Evaluation Of Reservoir Performance On Flood Discharge Plan Using HEC-HMS Modelling (Case Study: Selorejo Reservoir)

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Abstract. Water is a valuable resource for humanity, because of this fact humanity has to manage the amount of water resource whether it is in excess condition or scarce, excess water is a problem in water management. Because it can cause natural disasters and waste water in vain. Therefore, water needs to be properly regulated. One way to regulate water is by structural means or it can also be called water reservoirs. Reservoir is one of the structures that are suitable to hold water and become a means to regulate the water itself. Referring to the POW (dam operation pattern) and ROTW (annual reservoir operation plan) from the Ministry of PUPR, it is said that the condition of the reservoir must be reviewed for development and changes in its utilization at least every 5 years. The solution chosen to evaluate the selorejo reservoir is to use the Rain-runoff Relationship Model in this case using HEC-HMS version 4.2.1, to find out whether the reservoir is still able to accommodate the flood discharge that was planned at the beginning of construction. Due to the age of the Selorejo Reservoir which has reached 48 years, the Selorejo Reservoir itself is planned with an effective age of 50 years.

From analysis result we can conclude that even there is change in reservoir capacity due to sedimentation, Selorejo Reservoir still able to accommodate 1000-year Period Flood and if the reservoir kept in +610 m level, it will be able to accommodate PMF Flood.

Keywords: Flood, Reservoir, Capacity

1. Introduction
Water is one of the most important natural resources in life processes. The need for water in the community is very important, so in order not to cause water shortages, water needs to be accommodated. However, excess water is a bad thing. Because it can cause natural disasters and waste water in vain. Therefore, water needs to be properly regulated. One way to regulate water is by structural means or it can also be called water reservoirs. Reservoir is a civil building that functions as a water reservoir and can be used for hydropower, raw water, irrigation water, tourism objects, nature conservation and so on [1]. Among others, as flood control, hydropower, raw water supply and irrigation, tourism objects and so on. So that the operation can be successful and water is always available for the purposes above, it is necessary to make a rule or regulation so that there is a balance between input and inflow. If the inflow is greater than the need, then the rest will be transferred to the sewer. around the reservoir land itself
which has a function for hydropower, raw water, irrigation water, tourism objects, nature conservation
and so on. However, the condition of the reservoir itself changes every year, this is due to the buildup
in the reservoir which results in a reduction in the effective volume of the reservoir. Referring to the
POW (dam operation pattern) and ROTW (annual reservoir operation plan) from the Ministry of PUPR,
it is said that the condition of the reservoir must be reviewed for development and changes in its
utilization at least every 5 years. This is the basis for evaluating the performance of the reservoir, with
the Selorejo reservoir as the location of the case study which is used in Sambirejo, Pandansari, Ngantang
sub-district, Malang, East Java. Due to the age of the Selorejo Reservoir which has reached 48 years,
the Selorejo Reservoir itself is planned with an effective age of 50 years. The solution chosen to evaluate
the selorejo reservoir is to use the Rain-runoff Relationship Model in this case using HEC-HMS version
4.2.1, to find out whether the reservoir is still able to accommodate the flood discharge that was planned
at the beginning of construction. Along with the development of technology, there are many software
programs to model rain into discharge. One of these programs is the Hydrologic Engineering Center-
Hydrologic Modeling System (HEC-HMS). This program is a program developed by the US Army
Corps of Engineers. The HEC-HMS program has many methods in modeling rainfall and also has
automatic calibration facilities The use of the HEC-HMS model is expected to be able to imitate a
watershed system that has variability in the watershed system and input characters that have space and
time very high. [2] HEC-HMS stands for Hydrologic Engineering Center Hydrologic Modeling System.
HEC-HMS is a software developed by the Hydrologic Engineering Center of the US Army Corps of
Engineers. The HEC-HMS modeling is used to simplify the process of analyzing complex flood events.
In the HEC-HMS modeling, it is necessary to physically model the study area under review. This
includes the area, flow length and slope of the land and channels of the sub-watershed. In addition to
the physical component, there are three main hydrological components to model a flood event, namely
water loss (Losses), synthetic unit hydrograph (Transform), and base flow (Baseflow). In the analysis
of flood events, the Losses and Transform components in the form of a synthetic unit hydrograph
become the most important main component, while the Baseflow component has a smaller effect.

