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Optimization of Sustainable Drainage Strategies in Reducing Flood Risk

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ABSTRACT

Areas with suboptimal drainage systems, such as the Old Market Area in Serang City, often experience waterlogging when the volume of surface runoff exceeds the capacity of the available drainage channels. To address this issue, a comprehensive evaluation of the existing drainage system and the implementation of an environmentally friendly sustainable drainage concept are required. This research aims to evaluate flood discharge, assess the capacity of the existing drainage system, and design a new, more adaptive drainage system. The methods used include field surveys, observation of existing conditions, flood discharge analysis, and evaluation of channel dimensions based on road drainage planning guidelines. From the analysis results, it was found that the planned discharge for the primary channel is 0.247 m^3/second, while the actual channel discharge reaches 0.749 m^3/second, indicating a mismatch between the channel capacity and actual needs. The flat and uneven topography exacerbates flooding in this area, necessitating the redesign of the channel with a base width of 0.94 meters and a water surface height of 0.94 meters, as well as the installation of infiltration wells. With the implementation of infiltration wells, it is expected that runoff volume can be reduced, and the quality and quantity of groundwater can be improved, making the drainage system more resilient in facing the challenges of climate change and urbanization.

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1. INTRODUCTION

The rapid growth of urban areas, including in the City of Serang, drives the need for a drainage system capable of managing water runoff effectively and sustainably. Changes in land use, urbanization, and the increase in impermeable surface areas have significantly raised the volume of rainwater runoff, which ultimately triggers flooding in various important areas such as the Old Market of Serang City. The conventional drainage system, which has focused on rapid water disposal, is starting to be abandoned. The concept of sustainable drainage has now become a more relevant approach, prioritizing the principles of water conservation, runoff control, and increased groundwater infiltration (Sutomo, 2017). This principle not only aims to reduce the potential for flooding but also to maintain the balance of the natural hydrological cycle (Mahardika, 2025).

The implementation of sustainable drainage approaches has shown positive results in various regions of Indonesia. A study in the Cinambo River Basin, Bandung, for example, shows that the application of the Low Impact Development (LID) concept can reduce runoff volume by up to 72% through a combination of rainwater harvesting systems and retention ponds (Sururi & Fadlurrohman, 2024). A similar approach can be adapted to address the flooding issues in Pasar Lama, Serang City. Drainage problems in urban areas are not only caused by inadequate channel capacity but also by poor drainage networks and lack of maintenance. Research in the cities of Aimas and Palembang shows that clogged or poorly connected drainage systems exacerbate flooding events, even when rainfall is not extremely heavy (Musa et al., 2025; Aurdin, 2019). This underscores the importance of comprehensive and sustainable drainage planning.

In addition to considering technical aspects, sustainable drainage strategies also take into account cost efficiency through life cycle cost analysis. This approach ensures that the solutions implemented are not only effective in the short term but also financially efficient and durable (Hapsari et al., 2020). Thus, a sustainable drainage system becomes a profitable long-term investment. Studies in various locations such as Lorong Anoa, Tumpas Village, and the Malangbong-Wado road section, show that inadequate channel dimensions and sedimentation are the main causes of waterlogging that occurs every rainy season (Ridwan et al., 2025) (Fitriyadi & Permana, 2024). This situation certainly poses a real threat to densely populated areas such as Pasar Lama Kota Serang. The importance of implementing simulation-based technology is also becoming more prominent in modern drainage planning. The implementation of Low Impact Development (LID) in Serang City using SWMM simulation has proven effective in reducing surface runoff volume, increasing flow efficiency, and optimizing channel capacity, although there are still challenges such as suboptimal channel slopes (Amin et al., 2025).

