologies are as follows: 1) optimizing the operation for flood control (high flow); and 2) optimizing reservoir operation based on the benefits of irrigation water supply, raw water supply, and PLTMH (low flow).

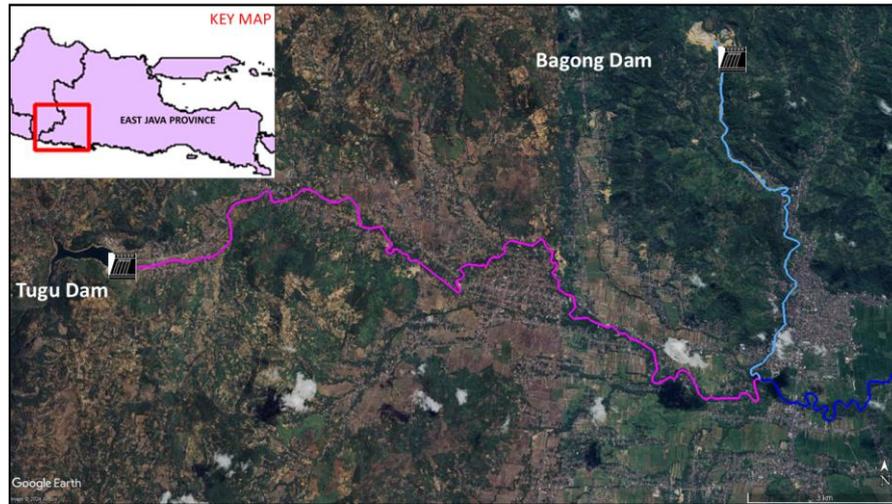


Figure 1. Location Map of Tugu and Bagong Dams-Trenggalek Regency

### 2.2. Existing Reservoir Operation Pattern

The Tugu reservoir has an irrigation area of 1,250 ha with a cropping pattern of paddy–paddy–second crop, and the irrigation water requirement is presented in Figure 2. In addition, the Tugu reservoir supplies 12 l/s of raw water to five villages in Tugu District, Trenggalek Regency. The discharge for PLTMH follows the outflow discharge for irrigation in each period. For flood control, the Tugu reservoir has prepared 1.8 million m<sup>3</sup> of flood storage by reducing the reservoir water level by about 5 m from the spillway crest. Thus, it is predicted that when a discharge corresponding to a 25-year return period occurs, there will be no release from the reservoir, and the reservoir water level will increase until it overflows through the spillway with a peak discharge of 115 m<sup>3</sup>/s, which is still less than the downstream river capacity of approximately 125 m<sup>3</sup>/s.

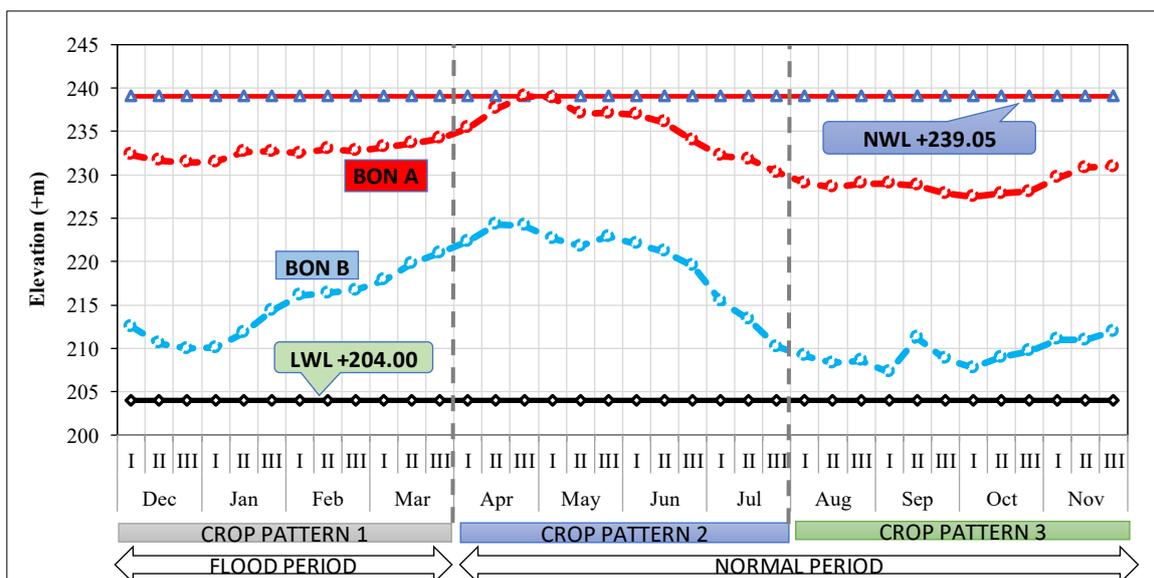


Figure 2. Existing Operation Pattern of Tugu Reservoir

The Bagong reservoir supplies irrigation to an area of 857 ha, with a cropping pattern of paddy–paddy–second crop, and the irrigation water requirement is presented in Figure 3. In addition, the Bagong reservoir also supplies 465 l/s of raw water to three districts in Trenggalek Regency. These two supplies do not intersect with each other; therefore, the reservoir operation simulation does not depend on the other reservoir, except for flood control. To control flooding, the Bagong reservoir has prepared 5.2 million m<sup>3</sup> of flood storage by lowering the reservoir water level by about 7 m from the spillway crest. Thus, it is predicted that when a discharge corresponding to a 25-year return period occurs, there will be no release from the reservoir, and the reservoir water level will rise until it overflows through the spillway with a peak discharge of 37 m<sup>3</sup>/s, which is still less than the downstream river capacity of about 44 m<sup>3</sup>/s.

