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Regional Case Study

Review-Design of Drainage System of Kedungmundu Road, Semarang City with the Implementation of the Sustainable Urban Drainage System (SUDS)

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Abstract

The drainage system in the Kedungmundu Road area has several channels that can no longer accommodate the rainwater discharge, resulting in runoff of rainwater in the drainage channel, which causes flooding and puddles of rainwater in the Kedungmundu Road Area. Drainage in the Kedungmundu Road area has problems such as silting channels due to garbage, soil sedimentation, and insufficient channel dimensions. In the hydrological analysis, the rainfall intensity is 129,586 mm/hour. As the hydraulic analysis, the drainage channel is normalised by dredging sediment in the channel. If there is still rainwater runoff, additional channel dimensions are carried out, taking into account the existing conditions that only Karanggawang Lama road, H. Abdurochman road, and Kedungmundu Lama road changed. Channel dimensions, while for other channels, it is not possible to change the channel dimensions for that, it is necessary to apply SUDS. The Sustainable Urban Drainage System, or in SWMM 5.1 called Low Impact Development, is carried out using rainwater harvesting (Rain Barrel) and Permeable Pavement. The recapitulation of the application of the LID concept in the planning area is known to cover an area of 8.3 hectares of the total planning area of 54.48 hectares. This LID concept can reduce the total runoff value in each sub-catchment, thereby reducing the amount of rainwater discharge that enters the drainage channel with a percentage decrease in the average total runoff value of 19%. The Budget Plan needed to rehabilitate canals and dredging sediments and implement the Sustainable Urban Drainage System (SUDS) is around IDR 5,405,300,000.

Keywords: Drainage; suds; rain water harvesting; permeable pavement

1. Introduction

In general, drainage can be defined as a technical action to reduce excess water, either from rainwater, seepage, or excess irrigation water from an area/land, so that the function of the area/land is not disturbed (Suripin, 2004). Drainage is to divert excess water (mainly rainwater) to the nearest water body. Excess water is immediately drained into drainage channels, rivers and the sea so as not to cause inundation or flooding (Hardjosuprapto, 1999). This concept is still practised by the community today. In each drainage project, efforts are made to make drainage channels from the inundation point towards the river with a sufficient slope to dispose of the puddle water as soon as possible (Suripin, 2004).

Semarang City is one of Indonesia's major cities and the capital city of Central Java Province. Semarang City is a major city with common problems, like floods. Almost every year, there are floods in the city of Semarang, whether from rainwater runoff or tidal flooding. Common causes of flooding in Semarang City are the lack of rainwater catchment areas, poor drainage systems due to silting drainage system damage, and lack of channel dimensions. Meanwhile, the cause of tidal flooding in Semarang City, especially in the coastal areas of Semarang City, was due to land subsidence, resulting in a lower land surface elevation than sea elevation, resulting in seawater inundating the land area (Wismarini et al., 2010).

The area of Kedungmundu street is one of the areas in the city of Semarang that is prone to puddles of rain and flooding. Floods and rainwater puddles in the Kedungmundu street area are caused by rainwater runoff due to problems with the drainage system. Drainage in the Kedungmundu Street area has issues silting the channel due to garbage, soil sedimentation, and the lack of channel dimensions. For this reason, it is necessary to review the design of the Kedungmundu Road Drainage System with the implementation of Sustainable Urban Drainage Systems (SUDS).

2. Methods

Data collection methods are distinguished based on the type of data. Primary data are obtained from surveys and documentation, while secondary data are obtained from literature studies, field notes or data stores. Conducting and processing of data analysis carried out primary and secondary. Meanwhile, the data analysis was carried out in the following stages:

2.1. Analysis of the Existing Condition of the Study Area

This stage is carried out to determine the existing condition of the study area in the form of an overview, the current drainage system and the inundation area. There are two ways to analyze the existing situation in the study area:

1. Location Survey
2. Condition analysis in the Kedungmundu Street area of Semarang City is carried out by analyzing the physical conditions, including contours, RTRW and the direction of the system flow.

