

*Regional Case Study***Hydrological and Hydraulic Analysis of Drainage System of Salamanmloyo Sub-district, Semarang, Indonesia****Anik Sarminingsih¹, Georgia Alma^{2*}, Winardi Dwi N¹**¹ Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Jalan Professor Soedarto, SH, Semarang, Indonesia 50275² Department of Computer Engineering, Universitas Diponegoro, Jl. Prof. Sudarto, SH, Tembalang, Semarang, Indonesia 50275, Semarang, Indonesia 50275*Corresponding Author, email: georgiaalma@students.undip.ac.id

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**Abstract**

Salamanmloyo, one of the sub-districts in West Semarang District, Semarang City, is a densely populated area with nearly all of its land built-up. Due to its location in the lower region of Semarang, it is vulnerable to flooding. Salamanmloyo has experienced floods and inundation due to insufficient pervious areas and inefficient drainage channels. This occurs when there is an imbalance between the drainage channel capacity and the discharge that needs to be handled, as well as when waste, sediment, and vegetation are present in the channel. As for the existing conditions in the Salamanmloyo Sub-district, no previous study regarding flooding and inundation has been conducted in this area. Therefore, it is necessary to conduct research and planning to determine the existing conditions of drainage channels, hydraulic and hydrological analysis results, and suitable SUDS types to decrease the flooding volume level. Hydraulic and hydrological analyses will be performed as a part of this planning, after which EPA SWMM 5.1 modelling will be performed under four different conditions: current, maximum SUDS application, channel normalization, and channel re-design conditions. The outcomes of the SUDS planning were applied in the form of 497 units of infiltration wells and 16,345.6 m² of permeable pavement. SUDS implementation, drainage channel normalization, and redesign helped minimize the total flooding volume by 66.3%, from 231,456 m³ to 78,008 m³.

Keywords: Drainage; flooding; planning; Salamanmloyo Sub-district; SUDS, EPA SWMM 5.1**1. Introduction**

The provision of urban infrastructure and facilities in urban areas has positively impacted people's lives. One of the urban infrastructures that needs to be developed to support the lives of urban communities is drainage channels. A drainage channel is a facility that flows excess water from a catchment area to the recipient water body (Suripin, 2004). Owing to urbanization, the total runoff volume that flows into the system also increases. This is caused by land-use changes in urban areas. In densely populated urban areas, where almost all pervious land surfaces are replaced by impervious surfaces, the volume of water that cannot be absorbed increases. Therefore, excess water flow increases the load that must be discharged by the drainage channels.

Urban communities, infrastructure, and the environment are threatened by the continuous increase in surface runoff, which leads to flooding and inundation. Flooding occurs when the surface runoff volume exceeds the capacity of the drainage channel. In urban areas, drainage channels are often

found under unsightly conditions, resulting in reduced capacity. The degradation of drainage channel capacity is caused by the undesired presence of solid waste, sedimentation, and vegetation. Furthermore, drainage channels are often not properly designed to accommodate large surface runoff volumes resulting from land-use and climate change. Runoff travels across surfaces and then accumulates in low-lying areas until it eventually percolates, drains, or evaporates.

To reduce the risk of potential flooding and inundation, conventional drainage evaluations and various sustainable urban drainage system/low-impact development practices must be carried out. Therefore, simulation models are required to predict and visualize the flooding information (Babaei *et al.* 2018). In this study, the EPA SWMM 5.1 was used to evaluate the current drainage system and plan suitable SUDS practices. This research was conducted in the Salamanmloyo Sub-district, one of the sub-districts in West Semarang District, Semarang City. The area of 54 hectares is one where the main activities are in the economy and service sector. Almost 97% of its area is built on, and it lies in the flood-prone area of Semarang City. According to government data, there are some inundation spots with varying heights, ranging between 5 and 50 cm. The cause of inundation is not limited to the small pervious area but also includes topographical conditions and some drainage channels that cannot operate optimally. Suboptimal drainage operations are caused by disturbances from solid waste, sediments, and vegetation. Based on the conditions mentioned above, further analyses and research are necessary. This study aimed to evaluate the condition of the drainage channel and its capacity, determine the results of hydrology and hydraulic analyses, and determine the recommended design of the drainage system with SUDS practices that are suitable for the conditions of the planning area.

