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Analysis of Drainage Channels using Storm Water Management Model (SWMM) (Case Study : Bungo Mas Housing Phase 1 Bungo Pasang Village, Koto Tangah District, Padang City)

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ABSTRACT

Drainage channels are water buildings that have an important function to channel excess water. With good drainage channels, excess water can be channeled and reduce the potential for waterlogging or flooding. Bungo Mas Tahap 1 Housing is located in Bungo Pasang Village which often experiences flooding or waterlogging due to high rainfall or long duration of rain. The problem of waterlogging in this area really needs attention because it disrupts various activities of the surrounding community and causes many losses. In addition to high rainfall, garbage and silt deposits in drainage channels are considered to be one of the causes of flooding. Therefore, it is necessary to analyze the existing drainage channels in Bungo Mas Tahap 1 Housing. The analysis process requires rainfall data for the last 10 years and the existing condition of the existing channels in the housing. One solution to assist in analyzing channels is using the Storm Water Management Model application (SWMM 5.2). After analysis of the channel, it was found that there was runoff in several channels so that the existing drainage was not effective because the dimensions of the channel were still not enough to accommodate the flow of water. Waterlogging that occurred in Bungo Mas Housing Phase 1 on the 2nd, 5th and 10th anniversary reached successive runoff peaks of 639.40 liters/s, 806.26 liters/s, and 914.87 liters/s which have been analyzed using SWMM 5.2 software.

Keywords: *Drainage; Flooding; Runoff; Hydrological; SWMM 5.2.*

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INTRODUCTION

Drainage is a series of water buildings that function for the disposal of unwanted excess water and ways to overcome the consequences of excess water. The use of this drainage channel is to drain muddy areas and puddles so that there is no accumulation of groundwater, lower groundwater levels at ideal levels, control soil erosion, damage to existing roads and buildings, control excessive rainwater so that flooding does not occur. Drainage structures are water constructions intended to control excess water, whether from rainwater, seepage, upstream and downstream water flows, in areas such as residential areas, commercial areas, industrial areas, office areas, airports, sports fields, and agricultural areas. In general, drainage can be defined as a series of water structures that function to reduce and/or remove excess water from an area or land, allowing the land to be used optimally [14].

Drainage channels are water buildings that have an important function to channel excess water. With good drainage channels, excess water can be channeled and reduce the potential for waterlogging or flooding. Drainage is designed as a system to meet the needs of the community and is an important component in infrastructure planning. In residential environments, drainage serves as a means of sanitation to prevent stagnant water that disturbs the comfort and health of the environment, as well as a means to prevent flooding. Floods that occur in residential areas are often caused by the failure of drainage channels to dispose of excess water. Where high rainfall is not offset by adequate channel capacity or even covered by garbage.

Good drainage construction in residential areas is necessary to channel runoff water, thereby reducing the potential for waterlogging that can lead to flooding. The purpose of having drainage channels is to dry wet and waterlogged areas to prevent the accumulation of groundwater, lower the groundwater level to an ideal level, control soil erosion, prevent damage to roads and buildings, and manage excessive rainwater to prevent flooding disasters. The operation and maintenance of urban drainage systems are crucial for the welfare of the community by reducing or eliminating waterlogging or floods that are highly detrimental to the public. Urban drainage refers to drainage systems in parts of or throughout a city, functioning to manage/control surface water so that it does not disrupt or harm the community [14].

Bungo Mas Tahap 1 Housing is located in Bungo Pasang Village which often experiences flooding or waterlogging due to high rainfall or long duration of rain. The problem of waterlogging in this area really needs attention because it disrupts various activities of the surrounding community and causes many losses. In addition to high rainfall, garbage and silt deposits in drainage channels are considered to be one of the causes of flooding. Hydrology is a branch of science that studies water and its movement on earth, both on the surface and in the soil. Hydrological science covers several aspects such as water resources, river flow, water quality, hydrological cycle, decision making on the utilization of water resources, and the impact of climate change on the hydrological cycle [12], [14].

Hydrological analysis needs to be done to be able to determine the amount of surface flow or discharge that must be accommodated. Hydrological data include the area of drainage, the magnitude and frequency of the planned rain intensity. Rainfall analysis is needed to determine the value of rain intensity. The planned rainfall referred to in the analysis is the maximum daily rainfall that will be used to calculate the intensity of rain, then this intensity is used to estimate the planned discharge [2], [13].