2.2. Analysis of Determination of Planned Flood Discharge

At this stage, the calculation of the planned flood discharge will be carried out. To calculate the rainfall discharge, data such as rainfall data, analysis of concentration-time, analysis of scheduled rain, and the area that becomes the flow area are needed. Thus, there are several stages of calculating the planned flood discharge, namely:

1. Analysis of areal rainfall
2. Frequency analysis
3. Testing goodness of fit
4. Rainfall design analysis
5. Calculation of rainfall intensity
6. Calculation of designed flood discharge

2.3. Drainage System Redesign Analysis with SUDS Concept

At this stage, the calculation and design of drainage channels with hydrological and hydraulic analysis methods will be carried out. Then an analysis will be carried out on the measures that have been carried out with the EPA-SWMM 5.1 application modelling. This simulation model checks the suitability of the drainage network capacity to accommodate the maximum runoff discharge in the planned rainfall.

2.4. Budget Design Analysis

At this stage, the calculation and design of drainage channels with hydrological and hydraulic analysis methods will be carried out. Then an analysis will be carried out on the measures that have been carried out with the EPA-SWMM 5.1 application modelling. This simulation model checks the suitability of the drainage network capacity to accommodate the maximum runoff discharge in the planned rainfall.

3. Result and Discussion

3.1 Existing Condition Analysis

The road area at this planning location is a protocol road dense with shops and settlements in Tembalang District, Semarang City. There is silting of the channel due to the garbage and soil sedimentation and insufficient channel dimensions, which results in puddles during the rainy season, flooding and rainwater runoff (Wicaksono et al., 2013).

Figure 1. Puddle and flood points on kedungmundu road

3.2. Hydrology Analysis

Hydrology analysis is needed to plan the drainage system (Xu et., 2020). Hydrology analysis is the most important factor in planning the size of storage and drainage facilities (Triatmojo, 2008). This analysis is necessary to overcome the surface runoff that occurs so as not to cause the inundation. The hydrological data was the basis for planning drainage channels, such as design discharge originating from the design rainfall in a certain return period. In carrying out a hydrology analysis after determining the amount of the planned flood discharge in the streamed channel, a hydraulic analysis can be carried out using the EPA-SWMM 5.1 software modelling to determine the dimensions of a more efficient drainage channel.

3.2.1. Areal Rainfall Analysis

Rainfall data is needed to calculate the maximum daily rainfall from the nearest rain gauge station in the study area (Isotta et al., 2014). One rain station is used to calculate the hydrology of the drainage system of the Kedungmundu Road Area. The rain station used in the hydrological calculation of the drainage system of the Kedungmundu Road Area is the Klipang Rain Post, with an observation period of 10 years from 2011 to 2020 obtained from the Semarang City Meteorology, Climatology and Geophysics Agency. Rainfall data used in the calculation can be seen in Table 1 below.

Table 1. Maximum daily period rainfall at klipang rain station

Year	**Klipang Rain Post**	
	Date	**Max Rainfall (mm)**
2011	14-Nov	120
2012	09-Apr	87
2013	10-Jul	93
2014	23-Jan	131
2015	13-Feb	119
2016	19-Apr	50
2017	18-Apr	95
2018	26-Dec	149
2019	21-Jan	95
2020	21-Apr	108

3.2.2. Frequency Analysis

In calculating the planned rain, it is necessary to analyze the frequency and has an effect in determining the amount of discharge for a certain return period. Frequency analysis relates to the frequency of events by applying probabilities based on the magnitude of extreme events in the future (Soewarno, 1995).