Furthermore, changes in land use in urban areas also significantly contribute to the increase in flood discharge. A study in the Krukut River Basin, Jakarta, showed that land use conversion leads to an increase in peak flood discharge, which ultimately requires the implementation of infiltration wells and spatial planning control based on regional spatial planning for mitigation (A. Firmansyah et al., 2024). This emphasizes that sustainable drainage strategies in Serang City need to carefully consider land use dynamics. Based on various experiences and best practices in other regions, this article aims to examine the existing conditions of the drainage system in the Old Market Area of Serang City and formulate a sustainable drainage strategy that can be implemented. With a holistic and innovative approach, it is hoped that this solution can reduce the risk of flooding, improve the quality of the urban environment, and support the sustainability of the City of Serang in the future.

2. METHOD

This research focuses on the drainage system located in the Old Market Area, Kota Baru Village, Serang District, Serang City, Banten Province. An overview of the research location can be seen in **Figure 1.**

Figure 1. Location of the Drainage System in the Old Market Area, Serang City

This research employs several stages of analysis and calculation methods, one of which is the hydrological analysis stage. At this stage, the design rainfall is statistically analyzed to understand the rainfall characteristics in the study area. A number of frequency distributions are used in this analysis, such as the normal distribution, log-normal distribution, log Pearson type III distribution, and Gumbel distribution. Complete information regarding the characteristics of each distribution is displayed in **Table 1.**

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Table 1. Characteristics of Various Frequency Distributions

Types of Frequency Distribution	Distribution Requirements
Normal Distribution	CS = 0 and CK = 3
Log Normal Distribution	CS > 0 and CK > 3
Gumbel Distribution	CS = 1,139 and CK – 5,402
Log Pearson Type III Distribution	CS between 0 until 0,9

(Fitriani et al., 2020)

Based on **Table 1**, this research was then continued with a goodness-of-fit test, which serves to assess the conformity between the frequency distribution of the sample data and the expected probability distribution function. The results of this test determine the most suitable distribution for the analysis. Additionally, the peak surface runoff is calculated using the rational analysis method, a standard method in drainage system design. The runoff coefficient is the ratio between the volume of surface runoff and the area of the region that receives rainfall within a watershed (Marlina et al., 2024). The value of this coefficient is dynamic and can change in response to changes in land use and the physical conditions of the river flow in the area. To determine the value of the runoff coefficient, the formula explained below is used.

$$C_{DAS} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i}$$

Rain intensity describes the rate at which rain falls in a certain area over a specific period, with common units such as mm/minute, mm/hour, or mm/day (Fatmawati et al., 2024). In this study, the analysis of rainfall intensity at the study location was conducted using a calculation method based on the Mononobe formula, which is formulated as follows.

$$I = \frac{R_{24}}{24}\left(\frac{24}{tc}\right)^{2/3}$$

Concentration time is the time required for rainwater falling at the farthest point of the catchment area to flow towards the nearest drainage channel. In this study, the calculation of concentration time is performed using the Kirpich Equation. Additionally, concentration time can also be obtained by dividing it into two main parts, namely surface flow time and channel flow time.

The time required for water to flow on the surface of the ground to the nearest channel (t0) and the travel time from the moment it enters the channel to the exit point (td).

$$t_c = t_o + t_d$$

with:

$$t_0 = \frac{2}{3} \times 3{,}28 \times I_0 \times \frac{nd}{\sqrt{i_s}}$$

$$t_d = \frac{L}{60 \times V}$$

The capacity of the drainage channel is determined based on the physical dimensions of the channel itself, such as width, depth, and slope of the channel. The magnitude of this capacity is calculated to ensure that the channel can accommodate the occurring flow discharge. To calculate the capacity of the drainage channel, the following analytical equation is used.

$$Q = V \times A$$

The flow velocity (V) is determined using the Manning equation, which is:

$$V = \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

The design of infiltration wells is influenced by the volume of rainfall in a given area and must meet capacity standards based on the intensity of rain over a specific period. The government mandates the construction of infiltration wells in residential yards for groundwater conservation and runoff control, although public awareness of technical standards is still low. Based on SNI No. 03-2453-2002, infiltration wells must be built on flat land, far from pollution sources such as septic tanks and garbage bins (at least 5 meters), and at least 1 meter away from building foundations (Rahman, 2022). Excavation is recommended to reach sandy soil or a maximum of 2 meters below the groundwater table, with a groundwater depth during the rainy season of at least 1.5 meters. The soil structure must have a permeability of at least 2.0 cm/hour, with infiltration rate classification based on soil type. The capacity of the infiltration well is calculated using the calculation method according to the SNI standard.

