P. ISSN 2527-9629, E. ISSN 2548-6675
JOURNAL OF ENVIRONMENTAL ENGINEERING AND WASTE MANAGEMENT
In Collaboration With:
Managed by Environmental Engineering Undergraduate Program, School of Engineering, President University, Jl. Ki Hajar Dewantara. Kota Jababeka, Cikarang Baru, Bekasi 17550 – Indonesia.

Analysing the drainage system using epa swmm 5.1 (study case: jababeka ii industrial, cikarang baru, bekasi regency)

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Manuscript History

Received
15-09-2020
Revised
17-10-2020
Accepted
11-12-2020
Available online
15-12-2020

Keywords

flooding;
swmm 5.1;
drainage;
rainfall

Abstract. Due to the data in 2030, the urban growth in developed countries is 83%, and developing countries is 53%. Jababeka II Industrial Estate is one of the urban industrialization located at Bekasi Regency. In its development, the consideration of drainage facilities is one thing that needs. Because with its function as a channel that carries runoff water to rivers/lakes/reservoirs to avoid flooding. **Objectives:** This study aimed to know the existing condition of the drainage system and the water balances in the form of runoff in Jababeka II Industrial Estate by the simulation of SWMM 5.1. **Method and results:** The process of this research used a quantitative method, and the data collection method used secondary data, include the information from existing drainage system with precipitation event in 12 years (2009-2020) are obtained from the WTP Jababeka Residential, drainage dimension, and masterplan of Jababeka II. To calculate rainfall planned used a fifth-year return period based, it's on the city's classification under study. The probability distribution method uses Log-Pearson III with a planned rainfall of 128.22 mm/d and the highest rainfall intensity of 54 mm. Based on the simulation results, it was found that the Jababeka II Industrial Estate contained puddles in several channels. The peak was at the 3rd hour of the simulation, which were 19 channels. It's influenced by the type of soil that is quickly saturated. **Conclusion:** The simulation of the existing condition at Jababeka II has the highest runoff at the 2nd hour of simulation, and floods occurred in 19 channels. It's affected by the impermeable sub-areas. The water balance result is the amount of precipitation 128.22 mm with the intensity is 54mm due to 5 years of forecasting, thus producing the outflow is 128.511 mm. Therefore the number of continuity errors of a surface is -0.227%.

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1 Introduction

Human activities significantly disrupt the natural hydrological cycle's quantitative and qualitative parameters. The statistics data are shown data 83% of developed worlds and 53% of developing societies predicted to live by 2030 in urban areas. Urban growth continues to occur in developing countries on broad spatial scales, with whole cities often built in a short time [1]. This change affects the function of the land where the water absorption area is reduced. The waterways' number and dimensions changed so that water infiltration reduces, and flooding is commonly occurring [2]. The UNESCO Press Paris in 1974 has mentioned the industrialization include in urbanization [3]. It can be considered human activities involving changes in land tenure and land use resulting from rural land conversion to industrial use and urban, suburban, and industrial communities. Surface runoff directly can convert from more than 40% of rainfall in urban areas with more than 50% of impervious surfaces 4]. Thus, a drainage system must be supported to prevent flooding due to flow exceeding the channel capacity.

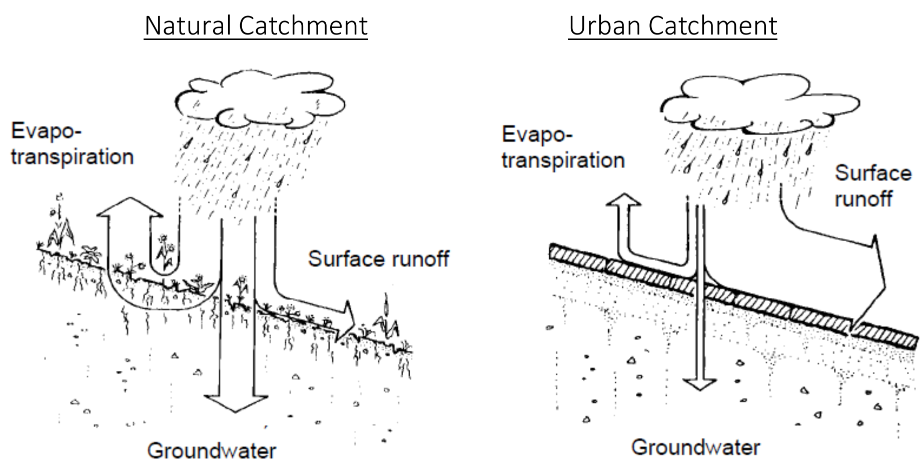

Fig 1.Volumetric hydrological process diagrams for natural catchment and urban catchment [5].

