The Effects of Spillway Width on Outflow Discharge and Flow Elevation for the Probable Maximum Flood (PMF)

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Abstract

The purpose of this study was to analyze the effect of spillway width on flow elevation at the weir crest based on the flood discharge design for the Probable Maximum Flood (PMF) return period using flood routing hydrologically at the Cacaban Dam (Indonesia). The rainfall Probable Maximum Precipitation (PMP) design uses the Hershfield Equation. The design of the flood discharge analysis of \(Q_{PMF}\) used the Nakayasu Synthetic Unit Hydrograph (HSS). Flood routing uses the hydrologic routing method. The Cacaban Dam is located in Jati Village, Kedung Banteng District, Tegal Regency, Central Java Province, Indonesia. The results of the research data analysis showed that increased spillway crest widths led to decreased flow evaluation at the spillway crest, and increased outflow discharge. Thus, if a large storage volume of the reservoir is intended, then the width of the spillway crest must be reduced. Otherwise, the width of the spillway crest must be increased. In terms of flood control in the Tegal Regency, it's better to make the crest of the spillway smaller.

Keywords: Flood Routing; Inflow and Outflow Discharge; Flow Elevation; Spillway, Dams and Reservoirs.

1. Introduction

Reservoirs, in the general sense, are places on the ground that are intended to store or retain water in the event of excess water in the rainy season. The abundant water is then used for agricultural and other purposes during the dry season. The reservoir serves as a water source. In addition, it also serves as a controller of floods and droughts and as a means for recharge to increase the availability of groundwater. Reservoirs also provide benefits for fishing, tourism, and other activities. So, if they are properly managed, their presence will add value to the surrounding area.

The Cacaban Dam (Indonesia) is geographically located between 109° 11’ 28” East and 109° 14’ 58” East and between 7° 1’ 31” South and 7° 4’ 18” South. It is located in Jati Village, Kedung Banteng District, Tegal Regency, Central Java Province, bordering Brebes Regency in the west and east and Pemalang Regency in the north. It is bordered by Tegal City and the Java Sea and by Brebes and Banyumas Regencies in the south [1]. The Cacaban Reservoir has a catchment area of 6,792 ha. The topography of the Cacaban Dam is a hill with an altitude of 85 m to 600 m above sea level. This dam is a homogeneous soil pile dam with a height of 38 meters and a length of 168 meters. The elevation of the peak of the dam is +80.50 m, the normal water level is +77.5 m, and the flood water level is +78.75 m. The total reservoir volume is 74.82 million m\(^3\), which is used to serve an irrigation area of 17,481 hectares.

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According to Anggara & Sundary (2017) [2], the Cacaban Dam at an elevation of normal water level (EL +77.50 m), the reservoir volume is 55.68 million m$^3$, and at an elevation of dead reservoir (EL +63.00 m), the reservoir volume is 0.50 million m$^3$. Also, the effective volume of the reservoir in 2016 was 55.18 million m$^3$. There was a difference in volume of 0.67 million m$^3$ compared to the measurement results in 2012.

The volume of the Cacaban Dam has decreased every year. Between 2012 and 2016, there was a volume reduction of 0.67 million m$^3$. In 2020, it is predicted that the volume decline will be much greater than that figure. The decrease in the volume of the Cacaban Dam is assumed to be one of the important parameters of flooding in Tegal Regency. Therefore, accurate information about the water elevation at the crest is required so that the renovation of the Cacaban Dam is right on target. Information on the parameters of the effective width and height of the flow elevation at the crest is closely related to the amount of budget that will be used in dam renovation activities.

The objectives of this research were (1) to analyze the effect of spillway width on inflow and outflow discharges based on the flood discharge design for the PMF return period using flood routing hydrologically at the Cacaban Dam; and (2) to analyze the effect of spillway width on flow elevation above the weir crest based on the flood discharge design for the PMF return period using flood routing hydrologically at the Cacaban Dam.