3. RESULT AND DISCUSSION

In this study, the daily maximum rainfall data used are the highest daily rainfall records over a 10-year period, from 2011 to 2020. This data was obtained from the Meteorological Station Dok II in Serang City. Complete details regarding this rainfall data can be seen in **Table 2.**

Table 2. Recapitulation of the Highest Daily Rainfall

No.	Research Year	Daily Maximum Rainfall (mm)
1	2011	122,00
2	2012	79,20
3	2013	150,40
4	2014	177,10
5	2015	248,80
6	2016	126,70
7	2017	174,20
8	2018	85,10
9	2019	138,50
10	2020	169,10

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Frequency analysis is conducted to determine the most suitable type of frequency distribution for analyzing rainfall data. The determination of this distribution requires an approach based on a number of statistical parameters. The details of the parameters used in this analysis can be seen in **Table 3.**

Table 3. Statistical Parameter Calculation Data

No.	X_i	$(X_i-\bar{X})$	$(X_i-\bar{X})^2$	$(X_i-\bar{X})^3$	$(X_i-\bar{X})^4$
1	122,00	-25,11	630,51	-15832,20	397545,51
2	79,20	-67,91	4611,77	-313185	21268405,01
3	150,40	3,29	10,82	35,61	117,16
4	177,10	29,99	899,40	26973,01	808920,54
5	248,80	101,69	10340,86	1051562	106933304,90
6	126,70	-20,41	416,57	-8502,15	173528,98
7	174,20	27,09	733,87	19880,49	538562,39
8	85,10	-62,01	3845,24	-238443	14785871,43
9	138,50	-8,61	74,13	-638,277	5495,57
10	169,10	21,99	483,56	10633,49	233830,37
Total	**1471,10**		**22046,73**	**532483,10**	**145145581,800**

Based on the calculation results, the skewness coefficient (Cs) value is 0.6099 and the kurtosis (Ck) value is 4.7992. Based on these parameters, the frequency distribution of rainfall data was analyzed using the Log Normal Distribution, with the calculation results detailed in Tables 4 to 6. Furthermore, from the distribution fit test, a Dmax value of 0.20202 was obtained, which is smaller than the critical Do value of 0.41, thus the Log Normal distribution is deemed acceptable. Meanwhile, the results of the flow discharge calculations in the primary drainage channel at the research location can be seen in **Table 7.**

Table 4. Log Normal Distribution Parameters

No.	Year	X_i	$Y=\text{Log } X_i$	$(Y-\bar{Y})$	$(Y-\bar{Y})^3$
1	2015	248,80	2,40	0,25	0,06
2	2014	177,10	2,25	0,10	0,01
3	2017	174,20	2,24	0,10	0,01
4	2020	169,10	2,23	0,08	0,01
5	2013	248,80	2,18	0,03	0,00
6	2019	126,70	2,14	-0,00	0,00
7	2016	174,20	2,10	-0,04	0,00
8	2011	85,10	2,09	-0,05	0,00
9	2018	138,50	1,93	-0,22	0,05
10	2012	169,10	1,90	-0,25	0,06
		Total	**21,45**		**0,20**

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Table 5. Parameters of the Log-Normal Distribution

Return Period	$\overline{Y}$	K_r	S_y	$Y=Log\text{-}X_T$	X_{Tr} (mm)
T_2	2,15	0,00	0,15	2,15	139,63
T_5	2,15	0,80	0,15	2,27	184,12
T_{10}	2,15	1,28	0,15	2,34	217,35
T_{20}	2,15	1,64	0,15	2,39	246,16
T_{50}	2,15	2,05	0,15	2,45	283,65