Before analyzing rain data, it is necessary to approach with statistical parameters to determine the exact distribution used. These parameters include average maximum rainfall, standard deviation, slope coefficient, pointing coefficient, and variance coefficient. The log Pearson Type 3 method can be used for all data distributions without having to meet the requirements of skewness and kurtosis coefficients. Hydrological analysis needs to be conducted to determine the magnitude of surface flow or discharge that needs to be accommodated. Hydrological data includes the area of the drainage basin, the magnitude, and frequency of design rainfall intensity. Frequency analysis is a hydrological data analysis using statistics aimed at predicting a certain amount of rainfall or discharge for a specific return period. Determining the design rainfall requires short-term rainfall data, or if such data is not available, maximum daily rainfall data can be used. This data is then analyzed using several frequency distributions [13].

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METHOD

This research uses quantitative methods. This study began with observations to the research location to find out the condition of the drainage canals in the housing. The conditions reviewed are in the form of shape, dimensions and flow direction of drainage channels. Furthermore, a literature study was carried out on the analysis of drainage channels obtained in the book, journal or aricle concerned. Furthermore, data collection was carried out in the form of rainfall data in the last 10 years by visiting related agencies, reports and other references. From these data, analysis of planned flood discharge and channel discharge is carried out using hydrological analysis and SWMM software assistance so that it can be known whether the drainage channel made is able to accommodate flood discharge [4].

The following is a brief description of the stages of research in analyzing drainage channels using Storm Water Management Model 5.2 software:

1. Literature Study
   Literature study is a library study to obtain theories or materials related to the main issues, including drainage, flooding, runoff, calculations, and hydrology.
2. Survey and Data Collection
   Field surveys aim to gather the necessary data as primary and secondary data. Primary data are sourced directly from the field, while secondary data are sourced from other parties supporting this research.
3. Frequency Distribution Test
   The frequency distribution test aims to determine the likelihood that a certain rainfall amount will be equaled or exceeded and can be used with several methods. In this study, the Normal, Log Normal, Gumbel, and Log Pearson Type III methods were used for the frequency distribution test [13].
4. Distribution Fit Test
   The distribution fit test aims to determine the suitability of a sample data distribution against a probability distribution function, which is expected to represent or depict a frequency distribution. In this study, the Chi-Square and Kolmogorov-Smirnov tests were used [13].
5. Design Flood Discharge
   The calculation of the design flood discharge aims to determine the estimated amount of water discharge that will flow to a particular area during a flood. This information helps in designing infrastructure appropriate to the water discharge amount, thus preventing floods and reducing flood hazards.
6. Drainage Channel Analysis using SWMM
   SWMM (Storm Water Management Model) is a periodic rainfall runoff simulation model used to simulate single or continuous events with the quantity and quality of runoff from the studied area. The runoff component of SWMM operates by summing the subcatchment areas that receive total rainfall and generate it as runoff [1]–[4].
   When observed flow or water-level data are available, sensitivity analysis and calibration should be performed to reduce parameter uncertainty and improve model reliability [8], [9].
7. Conclusion
   After obtaining the analysis results, it can be concluded whether the existing drainage channels in Bungo Mas Housing Stage 1, Bungo Pasang Subdistrict, are still adequate to accommodate the specified rainfall or if evaluation and improvement are needed in the area.

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RESULTS AND DISCUSSION

Data Analysis

1. Rainfall Analysis
   Based on the rainfall table at Simpang Alai station, the maximum daily rainfall is obtained as shown in Table 1.

Table 1. Maximum Daily Rainfall

No.	Year	Maximum Daily Rainfall (mm)
1	2013	167
2	2014	142
3	2015	126
4	2016	210
5	2017	181
6	2018	130
7	2019	91
8	2020	100
9	2021	175
10	2022	132

2. Frequency Analysis
   Based on the results of the maximum rainfall data testing, the type of distribution is determined using skewness, kurtosis coefficient, and variation coefficient values to decide the distribution type to be used. The calculations can be seen in Table 2.