2. Methodology

This research used a survey research method that is based on hydrological data. The rainfall data used were on the annual maximum daily rain. The rainfall data were obtained from the Tegal Regency Agriculture Office. The rain stations used for hydrological calculations were in Sirampok (109° 11’ 0.276” E; 7° 0’ 17.425” S), Lebaksiu (109° 8’ 23.879” E; 7° 3’ 26.368” S), and Jatinegara (109° 15’ 0.176” E; 7° 3’ 50.78” S). The length of time of the daily rainfall data was 10 years, from 2008 to 2017. The rainfall data used were to analyze the design rainfall, design flood discharge, and flood hydrograph, which were then used for the input-output analysis of flooding at the Cacaban Dam spillway's crest [1].

Software and hardware were used in this research. The research was conducted using Excel, ArcView GIS, and AutoCAD as the software tools. A computer, a camera, an Android, and GPS were used as the research hardware. The source of this research was a 1:50000 scale topographic map obtained from the most recent Google map in 2018. The Thiessen polygon was used to identify the distribution of the catchment area using topographic maps at a resolution of 1:50000. ArcView GIS and AutoCAD software were used to analyze the Cacaban watershed and sub-watershed [3].

Flood routing reservoirs were used in hydrologic routing based on the Continuity Equation 1 [4-6]:

$$I - Q = \frac{dS}{dt}$$  \hspace{1cm} (1)

where $I$ is the average inflow discharge in a small time interval $d_t$, $Q$ is the average outflow discharge in the same time interval (m$^3$/s), $dS$ is the corresponding change in the storage of the reservoir during the same time interval (m$^3$), and $dt$ is the flood routing period (s).

While $d_t$ is changed to $\Delta t$, $I_1$ and $I_2$ can be known from the hydrograph of discharge into the reservoir. $S$ represents the storage of the reservoir at the beginning of the routing period measured from the reference line of expenditure facilities (spillway weir or axis tunnel outlet). The flood routing equation according to Hossain (2015), Ionescu & Nistoran (2019) and Sutapa (2019) [4-6]:

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

if $\frac{S_1 - Q_1}{2} = \psi_1$ and $\frac{S_2}{2} - \frac{Q_2}{2} = \phi_2$.

Thus, Equation 2 can also be written as:

$$\frac{I_1 + I_2}{2} + \psi_1 = \phi_2$$ \hspace{1cm} (3)

where $I_1$ is the incoming discharge whose position in the calculation table is above the discharge to be found (m$^3$/s), $I_2$ is the incoming discharge to be found (m$^3$/s), $\psi_1$ is the conditions at the start of routing, $\phi_2$ is the conditions at the end of routing, $\Delta t$ is the flood routing period (seconds, hours, or days), and $S$ is the large storage reservoir (m$^3$). $Q$ is the outflow at the beginning of the routing period. If its expenditure is spillway, then the equation used is as presented Equation 4 [7-10]:

$$Q = CBH^{3/2}$$ \hspace{1cm} (4)

where $C$ is the discharge coefficient for spillway (1.7-2.2 m$^{1/2}$/s), $B$ is the weir width (m), and $H$ is the energy head at the crest (m).
The Cacaban Dam is of the homogeneous soil fill type, with a peak length of 168 m, a peak width of 6.0 m, and a peak elevation of +80.50 m. The spillway specification of Cacaban Dam is as follows: (1) doorless ogee type, (2) crest elevation of +77.50 m, (3) crest width of 58 m, and (4) spillway width of 16 m. Figure 1 shows the construction of the spillway and chute spillway of the Cacaban Dam [3].