2. Methods

This research was conducted in the Salamanmloyo Sub-district, which is located in the West Semarang District, Semarang City. The data required for this study were classified into primary and secondary data. Primary data consist of existing drainage channel data (dimensions and material included) and data on inundation points that can be collected through interviews and observations. Secondary data consisted of rainfall data from Simongan Station, drainage channel data from the Department of Public Works of Semarang City, and data on the study location's characteristics, which were obtained from the Department of Public Works and Spatial Planning of Semarang City. Simongan Rain Station was chosen because according to the Semarang City Thiessen Polygon, Salamanmloyo Sub-district was included in Simongan Station Area and highly affected by this station. This research was conducted in three phases: existing condition analysis, hydrological and hydraulic analysis, and drainage system modeling in EPA SWMM 5.1.

During the existing condition analysis, the drainage channel dimensions and materials were collected. The dimensions were measured process is done using tape measures. In this phase, interviews were also be conducted with local residents to learn more about the flood and inundation that have occurred in the study area. The dimension data and material will be used later in the calculation of the existing drainage capacity. The next phase is hydrological and hydraulic analyses. In this phase, the rainfall data obtained from the Simongan Station were processed to obtain further values, such as rain frequency, distribution, and intensity. Gumbel Distribution Method is used in this research, with rainfall repetition period of 2 and 5 years. These two repetition periods were chosen by considering the size of catchment land area and comparing it to the design module from the ministry. In addition, a rainfall repetition period of 5 years will be used for primary drain planning, and a rainfall repetition period of 2 years will be used for secondary and tertiary drains. The formula used to calculate the planned rainfall distribution using the Gumbel method is as follows:

$$KS = \frac{Y_{Tr} - Y_n}{S_n} \quad (1)$$

Where:

X_T = Planned rainfall

- \bar{X} = Average of rainfall data
 Y_T = Reduced variate
 Y_n = Reduction factor for n-number of data
 S_n = Standard deviation for n-number of data
 S = Standard deviation

It is necessary to calculate rain intensity to determine the planned flood discharge in this planning. To calculate rain intensity, Mononobe method is used in this planning with the availability of daily rainfall data. The Mononobe empirical formula is described below:

$$I = \frac{R_{24}}{24} \left[\frac{24}{t_c} \right]^{2/3} \quad (2)$$

Where:

- I : Rainfall intensity (mm/hour)
 R_{24} : Maximum rainfall (mm)
 T : Rainfall duration (hour)

After the hydrological analysis is carried out and rainfall intensity value is obtained, the hydraulic analysis is then carried out. The existing drainage channel capacity can be calculated from the dimensional and material data that were obtained from the survey. The planned flood discharge analysis was then calculated. The planned flood discharge analysis is carried out by rational method with reference to SNI 2415:2016. The formula to calculate the planned flood discharge is described below:

$$Q = 0,00278 \times C \times I \times A \quad (3)$$

Where:

- C : Runoff coefficient
 I : Rainfall intensity (mm/hour)
 A : Subcatchment's area (hectare)

In the analysis of planned flood discharge, the flood value of which are summarized with the domestic wastewater discharge. The domestic wastewater discharge calculation was done by calculating 80% of total water usage.

The last phase of this research is modeling drainage system using EPA SWMM 5.1. According to Semarang District Regulation No 7 of 2014, some of the models that can be carried out in SWMM are precipitation model, soil surface model, and groundwater modeling. In this phase, some scenarios will be carried out into the model, such as SUDS application, drainage normalization, and re-design.

3. Result and Discussion

3.1. Existing Drainage Conditon

Salamanmloyo Sub-district is located in West Semarang District, Semarang City. According to Semarang City Regulation No 7 of 2014, Salamanmloyo Sub-district belongs to Siangker River Sub-system. This planning area is a dense populated sub-district which is also productive for economic activity (office, shops, warehouses).

Based on the result of observation, it is know that some of the drainage channels in the study region cannot function optimally due to the deterioration of the channel's capacity. Channel's deterioration is caused by sediment, solid waste, and vegetation inside the channel. Another drainage related problem was found based on the interviews held with local residents. From the interview, it is known that there are a number of inundation with varying height, ranging from 5 to 50 centimeters. For example, inundation happened at Puspowarno X Street with 50 centimeters on its height. This interview data help to pinpoint the actual inundation places.