Jababeka Industrial Area, located in Bekasi Regency, is urban industrialization, which continues to grow. Therefore it is necessary to update the existing channel system periodically. According to Urban Cikarang news, Jababeka II Industrial Estate are frequent annual floods occur. The worst floods happened at the beginning of 2020, where floods were inundated as high as 20 – 150cm [6].

SWMM 5.1 is an application from the US EPA, which mainly consists of hydraulic and hydrology components that are very easy to use for the community to choose most often used by the professionals to do flood modeling on drainage channels. The runoff component of SWMM 5.1 operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. It transports through the channels ended up in storage/ treatment/ any outfall devices depend on the needed. SWMM 5.1 can track the quantity and quality of runoff generated within each subcatchment. The flow rate, flow depth, and water quality in each pipe and channel during the simulation period comprised multiple time steps.

This study analyzes the drainage channels in the Jababeka II Industrial Estate at a time of maximum rainfall for the last 12 years. Thus, this research has two purposes knowing the Jababeka II Industrial Estate water balances in the form of runoff during the simulation and knowing the flood occurred in the existing condition of drainage system using a simulation of SWMM 5.1.

2 Method

2.1 Research Location

The research was carried out from May to July 2020 during the dry season, located at Jababeka II Industrial Estate, Cikarang Baru, Bekasi Regency (Figure 2). The drainage system is used to collect rainwater and go to Cilemahabang River. The channel's location is along the shoulder side of the road with several dimensions that depend on the elevations.

Fig 2.The area of research location, Jababeka II Industrial Estate

2.2 Population and Sample

Population and sample are an essential part of a study where a community is a unit of individuals or subjects in the area and time with a certain quality. The research sample is part of the people used as the research subject as a representative of the population [15]. In this study, the community is the drainage system from the entire Jababeka Industrial Estate. At the same time, the sample used is the drainage system in the Jababeka II Industrial Estate with a maximum daily rainfall for 12 years, 2009 – 2020, as measured in the sample. Sampling using the purposive sampling method or judgment sampling is the choice of participants who deliberate because of the participants' quality and criteria. It's a non-random technique that does not require an underlying theory or some participants but is based on the researcher's sample criteria to achieve a specific goal [14]. Based on this study's standards, the sample taken was determined by the frequent flooding in the Jababeka Industrial Area and the maximum rainfall over the last ten years.

2.3 Tools and Materials

This study uses secondary data collection methods, which are collected from Jababeka WTP Residential. They are channel dimension, the water flow direction, topographic maps, masterplan of Jababeka II Industrial Estate drainage system, and the daily rainfall intensity data from 2009 – 2020. The tools used during this research were a laptop, stationery, calculator, Google Earth software, TCX Converter, Quikgrid, QGis, AutoCad, and SWMM 5.1.

2.4 Research Procedure

In the research procedure, there are several steps to get the data. They are frequency analysis of hydrological data, rainfall distribution, discharge channel capacity calculation, and the % impervious and %pervious [16]. The frequency analysis of hydrological data is the value of rainfall planned or equal to the definition of maximum probability of rainfall intensity with forecasting in the next few years, where it depends on the requirement. Then the result will be times with rainfall distribution according to the previous research. And the final product will become the time series. Continue to calculate the discharge capacity using manning's equation.

After getting the time series and the flowrate of discharge capacity, determine the %impervious and %pervious.

Below are the following data processing procedures were applied:

a. Frequency Analysis of Hydrological Data

i. Frequency Distribution Selection

This distribution has four types, are Normal Distribution, Log-Normal Distribution, Gumbel Distribution, and Log-Pearson III Distribution, which were commonly used for hydrology [17]. The aim to determine whether the choice of the frequency distribution method used can be accepted or rejected based on the frequency analysis of statistics parameter tests, which are skewness coefficient (Cs) and kurtosis coefficient (Ck). The distribution selected for this research is Log Pearson III that complied with the criteria.

ii. Testing the Suitability of Frequency Distribution

The frequency distribution that set should be tested using the suitability of frequency distribution testing. There are two distribution tests: the first is the chi-square test (1) and Smirnov-Kolmogorov (2) [18].

