Evaluation of the Drainage System in Kotabaru Village, West Bekasi, Using the EPA SWMM Model

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Abstract: The Kotabaru Village in West Bekasi District, Bekasi City, frequently experiences flooding. Flood events in this area have even reached depths of 100 cm. These events disrupt residents' activities and force them to evacuate. An evaluation of the drainage channels is necessary to identify the causes of flooding and develop solutions. This study aims to analyze the causes of flooding and provide recommendations for flood management based on simulations using EPA SWMM 5.2 software. The data used in this study include daily rainfall data from the GPM (Global Precipitation Measurement) satellite for the period 2013-2022, a contour map of Bekasi City, and a land cover map. Hydrological analysis methods and modeling using EPA SWMM 5.2 are employed to identify flood points and accurately calculate the capacity of the drainage channels. The hydrological analysis results show that rainfall in this area follows a Log-Pearson Type III distribution. The design rainfall with a 5-year return period is 267.87 mm. The SWMM model involves 30 subcatchments, 126 junctions, 168 conduits, and 1 outfall. A 24-hour simulation indicates that 5 channels are highlighted in red, meaning their capacity is insufficient, and the channel profiles show overflows due to flow queuing towards the Cakung River. Capacity analysis shows that the simulated discharge under existing conditions reaches 44.01 m^3/s. After improvements, the Cakung River and the residential drainage channels function properly without any overflows.

Keywords: Cakung river; Bekasi; drainage; EPA SWMM; floods; GPM

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1. Introduction

Drainage systems play a crucial role in various aspects of life. These systems are designed to manage excess water, both surface water and subsurface water [1]. This excess water occurs because water falling on the ground surface cannot infiltrate or be absorbed into the soil. The inability of water to infiltrate is due to hardened surfaces resulting from development, including roads, asphalt pavements, and buildings, which consequently increases surface runoff [2]. Drainage channels are necessary to convey this excess water. When these channels are unable to effectively convey water to the final discharge point, the risk of flooding increases [3].

Flooding has become a recurring phenomenon in several regions of Indonesia. According to data from the National Disaster Management Agency (BNPB), during 2024 there were 1,478 natural disasters in Indonesia, 814 of which were flood events [4]. Bekasi City is one of the areas in Indonesia that frequently experiences flooding. Data from the Bekasi City Public Works and Water Resources Agency recorded 111 flood events in Bekasi City in 2020.

Flooding also occurred in subsequent years. In 2021, there were 32 flood events, 32 in 2022, and 27 in 2023 in Bekasi City. The depth of flooding varied from 20 cm to over 100 cm. This high number of flood events increases public awareness, especially during periods of high rainfall intensity, because flooding causes losses to the community. The impacts include physical and mental health problems, loss of life, damage to public facilities, and property damage [5].

Residents in Kotabaru Village, especially in RW 02 (*Rukun Warga* 02) residential area, West Bekasi District, Bekasi City, have faced the effects of recurring flooding. Over the past four years, this location has consistently experienced flooding. The impacts include power outages, inundation of homes and roads, disrupting the activities of local residents and forcing them to evacuate [6].

An evaluation of the drainage channels in this area is necessary to identify the root causes of the flooding problems so that recommendations for improving and developing the drainage system can be provided to mitigate flood disasters. Furthermore, evaluating the drainage channels can serve as an initial flood mitigation measure, reducing the impacts felt by the community and the losses incurred by the government due to infrastructure damage. Various methods can be used to evaluate drainage channels. This research uses hydrological analysis and modeling with EPA SWMM 5.2. Based on previous research [7,8], EPA SWMM can identify flood points in the analyzed area and calculate drainage capacity more accurately. The EPA SWMM model has also been used to evaluate and provide recommendations for improving the drainage system in the Wisma Asri Housing Complex, North Bekasi [9]. Therefore, EPA SWMM is used in this study to model the drainage channels in the research area.

2. Methods

The research location is in Kotabaru Village, especially in the area of RW 02 (Harapan Baru 2 Housing Complex), West Bekasi District, Bekasi City, with an area of 6.33 hectares. The research site is located at coordinates 6°11'52.3" S and 106°58'59.7" E. The research location can be seen in **Figure 1**.