Figure 1. Existing drainage condition

3.2. Rainfall Data

For this research which located in Salamanmloyo Sub-district, The Simongan Rain Station is used to obtain rainfall data. Simongan Rain Station is located near Banjir Kanal Barat River. Rainfall data is required to calculate the annual maximum rainfall in the study area (Isotta et al., 2014). The used rainfall data is composed of 11-year data from 2013 – 2023. The highest daily rainfall occurred in 2015, which equivalent to 177 milimeters. To reduce the likelihood of over-design in drainage planning, Area Reduction Factor is used in this research. Based on the area of the study location, the ARF value equals to 0.99. The rainfall data used in this research is shown in the table below:

Table 1. Simongan rain station annual rainfall data

No	Year	Maximum Rainfall (mm)
1	2013	111
2	2014	125
3	2015	177
4	2016	98
5	2017	126
6	2018	123
7	2019	105
8	2020	139
9	2021	152
10	2022	92
11	2023	155

Furthermore, this rainfall data will be analyzed using the algebraic average method. The obtained average rainfall data will then be analyzed through frequency analysis to gain the planned rainfall value.

3.3. Frequency and Planned Rainfall Distribution Analysis

In this research, the Gumbel Distrubution Method is used to analyze planned rainfall distribution. The Gumbel Distribution can also be used to represent distributions of hydrological extreme values such as flood peak and maximum rainfall. Formula used in this analysis is displayed as Equation 1. The result of planned rainfall distribution is shown on Table 2 below.

Table 2. Planned rainfall distribution using the Gumbel Method

t	X	Yt	Yn	Sn	Xt
2	126.27	0.37			122.75
5	126.27	1.50			153.45
10	126.27	2.25			173.78
15	126.27	2.61	0.4966	0.9676	183.40
25	126.27	3.20			199.49
50	126.27	3.90			218.52
100	126.27	4.60			237.44

From the calculation results, it is obtained that the designed/planned rainfall for 2-years return period is 122.75 mm and for 5-years return period is 153.45 mm.

3.4. Goodness-of-Fit Test

The goodness-of-fit is conducted to determine whether the expected rainfall distribution agrees with the collected data or not. The Chi-Square test and the Smirnov-Kolmogorov test are used in this research. The Chi-Square test is performed to test the data against both a continuous and discrete distribution. Meanwhile, the Smirnov Kolmogorov test is used to test whether the data is distributed normally or not. The summary of goodness-of-fit test is shown in Table 3.

Table 3. Calculation result summary of Chi-Square Test and Smirnov-Kolmogorov Test

The Chi-Square Test			Smirnov-Kolmogorov Test		
X ² Count	<	X ² Critical	ΔP _{max} Count	<	ΔP Critical
0.073		0.575	0.07		0.391
Accepted			Accepted		

From the result of Chi Square Test and Smirnov-Kolmogorov Test above, it showed that the Gumbel Distribution planned rainfall data met the requirements for both goodness-of-fit tests. It is determined that the Gumbel Distribution was chosen as the most suitable distribution method for deriving the planned rainfall data. The Gumbel distribution planned rainfall data will further be used to carry out the planned rain intensity analysis.

3.5. Planned Rain Intensity Analysis

The calculation process of planned rain intensity was done using the Mononobe method, which described on Equation 2. This is due to the availability of rainfall data, which is the maximum daily rainfall data. As the area of the study site has a total area of 50 Ha, which belongs to the interval of 10 Ha – 100 Ha, and belongs to the large city typology, the rainfall repetition period of 2 and 5 years were used in this planning. The calculation result of the planned rain intensity analysis is shown in the table and figure below:

Table 4. Planned rainfall intensity calculation results

t (hours)	Rainfall Intensity (mm/hrs)			
	I ₂	I ₅	I ₁₀	I ₂₅
0.25	107.23	134.05	151.81	174.27
0.5	67.55	84.45	95.63	109.78
0.75	51.55	64.45	72.98	83.78
1.00	42.55	53.20	60.24	69.16

t (hours)	Rainfall Intensity (mm/hrs)			
	I ₂	I ₅	I ₁₀	I ₂₅
1.25	36.67	45.84	51.92	59.60
1.50	32.47	40.60	45.98	52.78

