Hydrological Study of the Nakayasu Hydrograph Method for Design of Water Retention in the JIIPE Gresik Industrial Estate

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Abstract. The development area of the JIIPE industrial estate could change the land use around the development site. The research area mostly has clay lithology. This development area must be protected from flood. This study aims to plan a reservoir that can process the drainage system. The data needed are geographic data, rainfall data, meteorological data, area data, and land function data. This study used the Nakayasu Hydrograph method. The Nakayasu hydrograph method parameters are time interval from the rain surface to the top of the hydrograph, period time from the center of gravity of the rain to the center of gravity of the hydrograph, period time for the hydrograph, the area of the river basin, and the length of the longest main river channel. The calculation result from this method is the peak discharge value and this calculated based on the existing and planned conditions. In this study, the calculation of the probability of discharge in the return period of 25 years is carried out. From this calculation, a hydrograph graph of the flood discharge from the existing and planned conditions is generated. The calculation for the difference between the maximum debit between of existing and planned conditions is to determine the debit that must be held every second in the storage. The generated discharge value is 18.7 m³/s. The calculation of storage volume the reservoir to control the volume need is 168,300 m³. The calculation of the storage volume based on the area of the reservoir is used as the volume of availability, which is 169,956 m³, so that the recommended water retention dimensions are obtained with an area value of 36,947 m² and depth of water retention of 4.5 m.

Keywords: Discharge, Hydrograph, Nakayasu, Water Retention.

1. Introduction

The study area shown in Figure 1 is located in Gresik, East Java. This area is included in the JIIPE industrial area. JIIPE industrial area as a development area that must avoid flooding. Most of them have clay lithology. The study area is an industrial area with a total area of approximately 185 hectares in Manyar, Gresik, East Java. This area is bordered by the Madura Strait, Daendels Street, and Kali Mireng which cross the area. The study area has a tropical climate with weather temperatures varying between 25 °C - 32 °C. Annual rainfall ranges from 900 mm to 2600 mm with an average of 1500 mm. As an industrial area, it must be free from the danger of flooding [1]. To avoid flooding, a hydrological study is needed.

Flood Study Area as a whole and plan a reservoir following the development area to hold and process the drainage system in the built area [2]. The research aims to plan a reservoir that can process the
drainage system. This study obtains a recommendation for the dimensions of the reservoir, namely the depth of the reservoir and the height of the guard from the storage volume data.

2. Methods

The study area seen in Figure 1 is located in Gresik, East Java. The research area is managed by the JIIPE industrial area. JIIPE industrial area as a development area that must avoid flooding [1]. Most of them have clay lithology [3].

![Figure 1. Study Region](image)

The data used are geographic data, rainfall data from 2003 to 2019, meteorological data, an area of 185 hectares, and data for calculating rainfall distribution using the Log Pearson type III method. The land functions as a light industrial area of 1,295,000 m², 370,000 m² of paved public roads, and 185,000 m² of open land facilities. The method used is the Nakayasu hydrograph method.

2.1. Calculation of rainfall distribution using Log Pearson type III method

Calculation of rainfall distribution is based on maximum annual rainfall data. The maximum annual rainfall data are taken from the Manyar rain station. The average rainfall data is calculated as the probability distribution Log Pearson III. Furthermore, the frequency distribution test is carried out on the calculation of rainfall results from the Log Pearson type III method [4]. The results of the Log Pearson type III method are matched with the requirements of the frequency distribution test. From these data, the calculation of rain distribution is obtained using Log Pearson III [5].

2.2. Calculation of the Debit Amount for the Return Period of the Exiting Condition

The method used in calculating the amount of discharge for the return period is the Nakayasu Synthesis Unit Hydrograph method. The following formula is used

\[
Q_p = \frac{C \cdot A \cdot R_0}{3.6(0.3 T_p T_0 / 3)}
\]  

[1]

Where \( Q_p \) is the peak discharge (m³/s), \( C \) is the coefficient of land, \( A \) is the area of the catchment area (km²), \( R \) is the amount of return period rainfall (mm). Calculation of the discharge amount for the return period of the existing condition of the Kalimati channel with the function of pond land [6]. The
calculation of the hydrograph of the Nakayasu Unit in the existing condition is obtained by calculating the concentration-time, the time unit of rain, the initial time of rain to the peak of the flood, the decrease in peak discharge, and the resulted Qp value (the peak discharge). After those calculations, the tables and graphs of the Nakayasu flood hydrograph of the existing condition in 25 years return period are obtained [7].

2.3. Calculation of the Debit for the Return Period of the Plan Condition

This calculates the discharge amount for the return period of the plan condition that will be converted into industrial land in the JIPE area. The calculation of the Nakayasu Unit Hydrograph for the plan condition is obtained by calculating the concentration-time, the time unit of rain, the initial time of rain to the peak of the flood, the decrease in peak discharge, and the resulted Qp value (the peak discharge) [7]. From there, the obtained graphs of the Nakayasu hydrograph of the flood conditions for the 25 years return period plan is obtained [8].