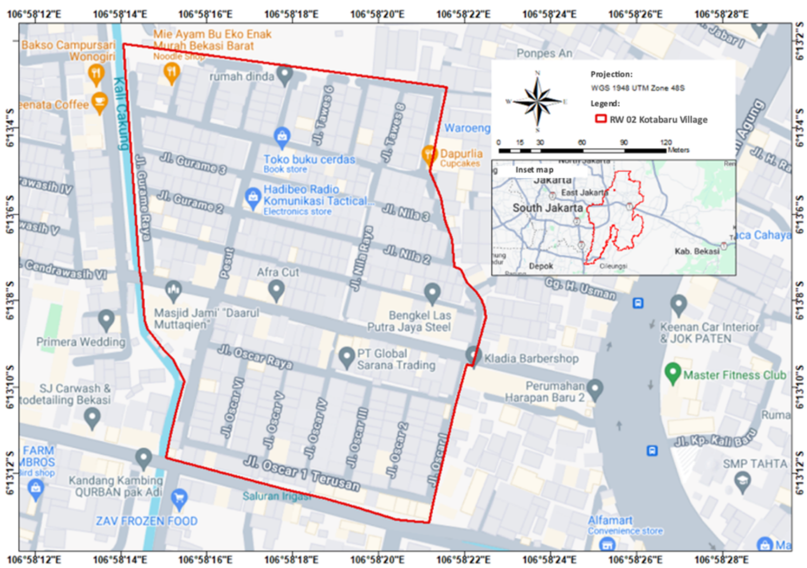

Figure 1. Location map of the study area

This research utilizes primary and secondary data for analysis. Primary data consists of the characteristics and dimensions of the existing drainage channels within the RW 02 area of Kotabaru Village. This data was obtained through field observations and direct measurements. The secondary data used includes 10 years of maximum daily rainfall data obtained from the GPM (Global Precipitation Measurement) satellite, a contour map of Bekasi City, and a land cover map. The tools used in this research include a measuring tape to measure the dimensions of the existing channels, a laptop equipped with ArcMap 10.4.1, Google Earth, AutoCAD, EPA SWMM 5.2, Microsoft Word, and Microsoft Excel.

2.1. Hydrological Analysis

Hydrological analysis is conducted to determine the discharge that needs to be conveyed, allowing for the determination of drainage channel dimensions for the study area. The initial step in hydrological analysis is to calculate the average rainfall, where maximum daily rainfall data plays crucial role. In this study, rainfall data from the GPM (Global Precipitation Measurement) satellite, obtained from the Giovanni website, is used. However, this satellite data requires correction using surface rainfall data to ensure that the resulting data accurately represents the rainfall in the study area. The advantage of using GPM satellite rainfall data is that it provides detailed rainfall measurements, both hourly and annually [10].

Subsequently, a rainfall frequency analysis is performed to determine the frequency of rainfall occurrence over a specific period [11,12]. Rainfall frequency analysis involves calculating several statistical parameters, including the mean, standard deviation, coefficient of variation (Cv), coefficient of skewness (Cs), and coefficient of kurtosis (Ck). The calculated Cs and Ck values are then compared with standard Cs and Ck values. These Cs and Ck values are used in probability distribution analysis.

Determining the design flood discharge is a crucial factor in determining the required capacity of drainage channels. This analysis aims to determine the runoff discharge using the Rational method. In addition to calculating the flood discharge, calculating rainfall intensity is also an important factor in determining the required channel capacity. This is because rainfall intensity is a parameter in the calculation of flood discharge. In this study, rainfall intensity is calculated using the Mononobe formula, and flood discharge is calculated using the Rational method. The calculation of rainfall intensity (I) and design flood discharge (maximum discharge) (Q) can be performed using **Equations (1) - (2)**, respectively. Furthermore, discharge can also be calculated using the Manning equation, as shown in **Equation (3)** [11].

$$I = \frac{R24}{24}\left(\frac{24}{tc}\right)^{\frac{2}{3}} \quad (1)$$

$$Q = 0.278\ x\ C\ x\ I\ x\ A \quad (2)$$

$$\mathrm{Q} = \mathrm{A}\ \mathrm{x}\ V = A\ x\ \frac{1}{n} x\ R^{\frac{2}{3}}\ x\ S^{\frac{1}{2}} \quad (3)$$

where,

Q : peak discharge resulting from rainfall with a specific intensity, duration, and frequency (m^3/s)
I : rainfall intensity (mm/h)
A : catchment area (km^2)
C : runoff coefficient, dependent on the type of land surface
R_{24} : maximum daily rainfall (over a 24-hour period) (mm)
t : rainfall duration (h)
v : velocity (m/s)
n : Manning's roughness coefficient
S : channel slope (m/m)
R : hydraulic radius (m)
A : cross-sectional area of the channel (m^2)

