Flood Discharge Analysis with Nakayasu Method Using Combination of HEC-RAS Method on Deli River in Medan City

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Abstract - The problem in this research is how in the rainy season the water does not overflow, does not occur flood and during the dry season does not occur drought so it can adjust the condition or existence of Deli river which is around Medan city. Deli River floods often occur, either caused by a smaller capacity than the existing discharge, lack of maintenance and drainage and disposal systems that do not fit with the environment, resulting in flood subscriptions every year. The purpose of this research is to know flood discharge at Deli river as Flood control in Medan city. This research is analyzed on several methods such as log Pearson, Gumbel and hydrograph unit, while HEC-RAS method is modeling conducted in analyzing the water profile of the Deli River. Furthermore, the calculation of the periodic flood discharge using the Nakayasu Method. Calculation result at Deli River return period flood discharge 2 years with an area of 14.8 km² annual flood hydrograph the total is 26.79 m³/sec on the hours at the 4th time. Return period flood discharge 5 years with an area of 14.8 km² annual flood hydrograph the total is 73.44 m³/sec. While 25 annual return period total flood hydrograph is 146.50 m³/sec. With flood analysis can reduce and minimize the risk of losses and land can be mapped if in the area there is flooding.

1 Introduction

At this time is often the occurrence of floods in every area where the flood is an event where there is excessive water overflow somewhere. According to [1] The high rainfall and the inability of the river to accommodate the rain water is blamed as the culprit of the flood. Thousands of people became victims, homes of residents submerged, even some residents who died was washed away by floods. The presence of uniform rainfall, high intensity and continuous in some areas in the city of Medan has caused many floods. So many residents are displaced in a safe place [2].

Hydrologically watershed management is an attempt to manage the Earth's surface biophysical conditions in such a way as to obtain a maximum water discharge yield and have a distributed flow regime evenly distributed throughout the year [3]. Based on the hydrological data can be determined the flood index in a river that will be useful in managing the watershed environment. Until now the flood index in the Asahan River based on hydrological data for several periods of flood discharge has never been determined. From the hydrological data obtained an average discharge of 400 m³/s in the downstream area [4]. The design of flood discharge calculations were performed using the Nakayasu Hydrograph Synthetic Unit method. The Nakayasu Hidrograph Synthetic Unit is widely used in dam planning and river improvement in Brantas (East Java) projects, among others to determine the discharge planning of Lahor Dam, Sengguruh, Wonorejo and Brantas River Basin Improvement.
To solve the river problem is closely related to the hydrological aspect, especially the rain problem as a source of water that will be streamed to the river system and runoff as a result does not have a river system to drain into the final disposal at sea. Hydrological design is necessary to know the flow of drainage. [5]. In the River channel planning the return period used depends on the channel function and the rain catchment area to be dried. According to experience, the use of return period for planning: Kwarter Channel (1 year return period), Tertiary Channel (2 year return period), Secondary Channel (5 year return period), Primary Channel (10 year return period) [6]. In the science of statistics is known several kinds of frequency distributions that are widely used in the field of hydrology. The following four types of frequency distributions are most widely used in the field of hydrology such as: Normal Distribution, Normal Log Distribution, Log Person Distribution III and Gumbel Distribution [7].

2 Materials and Methods

2.1 Metode Log Pearson type III

To estimate the magnitude of the flood discharge with a particular period, first the rain data is brought closer to a distribution spread, in order to estimate the magnitude of the flood discharge so not to go far from the reality of the flood that occurred. The most widely used distribution size is the standard deviation. If the spread is very large to the average value then the value of standard deviation will be large, but if the data distribution is very small to the average value then the value of standard deviation will be small. The formula used in the Log Pearson type III method is:

\[ \log X_T = \log X + G.s \]  

1. Mean

\[ \log X = \frac{\sum_{i=1}^{n} \log X_i}{n} \]  

2. Skewness

\[ C_s = \frac{\sum_{i=1}^{n} (\log X_i - \bar{\log X})^3}{(n-1)(n-2)S^3} \]  

3. Standard Deviation

\[ S = \sqrt{\frac{\sum_{i=1}^{n} (\log X_i - \bar{\log X})^2}{n-1}} \]  

Probability density function of this distribution are:

\[ P'(X) = P_0' (1 + X/a)e^{-cx/a} \]  

2.2 Hydraulic Analysis

The open channels flow consists of natural channels, such as upstream small rivers (mountain) to large rivers in the estuaries, and artificial channels, such as river channels, irrigation channels to irrigate rice fields, sewers, drains to carry water to hydroelectric power, drainage water supply, and
flood channels. Artificial channels can be triangular, trapezoidal, rectangular, round, semi-circular, and arranged shapes [6].

