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EVALUATION OF BAGONG DAM SPILLWAY AND STILLING BASIN DIMENSIONS COMPARING SYNTHETIC UNIT HYDROGRAPHS

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ABSTRAK

Pada tahun 2022, Trenggalek mengalami banjir cukup besar yang mengakibatkan tenggelamnya beberapa kecamatan. Oleh karena itu, diperlukan penanggulangan dengan membangun bendungan, khususnya bangunan spillway untuk mengamankan tubuh bendungan. Focus penelitian ini adalah Bendungan Bagong yang terletak di Trenggalek. Penelitian ini bertujuan untuk mengevaluasi dimensi pelimpah dan kolam olak menggunakan perbandingan metode hidrograf satuan sintetik Nakayasu dan Gama I guna menentukan metode yang optimal. Hasil evaluasi menunjukkan bahwa metode Nakayasu memiliki nilai QPMF sebesar 804,173 m³/detik, sedangkan metode Gama I memiliki nilai QPMF sebesar 497,787 m³/detik. Berdasarkan banjir historis di Trenggalek, metode Nakayasu dinilai lebih optimal dengan nilai QPMF 804,173 m³/detik. Evaluasi dimensi spillway menggunakan metode Nakayasu menghasilkan lebar mercu spillway 35 m dengan tipe U.S.B.R Ogee I, panjang saluran peluncur 1 sebesar 132 m dengan lebar 35 m, panjang saluran peluncur 2 sebesar 134,5 m dengan lebar 35 m, panjang saluran peluncur 3 sebesar 94 m dengan lebar 35 m, serta stilling basin tipe USBR III dengan lebar 35 m dan panjang loncatan 14 m. Estimasi rencana anggaran biaya total sebesar Rp. 258.896.452.000,00.

Kata kunci: Pelimpah, Kolam Olak, Nakayasu, Gama I

ABSTRACT

In 2022, Trenggalek experienced a significant flood that submerged several sub-districts. Therefore, mitigation measures are needed by constructing a dam, especially a spillway structure to save the main dam building. The focus of this research is Bagong Dam located in Trenggalek. This study aims to evaluate the spillway and stilling basin dimensions comparing synthetic unit hydrographs methods, especially Nakayasu and Gama I, to determine the optimal method. The evaluation results indicate that the Nakayasu method has a QPMF value of 804.173 m³/second, while the Gama I method has a QPMF value of 497.787 m³/second. Based on the historical floods in Trenggalek, the Nakayasu method is considered more optimal with a QPMF value of 804.173 m³/second. The dimension evaluation of the spillway using the Nakayasu method results in a spillway crest width of 35 meters with U.S.B.R. Ogee Type I, a floodway channel 1 length of 132 meters with a width of 35 meters, a floodway channel 2 length of 134.5 meters with a width of 35 meters, a floodway channel 3 length of 94 meters with a width of 35 meters, and a USBR III type stilling basin with a width of 35 meters and a jump length of 14 meters. The estimated cost totals Rp. 258,896,452,000.00.

Keywords *: Spillway, Stilling Basin, Nakayasu, Gama I*

1. INTRODUCTION

According to Wahyudiono (2023: 1) "Trenggalek Regency is situated around the equator, experiencing a dry season from May to August and a rainy season from September to April However, in 2022, Trenggalek experienced heavy rainfall, with the highest recorded precipitation of 757 mm and 23 rainy days occurring in October" [19]. To mitigate such disasters, there is a need for dam construction planning, such as the construction of Bagong Dam. The dam serves functions including flood control, a raw water source, irrigation, and a tourism destination. Bagong Dam is a rock-fill dam that has a weakness in its inability to withstand overtopping. The Bagong Dam Supervision Consultant explained that the spillway and stilling basin in the 2018 design have changed due to several factors, such as hydrological design, hydraulic design, and geological conditions. So, there is a need for hydrological and hydraulic evaluation as it can affect the safety, dimensions, capacity, and flood discharge through the structure.

Hydrological analysis is crucial for determining the design flood. Therefore, the hydrological analysis must be conducted carefully, as it can affect the structure's safety [20]. The flood design process has many methods available, one of which is the synthetic unit hydrograph. The Synthetic Unit Hydrograph consists of the Synder, Nakayasu, Gama I, Limantara, and ITB methods. However, this study will compare Nakayasu and Gama I to determine the optimal method for this design flood. The optimal means to select an efficient method based on the analysis results and historical floods. Based on the hydrograph parameters Nakayasu and Gama I are synthetic unit hydrographs that can be utilized in the Bagong Dam Watershed. This is also influenced by data limitations.