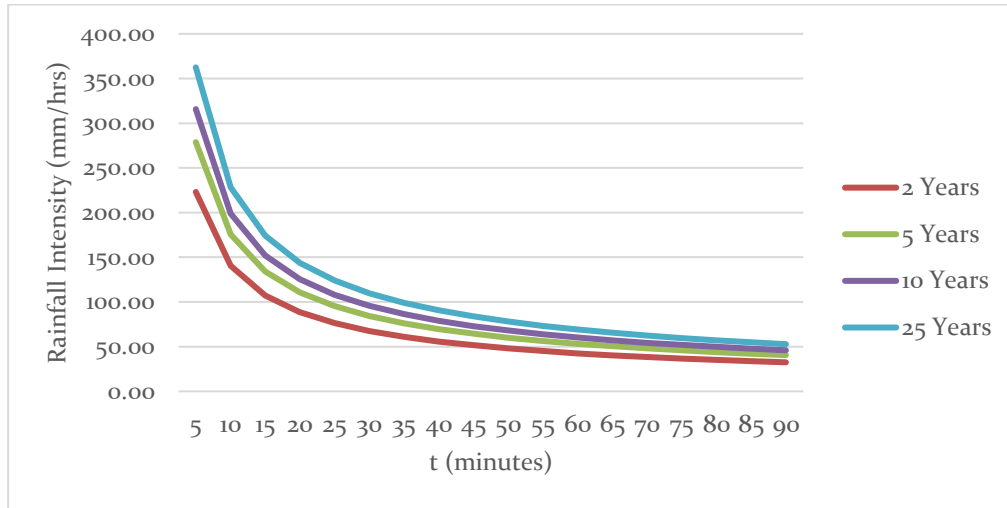


Figure 2. Mononobe IDF Curve

3.6. Existing Drainage Capacity Analysis

This analysis is conducted to find out the existing drainage capacity on the study location. The existing drainage capacity analysis is closely related to the Mononobe planned rainfall intensity, the area of the subcatchment, and the runoff coefficient which is based on the land use in the specified area. the capacity analysis is carried out using the flow formula which is done by multiplying the value of area and velocity. The area of drainage channel is determined by multiplying the channel's height and width. The existing drainage capacity analysis for Channel 1 until Channel 5 is displayed in the table below:

table 5. calculation result of existing drainage capacity analysis

Channel	H (m)	B (m)	A (m ²)	Q (m ³ /s)
C1	0.4	0.5	0.2	0.22
C2	0.4	0.5	0.2	0.14
C3	0.9	1.0	0.9	0.65
C4	0.4	0.5	0.2	0.09
C5	0.3	0.3	0.1	0.03

3.7. Planned Flood Discharge Analysis

In this research, the planned flood discharge value was highly affected by the domestic wastewater discharge and the recieved planned flood discharge. Thus, the calculation of the domestic wastewater discharge and the recieved planned flood discharge must be performed. The intial planned flood discharge analysis is carried out by each subcatchment area using the rational method formula which shown in Equation 3.

The domestic wastewater discharge needs to be calculated alongside with the stormwater runoff due to the combined drainage system that is used in the study location. In this analysis, the calculation of domestic wastewater discharge was done using water usage approach which is based on

land use at each catchment area. Then, the amount of domestic wastewater discharge was then calculated by calculating 80% of total water consumption. A recieved planned flood discharge calculation must be performed because of a drainage channel at the study location also accommodated stormwater runoff from another sub-district,. To calculate it, the watershed around the drainage channel must be digitized first. After that, the calculation is continued by calculating the recieved planned flood discharge using rational method formula which shown in Equation 3. The total planned flood discharge analysis is conducted by adding up the value of the intial planned flood discharge, the domestic wastewater discharge, and the recieved planned flood discharge. The calculation result is shown on Table 6 below:

Table 6. Calculation result of total planned flood discharge analysis

Channel	C	Q Flood (m ³ /s)	Q Domestic Wastewater (m ³ /s)	Q recieved (m ³ /s)	Q total (m ³ /s)
C1	0.80	0.42	0.13		0.56
C2	0.80	0.08	0.06		0.14
C3	0.80	0.49	0.26		0.74
C4	0.80	0.12	0.10		0.23
C5	0.48	0.11	0.10		0.21
C60	0.55	0.35	0.12	2.81	3.29
C61	0.57	0.10	0.04		0.14
C62	0.57	0.12	0.03		0.15
C63	0.60	0.16	0.09		0.26
C64	0.59	0.42	0.11		0.53
C65	0.49	0.69	0.10		0.79

3.8. EPA SWMM 5.1 Analysis

For the SWMM analysis, Salamanmloyo Sub-district is divided into 71 subcatchment areas, which are shown in the Figure 3 below. Existing drainage model construction is conducted by on-screen digitalization on the Google Earth map to map Subcatchments, Nodes, Junctions, and Outfalls. In this reseach, SWMM analysis is done four times on different conditions which are explained below.

