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Evaluation of an Urban Drainage Channel System on Tuamang Road, Medan

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Abstract. The population that continues to grow every time affects the total wastewater that is accommodated and channeled by drainage. This study aims to evaluate the existing condition of drainage dimensions on Tuamang Road, Medan. To determine whether the drainage can still channel the design wastewater discharge for the next 10, 20, and 30-year return periods or if it requires re-planning. The descriptive-evaluative method is used to evaluate drainage with stages starting from collecting data on population, annual rainfall, and measuring the dimensions of drainage channels; hydrological analysis, population projections for 10, 20, and 30-year; and evaluation of drainage channels. The research location is on Tuamang Road with a length of 1,200 m from Domestic House No. 130 to No. 101. The drainage system on Tuamang Road can still channel rainwater runoff and household waste for up to 10-year, based on analysis. 20 and 30-year, the dimensions must be enlarged to 1.0 m (bottom width) and 0.7 m (wet height of the channel). Cleaning sediment at the channel bottom must continue regularly to ensure the drainage system is working properly.

Keywords: evaluation, domestic wastewater, runoff, dimension, urban drainage

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1 Introduction

Medan is the capital city of North Sumatra Province, Indonesia, which is the third largest metropolitan city in Indonesia and is one of the centers of economic growth. Due to transmigration and urbanization, the city has grown rapidly in the last decade. Compared with data in 2010, the population of Medan has increased by almost 340,000 people, or an average of 15,000-20,000 people/year [1]. Based on global population projections, it is predicted that the previous figure will continue to increase even until 2030. The population density of 9,000 people/km^2 is very large compared to the average population density of Indonesia, which is only

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161 people/km^2. Medan Tembung is the sub-district with the sixth largest population out of a total of twenty-one sub-districts in Medan, which will be more than 146,000 people in 2020. Its location in the city center contributes to the success rate of regional management in Medan. However, on the contrary, these facts bring new problems that have not been completely addressed. The massive reduction of environmental degradation factors due to the expansion of domestic land causes the impermeable surface to become wider and changes the natural hydrological cycle, which in fact, disrupts the functioning of the drainage system [2] [3] [4]. Extreme rainfall can cause massive flooding and paralyze a city, causing economic losses [5].

The problem that often occurs today is the ineffective dewatering process after the rain occurs due to changes in land use and outside the existing drainage capacity [6]. The drainage system must be able to reduce or divert excess water in an area. Providing adequate and integrated drainage channels in an urban drainage system is an absolute necessity. Most cities in Indonesia, including Medan, design drainage to drain rainwater into water bodies (runoff) as quickly as possible. Urban drainage fills up faster due to a large volume of water being collected at the same point. In contrast, the capacity of drainage tends to decrease due to erosion and sedimentation. Drainage systems that do not function properly can cause flooding [7]. Potential failures of urban drainage systems are generally caused by: (a) functional failure due to hydraulic overload on the system, for example, due to extreme rainfall, excessive infiltration, and (b) structural failure due to malfunctioning component systems [8]. In 2022, the flood disaster in Medan was recorded to have inundated 56 urban villages, with 4,306 families affected [9] [10]. This incident not only resulted in great financial losses reaching Rp. 26 billion, but the worst flood also caused the death of 3 people and the death of dozens of residents' livestock [11]. In the face of urban growth, urban planners have challenges to the demand for urban drainage infrastructure services that need to be improved. Drainage channels are very important for managing rainwater runoff and protecting road structures, so it is necessary to evaluate and maintain drainage systematically [12].

The same research study has been conducted to evaluate the urban drainage system. Sibagariang & Saputra [13] only evaluate the 10-year condition with a limit of 2005 to 2014 in a 5-year return period in Medan; Nusantara [14] examines the capacity of drainage channels to cope with flooding, not predicting certain return times in the evaluation of drainage channels; Putri [15] evaluated the urban drainage system with only a five-year return period. According to the researchers, the methods used in previous studies were deemed to be less extensive. Because drainage system concept in Indonesia is generally done with a hybrid system, this study was carried out by considering the generation of domestic wastewater and runoff during the rainy season. Therefore, researchers aim the evaluation of urban drainage on the ability to accommodate terrestrial runoff and domestic wastewater in the next 10, 20, and 30-year on a systematic basis. Hopefully, this research can be useful input for the government, especially

Medan city Stakeholder, in improving public facilities and infrastructure related to people's livelihoods.