Before evaluating the design flood by determining the optimal method, it is necessary to consider the trend tendencies. This trend analysis aims to detect any pattern trends that are influenced by the increase in extreme rainfall. Consequently, there will be changes in the spillway and stilling basin dimensions. Based on the previous explanation that Trenggalek experienced flooding in 2022, there is a problem with the spillway and stilling basin design at Bagong Dam, hydrological evaluation or analysis is important and determining the design flood by comparing synthetic unit hydrographs. So, this Research aims to discuss “Evaluation of Bagong Dam Spillway and Stilling Basin Dimensions Comparing Synthetic Unit Hydrograph”.

2. METHODS

This research uses secondary data, there are Catchment Area, Bagong Dam Technical Data, Topographic Map, and Rainfall Data. At this stage, rainfall trend analysis will be conducted by comparing the trend graph of rainfall between 2001–2014 and 2001–2023 at each rain station. This stage utilizes the Mann-Kendall method to determine the trend graph for those years. This research also utilizes the XLSTAT application and the regression linear graph to support rainfall trend analysis. Design rainfall will be conducted by determining consistency test, rainfall area, frequency analysis, and distribution test. The design flood will be determined by Probable Maximum Precipitation (PMP), rainfall intensity, rainfall distribution, and synthetic unit hydrographs using the Nakayasu and Gama I methods.

The optimal method will be determined using synthetic unit hydrographs. The optimal method is the efficient method used in this study by comparing Nakayasu and Gama I, which will be selected based on the flood discharge that is close to the historical flood discharge in Trenggalek. The discharge passing through the spillway will be determined by establishing the reservoir capacity curve and then analyzing flood routing. The directional channel, spillway crest, floodway channel, and stilling basin will be determined using the discharge through the spillway, which is Q1000, and controlled by QPMF. The cost estimation in this study consists of earthworks, concreting works, and grouting works.

3. RESULTS AND DISCUSSION

RAINFALL TREND ANALYSIS

The data used in the existing planning spans from 1990 to 2014. However, due to insufficient data, the analysis was conducted on data from 2001 to 2014. Additionally, data from 2001 to 2023 is used for planning or evaluation in this study.

Tabel 3.1 The Rainfall Trend Results

Station	p-value	
	(2001-2014)	(2001-2023)
Bendungan	1.00	0.71
Prambon	0.91	0.20

Source: XLSTAT Calculation, 2024

The results above show that in the years 2001-2014 and 2001-2023, the P-value at each station is greater than the significance level alpha = 0.05. This means that the null hypothesis (H0) cannot be rejected. During these periods, there is no significant trend pattern. However, this can be demonstrated through the linear regression equation graph.

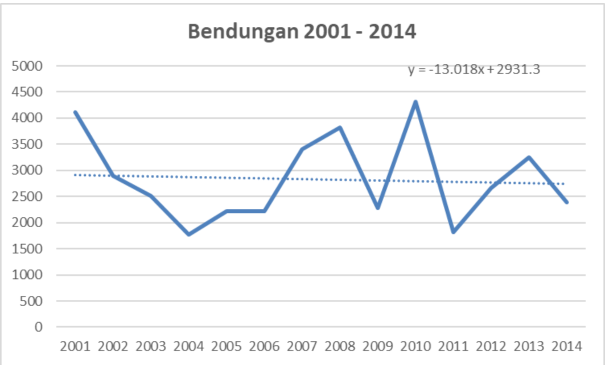

Figure 3.1 The Linear Regression Equation Graph in Bendungan 2001 – 2014
Source: Calculation Result, 2024

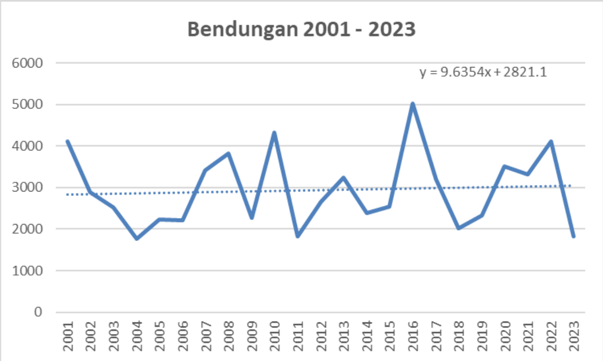

Figure 3.2 The Linear Regression Equation Graph in Bendungan 2001 – 2023
Source: Calculation Result, 2024