Changes in the function of the upstream area of the watershed ± 15% resulted in the balance of the river begin to be disrupted. This disorder contributes to the sharp increase in the quantity of flow discharge and the quantity of sedimentation in the river. It can also be interpreted that an unspoiled river basin and dense vegetation can be changed by 15% of the area without having to change the natural state of the river in question. Land use change can also increase peak discharge 5 to 35 times because the water absorbed into the soil slightly causes the runoff flow to be large, resulting in a large discharge. As shown in Figure 1 and Figure 2. The condition of the river banks in areas before and after develop.

![Figure 1. The Condition of River Banks in the Area Before Developing](image1)

![Figure 2. The Condition of River Banks in the Area After Developing](image2)

2.3 General Flow Formulas

As for finding the flow rate it can be used some Chezy formula (for uniformly fixed flow)

\[ V = C (R I)^{0.5} \]

2.4 Nakayasu Hydrograph Synthetic Unit

The calculation of the flood discharge design is using the Nakayasu method. The general equation of the Nakayasu Hydrograph Synthetic Unit is as follows:

\[ Q_p = \frac{C \cdot A \cdot R_0}{3.6 (0.3 T_p + T_{0.3})} \]  \hspace{1cm} (6)

\[ T_p = t_g + 0.8 t_r \]

\[ t_g = 0.21 x L^{0.7} \]  \hspace{1cm} (L < 15 km)

\[ t_g = 0.4 + 0.058 x L \]  \hspace{1cm} (L > 15 km)

\[ T_{0.3} = \alpha x t_g \]
Where:

- \( Q_p \) = flood peak discharge (m³/s)
- \( C \) = flow coefficient
- \( R^0 \) = rain unit (mm)
- \( A \) = watershed area (km²)
- \( T_p \) = the grace period from the beginning of the rain to the peak of the flood (hour)
- \( T_{0.3} \) = time required by the decrease of discharge, from peak discharge to 30% of peak discharge
- \( t_g \) = concentration time (hr)
- \( t_r \) = rain time unit, taken 1 hour
- \( \alpha \) = hydrograph parameter, worth between 1.5 - 3.5
- \( L \) = river length (m)

The research flow in this research can be described as follows:

![Flow Chart of Research](image)

**Figure 3.** Flow Chart of Research

### 3 Results and Discussion

Log-Pearson Type III distribution is widely used in hydrological analysis, especially in the analysis of maximum flood discharge and minimum discharge data with extreme values. Of the various types of distribution developed by Pearson, only Type III is the most widely used. The statistical data from Log-Pearson Type III distribution is not close to any of the distribution features. The probability line of Log-Pearson Type III distribution is a curved line, so its usage for flood
analysis is often used for its data logarithm (not its own data), so this distribution is called the Log-Pearson Type III distribution.

**Table 1. Rainfall Design Return Period Log Pearson Type III Method**

| Return Period | log X | Cs      | G   | log X | X (mm) |
|---------------|-------|---------|-----|-------|--------|
| 2             | 1,9873| 0,003353| -0,001 | 1,987 | 97    |
| 5             | 1,9873| 0,003353| 0,842 | 2,121 | 132   |
| 10            | 1,9873| 0,003353| 1,283 | 2,191 | 155   |
| 25            | 1,9873| 0,003353| 1,753 | 2,265 | 184   |
| 50            | 1,9873| 0,003353| 2,057 | 2,313 | 206   |
| 100           | 1,9873| 0,003353| 2,330 | 2,356 | 227   |
| 1000          | 1,9873| 0,003353| 3,098 | 2,478 | 301   |

**Figure 4. Recapitulation of Pearson III & Gumbell Log Distribution Results**

### 3.1 Deli Watershed

From the physical characteristics of the Deli River can be calculated two important elements that will determine the shape of the unit hydrograph, that is Time Lag (TL), Peak time (Tp) and base time (Tb). Height and duration of unit rain that Commonly used is 1 unit of rain duration is generally taken Tr = 1 hour, but can be selected another duration as long as it is expressed in hours then the height of rain every hour should be divided by 2 and distributed in 0.5 hour intervals as seen on Table 2.