![Figure 1. Construction of the spillway and chute spillway of the Cacaban Dam](image)

At normal water level elevation at +77.50 m, the reservoir volume was 55.51 million m$^3$, and at the elevation of dead storage at EL of +63.00 m the reservoir volume was 0.50 million m$^3$. In other words, the effective volume of the reservoir in 2016 was 55.51 million m$^3$. There was a volume difference of 0.84 million cubic meters when compared to the measurement results in 2012 (56.35 million m$^3$). Table 1 shows the reservoir capacity of the Cacaban Dam in 2016.

| Number | Elevation (m) | Storage (m$^3$) | Number | Elevation (m) | Storage (m$^3$) |
|--------|---------------|----------------|--------|---------------|----------------|
| 1      | 77.5          | 55514687.37    | 12     | 78.6          | 66136322.58    |
| 2      | 77.6          | 56480290.57    | 13     | 78.7          | 67101925.78    |
| 3      | 77.7          | 57445893.77    | 14     | 78.8          | 68067528.98    |
| 4      | 77.8          | 58411496.97    | 15     | 78.9          | 69033132.18    |
| 5      | 77.9          | 59377100.17    | 16     | 79            | 69998735.38    |
| 6      | 78            | 60342703.37    | 17     | 79.1          | 70964338.58    |
| 7      | 78.1          | 61308306.57    | 18     | 79.2          | 71929941.78    |
| 8      | 78.2          | 62273909.77    | 19     | 79.3          | 72895544.98    |
| 9      | 78.3          | 63239512.97    | 20     | 79.4          | 73861148.18    |
| 10     | 78.4          | 64205116.17    | 21     | 79.5          | 74826751.38    |
| 11     | 78.5          | 65170719.38    |        |               |                |

Table 1. Reservoir capacity of the Cacaban Dam in 2016 [2]

The steps of this research were as follows: (1) conducting a review of relevant previous research, followed by formulating the problem; (2) collecting daily rainfall data; (3) performing an analysis of the rainfall data; (4) examining the distribution of the rainfall data; (5) analyzing the planned rainfall; (6) determining the design flood discharge using the Nakayasu Synthetic Unit Hydrograph; (7) determining the discharge value of the Q$_{PMF}$ flood plan; (8) analyzing the flood tracking due to the Q$_{PMF}$; (9) analyzing the flood elevation above the spillway crest; (10) comparing the flow elevation above the calculated spillway crest with the flow elevation above the existing spillway crest (if $h_{analysis} < h_{existing}$, then the iteration process was stopped); and (11) compiling a graph of inflow and outflow discharge on the Q$_{PMF}$. Figure 2 shows the research flow chart.
3. Results and Discussion

3.1. Regional Rainfall Distribution

The rainfall data available were historical data. Thus, the hydrological calculation was based on the data at rain stations affecting the Cacaban Catchment area (Figure 3). The rain stations used for the hydrological calculations were those in Sirampok, Lebaksiu, and Jatinegara. The length of time of the three stations’ data were 10 years. The rainfall data used were annual maximum daily rainfall [3].
The rainfall data obtained were the point rainfall data of a station. Therefore, an analysis was required to process the data into regional rainfall data. This research used the point rainfall data at the three stations, so the regional rainfall data were processed based on the rainfall data at the three stations. The analysis used the Thiessen polygon method. Table 2 shows how the catchment area is split up when the Thiessen polygon method is used.

| Number | Station     | Catchment area or \(A_i\) (Km\(^2\)) | Thiessen's Coefficient (%) |
|--------|-------------|--------------------------------------|----------------------------|
| 1.     | Sirampok    | 27.667                               | 41.711                     |
| 2.     | Lebaksiu    | 12.707                               | 19.157                     |
| 3.     | Jatinegara  | 25.955                               | 39.130                     |
| Total  |             | 66.329                               | 100                        |

The rainfall distribution of each region was obtained by an analysis using the Thiessen polygon method, considering the factors involved in the Thiessen polygon. The results of the calculation of maximum regional daily rainfall are provided in Table 3.

