Hydraulics Engineering using HEC RAS in Drainage Inundation Management in the UNILA

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Abstract. Drainage is an artificial channel that functions to channel surface water flow. The ability of drainage to deliver water flow is very influential on infrastructure and socio-community. Drainage that does not match the flow discharge will cause water to overflow to the surrounding area. The current large rainfall conditions certainly have an impact on drainage channels. Monitoring the condition of the drainage channel as a whole is very difficult because it is necessary to manually calculate each dimension of the existing channel. This will certainly take time and money. Current IT developments make this no longer difficult because it can be done digitally using software that is widely developed today. One of the software in hydraulics modeling is HEC RAS 6.3.1. Based on the results of this study, it shows that the conductivity of surface water flow for drainage of building E FT UNILA is no longer able to deliver discharge. This is indicated by the overflow of water at the return period of 2 years, 5 years, and 10 years. The simulation of the research can be seen in chapter four which shows the return time discharge of the various return periods. The maximum discharge capacity of the current drainage conditions is only around 2 m3/second, while for a 2-year return period the maximum discharge is around 4.5 m3/second. Thus, hydraulics engineering is needed to overcome the overflow of water at the difference in discharge.

Keyword: HEC RAS 6.3.1, Hydraulics Engineering, Inundation Drainage, Faculty of Engineering, University of Lampung.

1. Introduction

Climate change is currently occurring very rapidly along with the high acceleration of global warming. The increase in earth surface temperature causes many aspects related to hydrology to change, resulting in changes in infrastructure planning at this time[1],

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[2]. Evaluation of the storage capacity of drainage channels needs to be done to adjust to the increase in rainwater flow discharge that occurs today. In all aspects of climate change today, what often occurs is surface water overflow during the rainy season due to an increase in surface flow discharge[3], [4].

This increase in surface flow discharge occurs not only due to climate change, but also due to changes in land use[5]. One of the areas affected by this surface water overflow is the Faculty of Engineering, University of Lampung. Overflows occur frequently during high-intensity rainfall. Overflows cause the left and right borders of the channel to be inundated ranging from a height of 5 cm to 20 cm. This overflow certainly causes losses from accelerated damage to road infrastructure and other facilities affected by this inundation[6].

Based on this problem, the author evaluates the cross-section of the channel for its discharge capacity. In this study, it is planned to conduct a hydrological analysis in determining rainfall discharge and return time discharge at several rainfall return periods. Based on the resulting return period discharge, the water flow in the drainage channel will be simulated to observe the phenomena that occur. It is hoped that this research can provide information to all parties in the insight of science and especially as an evaluation aspect for related parties.

2. Methodology

This research starts with secondary and primary data collection. Secondary data needed in this study are rainfall data for the last 10 years and calibration rainfall data during field discharge measurements. In this hydrological analysis, the calculation of average rainfall is carried out using the arithmetic method. The use of this method is due to the available rainfall data of only one influential rainfall station. Rainfall data is obtained from BMKG online data on the website https://dataonline.bmkg.go.id/home. The arithmetic method used is using the equation[7], [8]:

$$\bar{P} = \frac{P_1+P_2+\cdots+P_N}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i \quad (1)$$

Where P is the average rainfall (mm), P1 is the 1st rainfall (mm), P2 is the 2nd rainfall (mm), PN is the nth rainfall (mm), and N is the amount of rain data (Subramanya, 1995). Furthermore, using the Soil Conservation Service (SCS) Curve Number (CN) method, the rainfall calculation model is a function of the cumulative amount of rain, the outer layer of soil, land use, and evaporation on the land, using the following equation[8]:

$$P_e = \frac{(P-I_a)^2}{P-I_a+S} \quad (2)$$

Where Pe is the excess rainfall accumulated, P is the accumulated rainfall height at time t, Ia is the initial abstraction (initial loss), and S is the maximum potential storage. Based on analysis reports from many small experiments, SCS was developed as an empirical relationship of Ia and S:

Ia = 0.2 S

Then, the cumulative excess at time t is[9]:

$$P_e = \frac{(P-0.2)^2}{P-0.8S} \quad (3)$$

Furthermore, the Gumbel Method is often used to predict the probability of extreme values of a distribution. Gumbel defines a flood as a flow larger than 365 days and the daily series of flood flows can be repeated in a certain time series. The Gumbel equation that is often used practically is[10].