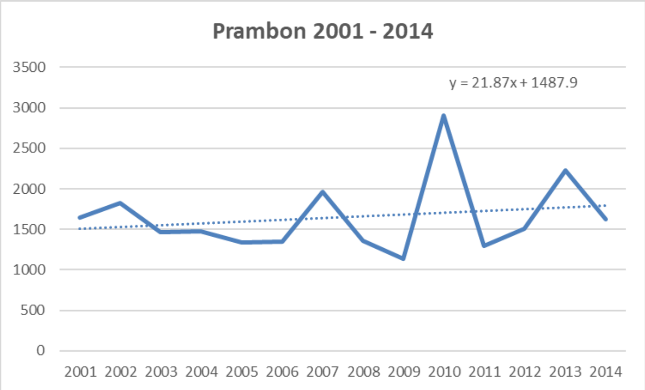

Figure 3.3 The Linear Regression Equation Graph in Prambon 2001 – 2014
Source: Calculation Result, 2024

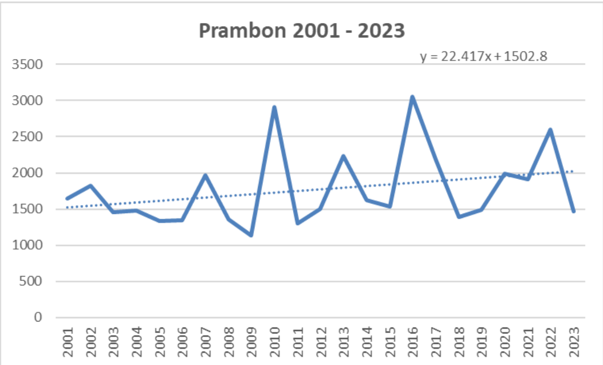

Figure 3.4 The Linear Regression Equation Graph in Prambon 2001 – 2024
Source: Calculation Result, 2024

Based on the results of the Mann-Kendall calculation using XLSTAT and the linear regression graph, it can be concluded that the null hypothesis (H0) cannot be rejected in the years 2001-2014 and 2001-2023. However, there is an increase in rainfall at each rain station during 2001-2023.

DESIGN RAINFALL

Based on the calculation result, the continuous probability distribution suitable for the parameter requirements in frequency analysis is Gumbel I with Cs =1,04 and Ck = 2,35. The periods used are 1,01 2, 5, 10, 25, 50, 100, and 1000 years at this stage have results at a return period of 1,01 years = 56,159 mm at a return period of 2 years = 98,162 mm, at a return period of 5 years = 123.273 mm, at a return period of 10 years = 139,899 mm, at a return period of 25 years = 160,906 mm, at a return period of 50 years = 176.490 mm, at a return period of 100 years = 191.959 mm, at a return period of 1000 years = 243.073 mm. Based on the distribution test, the chi-square design value (X^2design) is 10.532, while the 5% significance chi-square value (X^2cr) for some data 23 is 31.410. Therefore, Gumbel I is considered appropriate because the design chi-square (X^2design) is less than the critical chi-square (X^2cr). Sedangkan Smirnov-Kolmogorov the |ΔP|max is 19.17%, while the 5% significance value (D0) for some data 23 is 27,8%. Therefore, Gumbel I is considered appropriate because the |ΔP|max is less than the 5% significance value (D0).

FLOOD ANALYSIS

Probable Maximum Precipitation (PMP) is the largest rainfall with a certain duration. The result obtained for probable maximum precipitation (PMP) is 471.908 mm. The Mononobe method is used to determine the rainfall intensity and rainfall distribution for return periods of 25 years, 50 years, 100 years, 1000 years, and PMP.

Table 3.2 Rainfall Intensity dan Rainfall Distribution Results

Start of Rain in Hours (T)	Rainfall Intensity (I) (mm/hour)	Rainfall Distribution (mm)	Ratio (%)	Cumulative (%)
1	0.550	0.550	55.03%	55.03%
2	0.347	0.143	14.30%	69.34%
3	0.265	0.100	10.03%	79.37%
4	0.218	0.080	7.99%	87.36%
5	0.188	0.067	6.75%	94.10%
6	0.167	0.059	5.90%	100.00%