$$X^2h = \frac{\sum_{i=1}^{Q}(O_i - E_i)^3}{E_i} \quad (1)$$

$$D = maximum\ |F_s(X) - F_t(X)| \quad (2)$$

b. Rainfall intensity

The planed rainfall value can be calculated after determining the frequency distribution to be used. Nevertheless, SWMM 5.1 claims that the rainfall value is a constant value that uses time series to continue over a given recording period for rainfall measurements. So what is calculated in the other SWMM 5.1 time-series is between the reported values [11]. In this case, the rain distribution value derived from the literature can be used as a time series for modeling [13].

c. Discharge Channel Capacity

Data needed for the addition of discharge outflow (initial flow) from the runoff into the channel uses Manning's equation (3) [8]:

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

$$\mathrm{Q} = \mathrm{A} \times \mathrm{V} \quad (4)$$

Where :

Q = flow rate (m^3/s)
A = channel cross-section area (m^2)
V = velocity (m/s)
R = hydraulic radius (cross-section area divided by wetted perimeter) (m)
S = slope of the channel at the point of measurement (%)

d. Determining the %impervious and %pervious

To determine the percent of impervious and pervious values, analyze from the location map. As mentioned from SWMM 5.1 Modul, subcatchment is an area of land comprising a mixture of pervious and impervious layers, the runoff of which drains to a specific outlet site. Surface runoff may permeate but not through the impermeable sub-area into the pervious sub-area's upper soil zone. Impermeable areas are themselves divided into two sub-areas-one that includes depression storage and one that does not. Storage depressions are used for water reservoirs in the field that are permeable to infiltration in subsequent periods. Depression storage is rainwater that stagnates in impermeable soil until it evaporates. The percentage of impervious areas inside the subcatchment is except depressions in storage [11]. Equation numbers 5 and 6 are the formula to get impermeable and permeate percentage values.

$$\%\text{impervious} = 100\% \text{ x } \left(\frac{\text{impervious area}}{\text{total area} - \text{LID area}}\right) \tag{5}$$

$$\%\text{pervious} = 100 - \%\text{impervious} \tag{6}$$

The method of infiltration calculation used for modeling is the Horton method. Based on the interpolation of observations, the infiltration decreases exponentially from the initial maximum to the minimum rate during extended rainfall. The required parameters include the maximum and minimum infiltration rate, the decay coefficient, which describes how fast the rate of decay over time, and the time it takes for the saturated soil to dry again completely. After ensuring that all the required data is entered into the modeling process, the modeling can be started [11].

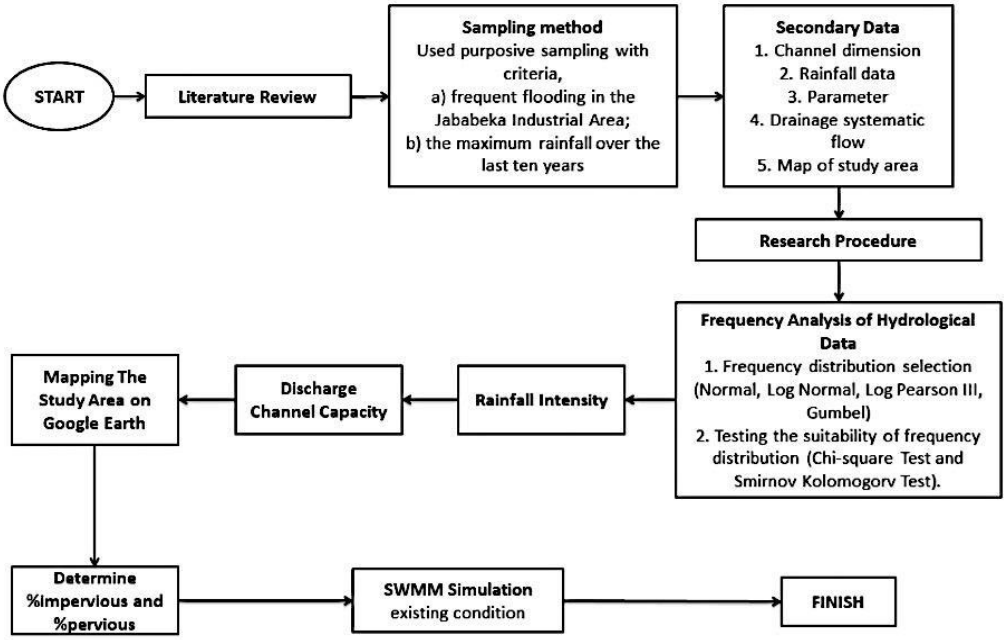

Fig 3.Research Framework

3 Result and Discussion

3.1 Study of General Condition of The Location (Jababeka Industrial Estate II) in The Research Framework

Jababeka II Industrial Estate is part of the PT Jababeka Industry, divided into several regions. Jababeka II is ± 172 ha, and the average height of 24 meters above sea level due to the masterplan area and google maps. Land use status at the research site is dominated by industrial buildings and several settlements around the area. Two problems occur in Jababeka II Industrial Estate, first is due to a small size of absorption caused by the limited green surface, shown in Figure 6. Lastly, because Jababeka II has saturated soil, which easy to be watered, this affects the earth's character at the time of infiltration due to observation results.