$$x_T = \bar{x} + K\sigma_{n-1} \quad (4)$$

Where σ_{n-1} is the standard deviation of the sample size N = $\sqrt{\frac{\sum(x-\bar{x})^2}{N-1}}$, K is frequency factor = $\frac{y_T-\overline{y_n}}{S_n}$, y_T is the variation of reduction = $-\left[ln.\,ln\frac{T}{T-1}\right] = -\left[0.834 + 2.303\log\log\frac{T}{T-1}\right]$, S_n is obtained from the table, and $\bar{y}_n$ is obtained from the table (Subramanya, 1995). Confidence Limits of the Gumbel Method. In a method there are limitations in making predictions from a distribution. In this case, the Gumbel method has distribution limits that can be determined using the following equation[11].

$$X_{1/2} = X_T \pm f(c)S_e \quad (5)$$

Where f(c) can be determined based on the following Table 1 regarding c (confidence coefficient).

Table 1. Coefficient of Confidence (c) Gumbel Method.

C (%)	50	68	80	90	95	99
f(c)	0.674	1.00	1.282	1.645	1.96	2.58

Source: [12]

With S_e Error = $b\frac{\sigma_{n-1}}{\sqrt{N}}$, $b = \sqrt{1 + 1.3K + 1.1K^2}$, K is frequency factor, σ_{n-1} = Standard Deviation, dan N = number of sample [12].

The determination of hourly rainfall is carried out to determine the rainfall of the return period plan every few hours. In this study, 5 hours of hourly rain was determined. The equations used in determining the hourly rainfall are[13]:

$$R_t = R_0\left(\frac{5}{T}\right)^{2/3} \quad (6)$$

Where R_t = average rainfall from the beginning to the Tth hour, $R_0 = \frac{R_{24}}{5}$, T = rainfall time from the beginning to the Tth hour, dan R_{24} = effective daily rainfall (net rain that causes runoff). Furthermore, to determine the amount of rainfall at hour T, the following equation can be used[11]:

$$R_T = t.R_t - (t-1)R_{(t-1)} \quad (7)$$

Where R_T= the amount of rainfall at hour T, t= rainfall time from start to hour T, R_t= average rainfall from the beginning to hour T, dan R_((t-1))= average rainfall from the beginning to hour (t-1). By using HEC RAS software, a flow simulation is carried out on the drainage channel so that the ability of the existing storage capacity is known.

3. Result and Discussion

Based on observations in the field, it is known that the condition of the drainage channel is as shown in Fig. 1 below.

(a) Drainage of Building E (b) Junction of Building E (c) Upstream of Drainase

Fig. 1. Existing condition of drainage channel in Building E of Faculty Engineering.

Based on these existing conditions, the channel geometry size is known so that the optimum discharge can be estimated. In this study, to get the elevation of the slope of the bottom of the channel and land, drone data was taken to get the value of the ground level elevation. Based on the results of taking drone imagery, it is known that the ground level elevation at the location is as shown in Fig. 2 below.

Fig. 2. Digital Elevation Model of the study location.

Based on the elevation data, the slope of the land and the slope of the channel base can be determined. Furthermore, the land area of surface water flow that becomes the area of influence of the discharge that occurs in the drainage channel is determined. Based on google earth satellite photos, the land use in the flow area can be determined, and based on the results of field observations, DEM data, and satellite imagery, the study area can be determined as in the following Fig. 3.

Fig. 3. Infiltration area at the location of surface water flow.

Based on the figure above, it shows the infiltration area which is green open land in the study location. Furthermore, the location of water flow from the drainage channel is depicted as in the following Fig.4.