2. Main Problems
The main problem in this study is that in Selorejo Reservoir effective year is only 50 Year and it has
been operating for 48 years and there is decrease in effective storage due to sediment. So it is essential
to check whether the current condition of Selorejo Reservoir still able to operate as its specific design.

3. Goals
In general, this study aims to evaluate the Selorejo Resevoir condition. To achieve those goals there are
several specific goals to help answer the main goals such as:
• To find out whether the Selorejo reservoir is still able to accommodate the flood water discharge that
  was planned at the beginning of construction or not.
• To achieve this goal, it is carried out:
  1. return period rain analysis
  2. flood event model parameter calibration
  3. evaluation of Selorejo reservoir

4. Research Methods
The location for this research is the Selorejo reservoir located in Sambirejo, Pandansari, Ngantang sub-
district, Malang, East Java. The data is obtained from the Selorejo reservoir construction project and
also rain posts around the reservoir to obtain supporting data. The data obtained is continued with
modeling on HEC HMS. This research was conducted using multi-basin analysis, namely by dividing
the main watershed into several sub-watersheds. The division of sub-watersheds is carried out using the
help of GIS software, where the Selorejo Reservoir watershed is divided into 6 sub-watersheds. SCS
Synthetic Unit Hydrograph parameter Lag Time (Lag Time) is calculated by HEC-GeoHMS and
Program TR-55. To analyze the research results, data processing is needed, the data obtained will be
processed by calibration from the obtained modeling, After that, an analysis of the calibration results is
carried out to obtain results which will later be evaluated for the capacity of the reservoir capacity. The results of the evaluation will be put into the final conclusion.

![Figure 1. Research Flowchart](image)

5. Data and Analysis

5.1. Loss Method.

The study location used in this research is located in the Selorejo Reservoir which is located in Pandansari Village, Ngantang District, Malang Regency. While the location of the dam is on K. Konto, a tributary of K. Brantas, just below its confluence with K. Kwayangan, + 50 km west of Malang city, at an altitude of + 650 m above sea level. Initially, the Selorejo Reservoir was built for flood control, irrigation water supply, electricity generation, inland fisheries and tourism. The following is a description of the Selorejo Reservoir watershed shown in Figure 2.
5.2. Analysis of flood discharge and return period rainfall

In evaluating reservoir storage, it is necessary to analyze rainfall at various return periods. This analysis aims to determine the ability of the reservoir to accommodate rainfall in a certain return period. So this analysis is carried out in order to get the return period flood value which will be used to analyze the calculation of rainfall in the return period that you want to know. Referring to the prevailing rules and regulations in Indonesia, the calculation of the return period rainfall uses 5 distributions, namely the Normal Distribution, Log Normal, Gumbel, Pearson III, and Log Pearson III. In this study, all calculations are used in order to meet the requirements for calculating rainfall. Based on the maximum daily rainfall data obtained, then the frequency analysis can be carried out using the distribution method that is the reference in the SNI, namely the 5 distribution methods previously mentioned to determine the value of rainfall at various return periods. The following are the results of the frequency analysis at the Selorejo rain post.

