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Study of Alternative Inundation Management Based on Water Conservation in Sub Drainage System of Parung River, Kediri City

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Abstract

Parung River drainage sub system is located in Kediri City. At the peak of the rainy season inundation often occurs on hos cokroaminoto road, kilisuci road and terusan kaliombo road, the cause is reduced water catchment areas and drainage capacity can't accommodate discharge, so it is necessary to handle water conservation-based inundation. The analysis conducted was modelling the sub-system using the Storm Water Management Model (SWMM) version 5.1 with a 5-year return period. Rainfall calculation used daily rain data (2012-2021) from 2 rain stations (UPT Kediri and Pesantren). The 5-year return period results is 129.4 mm/day, then the intensity of rain is calculated using the Mononobe formula. To calibrate the model, comparing observation discharge with simulated discharge of SWMM resulted the Nash-Sutcliffe efficiency number is 0.74 and the correlation R is 0.95. The results of the existing simulation show that Parung River drainage sub-system was not able to accommodate the 5-year return period discharge, impacting 27 overflow points. Water conservation based handling with the application of infiltration wells and rainwater harvesting can reduce discharge on land ranging from 51.58% to 90.91%, while in the channel successfully reduces discharge from 1.73% to 90.40%.

Keywords: inundation, infiltration wells, rainwater harvesting, water conservation

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1. Introduction

Drainage is a mechanism for directing water away from a specific area, either naturally or with human intervention, to the ground or within the ground.(Putra et al., 2021) In general, drainage is defined as technical activities in an effort to reduce excess water, which comes from rainwater, seepage, to excess irrigation water from an area / seepage so that it does not interfere with the function of the land / area.

The common drainage concept in many areas of Indonesia is conventional, focusing on quickly discharging rainwater into rivers without delaying soil infiltration. This practice can lead to river overload, overflow, and flooding.(Muliawati & Mardyanto, 2015)

Special attention needs to be paid to drainage planning based on the concept of environmentally sound development. For example, the application of the concept of environmentally (eco-drainage) where an area uses infiltration wells, bioretention, permeable pavement and Rainwater Harvesting as temporary reservoirs before heading to existing drainage channels.(Ardiyana et al., 2016)

Some examples of low impact development in swmm that can be developed and used to solve urban drainage problems include: rain barrels, bio-retention, rain gardens, green roofs, and permeable pavement.(Fan et al., 2022)

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This concept relates to Water Resources conservation efforts, which aim to control stormwater runoff so that it does not become surface runoff.

Urbanization, characterized by continuous population growth and land development, has altered the urban water cycle. The expansion of impermeable areas in urban settings disrupts the infiltration process, leading to a notable increase in surface water runoff. This, in turn, raises the frequency and severity of flooding.(Cao et al., 2023). Insufficient planning of drainage systems and inadequate drainage infrastructure in the development of residential areas may result in inundation or flooding.(Souza et al., 2019)

The drainage sub system of Kali Parung is located in Kediri City. The rapid increase in population and the increase in settlement / housing development and other supporting facilities are not accompanied by good drainage system planning, inundation arise at several points in the center of Kediri City. Inundation often occur on Hos Cokraminoto Road, Kilisuci Street and Kaliombo Canal Road with a height of 30-40 cm.

The impact of inundation is the disruption of residents' activities and causes material losses and makes the city environment slum. Material losses in the form of disrupted transportation activities resulting in disrupted economic activities and so on. Environmental losses will affect public health because there are slums that can be mosquito nests. To reduce the impact on these problems, it is necessary to plan a good drainage system based on water conservation.

2. Metodology

This research was conducted on the drainage sub-system of Kali Parung Kediri City which covers 2 districts, namely Pesantren District and Kota District has an area of 308.83 ha. The boundaries of the study location are shown in figure 1.