2.2. EPA SWMM 5.2 Modeling

Data analysis using EPA SWMM 5.2 modeling is employed to determine the hydraulics of the channels by comparing the flood discharge with the channel capacity [13]. The initial step in this modeling process is to input the hydrological and hydraulic parameters obtained from the processed primary and secondary data. The required hydrological parameters include design rainfall data and the area of the subcatchments, with areas classified as pervious and impervious. A pervious area is one that can absorb rainwater through infiltration, while an impervious area is one that cannot absorb water. The determination of these areas was analyzed through ground checking. The required hydraulic parameters include the dimensions of the existing channels. These data serve as input for the EPA SWMM 5.2 module [14]. The workflow using the EPA SWMM 5.2 software is as follows.

1) Subcatchment delineation. The parameters required for subcatchment delineation include information on area, land slope, and the percentage of impervious area (area that cannot infiltrate water).
2) Drainage network model creation. This modeling process involves both hydraulic and hydrological aspects. Hydraulic aspects include the presence of conduits, junctions (intersections between conduits), subcatchments (catchment areas), and outlets (downstream boundary areas). Hydrological aspects include design rainfall (rain gauge) and rainfall duration (time series).
3) Time series flow response simulation. Simulating the flow response in a time series is done to observe the response of flow discharge to time based on the rainfall distribution. The input values are the distribution of rainfall over time, with the total value corresponding to the design rainfall derived from the hydrological analysis.
4) Drainage network model simulation. The created drainage network model is then run by activating the "run a simulation" tool. The simulation is considered successful if the percentage of continuity error at the end of the simulation is less than 10%. This indicates that the data and the running model have a low error rate, and the data generated from the simulation can be used.
5) EPA SWMM Simulation Output. The drainage network simulation produces data used to analyze the suitability of discharge in conduits or junctions with the occurring runoff. The output data presented in the summary result window can be in the form of statistical data in tables, such as runoff from subcatchments, flow and water depth at nodes (node flooding), discharge in conduits (link flow), and outlet capacity, as well as graphs such as time series, runoff, flow profiles, and duration curves.

3. Results and Discussion

3.1. General Conditions of the Study Area

This research is located in the RW 02 area of Kotabaru Village, specifically within the Harapan Baru 2 Housing Complex, Kotabaru Village, West Bekasi District, Bekasi City. The study area is part of the Cakung River Catchment (Watershed) and is directly adjacent to the Cakung River. The drainage network pattern in the Harapan Baru 2 Housing Complex is classified as a grid pattern, consistent with the flat topographical characteristics of the location [11]. The drainage characteristics in the Harapan Baru 2 Housing Complex include surface drainage with open channels and rectangular cross-sections. The channel dimensions in this housing complex vary, including 1.75 x 2.00 m, 0.35 x 0.40 m, 0.40 x 0.35 m, 0.40 x 0.45 m, 0.50 x 0.40 m, 0.60 x 0.40 m, 0.80 x 0.95 m, and 0.70 x 0.60 m.

Based on field observations, the condition of the drainage channels in the RW 02 area shows sediment accumulation in almost every channel, as well as garbage and aquatic plants in some channels. The flow condition of the Cakung River, which passes through the RW 02 area, also shows garbage along its course. As a result, the channels do not function properly, leads to reduction in channel capacity and increased flood risk.

3.2. Maximum Daily Rainfall Analysis

Maximum daily rainfall data is crucial for hydrological analysis. In this research, rainfall data was obtained from the GPM (Global Precipitation Measurement) satellite via the NASA Giovanni website, using 10 years of rainfall data (2013-2022). The advantage of using this data is that the maximum 24-hour rainfall distribution can be obtained, allowing for more detailed simulations for analysis needs such as drainage. However, before using satellite rainfall data for analysis, this data needs to be corrected. This is because the accuracy of satellite data is not yet as accurate as surface rainfall data [15]. Data correction in this study uses satellite data and surface rainfall data (BMKG data) that are closest and most complete from the research location. In this case, satellite data and BMKG data from the Tanjung Priok Maritime Meteorological Station are used. The data obtained is divided into five classes according to the threshold values set by BMKG. The resulting correction factors can be seen in **Table 1**.