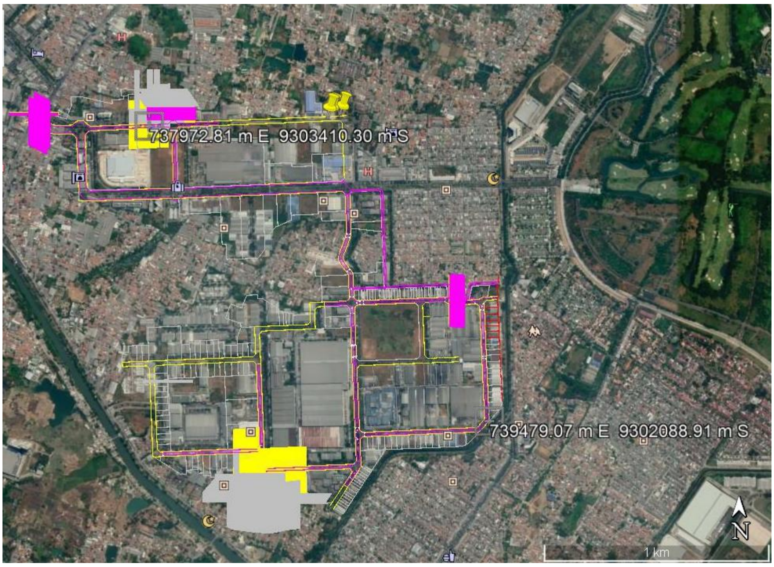

Fig.4. Georeference the masterplan of Jababeka II Industrial Estate into map; Google Map.

3.2 Result of Frequency Analysis of Hydrological Data

Rainfall analysis is carried out using daily rainfall data from 2009 to 2020, belonging to the WTP Jababeka Residence. Plan rainfall is calculated based on the 12-year daily rain, as shown in Table 1.

Table 1. Maximum daily rainfall data at WTP Station for 12 years.

Year	Maximum Rainfall (mm)	Year	Maximum Rainfall (mm)
2009	83.00	2015	66.50
2010	95.20	2016	129.00
2011	79.70	2017	120.00
2012	109.70	2018	75.00
2013	105.00	2019	120.00
2014	184.00	2020	175.00

In the hydrological analysis, a frequency analysis is used to estimate the maximum probability of precipitation during a given period. The frequency analysis results serve as the basis for calculating the anticipation of any likelihood of occurrence. Rainfall data from rainfall recording stations around or near study sites are hydrological data required for drainage design [12]. Frequency analysis can be carried out using four probability distribution methods shown in Table 2 along with 2, 5, 10, and 50-year rainfall and return period.

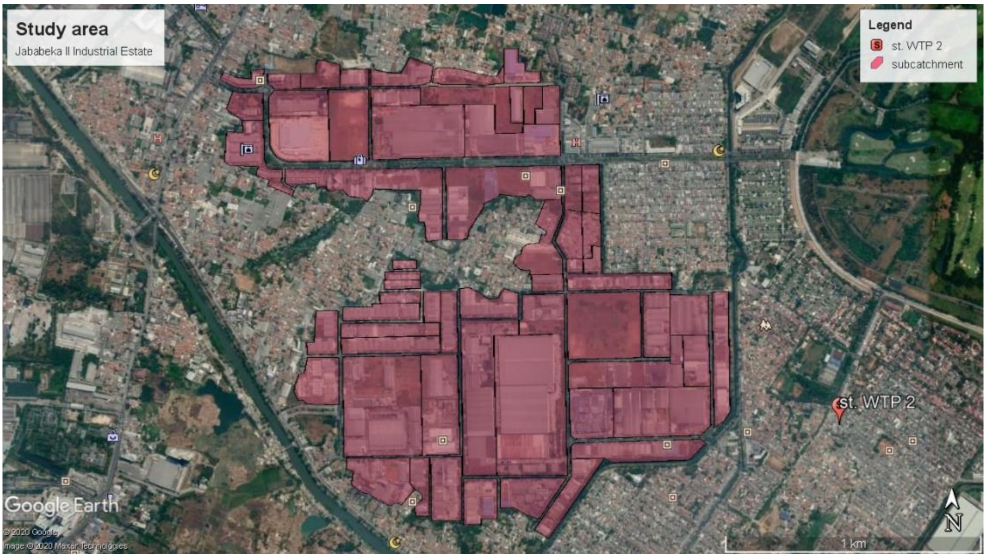

Fig.5. The location of station rainfall around the study area.