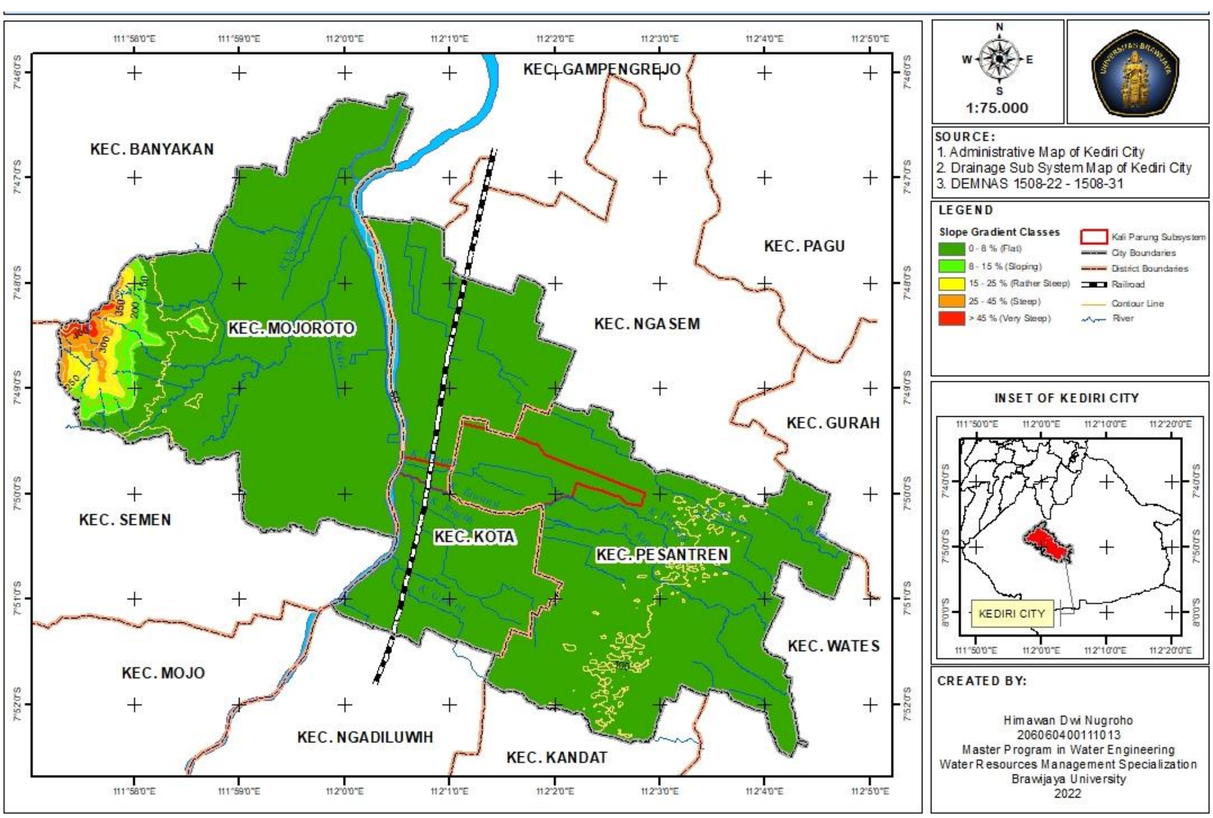


Figure 1. The boundaries of the study location.

The data used for this research process is in the form of primary data and secondary data. Primary data includes field condition surveys for checking channel dimensions, while secondary data consists of: Rainfall data from 2012 to 2021 from UPT PSDAWS Puncu-Selodono, land use map, topographic map and trends, Map of drainage and inundation network systems, Kediri City Drainage Master Plan 2016, and Population data.

The steps in the research work are as follows:

a) Conduct a literature review of the literature

b) Collection of primary data and secondary data

c) Define the area limitation of the catchment sub catchment area (Juliastuti et al., 2023)

d) Test the consistency of rainfall data with Rescaled Adjusted Partial Sums (RAPS) analysis(Sri Harto,200 in (Ardiyana et al., 2016) and Double Mass Curve Method(Limantara, 2018)

e) Perform trend absence test : Spearman method, stationary test : t- test and F-test method, persistence test : t-test method, outlier test : Grubbs and Beck method(Limantara, 2018)

f) Calculation of regional average rainfall thiessen polygon method(Prawati & Dermawan, 2018)

g) Frequency analysis Log Pearson Type III, 5th return period(Prawati & Dermawan, 2018)

h) Distribution conformity test chi squared test and smirnov-kolmogorov test(Prawati & Dermawan, 2018)

i) Create a rain intensity-duration curve using Mononobe formula(Triatmojo, 2008)

j) Calculating the discharge of dirty water discharged by residents

k) Model rain runoff under existing conditions with SWMM 5.1 and then test statistics using Nash–Sutcliffe Efficiency (NSE), (Mengistu et al., 2022) correlation coefficients to measure the accuracy of the model's forecasts.(Suhartanto, 2016) The NSE value and the resulting correlation coefficient when approaching 1 (one) indicate that the variation in values produced by a forecast model is close to the variation in the observed value.

l) Evaluation of the performance of existing drainage channels using runoff rainfall simulation with SWMM 5.1.(Kartiko & Waspodo, 2018)

m) Determination of the location application of infiltration well solutions and rainwater harvesting.(Kustyaningrum & Lasminto, 2023)

n) Simulated solution on existing conditions of drainage channels

o) And then simulate runoff rainfall with SWMM 5.1 in the handling application scenario

p) Draw conclusions about the results obtained

3. Result and Discussion

Testing of rain data results in that rain data is suitable for use in future analysis. From the results of the consistency test, it was found that the data were consistent, the Absence of Trend test was carried out with the Spearman Test showing independent data, the Stationary Test was used F Test and T Test produced stable data, the persistence test was used the t test showed the data was random, and for the outlier test using the Grubbs and Beck method produced normal data.

After testing the rain data was carried out, then analyzed the design rainfall with the log pearson III method for this study using a 5-year return period based on the area of Kediri City. The results of the calculation of the planned rainfall for each repeat period is 129.395 mm

The next step is the distribution suitability test using Chi Square and Smirnov Kolmogrov. From the test results, it was found that the rain data met the requirements, then the next step was the process of calculating rain intensity using the mononobe formula.