2 Methodology

2.1 Research Location

This research was conducted on Tuamang Road, Medan Tembung District, Medan, North Sumatra. This area is one of the densely populated areas, and almost the entire area is built-up land. Its location, on the border of Medan and Deli Serdang Regency, makes this area very strategic near a complex of public and private universities, one of which is the Universitas Negeri Medan. So, that many students come to live; in boarding house businesses, housing complexes; as well as places of business selling, such as cafes and food stalls. With high activity conditions, it is important to evaluate the condition of the drainage capacity in this area by projecting an increase in the number of residents within a certain period. The length of the drainage channel under review is 1,200 km (Figure 1), which is along the side of Tuamang Road.

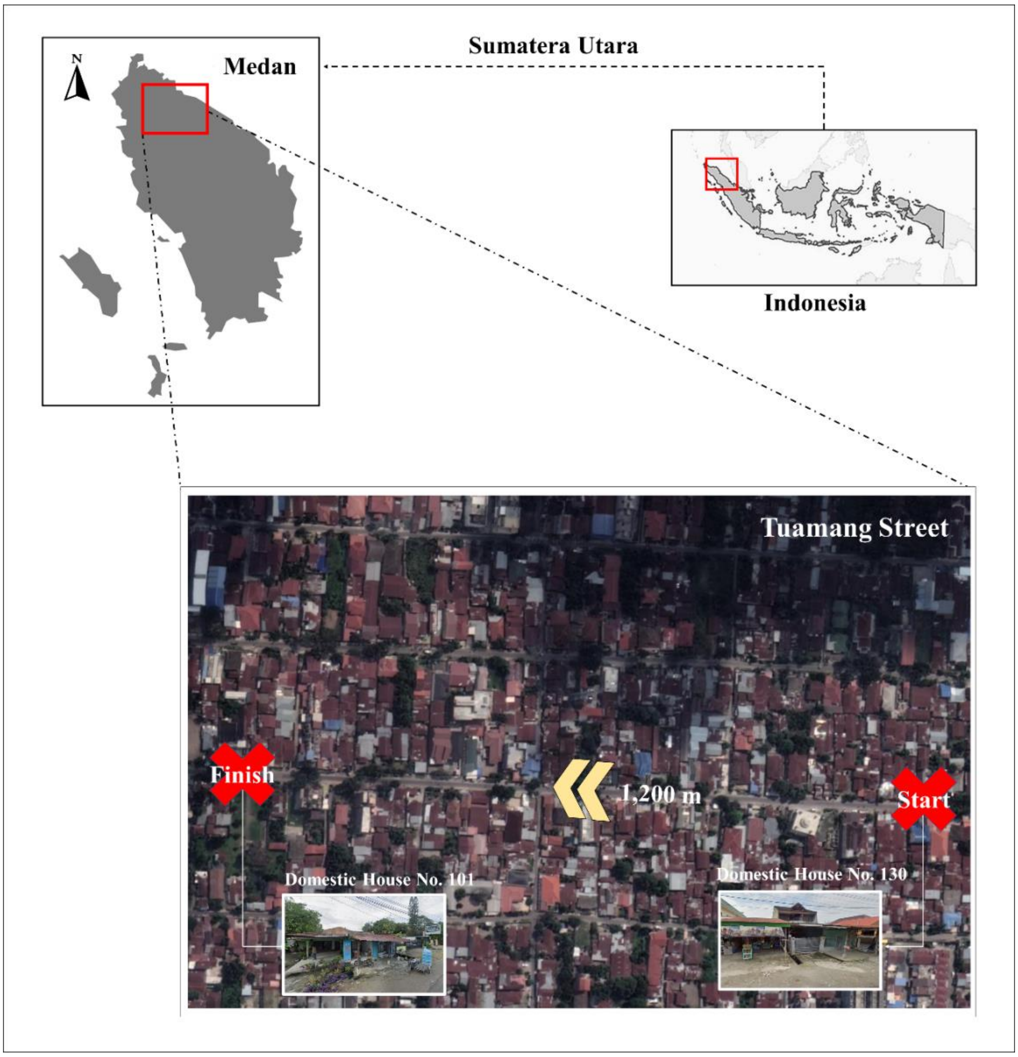


Figure 1 Site Map: Starting Point at Domestic House No. 130 (3°36'46.7064"N 98°42'6.714"E) and Finishing Point at Domestic House No. 101 (3°36'47.6316"N 98°41'51.4536"E)