| Return period (Year) | t | Normal 2 Parameters | Lognormal 3 Parameters | Gumbel | Pearson III | Log Pearson III |
|----------------------|---|----------------------|------------------------|--------|-------------|-----------------|
| 2                    | 0.00 | 123.40               | 120.90                 | 123.30 | 119.60      | 123.30          |
| 5                    | 0.84 | 144.30               | 143.00                 | 144.20 | 145.20      | 144.20          |
| 10                   | 1.28 | 155.20               | 156.10                 | 155.20 | 155.20      | 156.10          |
| 20                   | 1.64 | 164.20               | 167.80                 | 164.40 | 178.30      | 164.40          |
| 25                   | 1.75 | 166.80               | 171.40                 | 167.00 | 183.50      | 167.00          |
| 50                   | 2.05 | 174.30               | 182.10                 | 174.70 | 199.30      | 174.70          |
| 100                  | 2.33 | 181.10               | 192.20                 | 181.60 | 215.10      | 181.60          |
| 500                  | 2.88 | 194.80               | 214.60                 | 195.60 | 251.50      | 195.60          |
| 1000                 | 3.09 | 200.10               | 223.80                 | 201.00 | 267.10      | 201.00          |

Table 1 shows the results of the frequency analysis of the various distribution calculation methods used, for various return periods. The results show that each distribution shows good results where the maximum deviation value for each distribution is smaller than the critical delta value. However, for the selection of the best distribution, it can be seen from the smallest maximum deviation value from the entire distribution. Based on the results of the analysis shown in Table 1, at the Selorejo Rain Post the
The smallest maximum deviation value is indicated by the distribution of Log Pearson III with a value of 6.20. Based on the results of the analysis above, it can be concluded that for the Selorejo Rain Post, the best distribution method to use is the Log Pearson III distribution. In addition to the return period rain, it is also necessary to determine the maximum possible rain value or Probable Maximum Precipitation (PMP). This needs to be done because large reservoirs in Indonesia use the design discharge of the Probable Maximum Flood (PMF) which is the result of the PMP transformation as the reservoir design. Based on this, it is necessary to determine the PMP value. To determine the PMP value, the Hersfield method is used.

Table 2: Summary of Results of Rain Frequency Analysis in Selorejo Reservoir Watershed

| Year | Jombok  | Sekar  | Selorejo | Pujon  |
|------|---------|--------|----------|--------|
|      | Pearson III | Log Pearson III | Log Pearson III | Gumbel |
| 2    | 113.70  | 100.50 | 122.70   | 86.80  |
| 5    | 148.90  | 128.60 | 144.50   | 119.10 |
| 10   | 170.40  | 148.30 | 156.10   | 140.40 |
| 20   | 189.90  | 168.00 | 165.70   | 160.90 |
| 50   | 213.90  | 195.10 | 176.50   | 187.40 |
| 100  | 231.10  | 216.60 | 183.60   | 207.30 |
| 1000 | 284.80  | 296.80 | 203.10   | 272.90 |
| PMP  | 723.27  | 559.97 | 518.17   | 608.79 |

Rain data generated from the results of the frequency analysis is still in the form of point rain, therefore it needs to be converted into regional rain. Point rain must be converted into regional rain so that rain discharge calculations can be carried out based on each rain post. Later, even though it has turned into regional rain, the value is still less precise, this is because the value is still too large, therefore the rainfall value for the region needs to be multiplied by a reduction factor called the Area Reduction Factor (ARF) so that the regional rainfall value becomes more precise. The ARF equation used is the Modified Bell equation with the following equation:

\[
ARF_m = 1 - 0.4(A^{0.14} - 0.7 \log Td)Td^{-0.48} + 0.002A^{0.4}Td^{0.41}[0.3 + \log \left(\frac{1}{T}\right)]
\]

Where:
- \(ARF_m\) = area reduction factor;
- \(A\) = flow area (km²);
- \(T\) = birthday period (years);
- \(Td\) = storm duration (hours).