Table 3. Maximum regional daily rainfall at Sirampok, Lebaksiu, and Jatinegara Stations using the Thiessen polygon method (mm)

| Year | January | February | March | April | May | June | July | August | September | October | November | December |
|------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|
| 2008 | 64.501  | 44.118   | 68.943| 60.807| 22.368| 21.117| 0.000| 28.043 | 8.342     | 50.685  | 60.773   | 66.631   |
| 2009 | 81.429  | 76.713   | 52.462| 40.072| 40.803| 30.480| 5.870| 0.000  | 24.314    | 53.512  | 68.016   | 80.762   |
| 2010 | 65.239  | 96.720   | 92.777| 57.046| 52.139| 95.013| 49.114| 55.226 | 54.783    | 59.497  | 58.131   | 73.720   |
| 2011 | 74.910  | 111.752  | 65.709| 61.319| 62.576| 22.132| 31.999| 0.000  | 0.000     | 51.111  | 57.750   | 59.788   |
| 2012 | 97.131  | 85.446   | 45.598| 49.664| 30.329| 22.126| 18.760| 0.000  | 0.000     | 32.147  | 47.489   | 157.535  |
| 2013 | 102.883 | 50.719   | 49.309| 62.660| 21.026| 60.222| 90.894| 29.918 | 23.765    | 24.045  | 18.622   | 68.043   |
| 2014 | 50.894  | 122.276  | 84.218| 72.046| 46.817| 83.250| 53.515| 16.764 | 0.000     | 8.738   | 76.844   | 67.257   |
| 2015 | 92.064  | 107.295  | 82.963| 74.668| 61.455| 21.379| 0.000| 0.000  | 0.000     | 61.526  | 74.776   | 86.535   |
| 2016 | 40.023  | 111.752  | 82.781| 61.319| 39.561| 92.262| 36.667| 15.813 | 77.035    | 33.163  | 53.291   | 86.535   |
| 2017 | 104.764 | 90.484   | 116.091| 99.178| 53.337| 44.828| 13.766| 2.503  | 37.908    | 33.535  | 47.875   | 66.963   |
3.2. Rainfall Design with 20, 50, 100, 1000 Years and PMP Return Periods

The maximum rainfall for a given return period was determined using design rainfall analysis, which was then employed in the design discharge calculation. The study included return periods 20, 50, 100, and 1000 years as well as Probable Maximum Precipitation (PMP) return periods. The method for calculating rainfall was based on statistics or distribution methods of average daily rainfall in the catchment area. The Log Pearson Type III distribution was employed to establish the design rainfall in this study [11]. PMP was statistically analyzed using the Hershfield equation [12-14]. Figure 4 shows a map of the catchment area of the Cacaban Dam.

![Figure 4. Map of the location: Catchment area in Cacaban](image)

Table 4 shows that the design rainfall was as follows: 147.97 mm in the return period of 20 years; 161.31 mm in return period of 50 years; 169.37 mm in return period of 100 years; 192.96 mm in return period of 1000 years; and 588.99 mm in the PMP. Rainfall (R24/daily) of 147.97, 161.31, 169.37, 192.96, and 588.99 mm are included in the category of heavy to very heavy [15].

| T (year) | k   | Log $X_T$ (mm) | $X_T$ (mm) |
|----------|-----|----------------|------------|
| 20       | 1.514 | 2.170          | 147.97     |
| 50       | 1.898 | 2.207          | 161.31     |
| 100      | 2.115 | 2.228          | 169.37     |
| 1000     | 2.695 | 2.285          | 192.96     |
| PMP      | -    | -              | 588.99     |

$X$ is the observational variation value, $X_T$ is the expected $X$ variant value occurring in the return period of $T$, and $k$ from the table is a function of the return period and the coefficient of variation [16].

3.3. Hydrograph of the Flood Design in the 20, 50, 1000 Years and PMF Return Periods

The design flood discharge of the Cacaban Reservoir was calculated using the design rainfall calculation as a commonly used hydrological approach. The Nakayasu Synthetic Unit Hydrograph was used to calculate the design flood discharge (HSS). The equation for the Nakayasu Synthetic Unit Hydrograph (HSS) is as follows [17-19]:

$$Q_P = \frac{AR_o}{3.6(0.3T_p + T_{0.3})}$$  \hspace{1cm} (5)

where $Q_P$ is the flood discharge peak (m$^3$/s), $A$ is the catchment area of Cacaban reservoir (km$^2$), $R_o$ is the rain unit (mm), $T_p$ is the time lag from the beginning of the rain to the peak of the flood (hour), and $T_{0.3}$ is the time required by the discharge to descend from the peak discharge to 0.3 times the peak discharge (hour).