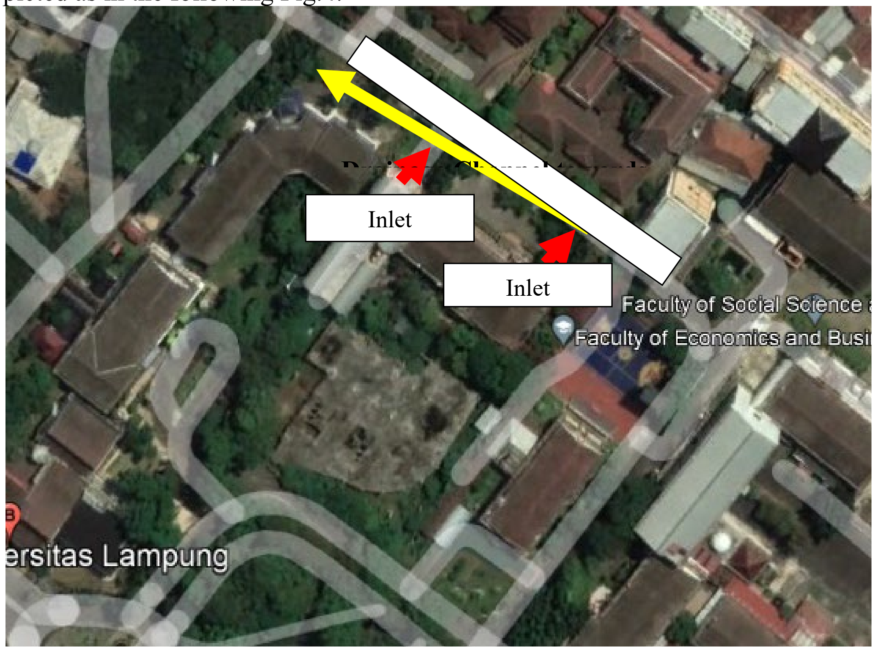

Fig. 4. Water flow in drainage channels.

Based on the above data, the calculation of rainfall discharge can be analyzed using rainfall data for ten years from 2012 to 2022. By using the arithmetic average rainfall data analysis method, the maximum average rainfall is known each year. The maximum rainfall each year can be seen as in the following Table 2.

Table 2. Maximum rainfall over the last ten years.

No	Years	Rainfall (mm)
1	2012	70.00
2	2013	204.90
3	2014	110.00
4	2015	103.10
5	2016	112.40
6	2017	80.50
7	2018	81.40
8	2019	109.80
9	2020	115.30
10	2021	70.70
11	2022	138.60

Based on the maximum rainfall data above, the return period frequency distribution test is carried out using the Gumbel method. Based on the results of the Gumbel method analysis, the hourly rainfall analysis is then carried out. The hourly rainfall used in this case is centered rainfall for five hours. This is determined based on data on the occurrence of rain in general in the Bandar Lampung area, which is the longest for five hours. The distribution of the hourly rainfall of the return period can be seen as in the following Table 3.

Table 3. Hourly rainfall distribution of return period.

Time	Hourly Rainfall (mm)				
(Hour)	2	5	10	15	20
1	9.18396	22.10079	33.58214	35.48779	44.00694
2	2.533506	6.096769	9.264037	9.789736	12.13984
3	1.583441	3.810481	5.790023	6.118585	7.587403
4	1.266753	3.048384	4.632019	4.894868	6.069922
5	1.266753	3.048384	4.632019	4.894868	6.069922

With the above hourly rainfall data at several return periods, rain flow discharge can be determined using HEC HMS software. In calculating using HEC HMS, several parameters need to be determined first, including:

1. Area of Subbasin

   The area of each subbasin can be seen as in the following Table 4.

Table 4. Area of Subbasin.

Subbasin	Area (km^2)
Subbasin-3	0.72
Subbasin-2	0.5
Subbasin-1	0.21
Subbasin-4	0.5

2. Value of impervious coefficient, initial loss, storage coefficient.
3. Time of concentration values in subbasin and reach.
   The time of concentration in each subbasin can be known as in Table 5 below.

Table 5. Surface flow concentration time in each sub basin.

Subbasin	Time of concentration (hour)
Subbasin-3	0.088521
Subbasin-2	0.088521
Subbasin-1	0.099636
Subbasin-4	0.024887

4. Time lag value of reach

These values can be determined using the equations presented in the research methods chapter. In the calculation with HEC HMS, a hydrological model is first established by describing the shape of the subbasin, junction, and reach. The model that has been made can be seen as in the following Fig. 5.