Table 2. Frequency analysis results

No	**Distribution Type**	**Terms**	**Calculation Results**	**Description**
1	Gumbel	Cs = 1.14	-0.414	Not Qualified
		Ck = 5.4	4.789	
2	Log Normal	Cs = 1.104	-1.358	Not Qualified
		Ck = 5.24	6.685	
3	Log-Person type III	Cs = 0	-1.358	Qualified
		Cv = 0.3	0.065	
4	Normal	Cs = 0	-0.414	Not Qualified
		Ck = 3	4.789	

The calculation of the amount of planned rainfall using the Pearson III Log Method is calculated using the following equation:

$$\text{Log } X_T = \text{Log } \overline{X} + K.\text{Sd}$$

Where:

X_T = Return Period Rainfall (mm)
X = Average Rainfall
K = K value for Log Pearson type III Distribution
Sd = Standard Deviation

The results of the calculation of the planned rainfall using the Pearson III log method it is obtained

1. The return period is 2 years, and the rainfall value is 108,002 mm
2. The return period is 5 years, and the rainfall value is 129,586 mm
3. The return period is 10 years, and the rainfall value is 137,976 mm
4. The return period is 20 years, and the rainfall value is 140,172 mm
5. The return period is 50 years, and the rainfall value is 147,798 mm

3.2.3. Rainfall Intensity Calculation

Based on data from Semarang City's drainage system from the Semarang City Public Works Service, the planning area, namely the Kedungmundu Road Area, is a type of secondary channel. The return period used is a 5-year return period. The calculation of rain intensity in terms of using the Mononobe method is formulated as follows (Schulz1 et al., 2021):

$$I = \frac{R_{24}}{24}\left[\frac{24}{T_C}\right]^{2/3}$$

Where:

I = Rainfall intensity (mm/hour)

R24 = Rainfall designed return period (mm)

Tc = Duration of rain (hours)

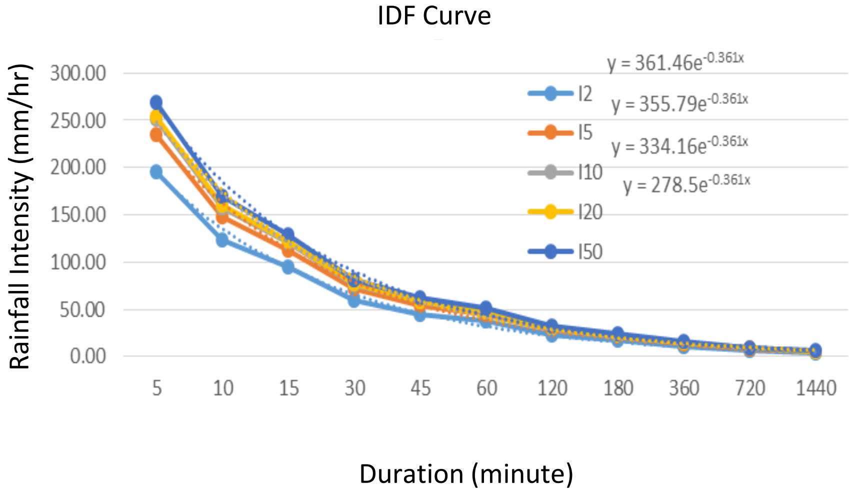


Figure 2. Rainfall intensity curve using the mononobe method

3.3. EPA SWMM 5.1 Modeling in Existing Condition

Existing canal data in the planning area comes from direct observations in the field and refers to the DED of the Semarang City Drainage System in 2021. The modelling of the existing Channel conditions is carried out with the EPA SWMM 5.1 software to determine the response of water flow, which shows the occurrence of water runoff on several roads in the planning area (Syuhada et al., 2016). The peak hour occurs at the sixth hour, indicating the highest runoff discharge. That the analysis in SWMM 5.1 is focused on the peak hour, which is the sixth hour, for analysis to overcome flooding in the drainage channel.