2.2 Collecting Data

In this study, two sources of data were used: primary and secondary. Primary data collection was carried out by observing the research area, identifying the drainage channel's existing condition and the channel's dimensions, interviewing the estimated number of households in the location along the drainage channel, and conducting interviews with residents about the drainage condition. Secondary data collection was obtained from the results of a literature review in the form of rainfall data from Sempali Climatology Station, Medan (Table 1). Secondary data was also obtained through literature studies related to the analysis of drainage channel capacity.

Table 1 Rainfall Intensity Data in Medan, especially around the Tuamang Road Area

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Agt	Sep	Oct	Nov	Dec	Max
2012	40	50	42	57	83	65	65	46	60	75	60	33	83
2013	29	66	53	63	27	39	58	33	32	77	21	111	111
2014	20	22	35	31	46	49	34	91	66	41	57	165	165
2015	42	46	10	12	39	11	86	50	52	76	90	43	90
2016	23	71	9	9	40	41	49	54	84	47	57	34	84
2017	37	6	40	44	22	64	32	82	34	84	65	135	135
2018	29	40	18	68	35	42	62	33	56	147	76	106	147
2019	27	20	9	46	159	21	31	65	102	70	50	54	159
2020	146	57	16	68	85	58	39	92	79	45	27	74	146
2021	103	12	19	26	36	45	52	104	80	89	124	53	124

The amount of wastewater that the canal can hold is calculated using the dimensions of the current drainage system. Based on the discrepancy between the actual drainage volume and the sediment volume, the dimensions of the current drainage are established. As part of the appraisal process, this information becomes crucial. In this investigation, measurements are taken at ten separate places, each of which is 12 m apart, to estimate the actual drainage dimensions. Because it is integrated with the residents' yard, the amount of points takes into consideration where there is a physical change in some areas of the channel. To lessen odors and the development of mosquitoes, some locals convert the canal into a closed canal, which makes measuring the canal impossible. The same spot where drainage volume is really measured also serves to measure sediment volume.

2.3 Projected Population Growth

The number of residents is taken into account to calculate the total production of domestic wastewater that flows into the drainage channel. Real wastewater is calculated based on the number of residents in the current year multiplied by the estimated wastewater discharge per person per day. The volume of wastewater per person per day is strongly influenced by economic factors, such as the type of residence. It is also a consideration in the calculation of production. Population projections use various methods to obtain a point that is closest to the characteristics of the area under review after a comparative analysis of each technique is carried out. Calculating Methods used in projecting the population include Geometric and Arithmetic.

a) Geometric

The geometric population projection approach makes the premise that the population will grow measurably based on multiple analysis. Every year the population growth rate is considered the same. Population growth in the-n (P_n) using the geometric method is determined by the equation $P_n = P (1 + r)$. Where, P_0 is the population data for the final year, r is the rate of population growth in the study area, and n is the number of base intervals with the nth year.

b) Arithmetic

Population projections using arithmetic method assume that the annual population growth will be constant, which is calculated by the equation $P_n = P_0 (1 + r n)$.

2.4 Hydrological Analysis

The hydrological analysis is the stage of processing rainfall data which is then compared to the volume of drainage channels to know the intensity of rainfall and the estimated volume of rainwater flowing into the drainage as runoff.

a) Frequency of rainfall

Analysis of the frequency of rainfall in the next 10, 20, and 30-year using the Gumbel and Log Pearson III Distribution methods [16].

1) Gumbel

The calculation of rainfall in the return period T year (X_t) using the Gumbel method is determined using the equation $X_t = X_r + (K \cdot S_x)$. Here, X_r is the average value, K is the frequency factor, and S_x is the standard deviation. The standard deviation (S_x) is determined using the equation ($\frac{\sqrt{(X_i - X_r)^2}}{n-1}$. Where, X_i is the average rainfall data, X_r is the average price, and n is the amount of data. The frequency factor (K) is determined using the equation $\frac{Y_t - Y_n}{S_n}$. Where Y_t is the reduced variate, Y_n is the average value of the reduced variate, and S_n is the reduced standard deviation.