Rain intensity analysis is used as a time series input in the SWMM program. The intensity entered is in the form of the intensity of rain in the hour. The calculation of rain intensity during the 5th return period will be presented in table 1

Table 1. Calculation of Rainfall Distribution

Time	Ratio	Cumulative (%)	Rain hours (mm)
			5
1	55	55	53.4
2	14	69	13.9
3	10	79	9.7
4	8	87	7.8
5	7	94	6.5
6	6	100	5.7
	Sum		97.0
	Rain Plan		129.4
	Flow Coefficient		0.75
	Effective Rain		97.0

Rain plans = 129.4 mm
Drainage coefficient = 0.75
Race = 55.03%
Effective rainfall = k x R5 Year = 0.75 x 129.4 mm = 97.0 mm/hari (1)
1st hour rain = Effective rain x Ratio / 100 = (97.0 mm/day x 55.03)/100) = 53.4 mm/day (2)

Evaluation of the existing drainage system was carried out using the SWMM auxiliary program version 5.1. The depiction of the Kali Parung sub-system in the SWMM 5.1 program is shown in figure 2.

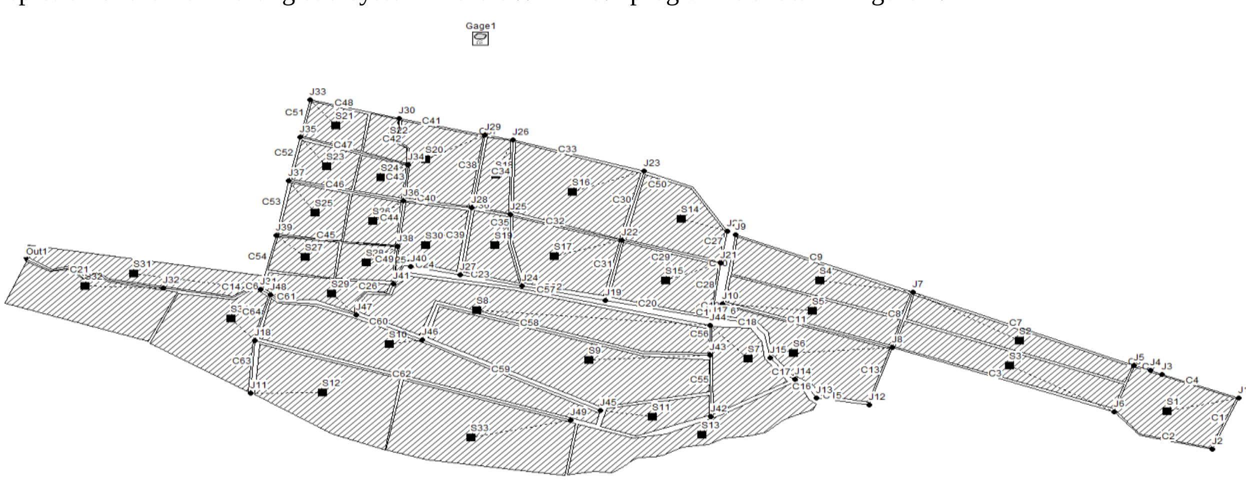


Figure 2. Schematic Modeling of Kali Parung Subsystem Drainage Network in SWMM 5.1

In figure 2 it is shown that the parung river sub-system is divided into 34 subscathments. After modeling on SWMM 5.1 is carried out, the next step is the calibration of field discharge with the discharge of SWMM simulation results. Field discharge data was taken on the rain on February 18, 2023 in channel C5 as shown in table 2.

Table 2. NSE and R Calibration Calculation

No	X-Y	X-$\bar{X}$	$(X-Y)^2$	$(X-\overline{X})^2$	X.Y	X^2	Y^2
	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1	0.0000	-0.0161	0.0000	0.0003	0.0000	0.0000	0.0000
2	-0.0010	-0.0161	0.0000	0.0003	0.0000	0.0000	0.0000
3	0.0006	-0.0145	0.0000	0.0002	0.0000	0.0000	0.0000
4	0.0029	-0.0112	0.0000	0.0001	0.0000	0.0000	0.0000
5	0.0070	-0.0041	0.0000	0.0000	0.0001	0.0001	0.0000
6	0.0092	0.0081	0.0001	0.0001	0.0004	0.0006	0.0002
7	0.0108	0.0187	0.0001	0.0004	0.0008	0.0012	0.0006
8	0.0118	0.0187	0.0001	0.0004	0.0008	0.0012	0.0005
9	0.0076	0.0115	0.0001	0.0001	0.0006	0.0008	0.0004
10	0.0019	0.0048	0.0000	0.0000	0.0004	0.0004	0.0004
11	0.0007	0.0016	0.0000	0.0000	0.0003	0.0003	0.0003
12	-0.0012	-0.0013	0.0000	0.0000	0.0002	0.0002	0.0003
Sum	0.0503	0.0000	0.0005	0.0018	0.0036	0.0049	0.0027

where

X = Discharge of Observation Results (m^3/dt)