Table 6. Smirnov-Kolmogorov Goodness of Fit Test (α=5%)

M	X	P(X)	K_t	P'(X)	P(x<)	P'(x<x)	D
1	248,80	0,10	1,67	0,11	0,91	0,89	0,02
2	177,10	0,18	0,69	0,22	0,82	0,78	0,04
3	174,20	0,27	0,64	0,33	0,73	0,67	0,06
4	169,10	0,36	0,55	0,44	0,64	0,56	0,08
5	248,80	0,45	0,22	0,56	0,55	0,44	0,10
6	126,70	0,55	-0,02	0,67	0,46	0,33	0,12
7	174,20	0,64	-0,28	0,78	0,36	0,22	0,14
8	85,10	0,73	-0,39	0,89	0,27	0,11	0,16
9	138,50	0,82	-1,43	1,00	0,18	0,00	0,18
10	169,10	0,91	-1,64	1,11	0,09	-0,11	0,20

Table 7. Primary Drainage Channel Flow Rate

Repetition Period	Rain Intensity (I) (mm/hour)	Coefficient C	Land Area (A) (Ha)	Débito (Q) (m3/s)
T_2	286,70	0,70	0,41	0,19
T_5	378,04	0,70	0,41	0,25
T_{10}	446,28	0,70	0,41	0,29

The results of the flow discharge calculations in the secondary drainage channel I are presented in detail in **Table 8.**

Table 8. Flow Rate of Secondary Drainage Channel I

Repetition Period	Rain Intensity (I) (mm/hour)	Coefficient C	Land Area (A) (Ha)	Debit (Q) (m3/s)
T_2	274,63	0,70	0,75	0,33
T_5	362,13	0,70	0,75	0,43
T_{10}	427,50	0,70	0,75	0,51

The results of the flow discharge calculations in the secondary II drainage channel are presented in detail in **Table 9.**

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Table 9. Flow Rate of Secondary II Drainage Channel

Repetition Period	Rain Intensity (I) (mm/hour)	Coefficient C	Land Area (A) (Ha)	Debit (Q) (m3/s)
T_2	275,09	0,70	0,74	0,32
T_5	362,74	0,70	0,74	0,43
T_{10}	428,21	0,70	0,74	0,51

The analysis of discharge in the existing channel is based on actual field conditions, where the primary, secondary I, and secondary II channels have uniform dimensions with a square cross-section. The parameters used in the calculation of the channel discharge are explained as follows:

Channel height (h) = 0,8 m
Channel width (b) = 0,8 m
Inclination (S) = 0,005

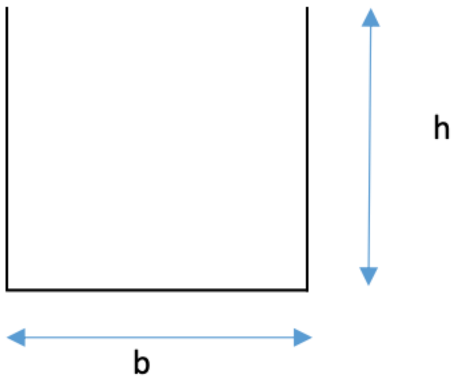

Figure 2. Existing Drainage Channel

In a channel with a square cross-section, it is applicable that the base width (b) is equal to the channel height (h).