2) Log Pearson III

The Log Pearson III will be a Log Normal Distribution if the slope coefficient C_S = 0.00. The calculation of rainfall using the Log Pearson III Distribution method is determined using the equation log $log\ R_t = log\ X + G_t \cdot S\ log\ X$.

b) Rainfall intensity

The method used is the Mononobe method $I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{2/3}$. Where, I is rainfall intensity (mm/hour), R is design rainfall (mm), and t is rainfall duration (hours).

c) Runoff flow rate

The planned runoff flow rate is sought using the rational method because this method is suitable for the condition of the drainage area, which is not too wide, and the rainfall is considered uniform. The sensible method has an equation, namely $Q_{ch} = 0{,}278\ CIA$. Where 0.0278 is the correction factor, C is the coefficient of runoff (0≤C≤1), I is the rainfall intensity (mm/jam), and A is the channel area (m^2).

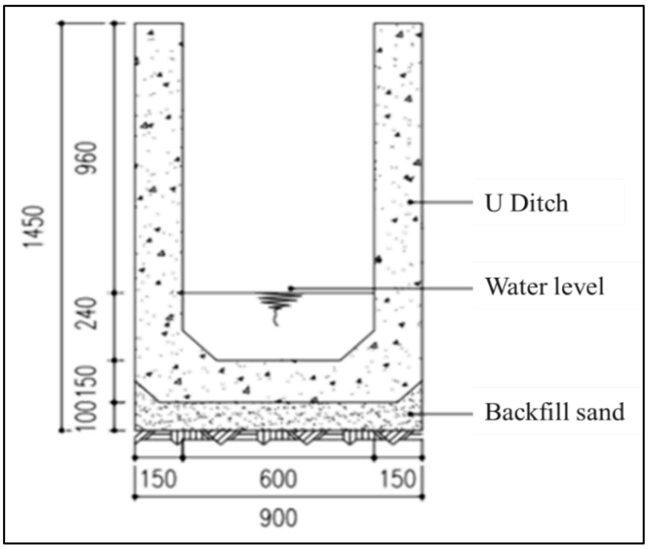
d) Domestic wastewater flow rate

Domestic wastewater flow rate is the amount of discharge from household activities that are channeled into drainage channels. The amount is largely determined based on the number of people per dwelling, type of activity, economic level, and type of dwelling. According to Sutjahjo [17], the consumption of clean water for the category of one-story housing with a building area of less than 90 m^2 is 150 L/person/day. The waste generated is around 80% of the total amount of clean water consumption.

3 Result and Discussion

3.1 Existing Volume of Drainage

At the research location along Tuamang Road, there is a tertiary channel. This channel uses a square type, as shown in Figure 2. From observation of 1,200 m drainage canals on Tuamang Road, illustrated in Figure 2, the average channel width is 0.6 m and the depth is 1.2 m. The volume of drainage in the initial planning of the city can be known, which is 864 m^3.



Information:

- Drainage length (p) = 1,200 m
- Drainage width (l) = 0.6 m
- Drainage height (t) = 1.2 m
- Sediment height (S) = 0.1 m
- Water depth (w_h) = 0.24 m
- Channel wall thickness = 0.15 m
- Number of HH = 138
- Average number of population/ HH = 4 person

Figure 2 Drainage Section at Tuamang Road

Sludge (sediment) is found at the bottom of the channel with varying thicknesses. Sludge can come from solids carried away with runoff and impurities from wastewater. This volume continues to fills some of the drainage channel volume if it is not dredged regularly. Measurements at 10 points randomly obtained an average mud thickness of 0.1 m. So, the sediment volume in this channel was 72 m³. The observation on drainage conditions showed that no part of the channel was damaged. Thus, based on the average data from the actual drainage volume and sediment volume measurement, the existing drainage volume is 792 m³.

3.2 Domestic Wastewater Flow Rate

Based on data obtained from the Sidorejo sub-district office, the number of houses located on Tuamang Road is 1,200 m from domestic house no. 130 to domestic house no. 101; on the left side, it is estimated as many as 130 houses with a scenario per house consisting of 4-6 people. Based on observation, data on the population in research location in 2020 was 683 people, while in 2021 increased to 692 people. The results obtained from the calculation of the population in the next 10, 20, and 30-year using Geometry and Arithmetic method are shown in Table 2.