Figure 5 presents the hydrograph of the flooding design for the 20, 50, 100, and 1000 years and PMF return periods.
Figure 5. The hydrograph of flood design for the 20, 50, 100, 1000 years and PMF return periods

Figure 5 shows that (1) the design flood discharge for the return period of 20 years is 247.750 m³/s, (2) the design flood discharge for the return period of 50 years is 283.343 m³/s, (3) the design flood discharge for the return period of 100 years is 305.116 m³/s, (4) the design flood discharge for the return period of 1000 years is 369.775 m³/s, and (5) the design flood discharge for the PMF return period is 1,559.429 m³/s.

3.4. Flood Routing Based on the PMF Flood Discharge Return Period

The PMF return period flood routing was conducted through several stages [20]: (1) arranging Table 5 on the relationship between water reservoir elevation, storage, and discharge (ψ); (2) determining the regression equation between water reservoir elevation and storage and between water reservoir elevation and discharge (ψ); (3) compiling Table 6; and (4) creating a chart of flood routing through a spillway (inflow and outflow discharge chart). The stages above follow the notion that flood routing through a spillway is aimed to figure out the level of runoff when the flood discharge passes the spillway. The flood routing result is to be used as a basis for determining whether overtopping occurred at the dam or not [21].

Table 5. The relationship between the water surface of the reservoir, the storage, and the discharge (ψ) at the Cacaban Dam (QPMF)

| Number | Elevation (h) (m) | H (m) | Storage (S) (m³) | S (m³/s) | I1/2 (m³/s) | ψ (psi) (m³/s) | ψ (phi) (m³/s) |
|--------|------------------|-------|-----------------|---------|-------------|----------------|----------------|
| (1)    | (2)              | (3)   | (4)             | (5)/3600| (6)         | (7)           | (8)            |
| 1      | 77.50            | 0     | 55514687.37     | 15420.746| 0.000       | 0.000         | 15420.746      | 15420.746      |
| 2      | 77.60            | 0.1   | 56480290.57     | 15688.970| 2.384       | 1.192         | 15687.777      | 15690.162      |
| 3      | 77.70            | 0.2   | 57445893.77     | 15957.193| 6.744       | 3.372         | 15953.821      | 15960.565      |
| 4      | 77.80            | 0.3   | 58411496.97     | 16225.416| 12.389      | 6.195         | 16219.221      | 16231.611      |
| 5      | 77.90            | 0.4   | 59377100.17     | 16493.639| 19.075      | 9.537         | 16484.102      | 16503.176      |
| 6      | 78.00            | 0.5   | 60342703.37     | 16761.862| 26.658      | 13.329        | 16748.533      | 16775.191      |
| 7      | 78.10            | 0.6   | 61308306.57     | 17030.085| 35.043      | 17.521        | 17012.564      | 17047.607      |
| 8      | 78.20            | 0.7   | 62273909.77     | 17298.308| 44.159      | 22.079        | 17276.229      | 17320.388      |
| 9      | 78.30            | 0.8   | 63239512.97     | 17566.531| 53.952      | 26.976        | 17539.555      | 17593.507      |
| 10     | 78.40            | 0.9   | 64205116.17     | 17834.754| 64.378      | 32.189        | 17802.566      | 17866.943      |
| 11     | 78.50            | 1     | 65170719.38     | 18102.978| 75.400      | 37.700        | 18065.278      | 18140.678      |
| 12     | 78.60            | 1.1   | 66136322.58     | 18371.201| 86.988      | 43.494        | 18327.707      | 18414.695      |
| 13     | 78.70            | 1.2   | 67101925.78     | 18639.424| 99.116      | 49.558        | 18589.866      | 18688.982      |
| 14     | 78.80            | 1.3   | 68067528.98     | 18907.647| 111.760     | 55.880        | 18851.767      | 18963.527      |
| 15     | 78.90            | 1.4   | 69033132.18     | 19175.870| 124.900     | 62.450        | 19113.420      | 19238.320      |
| 16     | 79.00            | 1.5   | 69998735.38     | 19444.093| 138.519     | 69.256        | 19374.834      | 19513.352      |
| 17     | 79.10            | 1.6   | 70964338.58     | 19712.316| 152.599     | 76.299        | 19636.017      | 19788.616      |
| 18     | 79.20            | 1.7   | 71929941.78     | 19980.539| 167.126     | 83.563        | 19896.976      | 20064.103      |
| 19     | 79.30            | 1.8   | 72895544.98     | 20248.762| 182.087     | 91.044        | 20157.719      | 20339.806      |
| 20     | 79.40            | 1.9   | 73861148.18     | 20516.986| 197.470     | 98.735        | 20418.250      | 20615.721      |
| 21     | 79.50            | 2     | 74826751.38     | 20785.209| 213.263     | 106.632       | 20678.577      | 20891.840      |
Table 6. Analysis of flood routing through spillway of PMF discharge