Application range:
- 1 km² ≤ A ≤ 10,000 km²
- T = 2 years – 200 years
- 18 hours ≤ Td ≤ 120 hours

[Source: Pietersen et.al., 2017]

The regional rainfall values for each subwatershed of the Selorejo Reservoir are shown in Table 2 and the ARF value based on the above equation is shown in Table 3. for the process of calibrating the regional rainfall value is carried out on the HEC-HMS.
Table 3. Rainfall in the Selorejo Reservoir Watershed Area

| Sub-Basin | 2   | 5   | 10  | 20  | 50  | 100 | 1000 | PMP  |
|-----------|-----|-----|-----|-----|-----|-----|------|------|
| R590W     | 93.39 | 123.83 | 143.87 | 163.16 | 188.28 | 207.28 | 271.52 | 590.91 |
| R600W     | 122.70 | 144.50 | 156.10 | 165.70 | 176.50 | 183.60 | 203.10 | 518.17 |
| R620W     | 117.28 | 140.62 | 154.20 | 166.26 | 181.04 | 191.66 | 225.98 | 528.38 |
| R630W     | 117.28 | 140.62 | 154.20 | 166.26 | 181.04 | 191.66 | 225.98 | 528.38 |
| R650W     | 100.53 | 128.62 | 148.31 | 168.00 | 195.07 | 216.55 | 296.66 | 559.91 |
| R660W     | 94.41  | 127.53 | 148.89 | 169.10 | 194.90 | 214.03 | 276.27 | 641.17 |

Before carrying out the process of analyzing the flood discharge in the Selorejo Reservoir watershed, the return period rain data needs to be distributed on an hourly basis. This was done because the availability of hourly rain data was only available at the Selorejo and Pujon rain posts while the Jombok and Sekar rain posts were not available. Due to this limitation, the rainfall data from the frequency analysis needs to be distributed over time based on several distributions. Distribution selection is done by selecting the maximum value between the hourly rain data at the Selorejo and Pujon rain posts. As can be seen in the hourly rainfall distribution data in Table 4.

Table 4. Hourly Rainfall Distribution

|       | R590W | R600W | R620W | R630W | R650W | R660W |
|-------|-------|-------|-------|-------|-------|-------|
| Jombok| 0.0099| 0     | 0     | 0     | 0     | 0.2829|
| now   | 0.2138| 0     | 0.2442| 0.2442| 0.9985| 0     |
| Selorejo| 0.0946| 1     | 0.7558| 0.7558| 0.0015| 0     |
| Pujon | 0.6817| 0     | 0     | 0     | 0     | 0.7171|

After all the parameters have been fulfilled, then the configuration is carried out on the Selorejo Reservoir watershed using HEC - HMS, all hydrological parameters, return period rain values, ARF values and hourly rainfall distributions are entered into the configuration, this aims to get the return period flood discharge values from the watershed. Selorejo Reservoir which will later be used to evaluate the performance of the reservoir in Selorejo Reservoir. The following is a summary of the configuration results obtained in Figure 3.

Figure 3. Summary of the Selorejo Reservoir Watershed Flood Discharge Analysis
Table 5 Peak Discharge Analysis of Flood Discharge in the Selorejo Reservoir

| Repeat Period | Peak Discharge (m3/s) |
|---------------|-----------------------|
| 2             | 81.0                  |
| 5             | 148.2                 |
| 10            | 197.5                 |
| 20            | 251.3                 |
| 50            | 322.3                 |
| 100           | 375.0                 |
| 1000          | 650.4                 |
| PMP           | 2341.0                |

5.3. Selorejo Watershed Evaluation

From the results of the previous flood discharge analysis, the evaluation of the reservoir of the Selorejo Reservoir has been carried out. The reservoir evaluation was carried out to see the potential for Overtopping of the Selorejo Reservoir due to a reduction in the reservoir volume of the Selorejo Reservoir. The following is an elevation-volume graph of the Selorejo Reservoir.

![Elevation-volume graph of the Selorejo Reservoir](image)

**Figure 4.** Comparison of Storage Elevation between 2010 Condition vs 2017 Condition

Based on the Figure above, it can be seen that the reservoir of Selorejo Reservoir has decreased in its capacity. This is due to the accumulation of sediment deposits carried by river flows that enter the Selorejo Reservoir from year to year. Evaluation of the performance of the Selorejo Reservoir reservoir was carried out under conditions in 2017 whether with the volume of the reservoir at that condition it was still able to carry out its function for flood control. Based on the results of modeling using HEC-HMS, a summary of the results is obtained as shown in Figure 5.