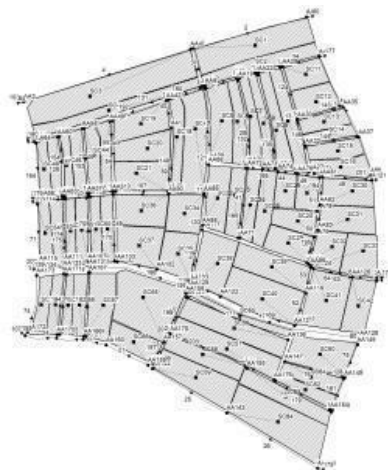


Figure 3. SWMM existing drainage model

3.8.1. Analysis on Existing Condition

This simulation is conducted based on the study location's existing condition. Horton

3.8.3. Analysis on Channel Normalization Condition

Drainage channel's capacity degradation, that was found during the survey and observation, was caused by sedimentation, waste, and vegetations. That condition was the cause of flood and inundation that happened in Salamanmloyo Sub-district. Thus, normalization operation must be perform. Normalization operation performed by cleaning/dredging the sediment at drainage channels. Drainage channel dimension changes due to the normalization are shown in the Table below:

Table 7. Channel dimension changes after normalization

Channel	Length	Existing Dimension		After Normalization Dimension	
		m	H (m) B (m)	H (m) B (m)	
C1	254	0.4	0.5	0.5	0.5
C2	251.3	0.4	0.5	0.6	0.5
C3	371.0	0.4	0.5	0.5	0.5
C5	150	0.65	0.25	0.75	0.25
C6	180	0.5	0.4	0.6	0.4
C7	182	0.5	0.4	0.6	0.4
C8	194	0.7	0.35	0.75	0.35
C9	190	0.7	0.35	0.75	0.35
C11	251	0.9	1	1.1	1
C12	94.2	0.25	0.45	0.3	0.45
C13	96.4	0.25	0.45	0.3	0.45
C14	108	0.35	0.28	0.4	0.28
C15	108	0.35	0.28	0.4	0.28
C17	211	0.3	0.35	0.4	0.35
C19	361.5	0.75	0.4	0.9	0.4
C21	142.2	0.4	0.5	0.6	0.5
C22	125	0.45	0.3	0.55	0.3
C23	141	0.45	0.4	0.5	0.4
C24	141	0.5	0.4	0.5	0.4
C34	84.4	1	0.7	1.1	0.7
C35	86.6	1	0.7	1.1	0.7
C38	109	0.3	0.3	0.5	0.3
C40	224	0.2	0.25	0.45	0.25
C61	122	0.4	0.3	0.5	0.3
C62	123	0.4	0.35	0.5	0.35
C63	183	0.4	0.35	0.5	0.35

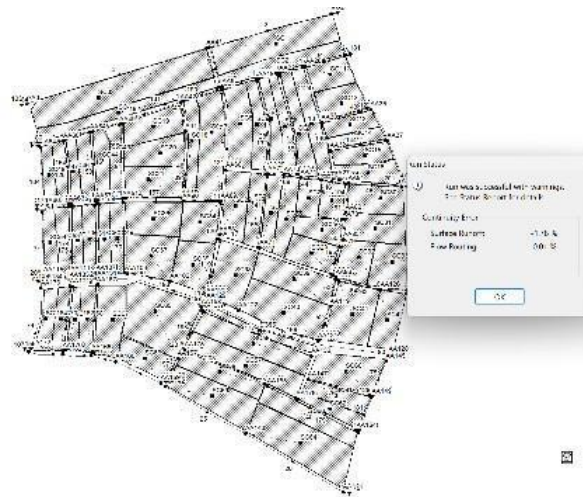


Figure 6. Normalization condition simulation result

From the figure above, it was known that the surface runoff value was -1.78% and the flow routing value was 0.01%. The simulation was considered successful because the result values were less than 5%. The operation of normalization was able to reduce the total flooding volume by 6.9% so that the remaining total flooding volume is 206,619 m³. It was also found out that some of the previously overflowed channels were no longer overflowed. After the normalization operation was carried out, it was found that there were still 69 nodes that still overflow. Since the goal of this study is to decrease the flooding/overflowing events, further action towards the remaining overflowing channel must be planned and performed. Hence, further operation of drainage remodelling must be carried out.