Source: Calculation Result, 2024

Table 3.3 Rainfall Distribution Results for Each Return Period

No	Start of Rain in Hours	Rainfall Distribution	25	50	100	1000	PMP
	(T)	(mm)	(year)	(year)	(year)	(year)	(year)
1	1	0.55	49.11	55.82	62.56	85.29	195.21
2	2	0.14	12.76	14.51	16.26	22.17	50.74
3	3	0.10	8.95	10.18	11.41	15.55	35.59
4	4	0.08	7.13	8.10	9.08	12.38	28.34
5	5	0.07	6.02	6.84	7.67	10.46	23.93
6	6	0.06	5.26	5.98	6.70	9.14	20.92
		100%					
Effective Rainfall (mm/hour)			89.24	101.43	113.68	154.99	354.72

Source: Calculation Result, 2024

DESIGN FLOOD DISCHARGE

This study uses the Synthetic Unit Hydrograph method to design flood discharge. Specifically Nakayasu and Gama I, with periods of 25 years, 50 years, 100 years, 1000 years, and PMF. After determining the parameters, the next is determining the rising limb and recession line curve coordinates in hours. The curve coordinates in hours will be used to design flood discharge based on the period.

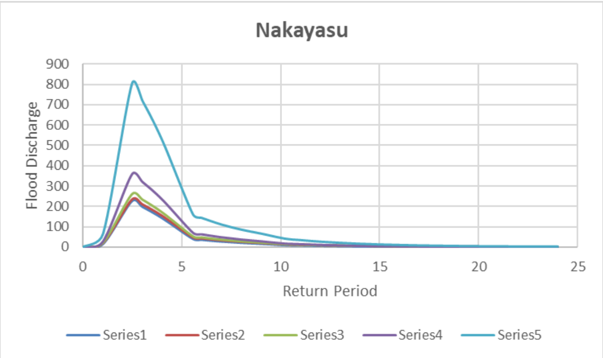

Figure 3.5 The Nakayasu Curve
Source: Calculation Result

Based on the calculation result, the design flood discharge in the Nakayasu Synthetic Unit Hydrograph includes Q25th = 226,204 m^3/sec, Q50th = 233,603 m^3/sec, Q100th = 261,813 m^3/sec, Q1000th = 356,945 m^3/sec, QPMF = 804,173 m^3/sec.

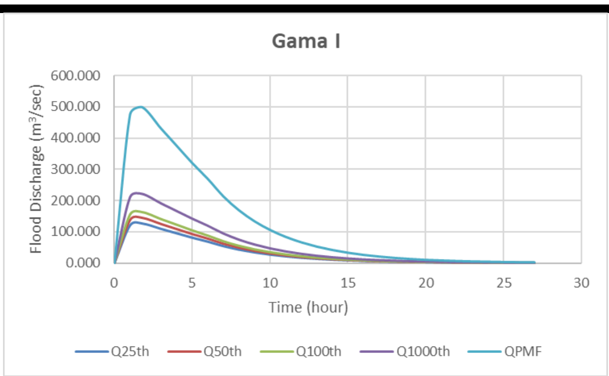

Figure 3.6 The Gama I Curve
Source: Calculation Result, 2024

Based on the calculation result, the design flood discharge in the Gama I Synthetic Unit Hydrograph includes Q25th = 127,218 m^3/sec, Q50th = 144,601 m^3/sec, Q100th = 162,063 m^3/sec, Q1000th = 220,951 m^3/sec, QPMF = 497,787 m^3/sec.

DETERMINE THE OPTIMAL METHOD

In 2022, Trenggalek Regency experienced flooding that resulted in the submergence of several districts. This event was caused by high rainfall. The high rainfall intensity impacted the Ngasinan River, causing an increase in its discharge. According to the East Java Provincial Communication and Information Agency, the discharge of the Ngasinan River was recorded at 569 m^3/second at 11:30 AM WIB and rose again at 7:00 PM WIB to 750 m^3/second [3].

Based on existing data, the Bagong Dam has significant benefits, one of which is flood control in Trenggalek. This dam will be fed by the Bagong River, which is a fourth-order stream in the Ngasinan – Ngrowo River system. This means that the Bagong River is formed from the confluence of several rivers that have passed through three previous levels in the Ngasinan – Ngrowo river system.

Therefore, to determine the optimal method for dimension evaluation, it is necessary to know the historical flood discharge. As previously explained, the historical flood discharge was 750 m^3/sec. Based on calculations using the Nakayasu and Gama I methods, indicating that the optimal method to use is Nakayasu with a QPMF of 804,173. m^3/sec.