| Time (hour) | Inflow discharge ($I_n$) (m$^3$/s) | ($I_n$+$I_{n-1}$)/2 (m$^3$/s) | $\psi$ (Psi) (m$^3$/s) | $\phi$ (phi) (m$^3$/s) | Outflow discharge ($Q$) (m$^3$/s) | $H$ (m) | Elevation ($\delta$) (m) |
|------------|------------------------------------|-------------------------------|-------------------------|-------------------------|---------------------------------|--------|------------------------|
| (1)        | (2)                                | (3)                           | (4) $\equiv$ equal (b)  | (5)                     | (6)                             | (7)    | (8) $\equiv$ equal (a) |
| 0          | 1.896                              | 0.948                         | 15431.000               | 15,431.948              | 0.000                           | 0.000  | 77.500                 |
| 1          | 106.388                            | 53.194                        | 15531.636               | 15,584.830              | 0.869                           | 0.038  | 77.538                 |
| 2          | 696.757                            | 348.378                       | 16189.901               | 16,538.279              | 18.005                          | 0.289  | 77.789                 |
| 3          | 1,599.429                          | 779.715                       | 17647.990               | 18,427.704              | 89.901                          | 0.844  | 78.344                 |
| 4          | 1,158.315                          | 579.158                       | 18658.641               | 19,237.799              | 157.924                         | 1.228  | 78.728                 |
| 5          | 842.227                            | 421.113                       | 19305.948               | 19,727.061              | 207.739                         | 1.475  | 78.975                 |
| 6          | 582.833                            | 291.417                       | 19660.763               | 19,952.180              | 236.915                         | 1.610  | 79.110                 |
| 7          | 448.734                            | 224.367                       | 19861.130               | 20,085.497              | 253.947                         | 1.686  | 79.186                 |
| 8          | 345.589                            | 172.795                       | 19947.818               | 20,120.612              | 261.438                         | 1.719  | 79.219                 |
| 9          | 266.254                            | 133.127                       | 19952.374               | 20,085.501              | 261.833                         | 1.721  | 79.221                 |
| 10         | 205.232                            | 102.616                       | 19898.832               | 20,001.448              | 257.196                         | 1.700  | 79.200                 |
| 11         | 164.568                            | 82.284                        | 19811.212               | 19,893.496              | 249.667                         | 1.667  | 79.167                 |
| 12         | 135.503                            | 67.751                        | 19703.219               | 19,770.971              | 240.491                         | 1.626  | 79.126                 |
| 13         | 111.631                            | 55.815                        | 19581.325               | 19,637.141              | 230.273                         | 1.580  | 79.080                 |
| 14         | 92.024                             | 46.012                        | 19450.551               | 19,496.563              | 219.475                         | 1.530  | 79.030                 |
| 15         | 75.921                             | 37.960                        | 19314.757               | 19,352.718              | 208.448                         | 1.478  | 78.978                 |
| 16         | 62.694                             | 31.347                        | 19176.884               | 19,208.231              | 197.447                         | 1.426  | 78.926                 |
| 17         | 51.831                             | 25.916                        | 19039.141               | 19,065.056              | 186.657                         | 1.373  | 78.873                 |
| 18         | 42.909                             | 21.455                        | 18903.164               | 18,924.619              | 176.206                         | 1.321  | 78.821                 |
| 19         | 35.581                             | 17.791                        | 18770.143               | 18,787.933              | 166.177                         | 1.271  | 78.771                 |
| 20         | 29.563                             | 14.781                        | 18640.914               | 18,655.695              | 156.624                         | 1.222  | 78.722                 |
| 21         | 24.619                             | 12.310                        | 18516.046               | 18,528.355              | 147.575                         | 1.174  | 78.674                 |
| 22         | 20.559                             | 10.280                        | 18395.897               | 18,406.177              | 139.038                         | 1.128  | 78.628                 |
| 23         | 17.225                             | 8.612                         | 18280.670               | 18,289.282              | 131.012                         | 1.085  | 78.585                 |
| 24         | 14.486                             | 7.243                         | 18170.443               | 18,177.686              | 123.485                         | 1.043  | 78.543                 |