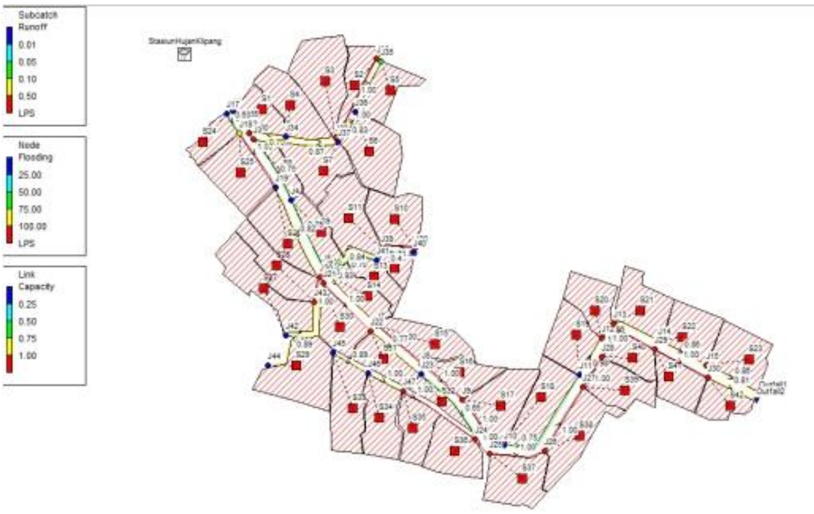


Figure 3. Results of existing conditions flow simulation at peak hours

From the simulation results of SWMM 5.1, the channel (conduit) that is not red is a drainage channel that does not overflow or runoff when it rains at peak hours. Then the channel can be said to be safe and able to accommodate rainwater discharge during peak hours even though there is sediment in the channel. These drainage channels include from the simulation results of SWMM 5.1, the channel (conduit) that is not red is a drainage channel that does not overflow or runoff when it rains at peak hours. Then the channel can be safe and can accommodate rainwater discharge during peak hours even though there is sediment in the channel. These drainage channels include:

Table 3. Channel (conduit) that does not overflow during peak hours based on existing conditions

No	Channel	Node (Junction)
1	Karanggawang Lama Street (ka) STA 0+206 + 0+412	J34-J2
2	Karanggawang Lama Street (left)	J35-J3
3	Kedungmundu Street (left) STA 0+278 - 0+461	J4-J5
4	H. Abdurochman Street (ka) STA 0+87 - 0+263	J39-J5
5	H. Abdurochman Street (left)	J40-J6
6	Kedungmundu Street (left) STA 0+466 - 0+656	J6-J7
7	Kedungmundu Street (left) STA 0+1117 - 0+1513	J10-J12
8	Kedungmundu Street(left) STA 0+1574 - 0+2001	J13-Outfall1
9	Kedungmundu Street (ka) STA 0+0.00 - 0+50	J17-J18
10	Kedungmundu Lama Street STA (ka)	J44-J21
11	Kedungmundu Street (ka) STA 0+819 - 0+1034	J23-J24
12	Kedungmundu Street (ka) STA 0+1850 - 0+2005	J30-Outfall2

Drainage channels still experiencing overflow need to be normalized by cleaning the channel from sediment by dredging sediment at channel points that experience overflow or rainwater runoff at peak hours or by adding the dimensions of the drainage channel.