Table 2 Population Growth Rate

Population Growth Rate (%)	Projected Population in Next Year (Person)					
	Geometry			Arithmetic		
	2032	2042	2052	2032	2042	2052
1.3	787	896	1020	782	872	962
* Domestic effluent production (L/day)	94,440	107,520	122,400	93,840	104,640	115,440

*Source: [17].

Based on field data results, houses located on Tuamang Road along 1,200 m on the left are, on average, a medium-type house buildings with type I. For this building, the amount of clean water consumption, according to Sutjahjo [17], is 150 L/person/day. Eighty percent of them will be released back into the environment in the form of wastewaterwater. The production of domestic wastewater is largely determined by the number of people living in an area. The estimated amount of domestic wastewater in 2022 that is channeled to the drainage on Tuamang Road is as follows:

3.3 Hydrological Analysis

Rainfall data for the last ten years, obtained from Sempali Climatology Station, is used to project future rainfall intensity. Rain intensity (mm/hour) each year can be seen in table 3 using the equation $I = \frac{R_{24}}{24} \times \left[\frac{24}{t}\right]^{2/3}$. Where, R_{24} is the rainfall in 24 hours and t is time [18].

Table 3 Rain Intensity

Year	Max. Rainfall	Rain Intensity
2012	83	1.88
2013	111	2.51
2014	165	3.73
2015	90	2.04
2016	84	1.90
2017	135	3.05
2018	147	3.32
2019	159	3.60

2020	146	3.30
2021	124	2.80
Total	1244	28.13
Max. Rainfall	165	-
Min. Rainfall	83	-
Average Rainfall	124.4	-

The Gumbel method of frequency distribution analysis is widely used in rainfall frequency analysis. The rainfall data obtained from Sampali Climatology Station in Medan are arranged in order of the amount of rainfall from the largest to the smallest. The analysis of the frequency distribution using Gumbel's method uses extreme values. The extreme importance of rainfall intensity is for several return periods of 10, 20, and 30-year. In calculating rainfall using the log pearson III method, the rainfall data is first converted into logarithmic form X = Log X; then, the average value is calculated using the equation $\text{Log X} = \frac{\sum_{i=1}^{n} \text{LogXi}}{n}$. The logarithm of planned rainfall with a certain return period is calculated by the formula $\text{Log}\,X_t = \text{Log}\,\overline{X} + (K_t x S \text{ Log X})$, where $S = \sqrt{\frac{\sum_{i=1}^{n}(\text{logXi}-\text{logX})^2}{n-1}}$. Then the calculation of C_s is carried out to find the value of K_t. From the results of the K value obtained, it can be calculated to find the planned rainfall volume. The calculation result details of rainfall projection (I) using some methods and design flow rate (Q_{plan}) are explained as shown in table 4-7.

Table 4 Rainfall Projection Using Gumbel-Method

t	Y_t	$\overline{X}$	$(Y_t-Y_n)/S_n$	X_t=X
10	2.2502	124.4	1.848	181.80
20	2.9606	124.4	2.596	205.03
30	3.1985	124.4	2.847	212.83

Table 5 Rainfall Projection Using Log Pearson III-Method

t	Log X_t	X_t
10	2.2687	185.65
20	2.3432	220.39
30	2.3923	246.77

Table 6 Rain Volume

t	log $\overline{X}_i$	S_d	C_s	K	X_t	I
10	2.081	31.06	0.218	1.30	185.7	4.2
20	2.081	31.06	0.218	1.81	220.4	5.0
30	2.081	31.06	0.218	2.15	246.8	5.6

To calculate the design channel discharge (Q, m^3/day) the equation Q = 0.00278 CIA is used.