Table 1. Rainfall data correction factors

Class Interval (mm/day)	BMKG Rainfall (mm)	GPM Rainfall (mm)	Correction Factors
0.5 - 20	4,756.70	10,277.13	0.46
20 - 50	5,905.30	3,949.12	1.50
50 -100	4,930.30	2,407.16	2.05
100 - 150	964.00	376.33	2.56
>150	182,20	83,51	2,18

3.3. Design Rainfall Analysis

The rainfall data used is the corrected 10-year rainfall data from 2013 to 2022. The correction factors used are in accordance with the class intervals presented in **Table 1**. The corrected 10-year rainfall data can be seen in **Table 2**.

Table 2. Corrected rainfall

Year	Date	Rainfall (mm)	Class Interval (mm/hari)	Correction Factors	Corrected rainfall (mm)
2013	18/01/2013	110.25	100 - 150	2.56	282.41
2014	12/01/2014	91.08	50 - 100	2.05	186.55
2015	09/02/2015	198.66	>150	2.18	433.44
2016	24/09/2016	78.54	50 - 100	2.05	160.87
2017	18/10/2017	48.18	20 - 50	1.50	72.05
2018	23/04/2018	84.46	50 - 100	2.05	173.00
2019	30/01/2019	70.05	50 - 100	2.05	143.48
2020	08/02/2020	88.17	50 - 100	2.05	180.59
2021	07/02/2021	96.32	50 - 100	2.05	197.29
2022	16/07/2022	82.15	50 - 100	2.05	168.26

Based on the 2014 Ministry of Public Works (PU) Regulation concerning drainage system management, the high rainfall conditions at the research location, as well as the frequent occurrence of flooding in the area and its prioritization for flood management by the Bekasi City government, a 5-year return period was selected [9]. The results of the rainfall distribution fitting analysis show that the rainfall data in this area conforms to the Log-Pearson Type III distribution. The design rainfall with this distribution for a 5-year return period is 267.87 mm.

3.4. Drainage Model Development

The first step is subcatchment delineation, which is based on land elevation and runoff movement during rainfall events [16]. The analysis resulted in the division of the area into 30 subcatchments. Based on field observations, the study area is predominantly characterized by impervious surfaces. Almost the entire area of RW 02, Kotabaru Village, consists of residential areas and roads with minimal vegetation. This results in a higher impervious value compared to the pervious value in the area analysis [17].

Next, the drainage network model is created in the EPA SWMM software. The parameters used include subcatchment (SC), junction (JC), conduit (C), outfall (O), rain gauge (R), and time series. The drainage network modeling in RW 02, Kotabaru Village, results in 30 subcatchments, 126 junctions, 168 conduits, and 1 outfall. The drainage network model for the RW 02 area of Kotabaru Village can be seen in **Figure 2**.

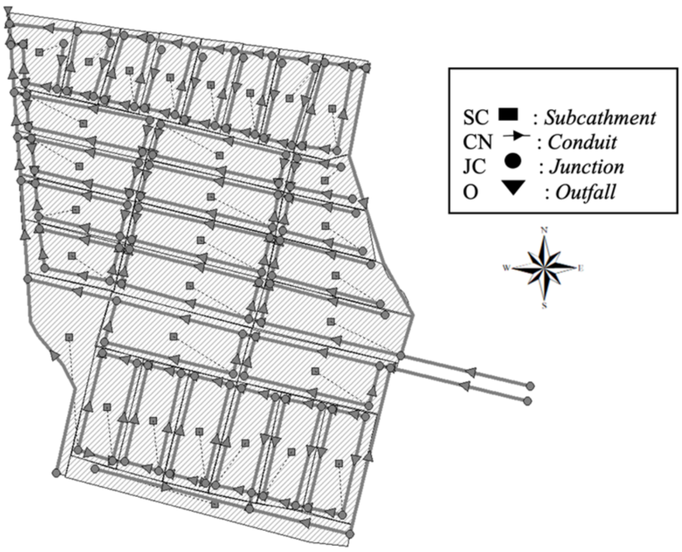

Figure 2. Drainage network model

3.5. Time Series Rainfall Analysis

Time series rainfall analysis was conducted using the design rainfall, which was determined using the Log-Pearson Type III distribution with a 5-year return period and a rainfall depth of 267.87 mm/day. The simulation used the average 10-year rainfall distribution occurring over a 24-hour period. After calculating the hourly rainfall distribution, the data was input into the model as a time series. Based on the rainfall distribution calculations, the rainfall distribution values show fluctuations, with the peak rainfall occurring at hour 5, amounting to 27.39 mm. The results of the rainfall simulation in the form of a time series can be seen in **Figure 3**.