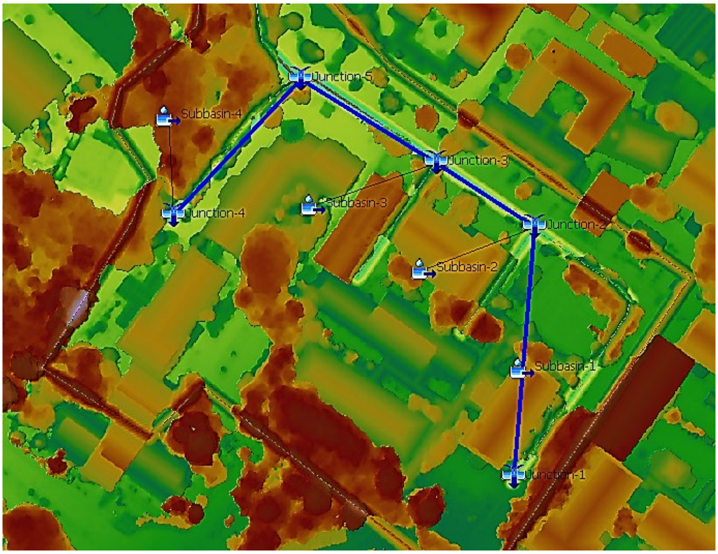

Fig. 5. HEC HMS hydrological model.

To simulate the flow at return periods of 2, 5 and 10 years, first the hydrological model needs to be calibrated. To calibrate, direct measurement of discharge during rainfall in the field was carried out. The results of direct measurements on July 9, 2023 were measured five times and the results are shown in Table 6 below.

Table 6. Measured Discharge.

No.	Time (s)	Stance (m)	Velocity (m/s)	Deep of water (m)	Channel Width (m)	Wet Area (m^2)	Discharge (m^3/s)
1	8.55	3	0.350877193	0.25	0.3	0.075	0.026316
2	8.45	3	0.355029586	0.25	0.3	0.075	0.026627
3	8.40	3	0.357142857	0.25	0.3	0.075	0.026786
4	8.65	3	0.346820809	0.25	0.3	0.075	0.026012
5	9.10	3	0.329670330	0.25	0.3	0.075	0.024725

Based on the direct measurement results as in the table above, the average discharge value of the measurement results is around 0.026 m^3 /second measured at 09:00 WIB on July 8, 2023. This value is the calibration discharge of the hydrological model created. Based on the results of hydrological modeling, it is known that the discharge on July 9, 2023 on the simulation of rain on that date, the value of the model discharge as in Fig. 6 below.

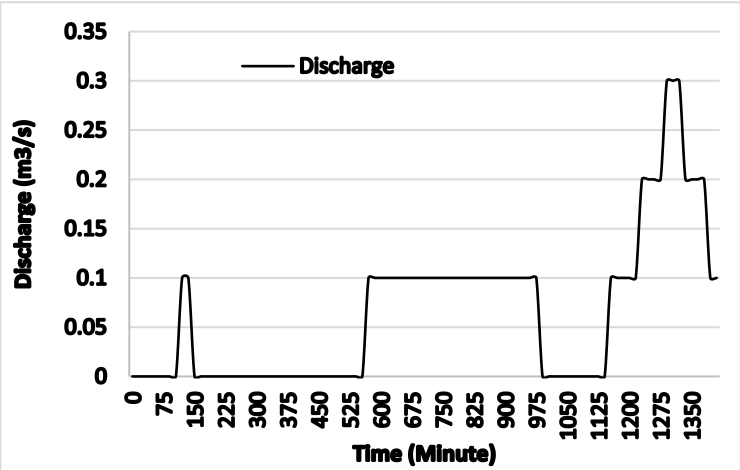

Fig. 6. Discharge on July 9, 2023 from HEC HMS Model.

Based on the results of the simulation discharge at 09:00 WIB, the discharge value is around 0.030 m3 /second. The relative error of the hydrological model can be calculated as follows:

$$E_M = \frac{X_M - X_E}{X_E} x100\% = \frac{0{,}030 - 0{,}026}{0{,}026} x100\% = 15\%$$

The relative error value of the hydrological model created is around 15%. Based on the effectiveness of modeling the value of the model below 20% can be used as a prediction model for the next [14]. Based on these results it can be concluded that the HEC HMS model made is feasible to use to predict the discharge of the return period for further calculations. Based on the simulation results using the hydrological model, it is known that the return period discharge is:

Table 7. Return period discharge at the surface flow area of the study area.

No.	Return Period (Year)	Discharge (m^3/s)
1.	2	4.5
2.	5	11.5
3.	10	17.7

Based on the discharge value above, it can be seen that the return time discharge value is much greater than the existing discharge value. This return time discharge value can be used in hydraulics simulations using HEC RAS software [6]. After knowing the value of the return time discharge on the Faculty of Engineering surface water flow that affects the drainage channel studied, then the hydraulics analysis is carried out. In this analysis, HEC RAS software is used as a surface flow simulator. Before the analysis is carried out, the shape of the channel that will be simulated using measured geometry data is formed first [15].