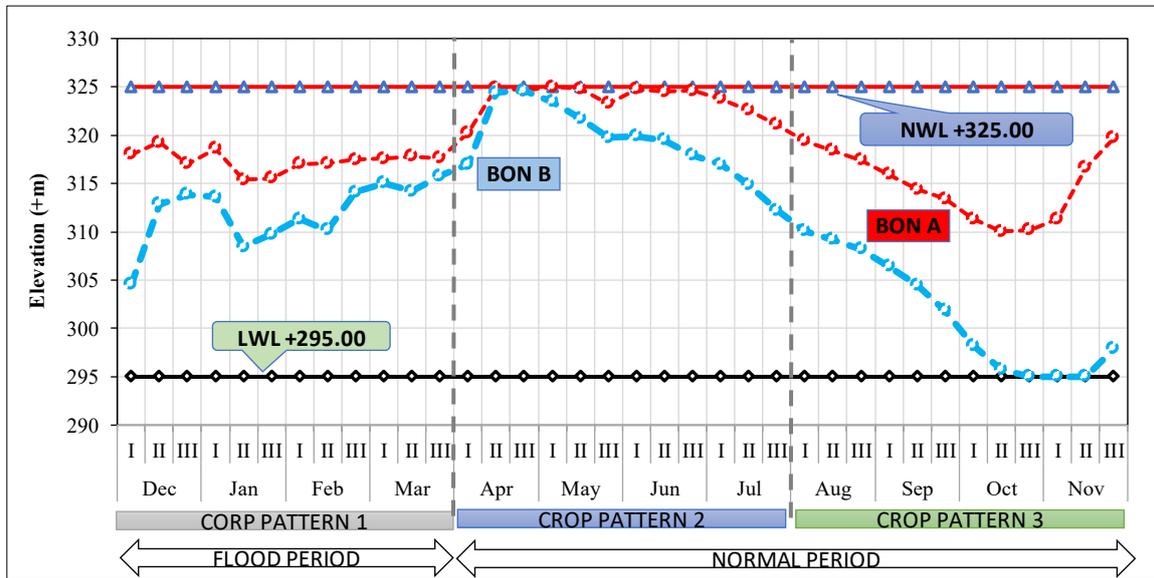


Figure 3. Existing Operation Pattern of Bagong Reservoir

In the initial stage of flood reduction using the prepared flood storage, optimization will be carried out by applying full gate opening at the reservoir outlet. The aim is to accelerate the predicted flood event, thereby achieving a higher reservoir water level elevation for flood control and increasing the potential production of PLTMH. The Tugu reservoir will also increase the head potential of the Bagong reservoir if it is utilized for hydropower in the future. The maximum capacity of the outlet gate in the Tugu reservoir is 10.35 m<sup>3</sup>/s, while in the Bagong reservoir it is 21.21 m<sup>3</sup>/s. When the reservoir water level exceeds the spillway crest, the analysis uses level pool routing, which is defined as the procedure for analyzing the outflow hydrograph from a reservoir with a uniform water level by inputting the inflow hydrograph and the storage–outflow characteristics [44]. The equation is as follows:

$$\left(\frac{2S_{n+1}}{\Delta t} + Q_{n+1}\right) = (I_n + I_{n+1}) - \left(\frac{2S_n}{\Delta t} - Q_n\right) \tag{1}$$

where,  $S_n$ : Storage on n-period (m<sup>3</sup>);  $S_{n+1}$ : Storage on (n+1)-period (m<sup>3</sup>);  $I_n$ : Inflow on n-period (m<sup>3</sup>/s);  $I_{n+1}$ : Inflow pada (n+1) period (m<sup>3</sup>/s);  $Q_n$ : Outflow on n-period (m<sup>3</sup>/s);  $Q_{n+1}$ : Outflow on (n+1) period (m<sup>3</sup>/s);  $\Delta t$ : Duration (hour).

By attending the reservoir water level elevation of flood control that has been obtained, then the analysis of water balance in the reservoir is carried out by using the equation as follows:

$$I = O \pm \Delta S \tag{2}$$

where,  $I$ : Inflow (m<sup>3</sup>/s);  $O$ : Outflow (m<sup>3</sup>/s);  $\Delta S$ : Storage change (m<sup>3</sup>).

### 2.3. Method of Multiplication Sinus

The approach for this method has been carried out by using the model with the sinus function for every period of water application is as follows [44]:

$$Yr_i = [\sin\{([AWr_i - a \sin(AWr_i \cdot 2\pi)] \cdot [1 - b \sin(AWr_i \cdot \pi)]^c)^d \pi/2\}]^e \tag{3}$$

where,  $Yr_i$ : Production of harvest on i-period;  $AWr_i$ : Water allocation on i-period.

Then, to carry out the optimization of parameters:  $a, b, c, d, e$  (in Equation 3 above) by using ADD-Ins Solver of MS-Excel 2019. Meanwhile, the function of crop production for cropping season is illustrated as follows:

$$Yr = Yr_1 \cdot Yr_2 \cdot Yr_3 \cdot \dots \cdot Yr_n \quad (4)$$

where,  $n$  : Number of periods in cropping season (= 36 periods).

$AWri$ ,  $Yri$ , and  $Yr$  are relative value (between 0 and 1).  $AWri$  relative to standard water requirement will produce  $Yr$  maximum, but  $Yr$  relative to the potency of maximum  $Yr$ .

### 3. Results and Discussion

This analysis begins by conducting a trial of flood storage to determine the optimal reservoir water level value, which is combined with reservoir outflow through the valve, resulting in a change in flood storage. For the Tugu reservoir, flood storage changes from 1.8 million  $m^3$  (at elevation 234 m) to 1.3 million  $m^3$  (at elevation 235.5 m), with a maximum discharge of 124.5  $m^3/s$ , which is still below the downstream river capacity of the Tugu reservoir (125  $m^3/s$ ). Meanwhile, for the Bagong reservoir, flood storage changes from 5.2 million  $m^3$  (at elevation 317 m) to 4.3 million  $m^3$  (at elevation 318.5 m), with a maximum discharge of 41.9  $m^3/s$ , which is still below the downstream river capacity of the Bagong reservoir (44  $m^3/s$ ). The reduction in flood storage results from the combination of reservoir outflow at the beginning of the flood event, which reduces the peak flood discharge. Due to this reduction in flood storage, the reservoir water level during the flood period increases, which in turn increases the reservoir head and enhances the production potential of PLTMH. Table 1 and Figure 4 present the flood control results for the Tugu reservoir, while Table 2 and Figure 5 present the flood control results for the Bagong reservoir.