The geometric calculation of the channel yields: The wet cross-sectional area is h x h = 0.6 m². The wet perimeter of the channel is h + 2h = 2.4 meters. The hydraulic radius of the channel is obtained as 0.26667 meters. The full capacity of the channel (Q) calculated reaches 0.75 cubic meters per second (m³/second). The comparison between planned Q and channel Q is conducted to identify channels that can accommodate flood discharge and channels that do not meet capacity. The results of this comparison are presented in **Table 10.**

Table 10. Analysis of Channel Discharge Comparison

Channel	Planned Channel Flow Rate (m3/s)	Full Channel Flow Rate (m3/s)
Primary	0,25	0,75
Secondary I	0,43	0,75
Secondary II	0,43	0,75

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Based on the calculation results, it is known that the planned flow rate (Q planned flow) is smaller than the channel capacity (Q channel). This means that the existing drainage channel is still capable of accommodating the planned flow rate for a 5-year return period, so in general, the existing channel is declared safe and does not experience overflow. However, attention must be paid to the topographic conditions around the Old Market Area. Naturally, the market area has flat land characteristics, but with an uneven ground surface. This condition causes the rainwater that falls in the area to flow towards lower areas, including the research location. The concentration of rainwater flow in this basin area is one of the main causes of flooding, as shown in **Figure 3.**

Figure 3. Water Catchment Area in the Old Market Area

Based on the obtained data, the catchment area in the Pasar Lama area is recorded at 197,106 square meters or equivalent to 19.711 hectares. The main channel that conveys water from this area has a length of approximately 814 meters or 0.814 kilometers. Meanwhile, the rainfall intensity in this area has been calculated, and the results are presented in **Table 11.**

Table 11. Results of Rain Intensity Calculation in the Pasar Lama Area

Repetition Period	Rainfall (R) (mm)	Effective Rain Duration (tc) (hours)	Rain Intensity (I) (mm/hour)
T_2	139,63	0,44	84,28
T_5	184,12	0,44	111,13
T_{10}	217,35	0,44	131,19

The rainfall discharge in the Old Market Area is listed in **Table 12.**

Table 12. Results of Rainfall Intensity Calculation in the Old Market Area

Repetition Period	Rain Intensity (I) (mm/hour)	Coefficient (C)	Área de Superficie (A) (Ha)
T_2	84,28	0,60	19,71
T_5	111,13	0,60	19,71
T_{10}	131,19	0,60	19,71

Based on the results shown in **Table 12**, the area discharge (QArea) is recorded to be greater than the channel discharge capacity (QChannel). This condition indicates that the existing drainage channels are currently unable to accommodate the entire water discharge, thereby posing a risk of overflow and flooding in the area. To address this issue, it is necessary to enlarge the dimensions of the drainage channel so that it can optimally convey the planned discharge. With the new dimension design, the channel's capacity is expected to accommodate the existing area discharge, or even more, thereby minimizing the risk of flooding.

$$Q\_Channel \leq Q\_Plan$$

In this analysis, *QChannel* refers to the water discharge that can be conveyed by the channel, while *QPlan* is the discharge calculated based on hydrological analysis. The calculations were performed using the trial and error method, with the details of the process shown in Table 13. The calculations were stopped when the difference between *QChannel* and *QPlan* (Qs - Qr) reached a tolerance limit of 0.0001.

$$Q\_Channel = Q\_Plan$$

$$6{,}99\,V^2 = 0{,}25 \times \left(\frac{24}{0{,}05 + \frac{0{,}23}{V}}\right)^{2/3}$$

Table 13. Results of Rainfall Intensity in the Old Market Area

Flow Velocity (V) (m/s)	Rain Intensity (I) (mm/hour)	Coefficient C	Land Area (A) (Ha)
0,10	0,00	1,23	-1,23
0,20	0,01	0,79	-0,78
0,30	0,06	0,61	-0,55
0,40	0,18	0,51	-0,33
0,50	0,44	0,44	-0,00
0,501	0,44	0,44	-0,00

Table 13 explains the flow velocity results obtained at 0.501 m/2 with a flow depth of 0.94 meters, and a channel width of 0.69 as shown in **Figure 4.**