Table 2. The results of the rainfall distribution of the WTP Station plan.

Return Period	Rainfall Plan (mm)			
	Normal	Log Normal	Log Pearson III	Gumbel
2	111.83	100.28	98.37	106.78
5	143.08	129.19	128.22	151.19
10	159.45	147.52	149.08	180.59
50	188.11	186.07	198.17	245.30

The time scale used to calculate the planned precipitation is 2, 5, 10, and 50 years. Return time is the estimated time at which a certain amount of rain is equal or exceeded. Table 2 shows the calculation of each distribution method's planned precipitation value having different values so that conformity testing with the nature of each distribution type is needed. It's done by reviewing the boundary parameters for each statistical parameter. The statistical parameters were used based on Cs and Ck values, respectively. A comparison of the probability distribution parameters can be found in Table 3. The results of the calculation of the Chi-Square Log Pearson III distribution are shown in Table 4.

Table 3. The result of the statistic parameters [9].

No	Frequency Distribution Types	Cs	Ck	Criteria	
				Cs	Ck
1	Normal	0.91	0.16	Cs ≈ 0	Ck ≈ 3
2	Log Normal	0.68	0.43	Cs = 0.43	Ck = 3.33
3	Gumbel	0.91	0.16	Cs = 1.14	Ck = 5.4
4	Log Pearson III	0.68	0.43	Apart from the above	

The chi-square test requirements can be accepted if the X2 value in the calculation results is less than the X2 value in the Chi-squared test table. Based on the products shown in Table 4, the resulting X2 value is 3.83, while the Chi-Square X2 test table is 5.991. It was concluded that the method of distribution of the Pearson III Log was used. The precipitation value used in the simulation shall be 128.22 mm/d with a return based on Regulation No 12/PRT/M/14 of the Minister of Public Works concerning the implementation of the 5-year urban drainage system [10].

Table 4. Chi-Square Log Pearson III Distribution testing results.

Class	Interval	Oi	Ei	Oi - Ei	$(Oi – Ei)^2$	$(Oi – Ei)^2/Ei$
1	51.81 - 81.19	3	2.4	0.6	0.36	0.15
2	81.19 - 110.57	4	2.4	1.6	2.56	1.07
3	110.57 - 139.94	3	2.4	0.6	0.36	0.15
4	139.94 - 169.3	0	2.4	-2.4	5.76	2.40
5	169.3 - 198.68	2	2.4	-0.4	0.016	0.07
		Total X^2				3.83

3.3 Result of Rainfall Intensity Calculation

The hourly rainfall distribution was used based on the distribution obtained by Fajri (2009)[13], as shown in Table 5. The value of rain distribution is used as a bulk time series plan for SWMM 5.1 model. The first hour has the highest percentage of the peak hour simulation to have a significant runoff potential.

Table 5. Distribution of the intensity of precipitation event

Time (h)	0	1	2	3
Rainfall distribution (%)	0	42.35	39.51	18.14
Rainfall plan (mm)	0	54	51	23

3.4 Result of Hydraulic Analysis on Existing Channels

The hydraulic analysis is carried out to determine whether the planned drainage system is following the requirements. This analysis includes the calculation of existing channel capacity and channel planning. Table 6 shows the results of the hydraulic study.

Table 6. Result of the analysis of discharge existing channel capacity

Name of channel	Area (A) m2	Wetted Perimeter (P) m	Hydraulic Radius (R) m	Velocity (V) m/s	Discharge Existing Channels (Qs) m^3/s
C1	1.51	3.65	0.414	0.490	2.67
C2	1.51	3.65	0.414	0.490	2.67
C3	1.90	3.98	0.478	0.540	3.699
C4	2.16	4.22	0.513	0.565	4.41
C5	2.13	4.18	0.509	0.563	4.32

The following Table 7 presents the results of the analysis of hydraulic discharge and hydrological discharge for the five year return period. The hydraulic analysis results are accepted because the hydrological capacity is smaller than the hydraulic capacity.