**Table 1. Flood Control through Tugu Reservoir**

T	n	$I_n$ [ $m^3/sec$ ]	$I_n + I_{n+1}$ [ $m^3/sec$ ]	$\frac{2S_n - Q_n}{\Delta t}$ [ $m^3/sec$ ]	$\frac{2S_{n+1} + Q_{n+1}}{\Delta t}$ [ $m^3/sec$ ]	$O_n$ [ $m^3/sec$ ]
0	1	0.5	7.8	4675.5	0	10.4
1	2	7.3	24.9	4662.5	4683.2	10.3
2	3	17.6	69.0	4666.7	4687.4	10.4
3	4	51.4	142.1	4715.0	4735.7	10.4
4	5	90.7	230.4	4836.2	4857.1	10.4
5	6	139.6	304.4	5045.6	5066.6	10.5
6	7	164.8	332.5	5328.8	5350.0	10.6
7	8	167.7	306.1	5528.7	5661.3	66.3
8	9	138.4	234.0	5585.8	5834.7	124.5
9	10	95.6	161.4	5581.7	5819.8	119.1
10	11	65.7	112.5	5558.2	5743.0	92.4
11	12	46.8	81.0	5532.3	5670.7	69.2
12	13	34.2	59.3	5508.8	5613.3	52.3
13	14	25.2	44.8	5488.0	5568.1	40.1
14	15	19.7	36.2	5470.0	5532.8	31.4
15	16	16.5	30.7	5455.2	5506.1	25.5
16	17	14.1	25.0	5443.1	5485.9	21.4
17	18	10.9	18.4	5432.0	5468.2	18.1
18	19	7.4	11.4	5420.0	5450.3	15.2
19	20	4.0	5.6	5406.2	5431.4	12.6
20	21	1.6	2.2	5390.0	5411.8	10.9
21	22	0.6	0.8	5371.0	5392.2	10.6
22	23	0.2	0.3	5350.5	5371.7	10.6
23	24	0.1	0.1	5329.6	5350.8	10.6
24	25	0.0	0.0	5308.5	5329.6	10.6

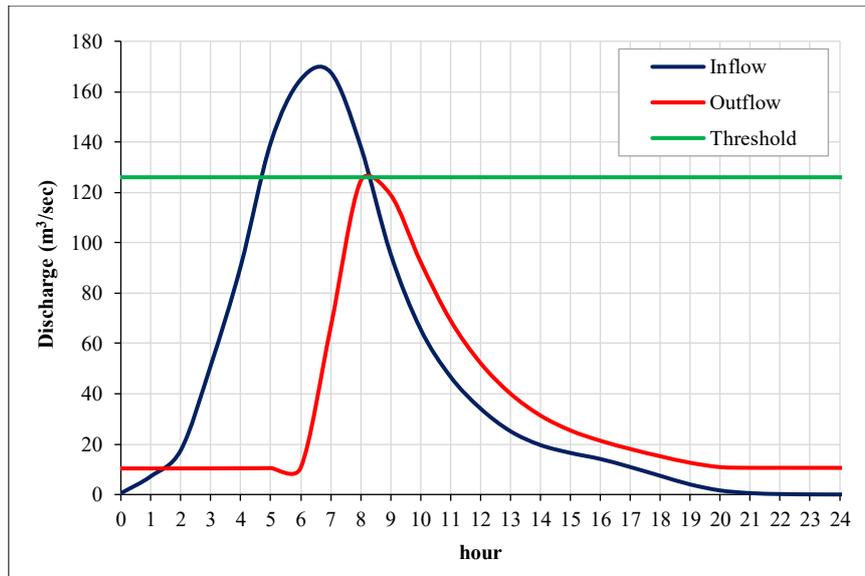


Figure 4. Flood Control in Tugu Reservoir

Table 2. Flood Control through Bagong Reservoir

T	n	$I_n$ [m³/sec]	$I_n + I_{n+1}$ [m³/sec]	$\frac{2S_n}{\Delta t} - Q_n$ [m³/sec]	$\frac{2S_{n+1}}{\Delta t} + Q_{n+1}$ [m³/sec]	$O_n$ [m³/sec]
0	1	1.8	3.7	7237.4	0	21.2
1	2	1.9	10.6	7198.8	7241.2	21.2
2	3	8.7	57.5	7167.1	7209.4	21.2
3	4	48.8	158.4	7182.2	7224.6	21.2
4	5	109.6	271.5	7298.1	7340.6	21.2
5	6	161.9	354.8	7526.8	7569.6	21.4
6	7	193.0	396.9	7838.6	7881.7	21.5
7	8	203.9	403.7	8192.1	8235.5	21.7
8	9	199.8	383.4	8552.1	8595.8	21.9
9	10	183.6	342.8	8891.4	8935.5	22.0
10	11	159.2	290.7	9189.8	9234.2	22.2
11	12	131.5	236.0	9435.9	9480.5	22.3
12	13	104.6	185.4	9627.2	9672.0	22.4
13	14	80.9	142.2	9754.6	9812.6	29.0
14	15	61.3	107.0	9820.7	9896.8	38.0
15	16	45.7	79.5	9843.9	9927.8	41.9
16	17	33.8	58.6	9840.8	9923.5	41.4
17	18	24.8	43.1	9822.8	9899.4	38.3
18	19	18.3	31.7	9797.0	9865.9	34.4
19	20	13.4	23.4	9767.6	9828.7	30.5
20	21	10.0	17.5	9736.7	9791.1	27.2
21	22	7.5	13.3	9705.1	9754.2	24.5
22	23	5.8	10.3	9672.8	9718.4	22.8
23	24	4.6	8.2	9638.4	9683.1	22.4
24	25	3.7	6.8	9601.88	9646.60	22.4

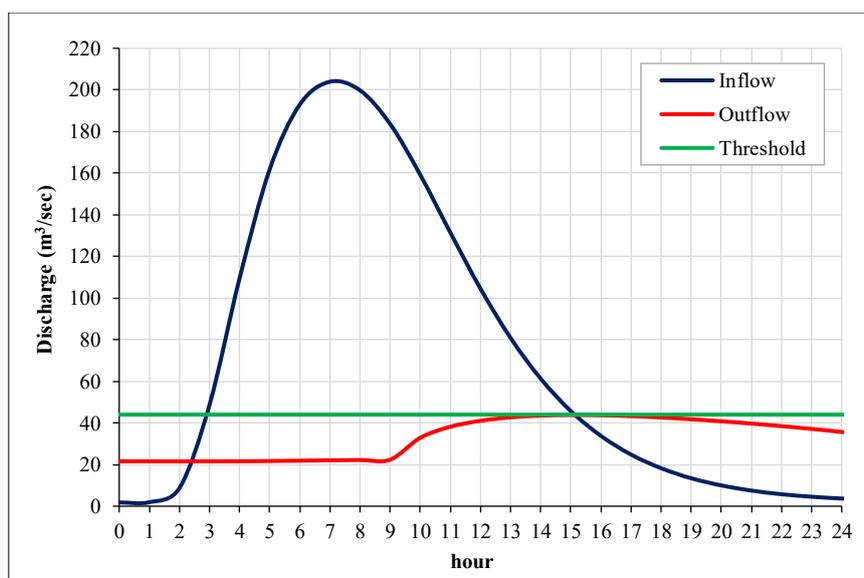


Figure 5. Flood Control in Bagong Reservoir

In Figures 4 and 5, the blue lines represent the flood inflow hydrograph with a 25-year return period, while the red lines represent the outflow hydrograph, which is a combination of valve and spillway discharge. It can be observed that the initial outflow through the valve has a significant impact on reducing the peak flood discharge, thereby allowing the reservoir flood storage to be reduced. However, in the Bagong reservoir, because the downstream river capacity is relatively small, a sufficiently large flood storage volume is still required, which results in the reservoir benefits not being achieved optimally. Under this condition, it is suggested to regulate the spillway gate with a width equal to that of the existing free spillway. In this way, the spillway outflow can be controlled to remain below the downstream river capacity of the Bagong reservoir, based on the flood routing result through a spillway gate opening of 0.25 m, as presented in Figure 5.