3.8.4. Analysis on Re-design Condition

Re-design operation is channel's dimension modification with the aim of increasing the channel capacity. The re-design operation is considered as needed because it was found that there were still 69 channels that experienced overflowing events even after SUDS implementation and normalization. The re-design operation of some drainage channel was performed by considering the availability of land under the existing conditions. If a drainage channel is found adjacent to houses and road bodies, resulting that there is no land that can be used for the dimensions change, then the re-design operation cannot be performed. The re-design results are shown in the table below:

Table 8. Existing and Planned Dimensions Comparisons

Channels	Existing Dimensions		Planned Dimensions		
	H (m)	B (m)	H+f (m)	H (m)	B (m)
C1	0.4	0.5	0.8	0.8	0.8
C4	0.2	0.25	0.5	0.5	0.5
C10	0.55	0.4	0.5	0.5	0.5
C12	0.25	0.45	0.5	0.5	0.5
C13	0.25	0.45	0.45	0.5	0.5
C14	0.35	0.28	0.4	0.4	0.4
C15	0.35	0.28	0.4	0.4	0.4
C16	0.4	0.4	0.5	0.5	0.5
C17	0.65	0.25	0.8	0.8	0.8
C18	0.5	0.2	0.5	0.5	0.5
C27	0.6	0.6	0.8	0.8	0.8

Channels	Existing Dimensions		Planned Dimensions		
	H (m)	B (m)	H+f (m)	H (m)	B (m)
C37	0.2	0.25	0.5	0.5	0.5
C38	0.3	0.3	0.6	0.6	0.6
C41	0.4	0.4	0.5	0.5	0.5
C42	0.45	0.45	0.5	0.5	0.5
C47	0.3	0.4	0.4	0.4	0.4
C52	0.3	0.4	0.4	0.4	0.4
C53	0.3	0.4	0.4	0.4	0.4
C56	0.2	0.2	0.5	0.5	0.5
C57	0.4	0.35	0.5	0.5	0.5
C58	0.4	0.35	0.4	0.5	0.5
C63	0.4	0.35	0.5	0.5	0.5



Figure 7. Channel re-design SWMM simulation result

After some dimension changes were made, the total flooding volume percentage was reduced by 62.2% and the remaining total flooding volume is 78,008 m³. The number of channels that experienced overflow event was also reduced to 51 nodes. This decreased number of overflowing channels indicates that the re-design operation succeeded on lowering both the flooding volume and flooding location points. Figure 8 and Figure 9 show examples of the channel's profile plot condition before and after re-design operation.

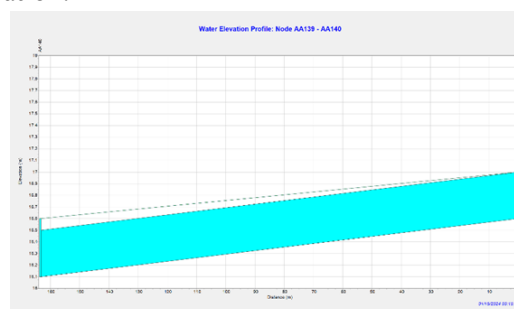


Figure 8. Cross section profile of node AA139 – AA 140 in existing condition

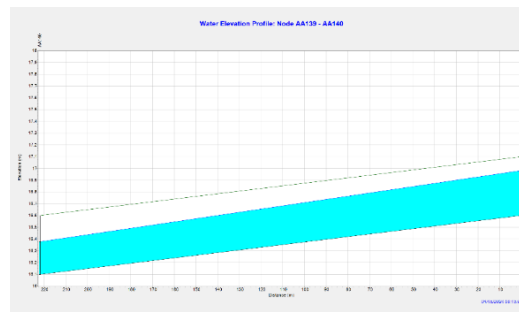


Figure 9. Cross section profile of Node AA139 – AA 140 After dimension change

After the SUDS implementation, the normalization, and the re-design of the drainage channels operations, there was a reduction in the total flooding volume percentage and it reached 66.30% so that the total flooding volume remains only 78,008 m³. To determine whether this condition has met the requirements to be categorized as safe flood conditions, it is necessary to calculate a flooding period graph. The flooding period graph is shown on Figure 10 below. While the summary of the total flood volume reduction is shown on Table 9 below:

Table 9. Flooding volume and percentage reduction summary

No	Condition	Total Flooding Volume (m ³)		% of Reduction
		Before	After	
1	Existing Condition	231,456	-	-
2	SUDS Application	231,456	228,990	1.07%
3	Normalization	228,990	206,619	9.77%
4	Re-design	206,619	78,008	62.25%
Total				66.30%

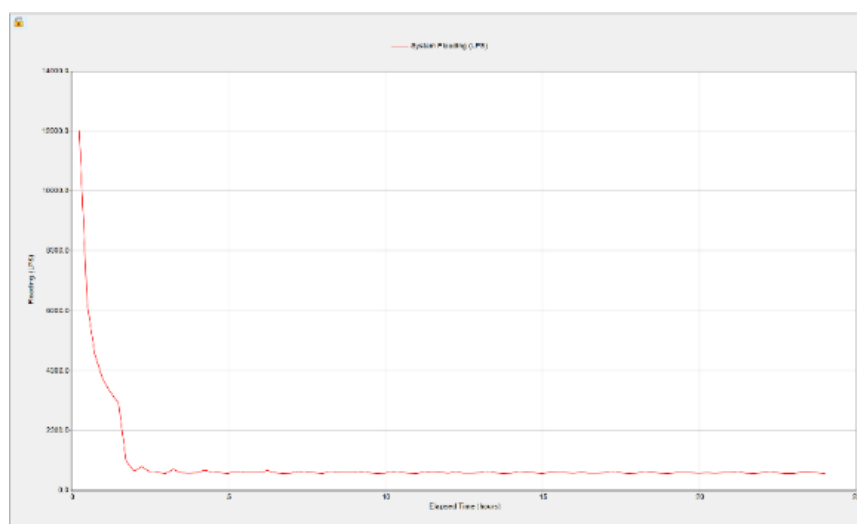


Figure 10. Flood graph after evaluation and planning

Based on Figure 10 above, it was known that the peak of flood occurs in the early hours of event and continue to decrease until the end of the second hours. According to the Flood Warning Module published by Indonesian Department of Public Works, flood condition that recedes in less than 6 hours, as shown in the graph above, are categorized as safe conditions. Thus, further construction work

planning is not needed. However it is essential to perform sequence of drainage channel maintenance program to keep the drainage performance optimized. Drainage channel maintenance operation can be performed referring to Appendix 3 of The Regulation of the Minister of Public Works Number 12 of the year 2014.

4. Conclusions

There are numbers of drainage channels in Salamanmloyo that are not capable to operate optimally. This condition is because the drainage channels are clogged with vegetation, sediment, and trash, as well as the unmatched capacity with the runoff that should be accommodated. The result of hydrological and hydraulic analyses also shows that there are numbers of channels that are unable to accommodate rainwater and domestic wastewater volume, resulting in sewage leakage. As for the hydrological analysis, it also shows that the designed/planned rainfall for 2-years return period is 122.75 mm and for 5-years return period is 153.45 mm. Several programs were modeled to decrease the flooding volume. Those programs were SUDS implementation, normalization, and channel re-design. For SUDS implementation, a total of 16,345 m² of permeable pavement was planned, distributed across 42 subcatchments. The planned number of infiltration wells is 497 wells with the planned dimension is 2 meters deep and a diameter of 1 meter. The SUDS application can reduce total runoff volume in each subcatchment by an average of 7.4%. Channel normalization operation is performed on several drainage channels which the channel flow was disturbed by sediment, waste and vegetation. Further channel re-design operation is also being carried out to optimize the drainage channel's performance. Overall, the efforts to implement SUDS, channels normalization, and redesign reduced the leakage percentage by 66.3% compared to the pre-implementation level, from 231,456 m³ to 78,008 m³.

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