Table 2. Testing of Maximum Rainfall Data

No.	Year	R (mm)	R - R̄	(R - R̄)²	(R - R̄)³	(R - R̄)⁴
1	2013	167	21.60	466.56	10077.696	217678.2336
2	2014	142	-3.40	11.56	-39.304	133.6336
3	2015	126	-19.40	376.36	-7301.384	141646.8496
4	2016	210	64.60	4173.16	269586.136	17415264.3856
5	2017	181	35.60	1267.36	45118.016	1606201.3696
6	2018	130	-15.40	237.16	-3652.264	56244.8656
7	2019	91	-54.40	2959.36	-160989.184	8757811.6096
8	2020	100	-45.40	2061.16	-93576.664	4248380.5456
9	2021	175	29.60	876.16	25934.336	767656.3456
10	2022	132	-13.40	179.56	-2406.104	32241.7936
Total		1454	0.00	12608.40	82751.280	33243259.6320
Mean rainfall (R)		145.40		Number of observations	10	
Standard deviation (S)		37.43		Kurtosis coefficient (Ck)	3.36	
Skewness coefficient (Cs)		0.22		Coefficient of variation (Cv)	0.26	

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Table 3. Testing for Determining the Type of Distribution of Maximum Rainfall

No.	Distribution	Acceptance criteria	Calculated value	Result
1	Normal	Ck ≈ 3 Cs ≈ 0	Ck = 4.16	Does not satisfy
2	Log-normal	Cv ≈ 0.06 Cs ≈ 3Cv + Cv² = 0.1482	Cs = 0.02	Does not satisfy
3	Gumbel	Cs ≈ 1.1396 Ck ≈ 5.4002	Cs = 0.02 Ck = 4.16	Does not satisfy
4	Log-Pearson Type III	Cs: unrestricted Cv: unrestricted	Cv = 0.05	Satisfies

Based on the calculations in Table 3, it can be concluded that the Log Pearson III Distribution meets the requirements.

3. Distribution Fit Test
After performing the test using Microsoft Excel by entering formulas and data, the results are obtained as shown in Table 4.

Table 4. Fit Test Using the Smirnov-Kolmogorov Method

No.	R	Log R	m	P(x)	P(x<)	f(t)	P'(x)	P'(x<)	D
1	210	2.322	1	0.091	0.909	1.506	0.111	0.889	0.020
2	181	2.258	2	0.182	0.818	0.944	0.222	0.778	0.040
3	175	2.243	3	0.273	0.727	0.817	0.333	0.667	0.061
4	167	2.223	4	0.364	0.636	0.640	0.444	0.556	0.081
5	142	2.152	5	0.455	0.545	0.027	0.556	0.444	0.101
6	132	2.121	6	0.545	0.455	-0.249	0.667	0.333	0.121
7	130	2.114	7	0.636	0.364	-0.307	0.778	0.222	0.141
8	126	2.100	8	0.727	0.273	-0.425	0.889	0.111	0.162
9	100	2.000	9	0.818	0.182	-1.299	1.000	0.000	0.182
10	91	1.959	10	0.909	0.091	-1.655	1.111	-0.111	0.202
Total	21.492							Dmax	0.202
Mean	2.149							Dmin	0.020
Standard deviation (S)	0.115							Dcritical	0.41
Number of observations (n)	10								
Skewness coefficient (Cs)	-0.247								

Table 5. Conditions for Smirnov-Kolmogorov Test Calculation

Criterion	Dmax	Dcritical	Decision
Dmax < Dcritical	0.202	0.41	ACCEPTED

Based on the calculations in Table 5, it can be concluded that the distribution test for Log Pearson Type III using the Smirnov-Kolmogorov method meets the requirements. After calculating the rainfall frequency and the fit test for Log Pearson Type III Distribution using Microsoft Excel, the data obtained is shown in Table 6.

Table 6. Calculation of Log Pearson Type III Distribution

No.	Xi	Log Xi	(Log Xi - mean Log X)²	(Log Xi - mean Log X)³
1	210	2.322	0.030	0.005
2	181	2.258	0.012	0.001

No.	Xi	Log Xi	(Log Xi - mean Log X)²	(Log Xi - mean Log X)³
3	175	2.243	0.009	0.001
4	167	2.223	0.005	0.000
5	142	2.152	0.000	0.000
6	132	2.121	0.001	0.000
7	130	2.114	0.001	0.000
8	126	2.100	0.002	0.000
9	100	2.000	0.022	-0.003
10	91	1.959	0.036	-0.007
Sum		21.492	0.118790799	-0.00269691
Mean Log X		2.1492		
S Log X		0.115		
Cs		-0.247		
Cv		0.053		