Furthermore, to obtain the optimum reservoir benefit, the benefits are measured in Rupiah for irrigation water supply, raw water supply, and PLTMH. The irrigation water supply benefit is measured using the production of paddy per hectare in irrigated rice areas, which is taken as 5.7 tons/ha according to the paddy production data for 2024. Corn production per hectare is taken as 6.32 tons, according to production data for 2023, with a price of Rp. 6,000,000 per ton. The raw water supply benefit is measured based on volume (m<sup>3</sup>), with the price determined according to the surface water base price for drinking water, estimated at Rp. 222/m<sup>3</sup>. Meanwhile, PLTMH benefits are measured using the amount of energy produced (kWh), with the price based on the surface water base price for electricity, which is Rp. 257/kWh. The irrigation parameters used in the optimization of the Tugu and Bagong reservoirs using Equation 3 are presented in Table 3.

Table 3. Parameter of Multiplication Sinus Method Equation

Parameter	Value
a	0.11942
b	0.241072
c	2.233331
d	0.090429
e	1.488946

The optimization of the objective function is carried out using the ADD-Ins Solver of MS-Excel 2019 with the GRG Nonlinear solving method until the iteration process in each period is less than 5. An example of the benefit optimization analysis for irrigation in 2012 is presented in Table 4 for the Tugu reservoir and Table 5 for the Bagong reservoir. The analysis results of benefit values for PLTMH and raw water supply, based on the optimal irrigation water release, are presented in Table 6 for the Tugu reservoir and Table 7 for the Bagong reservoir. Meanwhile, the optimization results for all years and the total benefit values are presented in Table 8 for the Tugu reservoir and Table 9 for the Bagong reservoir.

**Table 4. Benefit Value of Irrigation in Tugu Reservoir (2012) by Using Multiplication Sinus Method**

Crop Period		Water Irrigation Demand		Irrigation Discharge	Sine Product Model						Objective Function			
					AWri	Sine Product Equation				Yri	Yr	Max Yield	Real Yield	
CP	Period	[m <sup>3</sup> /dt]	[MCM]	[MCM]	[0 ~ 1]						[0 ~ 1]	[0 ~ 1]	[IDR Million]	[IDR Million]
CP1	1	2.1875	1.8900	1.370	0.725	-0.98755	-0.11793	0.81662	0.53608	0.99449				
	2	0.8750	0.7560	0.653	0.863	-0.75715	-0.09042	0.89962	0.75304	0.99882				
	3	1.8038	1.7143	1.275	0.744	-0.99928	-0.11933	0.82633	0.56380	0.99532				
	4	1.2663	1.0940	0.894	0.817	-0.91288	-0.10902	0.86887	0.67647	0.99779				
	5	1.4125	1.2204	0.978	0.801	-0.94872	-0.11330	0.85903	0.65132	0.99735				
	6	1.6500	1.5682	1.193	0.761	-0.99773	-0.11915	0.83537	0.58877	0.99599				
	7	1.8000	1.5552	1.186	0.762	-0.99696	-0.11906	0.83632	0.59134	0.99605	0.89132	42,975	38,304.43	
	8	1.6875	1.4580	1.076	0.738	-0.99728	-0.11910	0.82337	0.55547	0.99508				
	9	2.2875	1.5811	0.843	0.533	-0.20782	-0.02482	0.76025	0.30260	0.98082				
	10	2.2000	1.9008	0.921	0.484	0.09861	0.01178	0.75922	0.25541	0.97540				
	11	2.2750	1.9656	0.935	0.476	0.15289	0.01826	0.75964	0.24750	0.97434				
	12	1.4375	1.3662	0.782	0.573	-0.44079	-0.05264	0.76518	0.34394	0.98452				
CP2	1	1.4625	1.2636	0.676	0.535	-0.21710	-0.02593	0.76037	0.30413	0.98097				
	2	2.3250	2.0088	0.832	0.414	0.51235	0.06118	0.76760	0.19565	0.96577				
	3	2.2000	1.9008	0.814	0.428	0.43594	0.05206	0.76503	0.20681	0.96788				
	4	2.4250	2.0952	0.847	0.404	0.56574	0.06756	0.76974	0.18770	0.96415				
	5	2.4375	2.1060	0.849	0.403	0.57161	0.06826	0.77000	0.18681	0.96397				
	6	2.0571	1.9551	0.824	0.422	0.47315	0.05650	0.76621	0.20140	0.96688				
	7	2.1500	1.8576	0.807	0.435	0.40001	0.04777	0.76401	0.21200	0.96881	0.71479	42,975	30,718.01	
	8	1.9000	1.6416	0.766	0.466	0.20996	0.02507	0.76028	0.23926	0.97317				
	9	1.8393	1.5891	0.755	0.475	0.15655	0.01870	0.75967	0.24697	0.97426				
	10	1.8000	1.5552	0.748	0.481	0.12009	0.01434	0.75936	0.25227	0.97499				
	11	1.5375	1.3284	0.695	0.523	-0.14377	-0.01717	0.75955	0.29225	0.97975				
	12	0.9500	0.9029	0.564	0.624	-0.70337	-0.08400	0.77704	0.40313	0.98861				
CP3	1	1.0750	0.9288	0.666	0.717	-0.97916	-0.11693	0.81303	0.52554	0.99414				
	2	0.4375	0.3780	0.325	0.859	-0.77388	-0.09242	0.89678	0.74606	0.99874				
	3	0.2500	0.2376	0.215	0.905	-0.56153	-0.06706	0.92919	0.82510	0.99945				
	4	0.5000	0.4320	0.364	0.843	-0.83314	-0.09949	0.88604	0.71953	0.99842				
	5	0.6750	0.5832	0.466	0.799	-0.95238	-0.11373	0.85788	0.64836	0.99729				
	6	0.8000	0.6912	0.534	0.772	-0.99013	-0.11824	0.84193	0.60647	0.99641				
	7	0.4000	0.3456	0.300	0.869	-0.73162	-0.08737	0.90383	0.76335	0.99893	0.97999	48,900	47,921.45	
	8	0.2875	0.2484	0.224	0.901	-0.58031	-0.06930	0.92656	0.81872	0.99941				
	9	0.4000	0.3802	0.358	0.941	-0.36376	-0.04344	0.95538	0.88881	0.99979				
	10	0.3375	0.2916	0.278	0.954	-0.28351	-0.03386	0.96547	0.91353	0.99988				
	11	0.6565	0.5672	0.517	0.911	-0.52832	-0.06309	0.93377	0.83622	0.99953				
	12	1.5625	1.3500	1.104	0.818	-0.91012	-0.10869	0.86955	0.67819	0.99781				