3.6. Drainage Network Model Simulation

The drainage network simulation for RW 02, Kotabaru Village, also considers inflow entering the study area. This inflow is input at JC1, JC77, and JC83. This flow represents runoff generated outside the study area but flowing into the drainage channels within the study area. The inflow discharge is 0.32 m^3/s to JC1, 0.04 m^3/s to JC77, and 0.10 m^3/s to JC89. Additionally, this simulation considers flow from the Cakung River Catchment, given that the study area is located beside the Cakung River and the outlet of the study area's drainage channels also discharges into the Cakung River. The discharge in the Cakung River is calculated using the Rational method, multiplying the upstream catchment area by the calculated rainfall distribution and the runoff coefficient. The peak flow discharge, occurring at the 5th hour of rainfall, is calculated to be 31.01 m³/s.

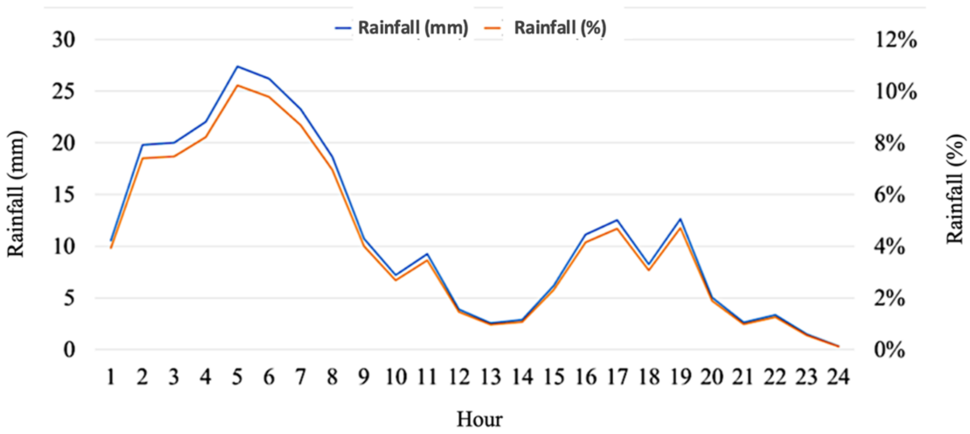

Figure 3. Rainfall time series distribution

The results of the drainage network model simulation can be seen in **Figure 4**, showing the condition of the subcatchments, nodes, and channel capacities at the peak rainfall hour, which is hour 5. There are 5 channels experiencing overflow, indicated by the channels colored in red, one of which is a river channel. The overflowing channels are CN97, CN100, CN101, CN102, and CNS2. The red color represents channels that are overflowing or exceeding their capacity. The largest maximum discharge in the residential channels occurs at CN97, with a value of 0.56 m³/s.