Table 7. The analysis of channel planning capacity

Name of channel	$Q_{hydrology}$		Discharge Existing Channels (Qs)	$Q_{hydrology} < Q_{hydraulic}$
	Return period	m^3/s	m^3/s	m/s

C1	5	0.092	2.67	accepted
C2	5	0.101	2.67	accepted
C3	5	0.180	3.699	accepted
C4	5	0.101	4.41	accepted
C5	5	0.246	4.32	accepted

3.5 %Impervious and %Previous

Table 8 shows the subcatchment parameter values, which consist of areas of subcatchment, length, and size. This width came from an average of the total length, percent of the impervious and pervious area. The value of the impervious percentage depends on the impermeable site on subcatchment. Other than that, it also represents the result comparing the subcatchment area with impermeable subarea.

Table 8. Subcatchment parameter modelling data

Name	Area (ha)	Length (m)	Width (m)	Pervious (%)	Impervious (%)
SUB 1	0.63	180.32	35.87	4.98	95.02
SUB 2	0.68	137.47	38.71	11.79	88.21
SUB 3	1.21	151.24	68.89	71.56	28.44
SUB 4	0.68	110.24	38.71	25.16	74.84
SUB 5	1.65	245.6	93.94	19.92	80.08

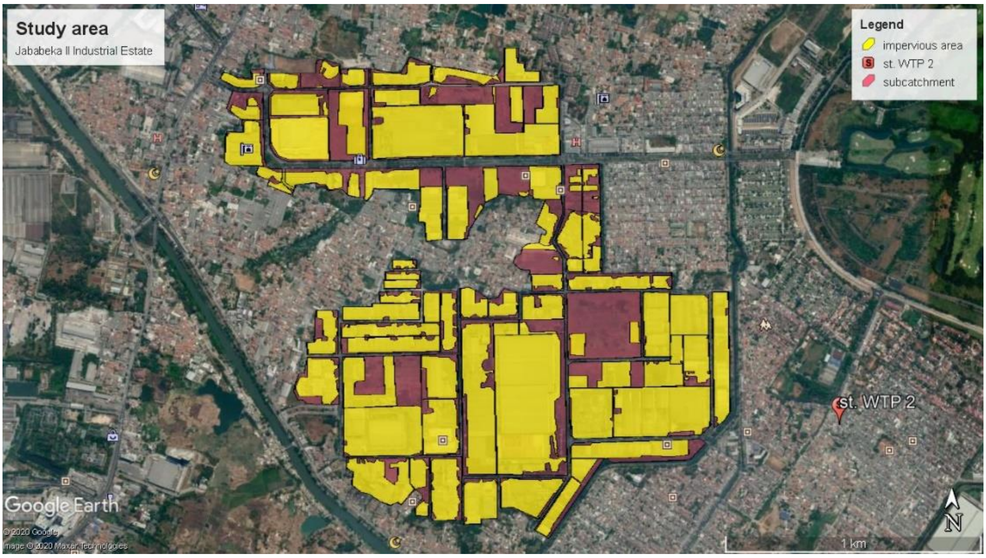

Fig.6. The impervious area condition in subcatchment. (yellow color is impermeable sub-area and purple color is subctachment area)

3.6 The Analysis of Simulation Model

The drainage simulation network in the study area was carried out using SWMM 5.1. The hydraulic building software illustrated in the model carried out, and the form of the hydraulic buildings are subcatchments, junction nodes, duct links, and outfall nodes, based on data obtained from observations made by Google Earth and the Master Plan. The simulation is done for six days or 144 hours, and the numbers of hydraulic buildings in the study area are 77 subcatchments, 128 nodes, 126 conduits, and three outfall nodes. The research has the limitation: there are no channels outside the region entering the channel area, and that the river water's surface is below the body under the drainage.

Status report from the simulation showing the continuity error value is 8.98% for flow routing and -0.23% for surface runoff. SWMM 5.1 simulations have a validity number of continuity errors of less than 10%. If more than 10%, then the simulation analysis must be doubted [11]. The results of the change can, therefore, be accepted.