Table 7. Maximum Rainfall with Log Pearson Type III Distribution

Return period (years)	KTR	Maximum rainfall (mm)
2	0.041	142.527
5	0.851	176.605
10	1.252	196.342

4. Rainfall Intensity Analysis
   In processing rainfall intensity data, the Mononobe formula is used to calculate the occurring rainfall. Rainfall intensity is the amount of rainfall expressed in rainfall height (mm) per unit of time (seconds) per year. Rainfall intensity can be estimated using the Mononobe formula. The intensity varies depending on the duration and frequency of rainfall events. Rainfall intensity is obtained by analyzing rainfall data both statistically and empirically. The planned rainfall data obtained through the Log Pearson Type III Distribution yields the rainfall intensity values as shown in Table 8 [2].

Table 8. Rainfall Intensity Calculation

Duration / parameter	2-year return period	5-year return period	10-year return period
Design rainfall, Rt (mm)	142.257	176.605	196.3432
1 h	49.318	61.226	68.068
2 h	31.068	38.570	42.880
3 h	23.710	29.434	32.724
4 h	19.572	24.297	27.013
5 h	16.866	20.939	23.279
6 h	14.936	18.542	20.615
7 h	13.477	16.731	18.601
8 h	12.329	15.306	17.017
9 h	11.398	14.150	15.732
10 h	10.625	13.191	14.665
11 h	9.971	12.379	13.762
12 h	9.409	11.681	12.986
13 h	8.920	11.074	12.312
14 h	8.490	10.540	11.718
15 h	8.109	10.066	11.191
16 h	7.767	9.642	10.720
17 h	7.459	9.260	10.295
18 h	7.181	8.914	9.911
19 h	6.926	8.599	9.560
20 h	6.693	8.310	9.238
21 h	6.479	8.044	8.943
22 h	6.281	7.798	8.670
23 h	6.098	7.570	8.416
24 h	5.927	7.359	8.181

5. Time of Concentration

Time of concentration (Tc) is the time required to flow water from the furthest point in the watershed to the specified control point downstream of a stream. Time of concentration is determined by the parameters of the main channel length, along with the slope of the terrain. The time of concentration can be calculated by dividing it into two components: the time required for water to flow over the land surface to the nearest channel and the travel time from the point of entry into the channel to the outlet point. [2]

Parameter	Symbol	Value	Unit
Main channel length	L	250	m
Initial elevation	El. initial	4.625	m
Final elevation	El. final	3.814	m
Channel slope	S	0.3244	%
Time of concentration	tc	0.06	h
Time of concentration	tc	3.60	min

6. Design Flood Discharge

The design flood discharge is determined using the rational method. As shown in the table, the flood discharges for return periods of 2, 5, and 10 years are 1.430 m³/s, 1.772 m³/s, and 1.970 m³/s, respectively [2], [3].

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Table 9. Design Flood Discharge

Return period (years)	Maximum rainfall (mm)	Intensity, I (mm/h)	Runoff coefficient, C	Area, A (km²)	Discharge, Q (m³/s)
2	142.527	322.3982	0.6	0.0266	1.430441976
5	176.605	399.4831	0.6	0.0266	1.772458588
10	196.342	444.1285	0.6	0.0266	1.970544799

7. Simulation Using SWMM 5.2 Software
   Based on the simulation results using SWMM 5.2 with a 2-year return period, the map displays colors in the image. At 00:15 hours, only dark blue is shown, indicating that there are no issues with the channel, as seen in Figure 2 [1], [3].