RESERVOIR CAPACITY CURVE

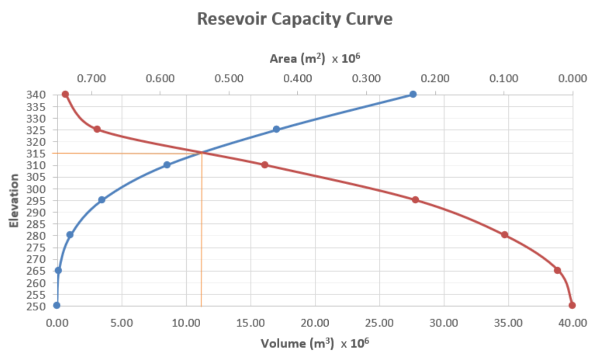

Figure 3.7 Reservoir Capacity Curve
Source: Calculation Result, 2024

Based on the analysis and the reservoir capacity curve, the storage volume is 11.40 x 10^6 m³ at an elevation of +315. This is determined by the intersection of the relationship lines between area, elevation, and volume.

FLOOD ROUTING

This analysis aims to determine the reservoir outflow that will pass through the spillway. This analysis uses the Q_{1000} return period and is controlled by Q_{PMF}. The analysis for QPMF can be conducted in the same calculation, where QPMF (inflow) = 804,173 m^3/sec. After determining the C-L-Q and H-S-Q relationships, the flood routing analysis or reservoir outflow through the spillway can be determined. This analysis plans t = 1 hour with a previously determined inflow.

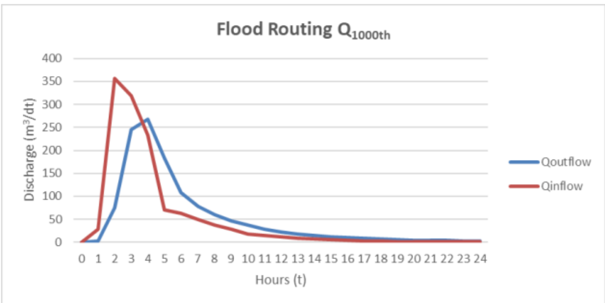

Figure 3.8 Flood Flood Routing Q1000th
Source: Calculation Result, 2024

The analysis for QPMF can be conducted in the same calculation, where QPMF (inflow) = 804,173 m^3/sec.

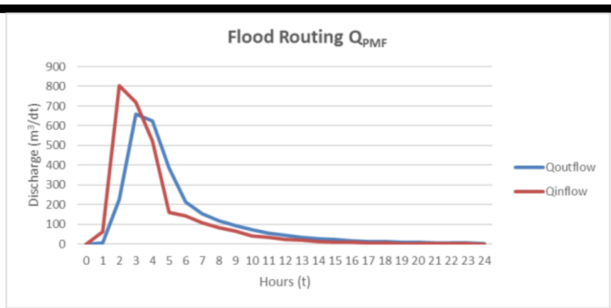

Figure 3.9 Flood Routing QPMF
Source: Calculation Result, 2024

Based on the calculations, the reservoir outflow through the spillway is 268,309 m³/sec with a flood water level elevation of +317,30 m and a reduction capacity of up to 24,83%. Additionally, based on Table 4.32 for QPMF, the reservoir outflow through the spillway is 657,857 m³/sec with a flood water level elevation of +319.22 m and a reduction capacity of up to 18,19%.

SPILWAY HYDRAULIC DESIGN

This design uses the Q1000 return period and is controlled by QPMF. Based on the calculations, the shape of profile spillway crest is U.S.B.R. Ogee Type I with a crest elevation of +315 m and a spillway width of 35 m. The final coordinates obtained are (3,84;2,96) with the wall height design of 9 m.

The directional channel is designed so that the velocity does not exceed 4 m/sec, and the channel depth is planned to be greater than 1/5 of the design flood height above the spillway crest. Based on the calculation of Q1000 controlled by QPMF shows that the planned channel depth spillway of 3 meters can be used. Because the velocity does not exceed 4 m/sec, and the channel depth is intended to be greater than 1/5 of the design flood height above the spillway crest.