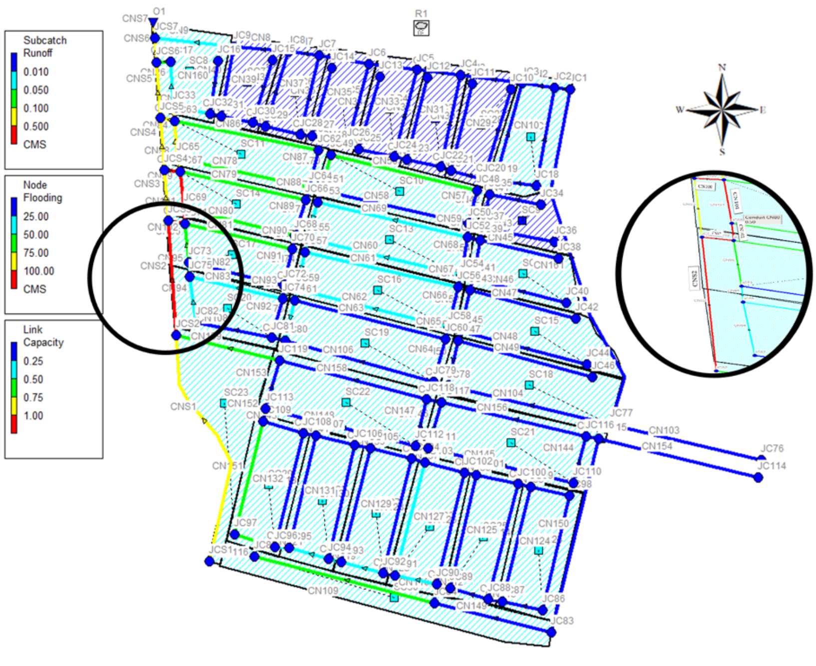

Figure 4. Drainage network model simulation results at peak rainfall hour

When compared to the channel capacity of 0.98 m³/s, this channel (CN97) should not be overflowing. However, because channel CN97 flows directly into the river, and the river is experiencing overflow during the peak hour, channel CN97 is unable to discharge into the river, causing it to overflow. As for the river flow, the highest discharge occurs in the channel leading to the outlet, CNS7. This is due to the combined flow from upstream in the Cakung River and runoff from the residential area.

Based on the channel profile analysis and the simulation conducted in EPA SWMM 5.2, the cause of flooding at the research location is due to the river overflowing, which prevents the residential drainage channels from discharging into the river. Field observations indicate that there is a significant amount of garbage and vegetation in both the river and residential channels, which also obstructs the flow. Additionally, the Cakung River is suspected to have sediment buildup, indicated by the turbidity of the water flowing in the river. Therefore, improvements are necessary to address the channel problems.

3.7. Drainage Channels Evaluation

After modeling and simulating the existing drainage network in RW 02, it was found that four residential channels and one river channel were overflowing. When examining the drainage channel profile simulation using EPA SWMM 5.2, it is evident that the residential channels overflowed due to a queue of flow entering the Cakung River as a result of the Cakung River's full capacity, causing water to back up in these channels and leading to overflow. The capacity analysis shows that the simulated discharge is smaller than the channel capacity, indicating that the residential channels are safe if the Cakung River discharge does not overflow. A comparison of channel capacity and simulated discharge can be seen in **Table 3**.

The capacity of CNS2 is equal to the simulated discharge entering that channel, causing the channel to become full and resulting in inundation. Therefore, an evaluation was conducted by performing dredging to increase the channel depth. For the Cakung River, dredging was performed to a depth of 1.5 m. The results of the improvement simulation show that the channels that were colored red (full) changed to green, indicating that water can flow safely without overflowing and creating inundation. The calculation results of channel capacity and simulated discharge before and after improvement can be seen in **Table 3**.

Table 3. Calculation results of channel capacity and simulated discharge

Channel	Existing condition			Improvement condition		
	Simulated discharge (m^3/s)	Channel capacity (m^3/s)	Dimension, H x B (m)	Simulated discharge (m^3/s)	Channel capacity (m^3/s)	Dimension, H x B (m)
CN97	0.56	0.98	0.60 x 0.40	0.12	0.98	0.60 x 0.40
CN100	0.38	1.09	0.60 x 0.40	0.03	1.09	0.60 x 0.40
CN101	0.21	0.23	0.60 x 0.40	0.02	0.23	0.60 x 0.40
CN102	0.24	0.27	0.60 x 0.40	0.02	0.27	0.60 x 0.40
CNS2	44.01	44.01	3.00 x 7.00	46.72	75.31	4.50 x 7.00

The discharge of channel CNS2 before improvement, based on the EPA SWMM simulation, was 44.01 m^3/s. After implementing improvements by deepening the channel, the simulated discharge changed to 46.72 m^3/s. This indicates that the channel, which was initially unable to accommodate the runoff discharge from the residential area, is now able to accommodate the runoff discharge after the improvements. Therefore, this demonstrates the need for channel improvements through dredging. In addition, it is necessary to remove sediment, garbage, and vegetation from the Cakung River and the channels in the RW 02 area. The results of the drainage network model simulation after improvement can be seen in **Figure 5**, and the cross-section of CNS2 (Cakung River) can be seen in **Figure 6**.