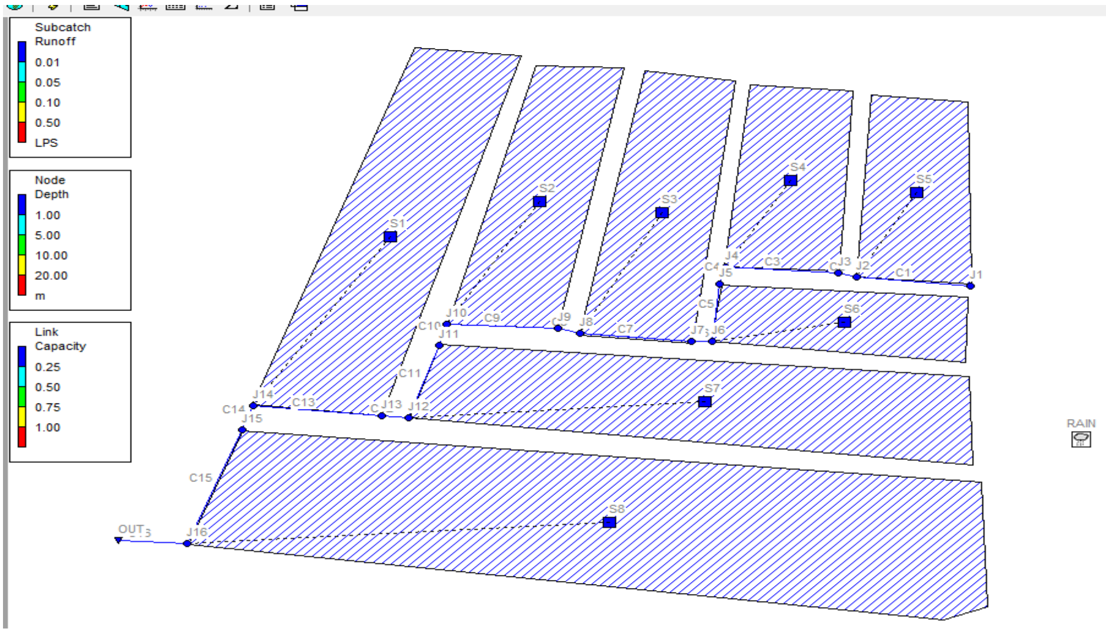

Figure 1. Simulation display using the map before runoff occurs

At 02:00 hours, the image shows several colors, including red, yellow, green, dark blue, and light blue. The red color appears in all subcatchments with peak runoff ranging from 25.95 liters/s to 639.40 liters/s. Additionally, the red color also appears in C4, C5, and C8, indicating that the channel capacity is quite high, reaching 4.73 m³/s. This can be seen in Figure 3 [5], [6].