**Table 2. The Results of the Calculation of Flood Discharge for 2 Year Return Period A= 14.8 km² L= 7 km**

| t (h) | U (t,1) (m³/s/mm) | R1 = mm/h | R2 = mm/h | R3 = mm/h | R4 = mm/h | R5 = mm/h | Flood Hydrograph (m³/s) |
|-------|-------------------|-----------|-----------|-----------|-----------|-----------|------------------------|
| 0     | 0,000             | 0,000     | 0,000     | 0,000     | 0,000     | 0,000     | 0,000                  |
| 1     | 0,859             | 5,541     | 0,000     | 0,000     | 0,000     | 5,541     | 17,025                 |
| 2     | 1,648             | 10,631    | 6,394     | 0,000     | 0,000     | 17,025    | 24,907                 |
| 3     | 0,840             | 5,421     | 12,267    | 7,219     | 0,000     | 24,907    | 26,786                 |
| 4     | 0,367             | 2,365     | 6,255     | 13,851    | 4,316     | 0,000     | 26,786                 |
| 5     | 0,191             | 1,231     | 2,729     | 7,063     | 8,280     | 0,986     | 20,289                 |
From Table 2, the calculation of flood discharge of 2 year return period design $A = 14.8 \text{ km}^2$, $L = 7 \text{ km}$ maximum flood discharge at 5 to 26,786 m$^3$/s while starting at 2.00 hrs 17.02 m$^3$/s. With such a high increase it is necessary to anticipate the discharge by normalizing the Deli river.

### Table 3. Flood Discharge Calculation Result of 25 Years Return Period $A = 14.8 \text{ km}^2$, $L = 7 \text{ km}$

| t (h) | $U(t,1)$ | R1 = NAKAYASU (mm/h) | R2 = (mm/h) | R3 = (mm/h) | R4 = (mm/h) | R5 = (mm/h) | Flood Hydrograph (m$^3$/s) |
|-------|----------|----------------------|----------|-----------|-----------|-----------|-----------------|
| 0     | 0.000    | 0.000                |          |           |           |           | 0.000           |
| 1     | 0.859    | 30.305               | 0.000    |           |           |           | 30.305         |
| 2     | 1.648    | 58.142               | 34.967   | 0.000    |           |           | 93.109         |
| 3     | 0.840    | 29.646               | 67.087   | 39.484   | 0.000    |           | 136.217        |
| 4     | 0.367    | 12.935               | 34.207   | 75.753   | 23.603   | 0.000    | 146.497        |
| 5     | 0.191    | 6.735                | 14.925   | 38.626   | 45.284   | 5.391    | 110.960        |
| 6     | 0.099    | 3.507                | 7.771    | 16.853   | 23.090   | 10.343   | 61.563         |
| 7     | 0.052    | 1.826                | 4.046    | 8.775    | 10.074   | 5.274    | 29.995         |
| 8     | 0.027    | 0.951                | 2.107    | 4.569    | 5.246    | 2.301    | 15.173         |
| 9     | 0.014    | 0.495                | 1.097    | 2.379    | 2.731    | 1.198    | 7.901          |
| 10    | 0.007    | 0.258                | 0.571    | 1.239    | 1.422    | 0.624    | 4.114          |
| 11    | 0.004    | 0.134                | 0.297    | 0.645    | 0.741    | 0.325    | 2.142          |
| 12    | 0.002    | 0.070                | 0.155    | 0.336    | 0.386    | 0.169    | 1.115          |
| 13    | 0.001    | 0.036                | 0.081    | 0.175    | 0.201    | 0.088    | 0.581          |
| 14    | 0.001    | 0.019                | 0.042    | 0.091    | 0.105    | 0.046    | 0.302          |
| 15    | 0.000    | 0.010                | 0.022    | 0.047    | 0.054    | 0.024    | 0.157          |
| 16    | 0.000    | 0.005                | 0.011    | 0.025    | 0.028    | 0.012    | 0.082          |
| 17    | 0.000    | 0.003                | 0.006    | 0.013    | 0.015    | 0.006    | 0.043          |
| 18    | 0.000    | 0.001                | 0.003    | 0.007    | 0.008    | 0.003    | 0.022          |
3.2 Hydraulics Analysis

The hydraulic analysis of the Deli River cross section on Maimun road is calculated using the HEC-RAS program. With this analysis, it can be seen the water level elevation at the river cross section when a water discharge through the river. The data required in river cross section analysis with the help of HEC-RAS software are:

a. Cross-section of the river
b. Cross section of the river
c. Data flow through the river
d. Figures manning cross-section of the river

Before beginning this hydraulic analysis, the necessary data must be prepared. The steps of hydraulic analysis with HEC-RAS program as in Figure 5.

![Figure 5: Main Display of HEC-RAS Program](image)

Draw a river flow by clicking on River Reach. To be able to draw according to the original map, you can use map image file for background drawing by click add/edit background picture. In drawing the river flow the first point made is a river upstream like in Figure 6.