**Table 5. Benefit Value of Irrigation in Bagong Reservoir (2012) by Using Multiplication Sinus Method**

Crop Period		Water Irrigation Demand		Irrigation Discharge	Sine Product Model					Objective Function				
CP	Period	[m <sup>3</sup> /dt]	[MCM]	[MCM]	AWri	Sine Product Equation				Yri	Yr	Max Yield	Real Yield	
					[0 ~ 1]						[0 ~ 1]	[0 ~ 1]	[IDR Million]	[IDR Million]
CP1	1	0.6581	0.5686	5.532	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	2	1.3130	1.1344	1.220	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	3	1.7126	1.6277	2.519	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	4	2.4204	2.0912	2.139	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	5	2.5685	2.2192	3.175	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	6	0.7982	0.7586	1.772	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	7	1.0441	0.9021	2.539	1.000	0.00000	0.00000	1.00000	1.00000	1.00000	0.99995		29,464	29,462.31
	8	1.1334	0.9792	1.070	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	9	1.0548	0.7291	1.258	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	10	1.1413	0.9861	2.441	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	11	1.2896	1.1142	1.989	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	12	1.1832	1.1245	1.093	0.972	-0.17613	-0.02103	0.97869	0.94622	0.99995				
CP2	1	2.5513	2.2043	1.437	0.652	-0.81551	-0.09739	0.78582	0.43731	0.99049				
	2	2.2657	1.9576	1.329	0.679	-0.90170	-0.10768	0.79599	0.47250	0.99212				
	3	2.2715	1.9626	1.331	0.678	-0.90006	-0.10749	0.79575	0.47170	0.99209				
	4	2.7701	2.3934	1.513	0.632	-0.73767	-0.08809	0.77937	0.41271	0.98917				
	5	2.7701	2.3934	1.513	0.632	-0.73767	-0.08809	0.77937	0.41271	0.98917				
	6	0.8962	0.8517	0.703	0.825	-0.89042	-0.10633	0.87417	0.68987	0.99800				
	7	1.4126	1.2205	0.940	0.771	-0.99172	-0.11843	0.84086	0.60360	0.99635	0.93127		29,464	27,438.50
	8	1.4045	1.2135	0.936	0.771	-0.99091	-0.11833	0.84141	0.60509	0.99638				
	9	1.3964	1.2065	0.932	0.772	-0.99007	-0.11823	0.84197	0.60658	0.99641				
	10	1.4627	1.2638	0.966	0.765	-0.99582	-0.11892	0.83751	0.59457	0.99613				
	11	1.4435	1.2472	0.956	0.767	-0.99441	-0.11875	0.83878	0.59802	0.99621				
	12	1.2416	1.1800	0.916	0.776	-0.98654	-0.11781	0.84410	0.61225	0.99654				
CP3	1	0.6822	0.5894	0.524	0.890	-0.63890	-0.07630	0.91812	0.79821	0.99925				
	2	0.5731	0.4952	0.448	0.905	-0.56110	-0.06701	0.92925	0.82525	0.99946				
	3	0.7162	0.6806	0.596	0.875	-0.70530	-0.08423	0.90803	0.77362	0.99903				
	4	0.7528	0.6504	0.572	0.880	-0.68429	-0.08172	0.91129	0.78159	0.99911				
	5	0.7237	0.6253	0.553	0.884	-0.66602	-0.07954	0.91408	0.78837	0.99917				
	6	0.8972	0.7752	0.668	0.861	-0.76562	-0.09143	0.89819	0.74953	0.99878				
	7	0.3652	0.3155	0.296	0.937	-0.38627	-0.04613	0.95251	0.88179	0.99976	0.99400		33,526	33,324.53
	8	0.5973	0.5161	0.465	0.902	-0.57920	-0.06917	0.92672	0.81910	0.99941				
	9	0.2972	0.2825	0.321	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	10	0.2168	0.1873	0.261	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	11	0.0000	0.0000	0.080	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				
	12	0.0000	0.0000	2.906	1.000	0.00000	0.00000	1.00000	1.00000	1.00000				

Table 6. Benefit Value of PLTMH and Raw Water in Tugu Reservoir (2012)

Period	Month	Micro Hydro Power Plant				Raw Water Supply		
		Averaged Head [m]	MHPP Discharge [m <sup>3</sup> /dt]	Generated Power [KW]	Generated Energy [KWh]	MHPP Benefit [IDR Million]	Raw Water Discharge [m <sup>3</sup> /dt]	Raw Water Benefit [IDR Million]
1		74.890	0.670	417.97	100,312	25.78	0.012	2.30
2	December	74.825	0.670	417.60	100,225	25.76	0.012	2.30
3		76.021	0.670	424.28	112,011	28.79	0.012	2.53
4		77.757	0.670	433.97	104,153	26.77	0.012	2.30
5	January	81.069	0.670	452.46	108,590	27.91	0.012	2.30
6		84.031	0.670	468.99	123,812	31.82	0.012	2.53
7		86.164	0.670	480.89	115,414	29.66	0.012	2.30
8	February	87.552	0.670	488.64	117,273	30.14	0.012	2.30
9		87.954	0.670	490.88	94,249	24.22	0.012	1.84
10		87.865	0.670	490.38	117,692	30.25	0.012	2.30
11	March	87.610	0.670	488.96	117,351	30.16	0.012	2.30
12		87.787	0.670	489.95	129,346	33.24	0.012	2.53
13		88.676	0.670	494.91	118,778	30.53	0.012	2.30
14	April	88.525	0.670	494.07	118,576	30.47	0.012	2.30
15		87.251	0.670	486.95	116,869	30.04	0.012	2.30
16		85.388	0.670	476.56	114,374	29.39	0.012	2.30
17	May	83.016	0.670	463.32	111,197	28.58	0.012	2.30
18		80.486	0.670	449.20	118,588	30.48	0.012	2.53
19		77.674	0.670	433.51	104,042	26.74	0.012	2.30
20	June	74.584	0.670	416.26	99,902	25.67	0.012	2.30
21		71.041	0.670	396.49	95,157	24.46	0.012	2.30
22		66.783	0.670	372.72	89,453	22.99	0.012	2.30
23	July	62.205	0.670	347.17	83,321	21.41	0.012	2.30
24		58.366	0.670	325.75	85,997	22.10	0.012	2.53
25		54.594	0.670	304.69	73,127	18.79	0.012	2.30
26	August	52.548	0.541	237.01	56,883	14.62	0.012	2.30
27		54.005	0.318	143.16	37,793	9.71	0.012	2.53
28		55.450	0.615	283.93	68,142	17.51	0.012	2.30
29	September	54.884	0.670	306.32	73,516	18.89	0.012	2.30
30		53.241	0.670	297.14	71,314	18.33	0.012	2.30
31		54.302	0.509	230.41	55,299	14.21	0.012	2.30
32	October	59.477	0.370	183.37	44,010	11.31	0.012	2.30
33		65.349	0.510	277.37	73,225	18.82	0.012	2.53
34		70.462	0.432	253.79	60,910	15.65	0.012	2.30
35	November	74.761	0.670	417.25	100,140	25.74	0.012	2.30
36		76.341	0.670	426.07	102,256	26.28	0.012	2.30