3. Results

3.1. The results of the calculation of the rainfall distribution using the Log Pearson type III method

The theoretical requirements for Cs and Ck values of the Log Pearson III method are flexible [2]. The Cs value in the Log Pearson III method is 0.4 and the Ck value is 1.534180. Thus the values of Cs and Ck pass the results of the frequency distribution test. Following are the results of the calculation of the rain distribution method Log Pearson type III

| Period Time (T) | K    | S log Xt | Xt (mm) |
|----------------|------|----------|---------|
| 2              | -0.064 | 2.173   | 149.07  |
| 5              | 0.817  | 2.443   | 277.11  |
| 10             | 1.316  | 2.595   | 393.61  |
| 25             | 1.875  | 2.766   | 583.59  |

From Table 1, in the return period 25, the value of the Log Pearson type III variable is 1.875. While the Xt value is 583.59 mm. The value of Xt represents the value of the planned rainfall.

3.2. Calculation of the Debit Amount for the Return Period of the Exiting Condition

The method used in calculating the amount of discharge for the return period is the Nakayasu Synthesis Unit Hydrograph method. Where Qp is the peak discharge (m³/s), C is the coefficient of land, A is the area of the catchment area (km²), R is the amount of return period rainfall (mm) [10]. The area of the watershed is 1.85 km², the length of the Mireng River is 19.4 km, unit rain (R 2th) is 149.07 mm, unit rain (R 5th) is 277.11 mm, unit rain (R 10th) is 393.61 mm, unit rain (R 25th) is 583.59 mm, the flow coefficient (C) is 0.3 with the function of the land as a pond, and the alpha value (α) is 2.4.
From the results of hydrograph calculations of the existing conditions shown in Figure 2, the peak discharge at the Q value is 5.062 m³/s at 2.5 hours.

3.3. Calculation of the Debit for the Return Period of the Plan Condition

This calculation is to determine the discharge amount for the return period of the plan condition that will be converted into industrial land in the JIIPE area. The calculation of the Nakayasu Unit Hydrograph for the condition of the plan obtained by calculating the concentration-time, the time unit of rain, the initial time of rain to the peak of the flood, the decrease in peak discharge, and the resulted Qp value (peak discharge). Then the graph of the nakayasu hydrograph for the flood condition plan for 25 years return period is obtained. Qp is the peak discharge (m³/s), C is the coefficient of land, A is the area of the catchment area (km²), R is the amount of return period rainfall (mm) [10]. Where the area of the watershed is 1.85 km², the length of the Mireng River is 19.4 km, the unit rain (R 2th) is 149.07 mm, the rain unit (R 5th) is 277.11 mm, the unit rain (R 10th) is 393.61 mm, the unit rain (R 25th) is 583.59 mm, the flow coefficient (C) is 0.65 as a combination due to switching functions, and the alpha (α) value is 2.4.

From the results of the hydrograph calculation of the plan conditions shown in Figure 3, the peak discharge at the Q value is 23.762 m³/s at 2.5 hours.
4. Discussion

From the calculation results of the Nakayasu Hydrograph formula, the maximum discharge value (Qmax) in the existing conditions is 5.062 m$^3$/s. Meanwhile, the maximum discharge value (Qmax) at the planned condition is 23.762 m$^3$/s. The difference between the maximum discharge value and the planned discharge is 18.7 m$^3$/s with a peak time of 2.5 hours which is obtained from the calculation of the difference in discharge. Then the storage volume that must be held when the maximum discharge generation occurs is 168,300 m$^3$.

In terms of the land availability function, an experiment was carried out. The storage area was 3.69 Ha. In order to meet the need for the availability of reservoirs in the water retention plan, a depth of 4.5 m and 30 cm high is recommended. The height of the guard is influenced by the area of the Mireng River watershed. Then the recommended reservoir depth for the zone is 4.8 m with the effective availability of the storage volume is 36,947 m$^2$ x 4.5 m = 169,956 m$^3$.

5. Conclusion

JIIPE's development industry activity is changing the land function. The existing land, which was pond, is changing into an industrial area. This also changes the coefficient value of the land (C) from 0.3 (C value of pond area) to 0.65 (C value of industrial area). The changes in land use resulted in a discharge generated value which is 18.7 m$^3$/s. The discharge generation can be controlled by constructing water retention. Water retention is not changing the surface flow. To obtain the dimensions of the reservoir with an area of 36,947 m$^2$ and a depth of 4.5 m. The peak time required to hold the reservoir volume is 2.5 hours. When the rainfall lasts for 2.5 hours, the reservoir hold the water flows into the sea or river.

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