3.4. EPA SWMM 5.1 Modeling in Normalized Condition

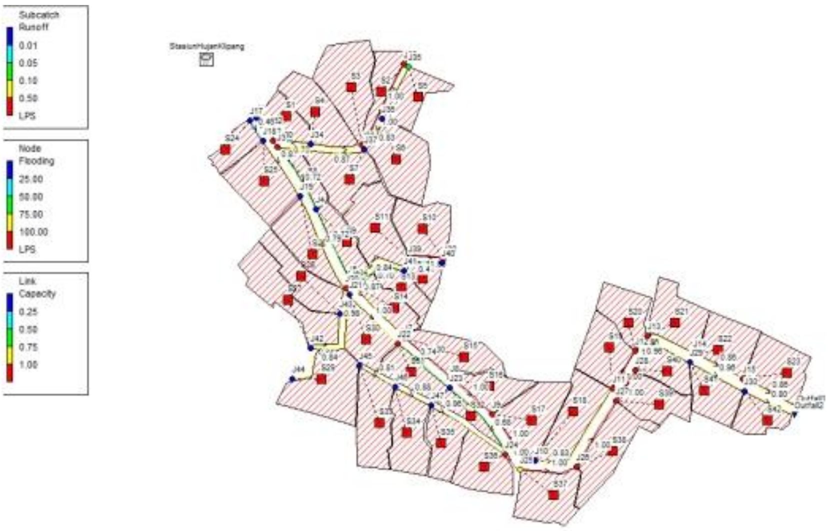
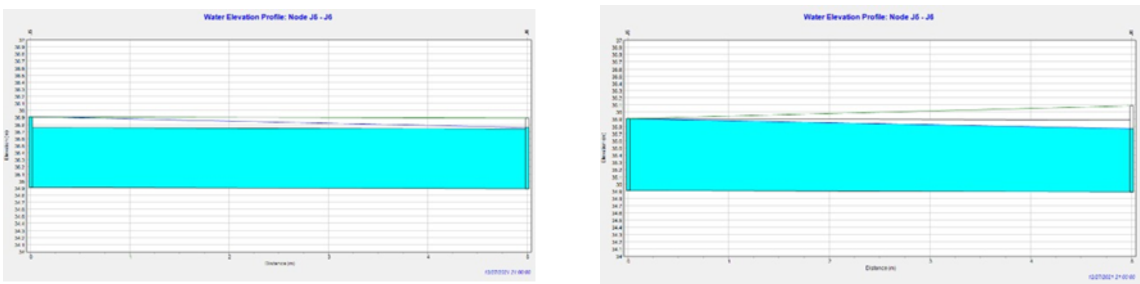


Figure 4. Simulation results of SWMM conditions after sediment dredging in channels experiencing rainwater overflow

Channels that previously experienced overflow after dredging sediments were able to accommodate rainwater discharge during peak hours. No flood occurred, namely the Kedungmundu Street channel (ki) with node points j5-j6, j9-j10, Kedungmundu street channel (ka) with node points J18 -J19, J20-J22, J28-J29, and the Sambiroto street Channel point node J45-J47. Meanwhile, the channels that previously overflowed after dredging the sediments were unable to accommodate the rainwater discharge the Kedungmundu street channel (ki) with node points j2-j3, j7-j9, J12-J13, old Karanggawang street channel (ka) with node point J32 -J34, H. Abdurochman street channel (ka) with node points j39-J38. Kedungmundu street channel (ka) with node points J24-J28, J29-30, and the old Kedungmundu street channel with node points j43-j20, and street Channel Sambiroto point nodes J47-J24.



Before After

Figure 5. Example of Kedungmundu street channel profile (ki) STA 0+461 - 0+466 nodes j5-j6 before and after sediment dredging

After dredging the sediments, it was found that there were still some channels unable to accommodate the rainwater discharge during peak hours. It was necessary to change the dimensions of the media that were no longer able to adjust the rainwater discharge by calculating the change in the dimensions of the planned channel. Based on field conditions, the drainage channels that can change to channel dimensions are the Karanggawang Lama street (ka), H.Abdurochman street (ka), and the old Kedungmundu street (ki) because there is still land to do. Widening of the drainage channel, while for Kedungmundu street and Sambiroto street, it is no longer possible to change the dimensions of the drain because the land use on Sambiroto street and Kedungmundu street is a protocol street and is dominated by shopping and office areas along the route. So that the available land is not sufficient if the channel widening is carried out and will disrupt traffic conditions.