Y = Simulated Discharge (m^3/dt)

$$NSE = 1 - \frac{\sum_{i=1}^{n}(X-Y)^2}{\sum_{i=1}^{n}(X-\bar{X})^2} = 1 - \frac{0.0005^2}{0.0018^2} = 0.74 \quad (3)$$

$$R = \frac{n\sum_{i=1}^{n}XY - \sum_{i=1}^{n}X\ \sum_{i=1}^{n}Y}{\sqrt{n\sum_{i=1}^{n}X^2 - (\sum_{i=1}^{n}X)^2}\sqrt{n\sum_{i=1}^{n}Y^2 - (\sum_{i=1}^{n}Y)^2}} = \frac{12\ x\ 0.004 - 0.193\ x\ 0.143}{\sqrt{12\ x\ 0.005 - (0.193)^2}\sqrt{12\ x\ 0.003 - (0.143)^2}} = 0.95 \quad (4)$$

From the results of the comparison calculation, an NSE value of 0.74 is obtained in the category of 0.3 < NSE > 0.75 meets, while for the R correlation a value of 0.95 is obtained in the range of 0.8 – 1 very strong R value. A comparison graph between field discharge and simulated discharge is shown in figure 3.

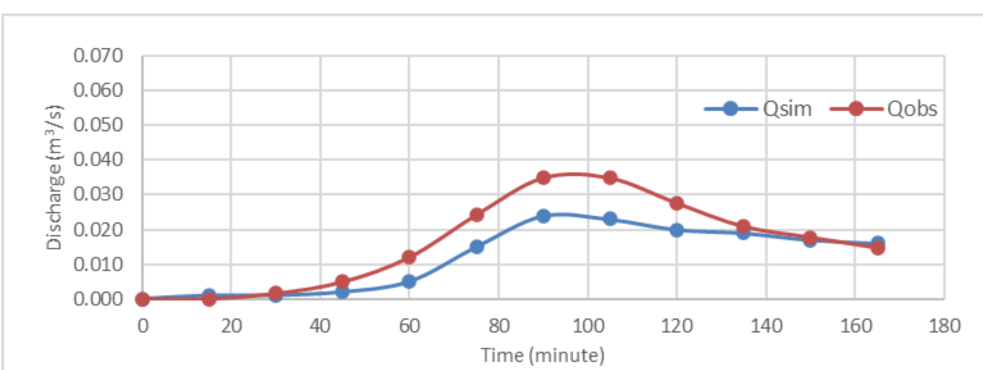
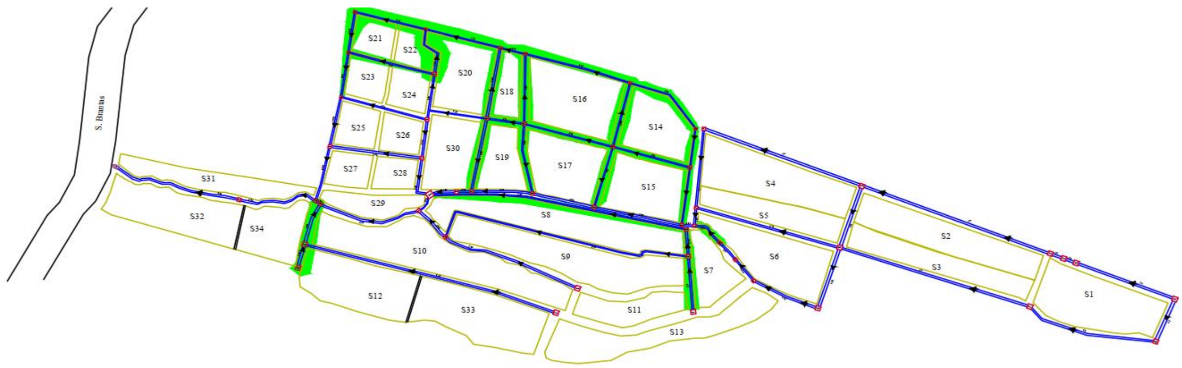


Figure 3. Comparison of Observation Discharge Hydrograph with Simulated Discharge



Sub-Catchment	Area (ha)	Sub-Catchment	Area (ha)	Sub-Catchment	Area (ha)	Sub-Catchment	Area (ha)
S1	10.59	S10	20.83	S19	4.83	S28	3.17
S2	10.31	S11	4.38	S20	9.08	S29	3.83
S3	9.01	S12	14.36	S21	4.01	S30	6.40
S4	10.98	S13	13.08	S22	2.84	S31	10.09
S5	8.68	S14	9.07	S23	3.91	S32	12.27
S6	10.77	S15	13.96	S24	3.38	S33	15.46
S7	4.77	S16	13.96	S25	4.78	S34	12.18
S8	20.98	S17	9.23	S26	3.27		
S9	18.56	S18	3.68	S27	3.78		

DESCRIPTION:
S1 : SubCatchment
C1 : Conduit
J-1 : Junction
O-1 : Outfalls
: Drainage Channel
: SubCatchment
: Junction
: Inundation

Figure 4. Map of Existing Inundation of DTA Kali Parung SWMM Simulation Results on 5 Years Return period

The distribution of the location of the puddle simulated by the existing conditions on the 5th return period is shown in figure 4. The location of the inundation will be the basis for inundation management based on water conservation in the form of placement of infiltration wells and rainwater harvesting. The choice of water conservation solutions in the form of infiltration wells and rainwater harvesting is due to seeing the conditions in the Kali Parung DTA, the majority of which have been filled by settlements and other buildings / facilities.