**Table 7. Benefit Value of Raw Water in Bagong Reservoir (2012)**

Period	Month	Raw Water Supply	
		Raw Water Discharge [m <sup>3</sup> /dt]	Raw Water Benefit [IDR Million]
1		0.153	29.35
2	December	0.153	29.35
3		0.153	32.28
4		0.153	29.35
5	January	0.153	29.35
6		0.153	32.28
7		0.153	29.35
8	February	0.153	29.35
9		0.153	23.48
10		0.153	29.35
11	March	0.153	29.35
12		0.153	32.28
13		0.153	29.35
14	April	0.153	29.35
15		0.153	29.35
16		0.153	29.35
17	May	0.153	29.35
18		0.153	32.28
19		0.153	29.35
20	June	0.153	29.35
21		0.153	29.35
22		0.153	29.35
23	July	0.153	29.35
24		0.153	32.28
25		0.153	29.35
26	August	0.153	29.35
27		0.153	32.28
28		0.153	29.35
29	September	0.153	29.35
30		0.153	29.35
31		0.153	29.35
32	October	0.153	29.35
33		0.153	32.28
34		0.153	29.35
35	November	0.153	29.35
36		0.153	29.35

**Table 8. Optimization Result of Tugu Reservoir by Using Multiplication Sinus Method for the Whole Years**

Year	$Y_{rcp1}$	$Y_{rcp2}$	$Y_{rcp3}$	BenY (Million IDR)	BenH (Million IDR)	BenR (Million IDR)	Ben (Million IDR)
2001	1.00000	0.99965	0.99999	134,834.54	949.36	84.01	135,867.91
2002	1.00000	0.98370	0.99798	134,050.84	917.95	84.01	135,052.80
2003	0.98958	0.86774	0.99220	128,337.20	884.70	84.01	129,305.91
2004	0.98321	0.88910	0.99323	129,031.57	895.27	84.01	130,010.86
2005	0.97928	0.95556	0.99591	131,849.64	854.42	84.01	132,788.08
2006	0.99152	0.89227	0.98731	129,235.91	915.09	84.01	130,235.02
2007	0.92745	0.86722	0.98736	125,407.60	864.56	84.01	126,356.17
2008	1.00000	0.97694	0.99884	133,802.08	940.50	84.01	134,826.59
2009	0.99617	0.91234	0.98970	130,414.49	896.41	84.01	131,394.90
2010	1.00000	1.00000	1.00000	134,849.98	1,100.90	84.01	136,034.89
2011	0.99999	0.98785	0.99939	134,297.40	910.46	84.01	135,291.88
2012	0.89132	0.71479	0.97999	116,943.89	884.88	84.01	117,912.78
2013	1.00000	0.99343	0.99941	134,538.57	885.07	84.01	135,507.66
2014	0.94378	0.81751	0.97895	123,561.98	860.49	84.01	124,506.49
2015	0.98666	0.95311	0.99423	131,979.75	878.18	84.01	132,941.94
2016	0.99198	0.98395	0.99964	133,798.42	975.92	84.01	134,858.35
2017	0.99483	0.91622	0.99469	130,767.64	861.17	84.01	131,712.83
2018	0.96436	0.80502	0.98772	124,338.67	857.63	84.01	125,280.32
2019	0.99569	0.82836	0.98410	126,510.59	893.25	84.01	127,487.86
2020	0.97681	0.93862	0.99506	130,974.01	837.51	84.01	131,895.53
2021	0.99984	0.94884	0.99723	132,508.71	913.58	84.01	133,506.30
2022	0.88172	0.69984	0.99215	116,483.58	944.19	84.01	117,511.78
2023	0.99980	0.96488	0.99872	133,269.77	879.71	84.01	134,233.49

**Table 9. Optimization Result of Bagong Reservoir by Using Multiplication Sinus Method for the Whole Years**

Year	$Y_{rcp1}$	$Y_{rcp2}$	$Y_{rcp3}$	BenY (Million IDR)	BenR (Million IDR)	Ben (Million IDR)
2001	1.00000	1.00000	1.00000	92,453.16	1,071.15	93,524.31
2002	1.00000	0.83845	0.98515	87,195.39	1,071.15	88,266.55
2003	1.00000	0.76401	0.98147	84,878.87	1,071.15	85,950.03
2004	0.99650	0.94339	0.99507	90,516.97	1,071.15	91,588.12
2005	1.00000	0.84991	0.98685	87,590.25	1,071.15	88,661.40
2006	1.00000	0.91933	0.99270	89,831.68	1,071.15	90,902.84
2007	1.00000	0.97958	0.99891	91,815.16	1,071.15	92,886.31
2008	1.00000	0.92391	0.99653	90,094.87	1,071.15	91,166.02
2009	1.00000	0.90836	0.99275	89,509.85	1,071.15	90,581.00
2010	1.00000	1.00000	1.00000	92,453.16	1,071.15	93,524.31
2011	0.99803	0.82188	0.98665	86,699.57	1,071.15	87,770.72
2012	0.99995	0.93126	0.99400	90,225.34	1,071.15	91,296.49
2013	1.00000	1.00000	1.00000	92,453.16	1,071.15	93,524.31
2014	0.99569	0.98827	0.99919	91,953.45	1,071.15	93,024.61
2015	1.00000	0.98825	0.99909	92,076.65	1,071.15	93,147.80
2016	1.00000	1.00000	1.00000	92,453.16	1,071.15	93,524.31
2017	1.00000	1.00000	1.00000	92,453.16	1,071.15	93,524.31
2018	1.00000	0.74779	0.98122	84,392.47	1,071.15	85,463.62
2019	1.00000	0.81897	0.98363	86,570.52	1,071.15	87,641.67
2020	1.00000	1.00000	1.00000	92,453.15	1,071.15	93,524.30
2021	0.99999	0.99980	0.99999	92,446.65	1,071.15	93,517.80
2022	1.00000	1.00000	1.00000	92,453.08	1,071.15	93,524.23
2023	1.00000	0.69928	0.97242	82,668.47	1,071.15	83,739.63