Table 7 Calculation of Q_{plan}

t	Coef.	C	I	A	Q
10			4.2	0.6	0.665
20	0.278	0.95	5.0	0.6	0.792
30			5.6	0.6	0.887

$Q_{wastewater}$ = 80% x population x use of clean water 150 L/person/day
= 80% x 692 person x 150 L/person/day

= 66,432 L/day
= 66,432 m^3/day
= 0.7689 m^3/s

Wet cross-sectional area of the channel (A, m^2):

A = l x w_h
= 0.6 m x 0.24 m
= 0.144 m^2

Wet Channel Circumference (P, m):

P = l + 2(w_h)
= 0.6 m + 2(0.24 m)
= 1.08 m

Hydraulic Radius (R, m):

$$R = \frac{A}{P} = \frac{0.144\ m^2}{1.08\ m} = 0.133\ m$$

Slope assumed (S) with 0.001 and manning coefficient (n) is 0.016. Flow rate on the drainage channel (Q, m^3/s):

$$Q = A \times \frac{1}{n} \times (R)^{2/3} \times (S)^{1/2}$$
$$= 0.144\ m^2 \times \frac{1}{0.016} \times (0.133\ m)^{2/3} \times (0.001\ m)^{1/2}$$
$$= 0.0742\ m^3/s$$

Q_{max} = Q_{plan} + $Q_{wastewater}$
= 0.8878 m^3/s + 0.0008 m^3/s
= 0.8886 m^3/s

This calculation shows that the daily domestic wastewater reaches 66,432 m^3/day, with the maximum flow rate in the drainage channel estimated at 0.8886 m^3/s atau 76,775 m^3/day. This quantity can increase/decrease depending on the type and intensity of the activity [19] [20] [21].

3.4 Drainage Plan Dimensions

Based on Rabori & Ghazavi [22], the design channel dimensions are calculated based on the discharge that must be accommodated by the channel greater than or equal to the design discharge caused by the design rain ($Q_{plan} \geq Q_{flow}$). From the design discharge obtained, namely m^3/s, the dimensions of the channel design can be found, where the roughness coefficient n is 0.016, and the slope of the channel base is assumed to be 1:1000. Thus, the dimensions of an economic drainage channel determined as follows:

P = B + 2h
= h + 2h
= 3h

A = B x h
= h x h
= h^2

$$R = \frac{A}{P} = \frac{h^2}{3h} = \frac{h}{3}$$

by using Manning's formula, then:

Q = A x V
$$= h^2 \times \frac{1}{n} \times R^{2/3} \times S^{1/3}$$
$$= \frac{h^2}{0.016} \times \left(\frac{h^{\frac{2}{3}}}{3^{\frac{2}{3}}}\right) \times \left(\frac{1^{\frac{1}{2}}}{1000^{\frac{1}{2}}}\right)$$

$$0.88776 = \frac{h^2}{0.016} \times \left(\frac{h^{\frac{2}{3}}}{3^{\frac{2}{3}}}\right) \times \left(\frac{1^{\frac{1}{2}}}{1000^{\frac{1}{2}}}\right)$$

$$h = 0.97 \text{ m}$$

From results of the h value (wet height of the channel), so B can be found using this equation:

$$B = h$$
$$= 0.97 \text{ m}$$

The formula for finding the freeboard height:

$$W = \sqrt{0.5 \times h}$$
$$= \sqrt{0.5 \times 0.97}$$
$$= 0.7 \text{ m}$$

From results it can be assumed that B (bottom width) is 1 m, while h = 1 m and W = 0.7 m.

Based on the research results, domestic waste generated in the next 10, 20, and 30-year is 93,840 L/day, 104,640 L/day, and 115,440 L/day. The design discharges at 10, 20, and 30-year are 0.665 m^3/s, 0.792 m^3/s and 0.887 m^3/s. The intensity of rain in the next 10, 20, and 30-year is 4.2 mm/day, 5.0 mm/day, and 5.6 mm/day. The drainage channel on Tuamang Road can accommodate runoff for the next ten years, but for the next 20 and 30-year, the dimensions must be enlarged to 1 m (bottom width) and 0.7 m (wet height of the channel). One solution we can suggest [23] [24] [25] [26] to the local community is to be diligent in cleaning the sediment or sediment at the bottom of the drainage by dredging so that there is no excessive deposition that can reduce the drainage capacity.

4. Conclusion

Based on the evaluation of the drainage channel on Tuamang Road starting from domestic house no. 130 to no. 101, the channel is still safe for flood discharge with a planned return period of 10-year. On the other hand, other periods must be re-planned because the capacity does not meet the planned flood discharge. For the re-planning of the drainage channel, a 30-year re-planned flood discharge was used because, in addition to producing a larger capacity, its dimensions were not much different from the channel capacity that used a 10-year flood discharge. In the future, there is hoped that research will discuss design evaluation in Medan City with a sustainable paradigm that uses a separate system.

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