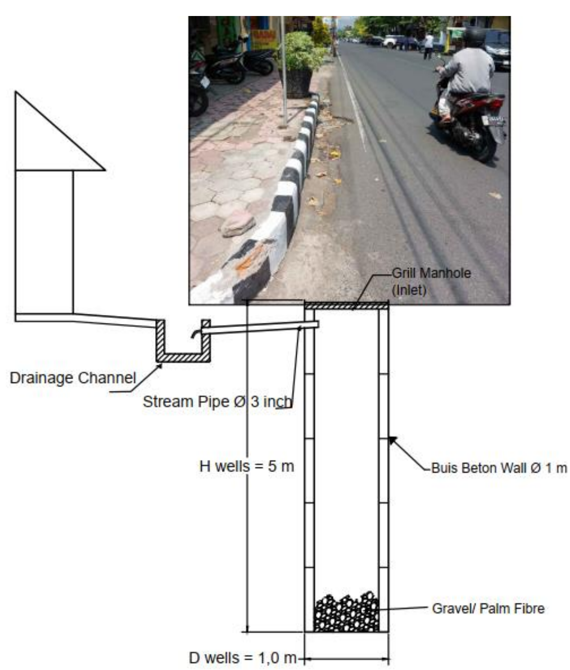


Figure 5. Cross section of infiltration wells on Cokroaminoto Hos Road code S20 on SWMM

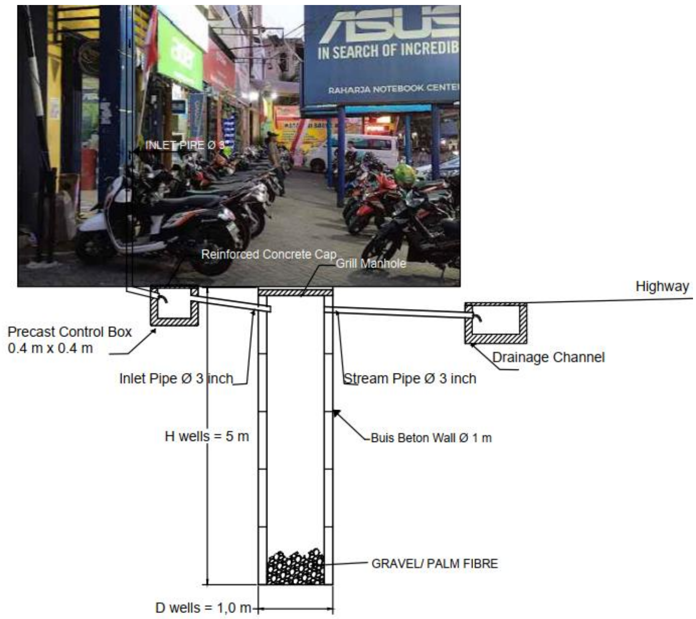


Figure 6. Cross section of the infiltration well in the parking lot of Jalan Kilisuci shopping mall code S21 on SWMM

The scenario of application of infiltration wells is applied uniformly at all points, namely deep infiltration wells (collective) with a circular shape, a depth of 5 meters and wall construction made of precast concrete. The placement of collective infiltration wells is in the location with the lowest elevation of the reservoir area, taking into account the requirements that have been written in table 1 of SNI 8456:2017.(Badan Standardisasi Nasional, 2017) In figures 5 and 6 is the appearance of the application of infiltration wells on highways and parking lots sequentially. The placement of infiltration wells will pay attention to the availability of land in the field.

The calculation of the number of infiltration wells is based on SNI 8456:2017.(Badan Standardisasi Nasional, 2017) An example calculation for S22 is as follows

$$Q = C \times I \times A = 0.95 \times 0.0014 \text{ m/hours} \times 9080 \text{ m}^2 = 12.397 \text{ m}^3\text{/hours} \quad (5)$$

$$H = \frac{Q}{2 \times \pi \times r \times K} = \frac{12.397}{2 \times \pi \times 0.5 \times 0.0221} = 5 \quad (6)$$

However, the number of collective infiltration wells is determined based on the results of field surveys according to the map of which DTA inundations are inundated, and DTAs have an effect on contributing to the inundation. The field review was aimed at meeting the requirements for placement of distance criteria, so that the number of collective infiltration wells was 85 units.