Tables 4 and 5 present examples of the optimization results for irrigation water supply in 2012 for the Tugu and Bagong dams, aimed at optimizing paddy harvest production and benefits. The variable optimized is the irrigation outflow for each period (at-i), shown in the irrigation discharge column, while considering the irrigation water requirement and the reservoir storage conditions in all periods. As a result, the level of irrigation discharge fulfilment according to irrigation water requirements is obtained, as shown in the AWri column. Then, to determine the agricultural production in the Yri column, the multiplication sinus method (Equation 3) is used with the parameters shown in Table 3.

The values ranging from 0–1 in the Yri column indicate the level of irrigation water supply fulfilment in each at-i period, while Yr indicates the level of irrigation water supply fulfilment for each cropping pattern. YrCP1, YrCP2, and YrCP3 represent the levels of irrigation water supply fulfilment for cropping patterns 1, 2, and 3, respectively. These values are then multiplied by the maximum potential production area shown in the Max Yield column, resulting in the actual benefit for each cropping period shown in the Real Yield column, expressed in IDR million. Based on the optimization results, in the 2012 example it can be observed that the YrCP2 value tends to be lower than YrCP1 and YrCP3, because this period corresponds to the peak of the dry season.

Table 6 presents another irrigation-related benefit in 2012 for the Tugu reservoir, namely energy generation from micro-hydro power, which depends on irrigation discharge releases and raw water supply with a constant discharge according to demand. Meanwhile, Table 7 presents another benefit in 2012 for the Bagong reservoir, namely raw water supply with a constant discharge according to demand. The complete optimization results for all years are presented in Table 8 for the Tugu reservoir and Table 9 for the Bagong reservoir.

Table 8 shows the optimal benefits of the Tugu reservoir. *BenY* represents the benefit value of agricultural production areas in million rupiah; the value fluctuates according to the level of area production. Meanwhile, *BenH* represents the benefit value of hydroelectric power in million rupiah, and its value fluctuates following the reservoir water elevation during the period. Because energy generation utilizes water released for irrigation supply, a higher *Yr* value results in a higher benefit value for hydroelectric production. *BenR* represents the benefit of raw water supply in million rupiah; this value remains stable throughout the year in every period because the demand is constant and not influenced by other factors. *Ben* represents the total benefit of all reservoir functions. The highest total benefit is Rp 136,049,678,661 and the lowest is Rp 117,511,783,815, where the dominant difference in benefit value is influenced by the level of fulfilment of irrigation water supply demand. Similar to the optimization of the Tugu reservoir, the notations shown have the same meanings. In the optimization results of the Bagong reservoir (Table 9), there is no *BenH* because the Bagong reservoir does not generate hydroelectric power. The highest total benefit is Rp 93,524,311,776 and the lowest is Rp 83,739,625,908.

Figures 6 and 7 show that the optimization of the Tugu and Bagong reservoirs is sufficiently optimal because there is an intersection between the inflow and outflow lines. In cropping season 1, the reservoir outflow is smaller than the inflow because this period corresponds to the peak of the rainy season and also serves to maintain the reservoir water level within the flood control storage. In cropping pattern 2, both reservoirs show a tendency to maintain balance in fulfilling all reservoir benefits by utilizing the effective reservoir storage, where the reservoir inflow is smaller than the reservoir outflow. Meanwhile, in cropping season 3, the reservoir outflow is far below the reservoir inflow because it marks the beginning of the rainy season, and the crop type is a second crop that does not require much water.