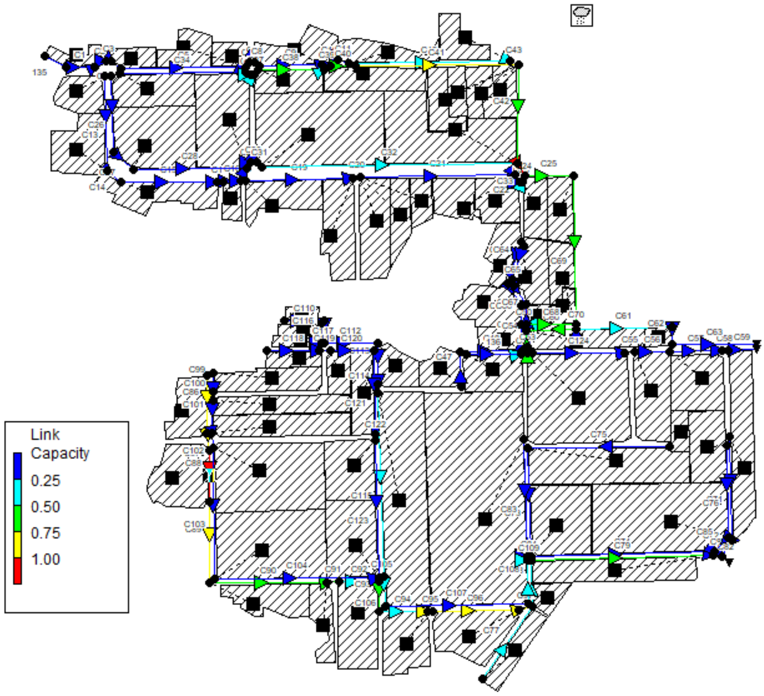

Fig.7. Simulation of drainage system models and study area flow patterns in the first hour.

The models and Figure 7 show the results of simulation of Jababeka II Industrial Estate using SWMM 5.1 on the first hour with the arrow as a direction of water flow that happened in the channel. The needle has color represent the drainage condition. Red color means an overflow in the track where the runoff discharge exceeds the channel's discharge capacity. Whereas in Figure 8, there is a simulation of the second-hour drainage network model. There are additional flood channels, namely C12, C25, C33, C36, C37, C40, C41, C42, C54, C55, C68, C69, C88, C96, C97, C103, C114, C115, and C123. As shown in Figure 9, the runoff water will peak in the second hour. In the time series case, this is influenced by the soil nature area and the second factor of flooding in which the soil type is saturated. So that in the first hour, the land is dry. The ground can then absorb rainwater, but in the next hour, the soil will be saturated and become runoff water.

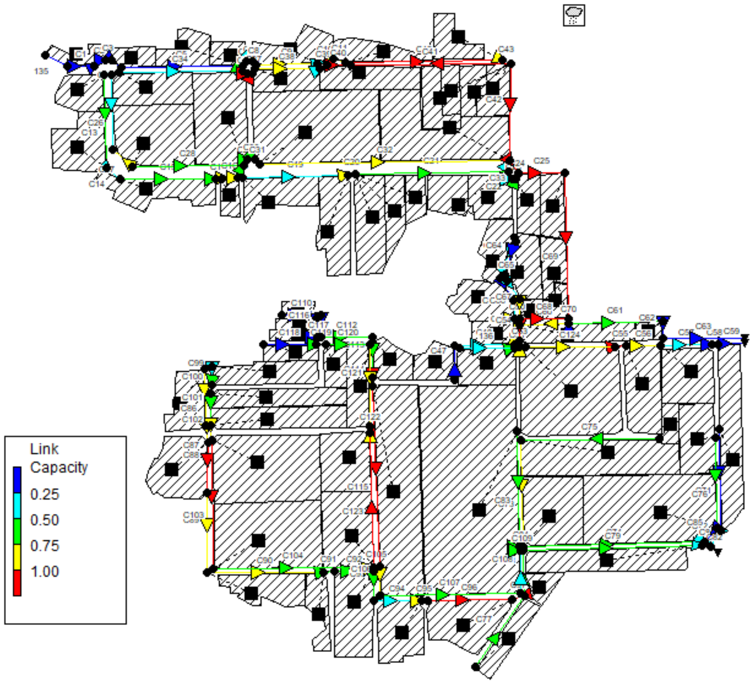

Fig.8. The second-hour simulation of drainage network models and research region flow patterns.

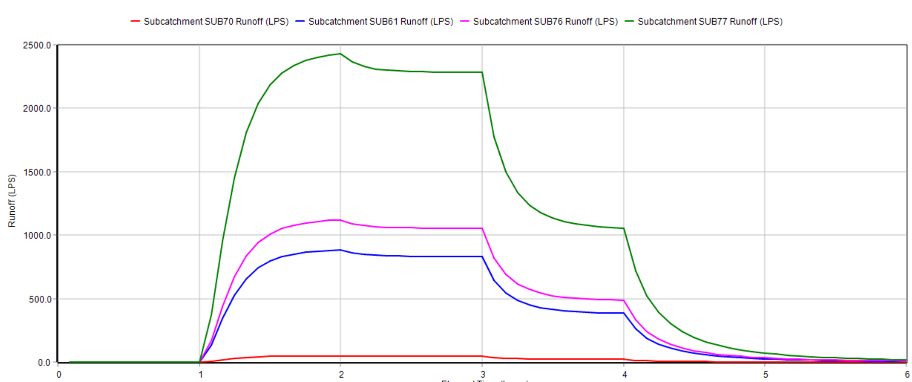

Fig.9. The graphic of runoff on the elapsed time.