The scenario of implementing rainwater harvesting in the field will be targeted at public facilities such as markets, places of worship, puskesmas, village offices, and schools. In this study, rainwater harvesting uses water tanks that have been widely sold in the market. The type of tank used is a tank with the brand "MPOIN" with a capacity of 2000 liters has dimensions of 1.54 m wide, 1.75 m high, and the design of this tank is made to be planted in the ground. An example of the application of rainwater harvesting in the pahing market is shown in figure 7.

In figure 7 of the design of the application of rainwater harvesting using 2 tanks, the purpose of the design of 2 tanks is the assumption that sediment from the roof will enter 1 tank and the other tank will receive clean water in the absence of sediment. A field review for the application of rainwater harvesting resulted in 17 location points to be applied to the solution.

Figure 7. Cross-sectional Pieces of the Application of Rainwater Harvesting at Pahing Market in Kediri City

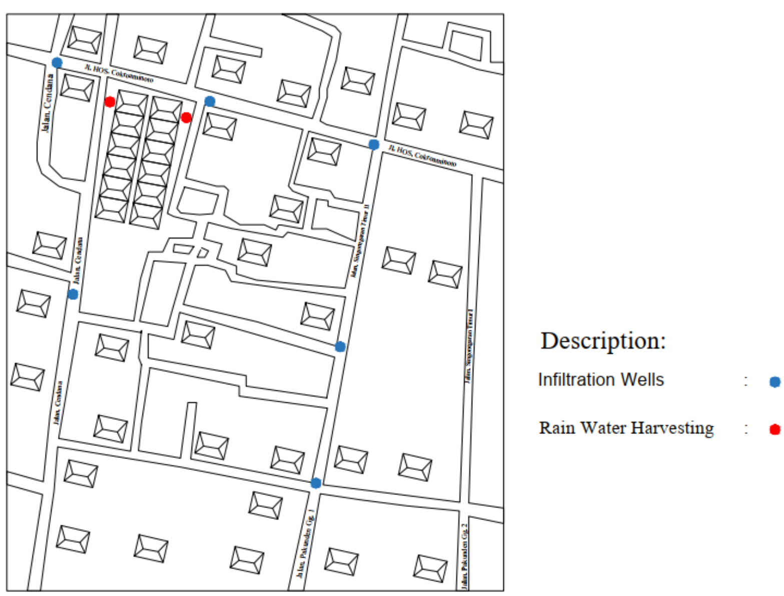


Figure 8. Scheme of Placement and Installation of Infiltration Wells and Rainwater Harvesting in Sub DTA S20

The placement scheme for the application of infiltration wells and rainwater harvesting will be shown in figure 8 and 9, where an example of placement is in the S20 subscatment with the placement of infiltration wells on the highway and rainwater harvesting is in the pahing market in Kediri City. As for the map of infiltration well placement and rainwater harvesting will be shown in figure 10.