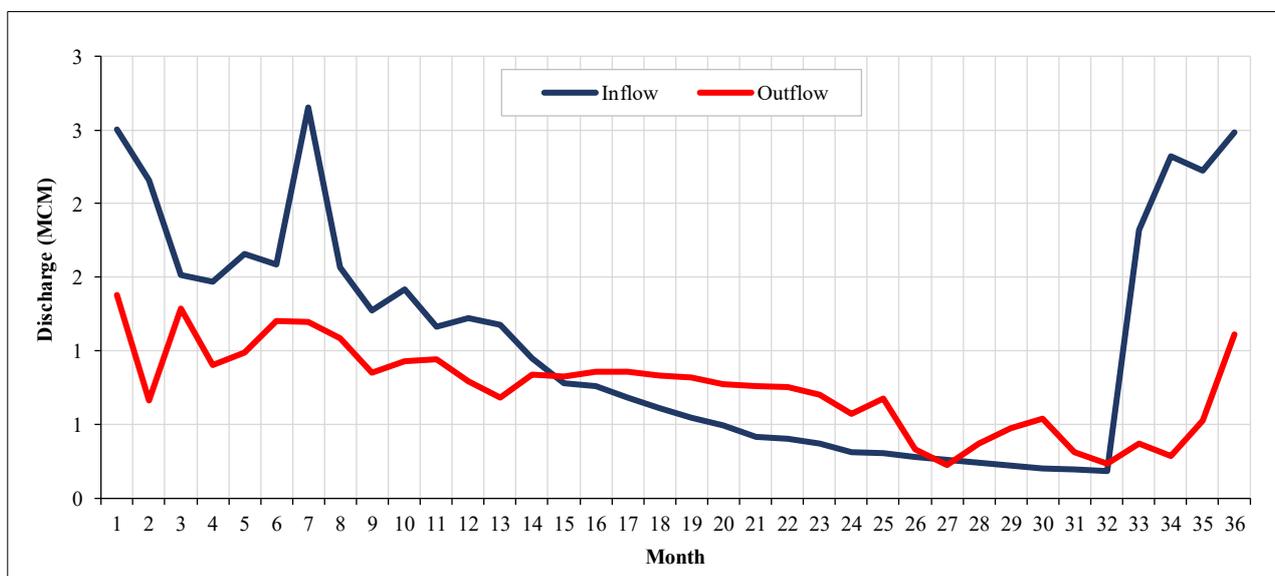


Figure 6. Comparisons between Inflow-Outflow in Tugu Reservoir on 2012

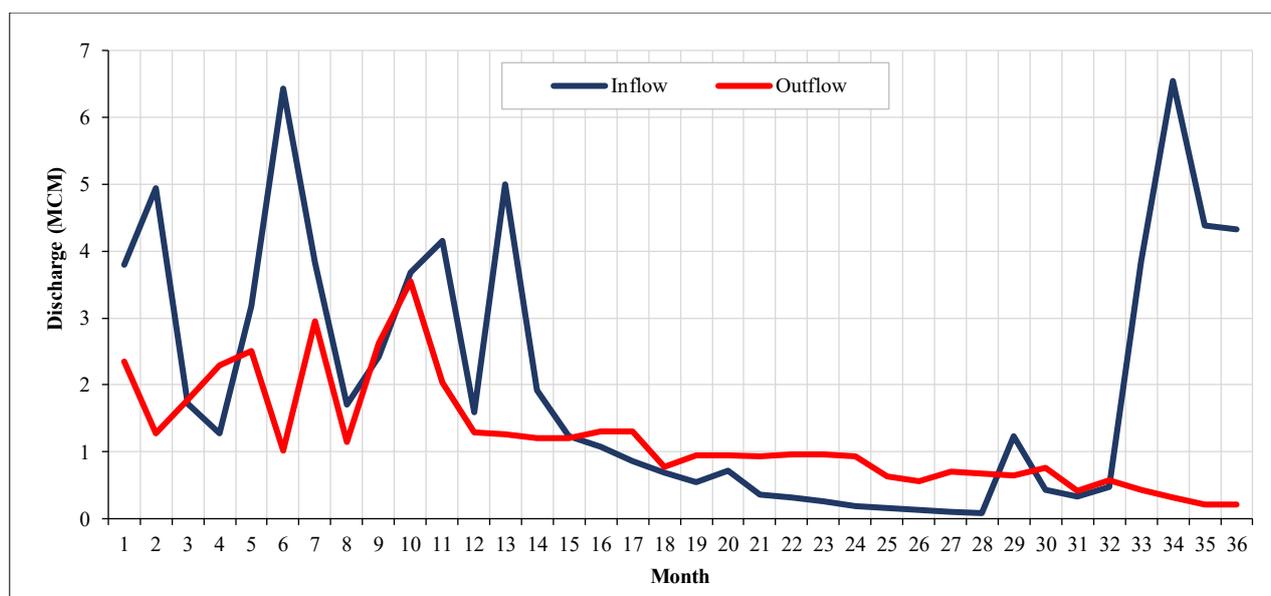


Figure 7. Comparisons between Inflow-Outflow in Bagong Reservoir on 2012

#### 4. Conclusions

This research shows that the application of the multiplication sinus method in optimizing the operation of two parallel reservoirs (Tugu and Bagong reservoirs) can increase the efficiency of multipurpose water resource utilization for irrigation, raw water supply, micro-hydro electrical generation (PLTMH), and flood control. Through this approach, the results show that the strategy of valve opening at the beginning of a flood event significantly reduces the volume of flood storage required. This makes it possible to increase the reservoir water level, thereby directly increasing the potential of water energy without exceeding the downstream river channel capacity.

Specifically, the Tugu reservoir changes from 1.8 million  $m^3$  (at elevation 234 m) to 1.3 million  $m^3$  (at elevation 235.5 m), with a maximum discharge of 124.5  $m^3/s$ , which is still below the downstream river capacity of the Tugu reservoir (125  $m^3/s$ ). Meanwhile, the Bagong reservoir changes from 5.2 million  $m^3$  (at elevation 317 m) to 4.3 million  $m^3$  (at elevation 318.5 m), with a maximum discharge of 41.9  $m^3/s$ , which is still below the downstream river capacity of the Bagong reservoir (44  $m^3/s$ ). This efficiency proves that coordinated flood management between the two reservoirs can be carried out without sacrificing other benefits.

From the economic perspective, the annual total value generated by the Tugu reservoir reaches a maximum of Rp. 136 milliard and a minimum of Rp. 117 milliards, with the main contribution coming from irrigation water supply. Likewise, the Bagong reservoir produces the highest annual benefit of Rp. 93.5 milliard and the lowest of Rp. 83.7 milliard, which comes entirely from irrigation and raw water supply. The highest economic value is achieved in years when irrigation demand is optimally fulfilled, whereas the lowest value occurs in years with inflow deficits, particularly during the dry season.

Based on previous studies, the average profit from irrigation and raw water benefits in the Tugu reservoir is Rp. 100,221,544,706 per year, while the optimization result in this research reaches Rp. 129,726,918,299 per year. Therefore, it increases by Rp. 29,505,373,592 per year. Meanwhile, for the Bagong reservoir, the average profit from irrigation and raw water benefits is Rp. 59,420,153,721 per year, while the optimization result in this research reaches Rp. 90,881,507,801 per year, resulting in an increase of Rp. 31,461,354,080 per year.

In general, this research concludes that the optimization of multi-reservoir operations using the multiplication sinus method is not only able to balance several competing reservoir functions but also significantly increases the economic benefit value. Optimization of the reservoir operation pattern using the multiplication sinus method calculates all periods within one cropping year, so that the reservoir water balance during the cropping year remains balanced in accordance with the boundaries of maximum operation and minimum reservoir water levels during both flood and normal periods.

Although there are still challenges in the Bagong reservoir, particularly due to limitations in spillway capacity and the narrow downstream channel, this research demonstrates the strong potential of this approach to be widely applied in other multipurpose reservoir systems, especially in Indonesia.

## 5. Declarations

### 5.1. Author Contributions

Conceptualization, Y.T.A. and R.A.; methodology, Y.T.A.; validation, Y.T.A.; formal analysis, Y.T.A.; investigation, Y.T.A. and M.S.; resources, Y.T.A. and L.M.L.; data curation, Y.T.A. and R.A.; writing—original draft preparation, Y.T.A. and H.S.; writing—review and editing, L.M.L. and M.S.; visualization, Y.T.A. and R.A. All authors have read and agreed to the published version of the manuscript.

### 5.2. Data Availability Statement

The data presented in this study are available in the article.

### 5.3. Funding

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### 5.4. Conflicts of Interest

The authors declare no conflict of interest.

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