By using the DEM data above, then the drainage channel studied is formed cross section to input the value of the existing channel geometry. Based on the data input, it is known that the shape of the cross section of the drainage channel of building E Faculty of Engineering, Lampung University is as shown in Fig. 7. below.

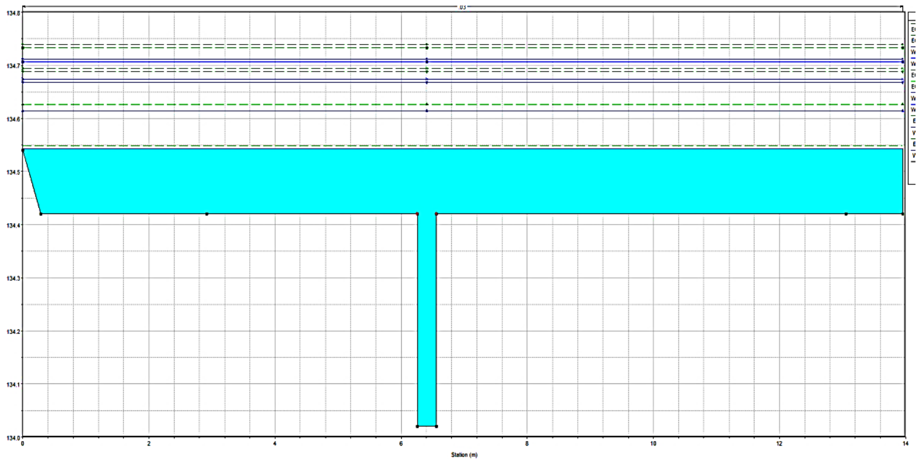

Fig. 7. The shape of one of the drainage channel cross section of building E Faculty of Engineering, University of Lampung

In the measurement results, the drainage channel geometry of building E Faculty of Engineering is around 25 cm wide with a depth of 30 cm. The geometry of the channel along the channel is sometimes not the same and changes like irregularities with a difference between one another between 1 cm and 5 cm. Based on this size variation, it is determined that the geometry of the E building drainage channel in this case is assumed to be 30 cm wide and 30 cm deep. After simulation using rainfall return period data as in the previous hydrological study, the following information was obtained:

Table 8. Channel Condition at Return Period Discharge.

No.	Return Period	Discharge	Condition
1.	2 year	4.5	Overflow
2.	5 year	11.5	Overflow
3.	10 year	17.7	Overflow

The overflow conditions that occurred as a visual result can be shown in the following Fig. 8.

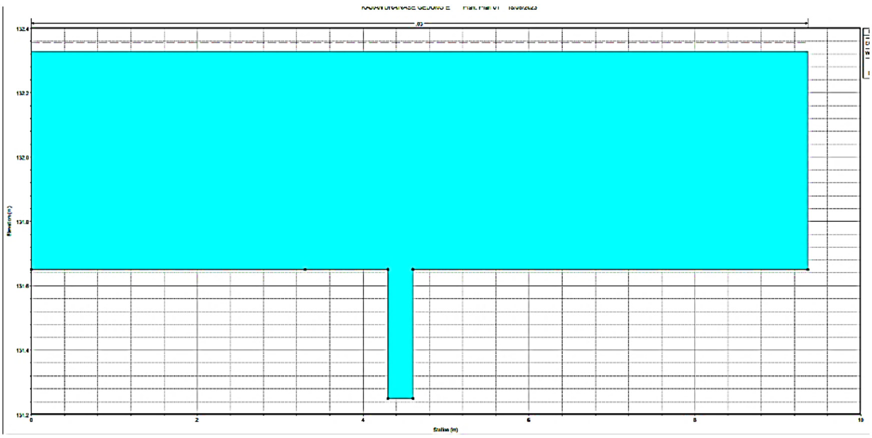

Fig. 8. 2 year of return period.