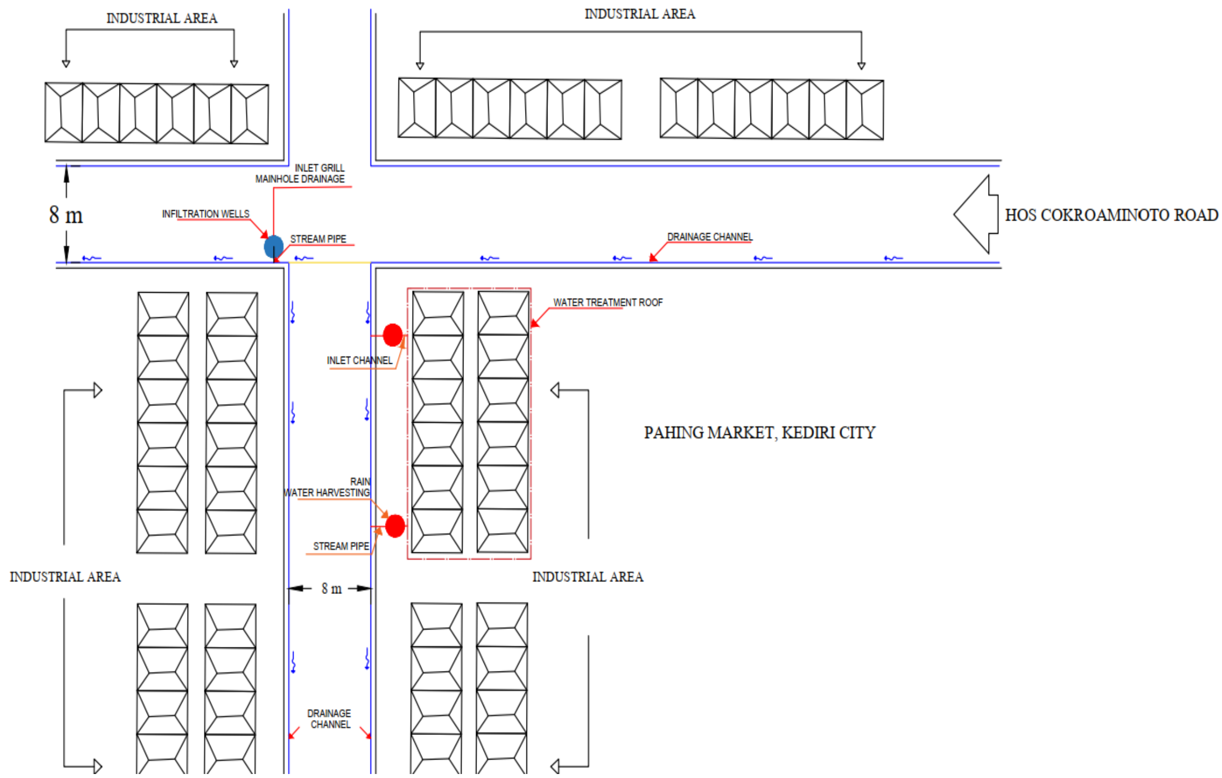


Figure 9. Detail Scheme of Placement and Installation of Infiltration Wells and Rainwater Harvesting in Sub DTA S20

Sub-Catchment	Area (ha)	Sub-Catchment	Area (ha)	Sub-Catchment	Area (ha)	Sub-Catchment	Area (ha)
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: Drainage Channel
: SubCatchment
: Junction
: Infiltration Wells
: Rain Water Harvesting

Figure 10. Map of Infiltration Well Placement and Rainwater Harvesting in Kali Parung Sub System

Simulation scenarios for the application of infiltration wells and rainwater harvesting in existing conditions with a 5-year period resulted in that the existing channel was able to accommodate discharge on the 5-year period, with infiltration wells and rainwater harvesting surface runoff was collected until it seeped into the ground before heading to the existing drainage channel. The following is a comparison between the existing conditions and after the application of the solution shown in figure 11.

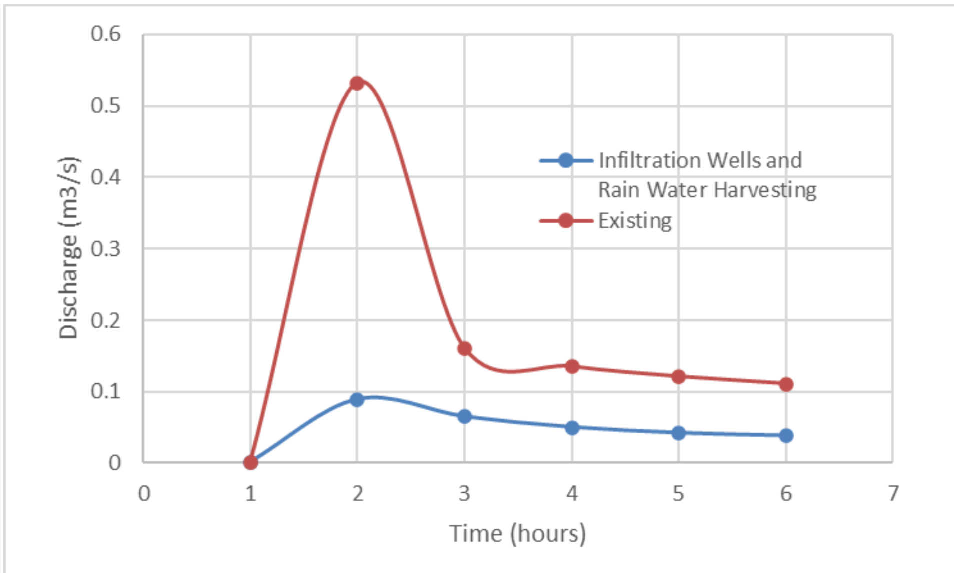

Figure 11. Comparison of Existing Simulation Hydrographs and Infiltration Wells in Channel C41

The application of infiltration wells and rainwater harvesting in sub-DTA S20 has an influence on channel discharge that occurs in channel C41. In the existing condition the channel discharge that occurred was 0.512 m^3 / sec and there was overflow / inundation, after efforts to implement 6 infiltration wells and 2 rainwater harvesting, the discharge in the channel decreased to 0.092 m^3 / sec decreased by 82.03%.