The coefficient of the relationship between the storage volume ($S$) and elevation ($\delta$) of the water reservoir obtained using the regression equation $\delta = -2 \times 10^{-2} \times S^2 + 1 \times 10^{-7} \times S + 77.5$ (a) ($R = 1.0$). Similarly, the coefficient of the relationship between the elevation ($\delta$) and Psi ($\psi$) of the water reservoir obtained using the regression equation $\psi = 2627.6 \times \delta - 188208$ (b) ($R = 1.0$).

The hydrograph of inflow flood discharge for the PMF return period and the outflow discharge is shown in Figure 6. According to Figure 6, the peak outflow discharge of 261.833 m$^3$/s (spillway width of 58 m) was found at the elevation of +79.221 m. It can be said that the flood discharge for the PMF return period did not result in overtopping because the top of the dam was at an elevation of +80.50 m. Meanwhile, the hydrograph of inflow flood discharge for the PMF return period and the outflow discharge is shown in Figure 6, according to which the peak inflow discharge of 1,559.429 m$^3$/s was reduced to 261.833 m$^3$/s (outflow). This was due to the reservoir storage and spillway capacity. Thus, the Cacaban Reservoir could accommodate or store flood discharge of 1,297.596 m$^3$/s.

Figure 6 shows the hydrograph of the inflow flood discharge and outflow discharge for the PMF return period, with the highest outflow discharge being 261.833 m$^3$/s (spillway width of 58 m) at a height of +79.221 m. As a result, because the dam peak height is +80.50 m, the flood discharge for the PMF return period did not result in runoff. Figure 6 shows the inflow flood hydrograph for the PMF return period and the outflow discharge, with the peak inflow discharge lowered from 1,559.429 m$^3$/s to 261.833 m$^3$/s (outflow). This is related to the storage capacity of the reservoir and the capacity of the spillway. As a result, the Cacaban Reservoir can accommodate or store 1,297.596 m$^3$/s of flood runoff.
3.5. The Effects of Spillway Width, Inflow-Outflow Discharge, and Flow Elevation on Weir Crest

Table 7 shows that as the width of the weir crest increases, the flow through the spillway increases, and as a result, the height of flow above the weir decreases. The inflow flood discharge to the reservoir was conducted to the downstream through the spillway; thus, the volume of flood in the dam reservoir is reduced. In other words, as the duration of the flood increases, followed by a stagnant reservoir volume, and the flood peak will be decreased. Therefore, the dam reservoir has the ability to store a small volume of flood discharge, it would not suffice to reduce the peak flood discharge. In this case, as the volume of the outflow approaches the volume of the inflow, the flow height above the weir decreases.