![Figure 6: The Input View of the River Geometry Data of the HEC-RAS Program](image)

Input the cross section then click on the cross section, exit the view as Figure 7. Water profile of the River Deli.
3.3 Normalization of Rivers and Levees

The plan to improve the flow is to make a narrow river section improvement. The shape of the river cross section is planned trapezoidal. In determining the cross-sectional dimension of the river it should be noted that existing river morphology is to keep the low flow of discharge remaining. For river bottom elevation still use the existing elevation, so the slope of the river does not change.

Normalization is done by enlarging the cross-sectional dimension of the river on the part of the river where the runoff of the river cross section is made so that no runoff occurs. Section planning is done with the help of the HEC-RAS program. The normalization carried out on the Deli River in order to flow the discharge is by dredging and raising the dike. Besides the irregular river cross section also made with trapezoidal shape. From the results of Hydraulics Analysis by using HEC-RAS modeling.
3.4 Flood Discharge Index

In the determination of flood index, the calculated discharge is the amount of discharge that causes the flood. So what is meant by the minimum discharge is the smallest discharge that causes the flood starts. Maximum discharge is the largest possible discharge due to the maximum rainfall occurring in the watershed. Based on the maximum and minimum discharge will get the average discharge. Average discharge is the average discharge rate that can cause flooding. The type or the number of variables in the ratio is the same, this is certainly reasonable because it can compare a value of the same object from one or a group of variables. While in its development, the value of the index can be a single value of one variable or the sum of several variables in the same unit about the flood index. The determining index variable is a single variable of the amount of rain in a given value. In this case the value of the flood index still has the value of the unit, but because only one variable that determines, then the determination of the index value is not problematic. The flood index in his dissertation [8] is the ratio between the discharge value and the index value with no units.

In determining the smallest peak discharge that can determine the flood, conducted a rainfall runoff simulation with real time rainfall peak data in each sub watershed. Each simulation of peak rain to one sub watershed, rain on another sub watershed corresponds to the same real time. The simulation starts from the lowest rain of 1 hour until the rain that can cause flood, so the discharge is called minimum discharge, Q_{min}. The inflow discharge index is formulated as the ratio of the flood discharge that occurs in reducing the minimum discharge with a discharge limit between maximum and minimum. The formula is as follows:

$$I_Q = \frac{Q_i - Q_{i}}{Q_{max}}$$

(7)

3.5 Index of Inundation Area

The inundation area is occurred in the floodplains due to overflow of water along the modeled river. It takes a great deal of effort to deal with the problem of inundation or floods, such as building floodways according to the needs/capacity planning [9]. The inundation area is a function of the size of the inflow discharge. The bigger the flood discharge, then the inundation that occur will be wider so that the area of inundation caused by the maximum discharge is called the A_{max}, and the extent of the...
inundation that occurs due to the minimum discharge is called $A_{\text{min}}$. Based on this analysis, the Index of Puddle Area can be formulated as follows:

The classification of the inundation area is adjusted by the flood discharge classification which causes the area of the inundation to obtain two classifications, namely the inundation width between the mean and maximum, and the width of the inundation between the minimum and the average. The inflow discharge index occurs subtracted by the minimum discharge with the grace of the discharge between the maximum and the minimum that has been obtained as in Table 4.

### Table 4. The Calculation of Inflow Discharge Index ($A = 14.8 \text{ km}^2$, $L = 7 \text{ km}$)

| Return Period | $Q_{\text{max}}$ | $Q_{\text{min}}$ | $Q_{t}$ | Indeks Discharge Inflow (100%) |
|---------------|------------------|------------------|---------|--------------------------------|
| 2             | 227.08           | 0.41             | 10.57   | 0.04                           |
| 5             | 622.55           | 1.13             | 18.92   | 0.03                           |
| 10            | 893.66           | 1.62             | 24.44   | 0.03                           |
| 25            | 1241.92          | 2.25             | 31.43   | 0.02                           |
| 50            | 1503.10          | 2.72             | 36.61   | 0.02                           |
| 100           | 1764.09          | 3.20             | 41.75   | 0.02                           |
| 1000          | 2635.02          | 4.78             | 58.75   | 0.02                           |

### 4 Conclusions

Based on the results of direct observation in the field, calculations both technically and program on existing data, the compiler can take some conclusions, namely:

1. Result of rainfall calculation of 5 years return period design with Log Pearson Type III method is 132 mm.
2. Flood Index model on Deli river as flood control in Medan city produce as follows:
   a. After analyzing the 5 years period, the average flood index is 30%. From these results, it can be concluded that the component of Discharge Index is relatively small compared to the composite index of the inundation. The wider the inundation occurs the smaller the Inundation Index ($L_t$), as well as the smaller the Flood Index.
   b. The direct benefit of this study, especially the case study model of the Deli river, is that the flood index can be estimated easily by knowing the maximum rainfall of the Deli River basin.

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