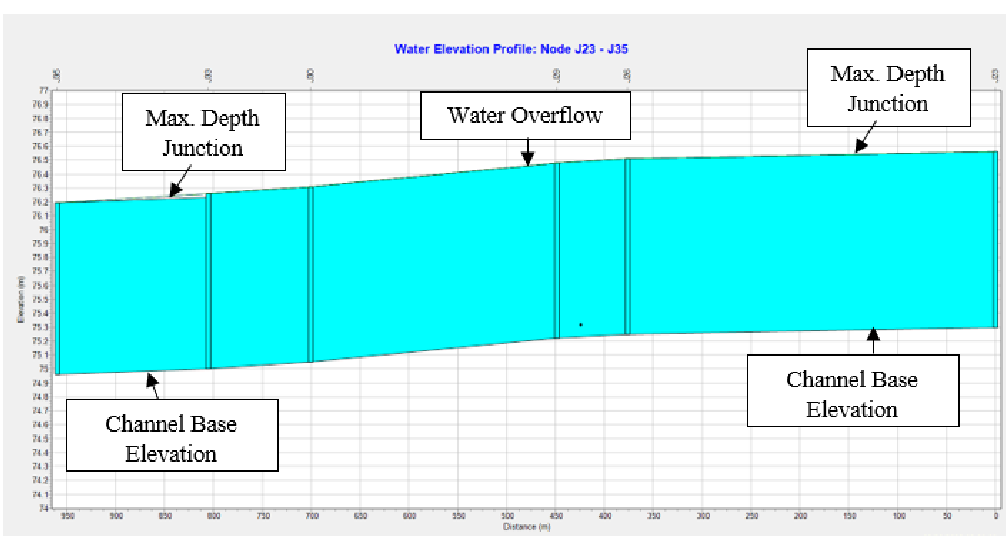

Figure 12. Water Level Profile Results of Simulation of Existing Conditions at C33 – C37 – C41 – C48 – C51 – C52 at 02:00

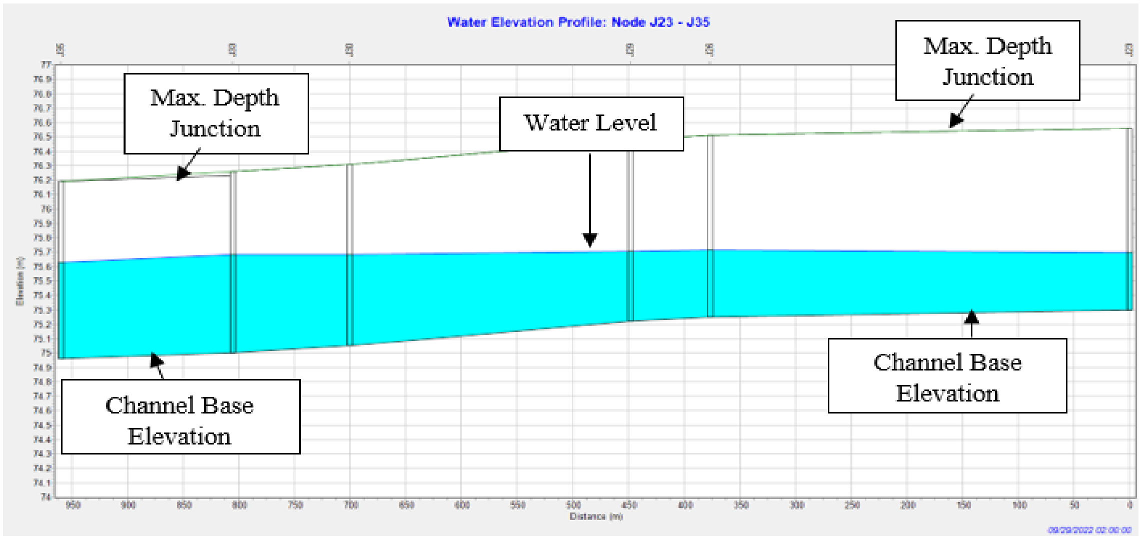

Figure 13. Water Level Profile Results of Simulation of Application of Infiltration Wells for Rainwater Harvesting at C33 – C37 – C41 – C48 – C51 – C52 at 02:00

It can be seen from figures 12 and 13 that there is a difference in the existing condition (figure 11) that the channel cannot accommodate discharge on the 5-year period resulting in overflow, while after the application of infiltration wells and rainwater harvesting (figure 13) shows that the channel can accommodate discharge on the 5-year period.

There is a decrease in discharge and a decrease in water level in the channel at each channel junction. With the application of infiltration wells and rainwater harvesting in existing conditions, it can overcome the inundation experienced when it rains when the 5-year return period occurs.

4. Conclusion

Based on the results of the analysis of water conservation-based inundation management in the Kali Parung sub-system of Kediri City, it can be concluded as follows:

a) Analysis of the existing drainage system in the Kali Parung Sub-System with a 5-year return period shows that the drainage system at the study site has not been able to accommodate the rain flood with the recurrence. This is indicated by the capacity of channels / conduit that experience overflow on 27 channels out of a total of 65 channels.

b) Water conservation-based inundation management, based on the results of SWMM 5.1 simulation in the Kali Parung Sub System with a 5-year return period resulted in handling in the form of infiltration wells and rainwater harvesting, here are the specifications of inundation handlers

- Infiltration Wells

  Collective infiltration wells placed on highways and parking lots with a circular shape, a depth of 5 meters, a diameter of 1 m and wall construction made of concrete buis. Placement pays attention to the criteria of distance from other buildings / objects and is at the lowest elevation.

- Rainwater Harvesting

  Using water reservoirs sold in the market with the selling brand "MPOIN" with a capacity of 2000 liters Using the type of water reservoir that can be planted into the ground Placement in public facilities such as markets, mosques, villages, mosques, and schools

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