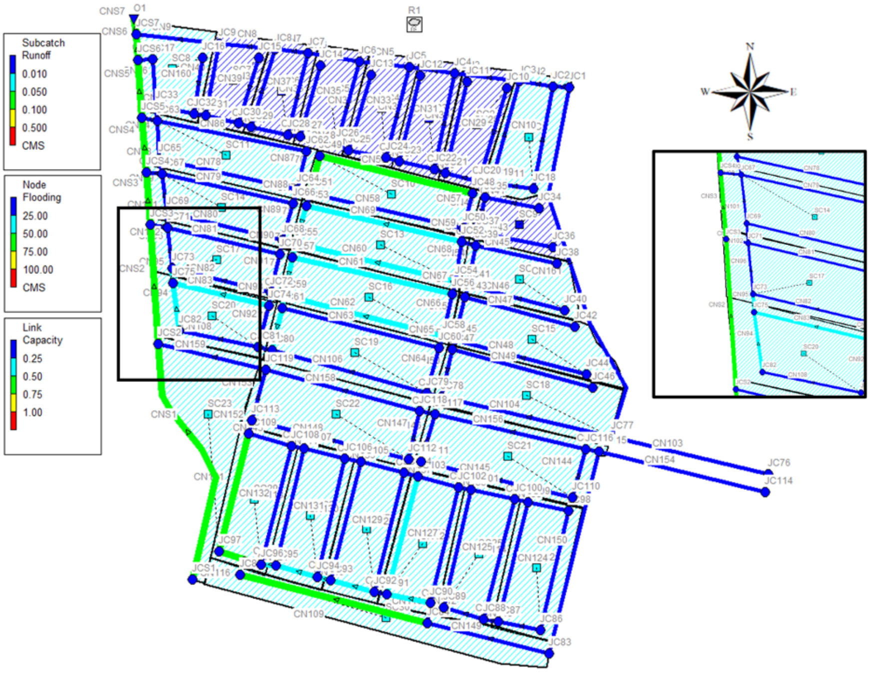

Figure 5. Drainage network model simulation results after improvements at peak rainfall hour

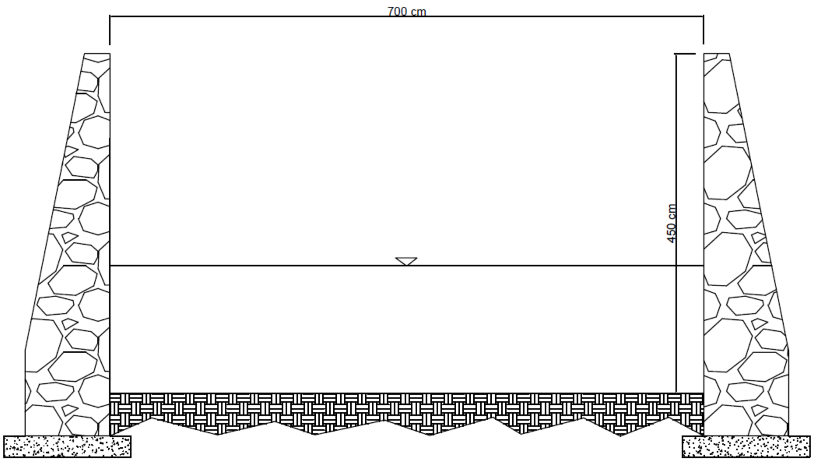

Figure 6. Cakung river cross-section after improvements

4. Conclusion

The drainage simulation results for RW 02, Kotabaru Village, using EPA SWMM 5.2, showed 5 channels highlighted in red, indicating insufficient capacity. Based on the channel profile analysis, the channels overflowed due to a queue of flow towards the Cakung River. The capacity analysis also showed the same result. The simulated discharge and the capacity of the Cakung River before improvements were the same, at 44.01 m^3/s. Channel improvements were focused on the Cakung River, increasing the depth from 3 m to 4.5 m while maintaining the width of 7 m. The simulation results show that after the improvements, the Cakung River and the residential channels exhibit good performance (indicated in green), without overflows or inundation. The simulated discharge and river capacity increased to 46.72 m^3/s and 75.31 m^3/s, respectively, indicating that the channels, which were initially unable to accommodate the runoff discharge from the residential area, are now able to accommodate the runoff after the improvements.

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