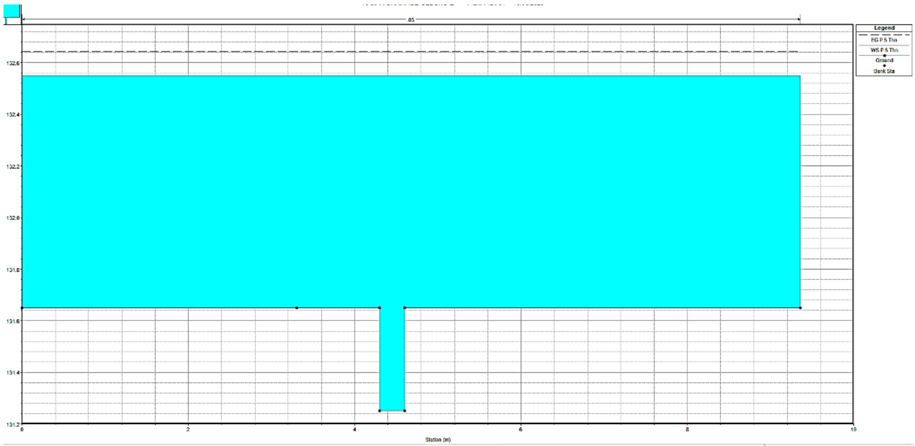

Fig. 9. 5 year of return period.

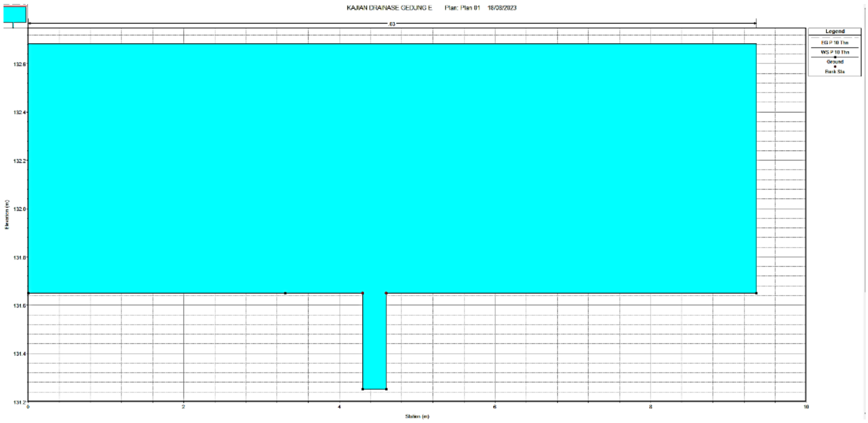

Fig. 10. 10 year of return period.

Different results are shown at 2, 5 and 10 year return periods. The height of the overflow water is already visible at the 2-year return period and continues to increase until the 10-year return period. The surface water level of this overflow shows that the drainage channel of building E is no longer able to deliver the surface flow discharge. Therefore, in this case a solution is needed so that the overflow stops or does not happen again.

To find out the maximum discharge conditions that can be flowed in the current existing channel conditions can be known based on hydraulics analysis. With a cross-sectional area of 0.075 m^2, the maximum discharge that can be delivered can be known as in the following calculations:

$A = 0.075\ m^2$

$P = 0.85\ m$

$R = \frac{A}{P} = 0.088\ m$

The chezy coefficient is determined by the relationship between the Manning coefficient and the hydraulic radius. This relationship is in the form of an equation:

$C = \frac{R^{1/6}}{n}$

The Manning coefficient for concrete channels is around 0.03, so the Chezy coefficient is 22.23. By using a Chezy constant of say 22.23 and a channel bed slope of 0.015, it can be estimated that the velocity ranges between:

$v = C\sqrt{RS} = 22.23\sqrt{0.088\ x\ 0.015} = 0.81\ m/detik$

The maximum discharge of the current drainage size is 1.99 m^3 /second or around 2 m^3 /second. While the lowest return period discharge is around 4.5 m^3 /second. This shows that there will be overflowing runoff discharge in the drainage channel. To overcome this, some hydraulics engineering is needed, among others[16], [17]:

1. Building a retention pond,
2. Increase the size of the drainage,
3. Increasing the infiltration area in the rainwater flow area such as making bio pores or infiltration wells.

Of the three engineering can be done by considering the size of the discharge period to be overcome.

4. Conclusion

Based on the results of this study, it shows that the conductivity of surface water flow for drainage of building E FT UNILA is no longer able to deliver rain discharge during high rainfall. This is indicated by the overflow of water at the return period of 2 years, 5 years, and 10 years. The simulation of the research can be seen in chapter four which shows the return time discharge of the various return periods. The maximum discharge capacity of the current drainage conditions is only around 2 m^3/second, while for the 2-year return period the maximum discharge is around 4.5 m^3/second. Thus, hydraulics engineering is needed to overcome the overflow of water at the difference in discharge.

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