The graphic from Figure 9 is shown the condition that happened for 6 hours. There are four subcatchments taken as the representative of runoff during the simulation. Green-line is the highest than the others following to the area of subcatchment, while the red-line is the lowest because the site is the small as well, for blue and purple-line are taken from random subcatchment. However, the whole four lines have the same graphic shape. Even the area of subcatchments is different, where it shows that the amount of runoff has a linear relationship with the subcatchment area.

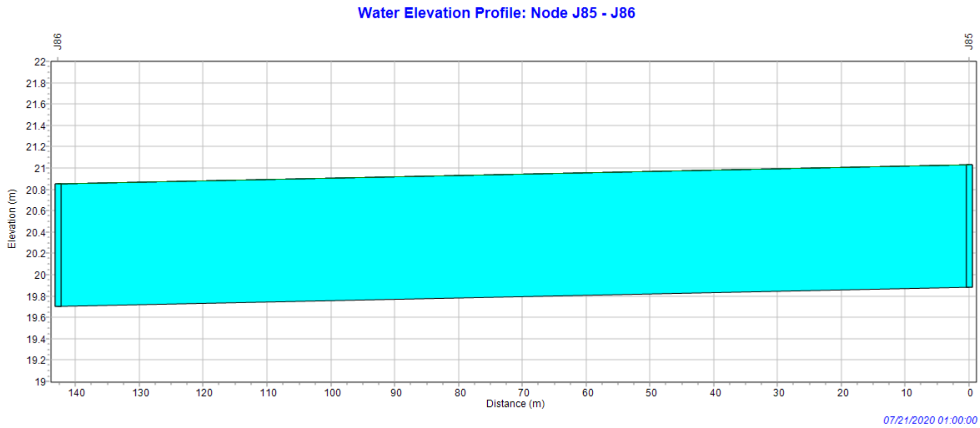

Fig.10. The condition of C88 profile of channel traffic.

Figure 10 shows the state of the C88 channel flooded due to the amount of runoff discharge so that the channel's capacity is not enough—the same as in Figures 6 and 7 for the red channels.

Table 9. The status report of runoff from the simulation

Runoff Quantity Continuity	Volume Hectare (m)	Depth (mm)
Total precipitation	37.088	128.220
Evaporation loss	0.000	0.000
Infiltration loss	0.315	1.089
Surface runoff	30.078	103.985
Final storage	6.779	23.437
Continuity error (%)	-0.227	

According to the current condition result, it can be seen that there is an imbalance in the water balance then resulting in flooding. The water balance of SWMM 5.1 is interpreted by a percentage of a continuity error, where it represents the differences between initial storage + total inflow and final storage + total outflow. Table 9 has shown the status report from simulation results in Jababeka II Industrial Estate, with the number of precipitation is 128.22 mm. As a result, the continuity error for surface runoff is -0.227% came from total outflow that consists of rain rather than divided with total inflow consisting of evaporation, infiltration loss, and surface runoff, and final storage. The number of precipitation came from the rainfall planned (mm), which is the water source that enters the study area. Meanwhile, the evaporation, infiltration loss, and surface runoff are the sources of runoff water.

4 Conclusion

The simulation carried out in Jababeka II Industrial Estate using SWMM 5.1, which showed that the highest runoff value occurs at the 2nd hour, which is influenced by a limited green surface. The total numbers of a channel that floods occurred during the 2nd hour are 19 channels with different channel sizes affected by land elevation. According to the water balances of rainfall planned, 128.22 mm, which is rainfall intensity 54 mm due to 5 years forecasting, and total outflow is 128.511 mm resulting continuity error of surface runoff is -0.227%.

5 Acknowledgment

Thank you to Dr. Ir. Yunita Ismail Masjud, M.Sc., who helped and guided through finish this research. As well as the WTP Jababeka Residence, who helped collect all data needed during this research. And also like to thank Mr. Rijal Hakiki S.S.T., M.T., which helped to do simulation modeling that could work well.

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