![Capacity Evaluation Results of Selorejo Reservoir](image)

**Figure 5.** Capacity Evaluation Results of Selorejo Reservoir
Table 6 Evaluation Results of Selorejo Reservoir Storage

| Return Period (year) | Elevation (m) |
|----------------------|--------------|
| 2                    | 620.4        |
| 5                    | 620.8        |
| 10                   | 621.1        |
| 20                   | 621.3        |
| 50                   | 621.7        |
| 100                  | 621.9        |
| 1000                 | 622.8        |
| PMP                  | 626.1        |

Based on the results of the evaluation of the Selorejo Reservoir reservoir and the Selorejo Reservoir Operation and Maintenance document, the highest elevation of the Selorejo Reservoir is +625 m. In Figure 10, it can be seen that the highest elevation for each return period is still below +625 m. The Selorejo Reservoir Operation and Maintenance document added that the Selorejo Reservoir was built with a discharge design for a 1000 year return period. Based on this explanation, the maximum elevation due to the 1000 year return period flooding is +622.8 m, which indicates that it is still below the peak elevation of the Selorejo Reservoir, which is +625 m. So it can be concluded that the reservoir of Selorejo Reservoir is still able to accept flooding with a return period in the early stages of design and construction.

Even so, the reservoir of the Selorejo Reservoir needs to be checked against its PMF discharge so that the safety of the Selorejo Reservoir is more secure. Based on the analysis carried out, the peak elevation of the Selorejo Reservoir due to the PMF discharge of +626.1 m is above the peak elevation of the Selorejo Reservoir at +625 m. This shows that under normal conditions the Selorejo Reservoir is not able to accommodate the PMF flood discharge. Therefore, several alternative ways were carried out so that the Selorejo Reservoir was able to accommodate PMF discharge. The alternative is to lower the initial water level in the Selorejo Reservoir. Under normal conditions, the reservoir water level is held at an elevation of +620 m, but seeing that under normal conditions the Selorejo Reservoir is unable to accommodate PMF discharge, the water level is lowered at several elevations.

The following are the results of the analysis of the water level tracing of the Selorejo Reservoir at various initial water level conditions.

Figure 6 Elevation of Selorejo Reservoir Reservoir Condition of PMF at Various Initial Water Level Conditions

Table 7 Peak Elevation of Selorejo Reservoir Reservoir Condition of PMF at Various Initial Water Level Conditions

| Initial Elevation (m) | Peak Elevation (m) |
|-----------------------|--------------------|
| 620                   | 626.1              |
| 610                   | 625.7              |
Based on the results shown, PMF flooding in the Selorejo Reservoir can be controlled or mitigated by carrying out an initial lowering of the water level in the Selorejo Reservoir. The decrease is carried out at the initial elevation of +610 m, then the peak elevation achieved will be at 625.7 m. Based on this value, the Selorejo Reservoir is still able to withstand PMF flooding. If you look at field observations and data collection, it is stated that above an elevation of +625 m, the Selorejo Reservoir still has a parapet as high as 1 meter. So it can be concluded that the Selorejo Reservoir is still able to accommodate floods up to an elevation of +626 m.

6. Conclusion
Based on the research and studies conducted, several conclusions can be drawn.

- Based on the analysis carried out with the existing parameters, it can be concluded that the Selorejo reservoir is still able to accommodate the flood water discharge in accordance with the initial development plan.
- The frequency analysis shows that the best rain distribution method to use is Pearson III, Log Pearson III and Gumbel.
- By using the parameters in the previous calibration process, the results of modeling using HEC – HMS show that the model is good and there are no errors (errors) and the resulting value also meets the objective function.
- Based on the results of the evaluation, it can be seen that the Selorejo Reservoir is still able to accommodate rain discharge up to the return period of 1000 years.
- The solution to control the PMF value based on the analysis value obtained from the PMP is to lower the initial water level to +610 m.

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