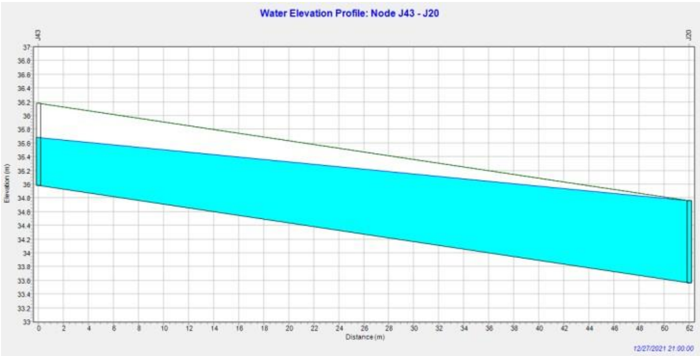


Figure 6. Simulation results of the profile plot of the kedungmundu lama street channel (ki) STA 0+137 - 0+189 After dimensional change at peak hours

The drainage channels are still overflowing on Kedungmundu street and Sambiroto street. In drainage channels still soaking, namely Kedungmundu street and Sambiroto street. The dimensions of the channel cannot be changed because the land use on Sambiroto and Kedungmundu street is a protocol street dominated by shopping and office areas along the route. So that the available land is not sufficient if the channel widening is carried out and will disrupt traffic conditions. The solution to this problem is an application of the Sustainable Urban Drainage System (SUDS) to reduce runoff on the land (sub-catchments) (Priyanto et al., 2016).

3.5. Implementation of Sustainable Urban Drainage System (SUDS)

LID engineering to build in the planning area must be adapted to the environmental and operational conditions of the Kedungmundu street (Rathnayake, 2017). Based on LID engineering, those feasible to apply are Rainwater Harvesting (RH) or Rainwater Harvesting (rain barrel) and Permeable Pavement. The reason for choosing Rainwater Harvesting and Permeable Pavement is because the planning area is an area of shops, settlements, and offices that have been built and also considers the conditions of land and building ownership. It is impossible to carry out infiltration wells, bioretention, green roofs, rain gardens, roof terminations, and vegetative swales, so the type of LID that is suitable to be applied in the Jalan Kedungmundu area is Rain Barrels and Permeable Pavement.

Table 4. Implementation of sustainable urban drainage system

Sub-Catchment	Area (Ha)	SUDS Application Area (Ha)	Implementation Percentage %	SUDS Type	% Total Runoff Decrease	% Peak Runoff Decrease
S1	0,92	0,3661	39,79%	Rain Barrel	40%	40%
S2	0,87	0,1825	20,98%	Rain Barrel	21%	21%
S3	2	0,2132	10,66%	Rain Barrel	11%	11%
S4	1,5	0,17	11,33%	Rain Barrel	11%	11%
S5	1	0,1779	17,79%	Rain Barrel	18%	18%
S6	1,87	0,255	13,64%	Rain Barrel	14%	14%
S7	1,43	0,2172	15,19%	Rain Barrel	15%	15%
S8	0,62	0,1312	21,16%	Rain Barrel	21%	21%
S9	0,95	0,3103	32,66%	Rain Barrel	33%	33%
S10	1,45	0,1993	13,74%	Rain Barrel	14%	14%
S11	1,76	0,346	19,66%	Rain Barrel	20%	20%
S12	0,5	0,1136	22,72%	Rain Barrel	23%	23%