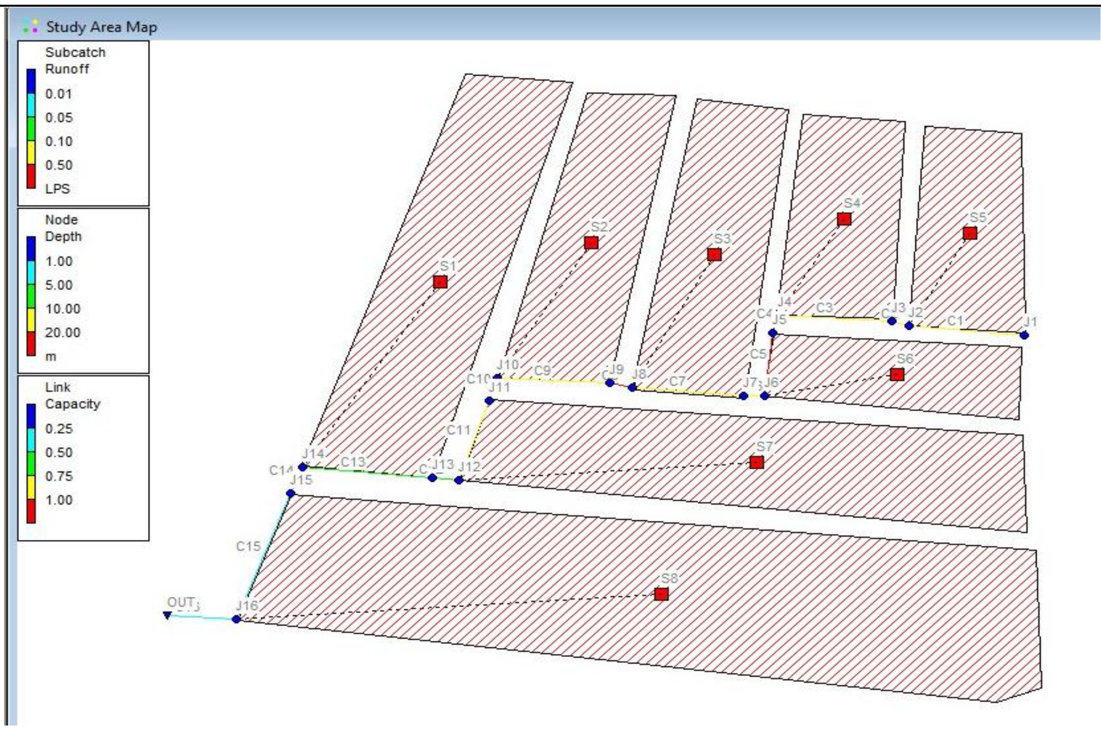

Figure 2. Simulation display using the map during runoff

The simulation results at 6 hours show that along the channel with a 2-year return period, there are several flood points, as seen in Figure 21. The 5-year and 10-year return periods have similar runoff or flow profiles but with greater rainfall intensity, resulting in higher discharge and capacity [7], [11], [15].

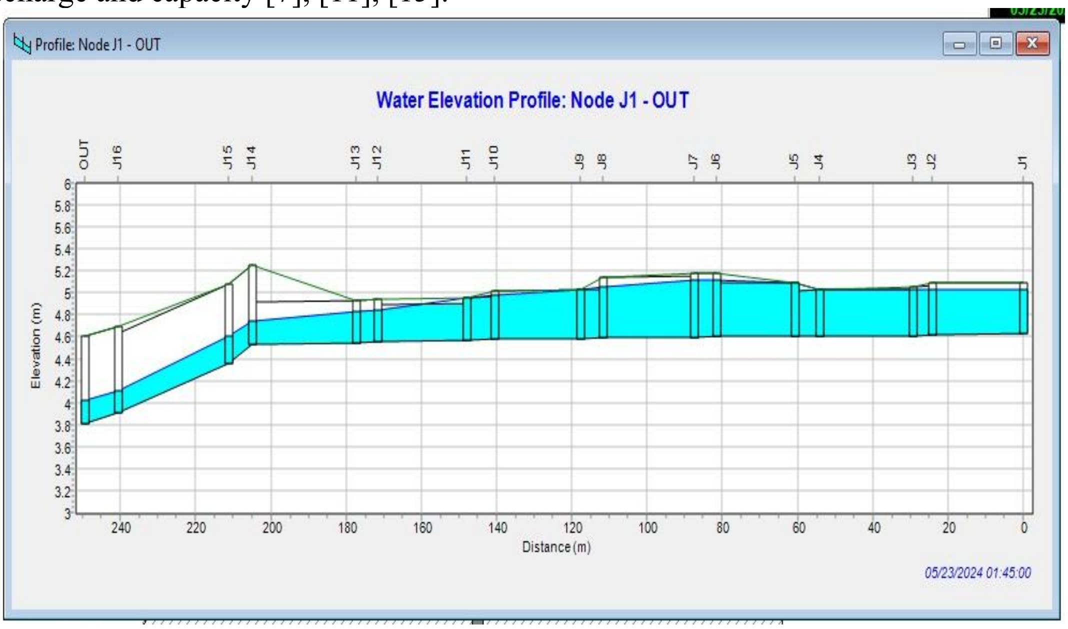

Figure 3. Simulation results of the flow profile

The Bungo Mas Stage 1 Housing located in Padang City is an area frequently affected by floods and waterlogging during the rainy season. The drainage channels are unable to optimally carry water due to sedimentation, garbage, and channels that are inadequate to accommodate the flood discharge. The results of this analysis show that the waterlogging in Bungo Mas Stage 1 Housing during the 2, 5, and 10-year return periods reaches peak runoff of 639.40 liters/s, 806.26 liters/s, and 914.87 liters/s respectively, which have been analyzed using SWMM 5.2 software [8]–[10], [12], [14].

CONCLUSION

Based on the discussion of drainage analysis in Bungo Mas Housing Phase 1 using SWMM 5.2 software, it can be concluded that. Based on the simulation results using SWMM 5.2 software with return periods of 2 years, 5 years, and 10 years, runoff occurs in several channels, indicating that the existing drainage system is not yet effective and requires improvement. From the research conducted, the dimensions of the drainage channels are still insufficient to accommodate water flow. Water pooling occurring in Bungo Mas Housing Phase 1 with return periods of 2 years, 5 years, and 10 years reaches peak runoff of 639.40 liters/s, 806.26 liters/s, and 914.87 liters/s, respectively, as analyzed using SWMM 5.2 software.

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