Table 7. $I_{\text{max}}$, elevation, $Q_{\text{max}}$, and new dam height values due to flooding of the PMF return period design

| No. | Spillway width (m) | Maximum inflow discharge or $I_{\text{max}}$ (m$^3$/s) | Flow height above weir (H) (m) | Elevation (h) (m) | Maximum outflow discharge or $Q_{\text{max}}$ (m$^3$/s) | New dam height Freeboard=2 m |
|-----|-------------------|----------------------------------|-------------------------------|------------------|---------------------------------|-----------------------------|
| 1.  | 58                | 1,559.429                        | 1.721                         | 79.221           | 261.833                         | +81.221                     |
| 2.  | 68                | 1,559.429                        | 1.667                         | 79.167           | 292.821                         | +81.167                     |
| 3.  | 78                | 1,559.429                        | 1.618                         | 79.118           | 321.059                         | +81.118                     |
| 4.  | 48                | 1,559.429                        | 1.787                         | 79.287           | 229.349                         | +81.287                     |

The findings of this study are matched to the results of Mediero et al. (2010) [22]. They stated that the width or length of the spillway crest is related to the elevation of the flow above the spillway crest, which is related to the size of the maximum outflow discharge in a sequential manner. From a hydrological standpoint, the relationship between the three parameters listed above is useful for determining the level of dam safety. Furthermore, the relationship between these parameters can be used as one of the criteria evaluated in flood management at the dam's downstream location, which in this case is the City and Regency of Tegal. The findings of Mediero et al. (2010) [22], which are supported by Volpi et al. (2018) [23], show that the spillway crest dimension is one of the most critical elements in reducing flood peaks or increasing and decreasing reservoir water storage capacity.

4. Conclusion

The spillway crest width of 58 m indicates that the inflow discharge was 1,559.429 m$^3$/s and the outflow discharge was 261.833 m$^3$/s during the PMF return period, with a flow elevation of +79.221 m; there was no overtopping because the dam's top height was +80.50 m. In addition, the Cacaban Reservoir could lower flood discharge by 1,297.596 m$^3$/s (83.21%). The spillway crest width of 48 m indicates that the inflow discharge was 1,559.429 m$^3$/s and the outflow discharge was 229.349 m$^3$/s during the PMF return period, with a flow elevation of +79.287 m; there was no overtopping because the dam's top height was +80.50 m. In addition, the Cacaban Reservoir could reduce flood discharge by 1,330.08 m$^3$/s, or 85.29%. As a result, the flow elevation above the spillway crest decreased as the breadth of the spillway crest increased, while the maximum outflow discharge increased. Thus, if a large storage volume in the reservoir is required,
the width of the spillway crest must be reduced; alternatively, the spillway crest must be increased. The height of the flow above the spillway crest is related to the size of the maximum outflow discharge, which is related to the breadth or length of the spillway crest. In this study, flood control downstream of Cacaban Dam has been done based on determining the relationship between different hydraulic parameters that can improve the safety level of the dam.

5. Declarations

5.1. Author Contributions

Conceptualization, Y.S. and K.S.U.; methodology, Y.S. and K.S.U.; software, Y.S., K.S.U. and N.T.; validation, Y.S., K.S.U. and N.T.; formal analysis, Y.S. and K.S.U.; writing—original draft preparation, Y.S.; writing—review and editing, Y.S.; visualization, N.T.; supervision, K.S.U.; project administration, Y.S.; funding acquisition, Y.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this research were collected from the Regional Planning, Development, Research, and Development Agency (BAPPEDA) of Tegal Regency and the Pemali Juana River Basin Center (BBWS) of Semarang City. The data from the aforementioned agencies were complemented with the rainfall data from the Public Work Center for Water Resources and Spatial Planning (PU SDA TARU) of Central Java Province.

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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