Sub-Catchment	Area (Ha)	SUDS Application Area (Ha)	Implementation Percentage %	SUDS Type	% Total Runoff Decrease	% Peak Runoff Decrease
S13	0,76	0,1251	16,46%	Rain Barrel	16%	16%
S14	0,98	0,3939	40,19%	Rain Barrel	40%	40%
S15	1,4	0,4686	33,47%	Rain Barrel	33%	33%
S16	0,95	0,2723	28,66%	Rain Barrel	29%	29%
S17	1,83	0,3081	16,84%	Rain Barrel	12%	12%
S18	1,78	0,4796	26,94%	Rain Barrel	19%	19%
S19	1,41	0,2613	18,53%	Rain Barrel	18%	19%
S20	1,18	0,1179	9,99%	Rain Barrel	10%	10%
S25	1,73	0,1814	10,49%	Permeable Pavement	5%	5%
S26	1,31	0,1562	11,92%	Rain Barrel	12%	12%
S27	1,8	0,2943	16,35%	Rain Barrel	16%	16%
S28	1,33	0,2962	22,27%	Rain Barrel	22%	22%
S29	2	0,2088	10,44%	Rain Barrel	10%	10%
S30	1,18	0,3367	28,53%	Rain Barrel	28%	29%
S31	1,1	0,2316	21,05%	Rain Barrel	21%	21%
S32	0,54	0,1212	22,44%	Rain Barrel	22%	22%
S33	1,67	0,2981	17,85%	Rain Barrel	18%	18%
S34	1,49	0,1869	12,54%	Rain Barrel	13%	13%
S35	1,1	0,1316	11,96%	Permeable Pavement	12%	12%
S36	1,45	0,1358	9,37%	Permeable Pavement	4%	4%
S37	1,61	0,384	23,85%	Rain Barrel	24%	24%
S38	1,72	0,406	23,60%	Rain Barrel	24%	24%
S39	1,27	0,2069	16,29%	Rain Barrel	16%	16%

Based on calculations made on the implementation of SUDS, the application area is 8.3 Ha or about 15.16% of the existing site. In sub-catchment 1, applying a rain barrel can reduce the total runoff rate by 40%, while the decrease in the absolute peak runoff is obtained by 40%. A reduction of overall runoff received an average of 19% indicates that applying a rain barrel can reduce the runoff from the sub-catchment to the drainage channel.

3.6. Budget Plan

Improve the drainage system in the study area, including channel normalisation, rain barrels installation, and permeable pavement. It costs approximately IDR 5,405,300,000. These costs have included preparation costs, sediment dredging work, earthworks, and others.

4. Conclusions

In the drainage system of the Kedungmundu street, several channels can no longer accommodate the rainwater discharge, resulting in runoff of rainwater in the drainage channel, which causes flooding and puddles of rainwater in the Kedungmundu street. Kedungmundu street Drainage system still has some problems in silting media due to the garbage and soil sedimentation, damaged channels, and lack of channel dimensions. In the hydrological analysis, the rainfall intensity is 129.586 mm/hour. As for the hydraulic analysis, the drainage channel is normalised by dredging sediment in the channel. If there is still rainwater runoff, additional channel dimensions are carried out, taking into the existing conditions that what can be changed is only the Karanggawangs street, H.Abdurochman street, and Kedungmundu street. The dimensions of the channel can't vary the Kedungmundu street and Sambiroto street to the channel dimension to overcome overflow in the drainage channel, so it is necessary to apply the SUDS concept as an alternative solution to overcome this problem.

The Sustainable Urban Drainage System, or in SWMM 5.1 called Low Impact Development, is carried out using rainwater harvesting (Rain Barrel) and permeable Pavement. The recapitulation of the LID concept application in the planning area is known to cover the area of 8.3 Ha out of a total planning area of 54.48 Ha, with the application of SUDS spread over 35 sub-catchments out of a total of 42 existing sub-catchments. This LID concept can reduce the total runoff value in each sub-catchment, thereby reducing the amount of rainwater discharge that enters the drainage channel with a percentage decrease in the total runoff value of this planning average of 19%. The budget plan needed to repair the channel, dredge sediment and apply the concept of Sustainable Urban Drainage System (SUDS) in the form of rainwater harvesting (Rain Barrel) and Permeable Pavement IDR 5,405,300,000.

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