The floodway channel is designed to be in a supercritical condition. This is to prevent backwater from occurring in the floodway channel. With the Q1000 design controlled by QPMF, the supercritical condition floodway channel results are floodway channel 1 with a width of 35 m, upstream elevation of +311.163 m, downstream elevation of +281.00 m, length of 132.00 m, and a slope of 0.230 m. For floodway channel 2, the width is 35 m, upstream elevation of +281.00 m, downstream elevation of +249.00 m, length of 134.5 m, and slope of 0.238. For floodway channel 3, the width is 35 m, upstream elevation of +249.00 m, downstream elevation of +213.00 m, length of 94 m, and slope of 0.382. Then the wall height design of floodway channel is 3 m. Based on the cavitation analysis, the Q1000 design controlled by QPMF indicates no cavitation in the floodway channels. Therefore, the floodway dimensions are safe from the danger of cavitation.

The stilling basin design uses the hydraulic floodway design analysis as the basis for calculations. Based on the planned calculation data for Q1000, the appropriate type of stilling basin can be determined. The suitable type is USBR III, where $q < 18.5\ m^3/sec$, $V < 18.0\ m/sec$, and Froude > 4.5. Based on the design calculations, the stilling basin has a base elevation of +213 m, a width of 35 meters, a length of 14 meters, and a wall height of 11 meters with type USBR III.

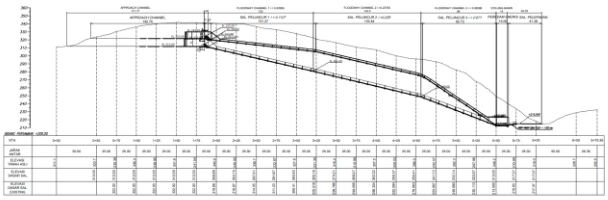

Figure 3.10. Long-Section of Spillway and Stilling Basin
Source: Calculation Result, 2024

COST ESTIMATION

Determining the volume calculation based on the design specified for each planned job. The planned jobs consist of concrete works, and grouting works. This analysis uses the Peraturan Menteri Pekejaan Umum dan Perumahan Rakyat No. 28 tahun 2016 for analyze the unit price of work. This analysis aims to determine the cost estimation that will be incurred for the spillway and stilling basin. Based on the cost estimation analysis in the evaluation of Bagong Dam spillway and stilling basin comparing synthetic unit hydrographs, the total is Rp. 258,896,452,000.

4. CONCLUSIONS

Based on the analysis and discussion results can be concluded that the difference in rainfall trend analysis for rainfall in 2001-2014 and 2001-2023 at Bagong Dam there is no significant trend between 2001-2014 and 2001-2023. However, there is an increase in rainfall at each rain station during 2001-2023. The rainfall design for the Bagong Dam at a return period of 1.01 years = 56.159 mm, a return period of 2 years = 98.162 mm, a return period of 5 years = 123.273 mm, a return period of 10 years = 139.899 mm, At a return period of 25 years = 160.906 mm, a return period of 50 years = 176.490 mm, At a return period of 100 years = 191.959 mm, a return period of 1000 years = 243.073 mm and Probable Maximum Precipitation (PMP) = 471.908 mm. The design flood discharge using synthetic unit hydrographs for Nakaysu there are Q25th = 226,204 m^3/sec, Q50th = 233,603 m^3/sec, Q100th = 261,813 m^3/sec, Q1000th = 356,945 m^3/sec and QPMF = 804,173 m^3/sec while for Gama I there are Q25th = 127,218 m^3/sec, Q50th = 144,601 m^3/sec, Q100th = 162,063 m^3/sec Q1000th = 220,951 m^3/sec and QPMF = 497,787 m^3/sec. Based on calculations using the Nakayasu and Gama I methods, indicating that the optimal method is Nakayasu with a QPMF of 804,173 m^3/sec. Because it is close to the historical flood discharge value. The discharge will pass through the spillway as Q_{1000} = 268,309 m^3/sec with flood water level elevation = +317,30 m and reduction capacity = 24,83% while for QPMF = 657,857 m^3/sec with flood water level elevation = +319,22 m and reduction capacity = 18,19%. The dimensions for the spillway and stilling basin results in a spillway crest width of 35 meters with U.S.B.R. Ogee Type I, a floodway channel 1 length of 132 meters with a width of 35 meters, a floodway channel 2 length of 134.5 meters with a width of 35 meters, a floodway channel 3 length of 94 meters with a width of 35 meters, and a USBR III type stilling basin with a width of 35 meters and a jump length of 14 meters. The estimated cost totals Rp. 258,896,452,000.00.

However future researchers can develop the discussion by analyzing the sedimentation rate, the concrete structure, the spillway and stilling basin stability, the optimization of reservoir utilization, and excavation volume.

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