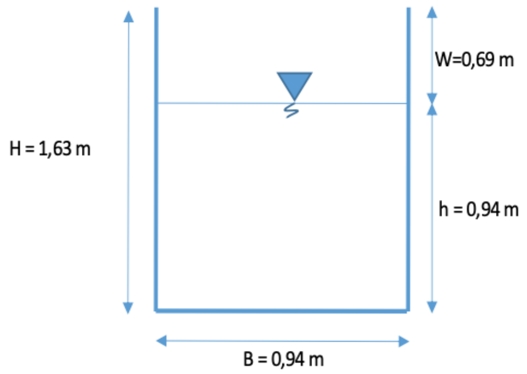

Figure 4. Development Drainage Channel Design

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The newly designed drainage channel has larger dimensions compared to the existing channel. This enlargement aims to ensure that the channel can accommodate the planned area runoff in the Old Market Area. The new dimensions are based on the calculated design runoff for a five-year return period, thus it is expected to reduce the risk of overflow and improve the reliability of the drainage system in the area (Simanungkalit et al., 2020).

The arrangement and placement of the infiltration wells in relation to the drainage channel can be seen in **Figure 5.**

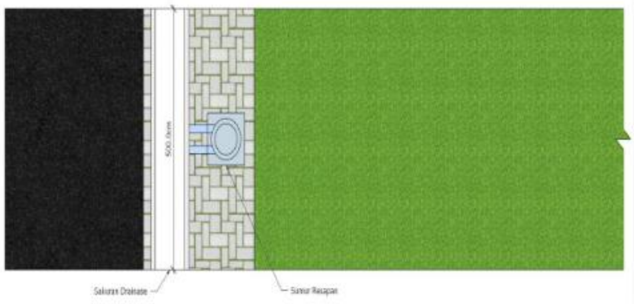

Figure 5. Infiltration Well Placement Scheme

In the proposed drainage network design, infiltration wells function as the terminal storage and infiltration units for surface runoff management. These wells are strategically positioned along both sides of the drainage channel and hydraulically interconnected using polyvinyl chloride (PVC) pipes with a nominal diameter of 10 cm to facilitate the conveyance of excess runoff into the subsurface. The design adopts a modular layout in which one infiltration well is installed at every 5 m interval along the drainage alignment, optimizing both the spatial distribution and the efficiency of infiltration. This configuration aims to enhance the uniformity of water absorption, minimize surface flow concentration, and improve the overall performance of the drainage system in mitigating localized flooding and increasing groundwater recharge potential (Bayat et al., 2023; Yang, 2024). Next, the placement of infiltration wells designed to be integrated with the drainage system can be seen in **Figure 6.**

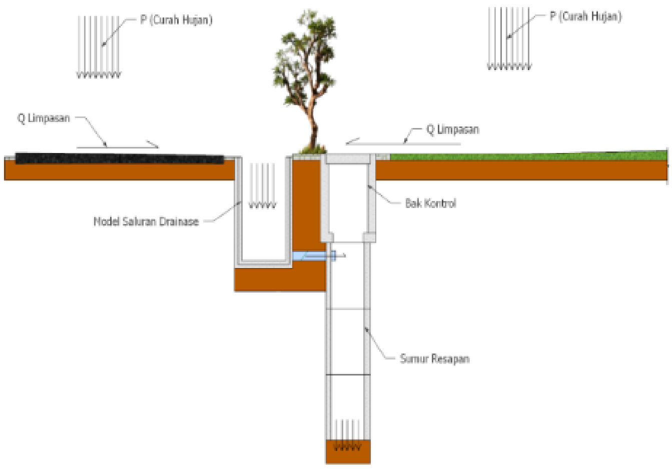

Figure 6. Placement of Infiltration Wells Relative to Drainage Channels

Infiltration wells serve a vital function within the broader framework of sustainable urban drainage and groundwater management systems. These structures facilitate the direct percolation of surface runoff into the subsurface, thereby enhancing groundwater recharge and contributing to the stabilization of local hydrological cycles. By enabling the infiltration of rainwater at its point of incidence, infiltration wells effectively reduce surface flow volumes and peak discharge rates, mitigating the potential for water accumulation, ponding, and urban flooding in adjacent or downstream areas. Furthermore, the implementation of infiltration wells supports the conservation of water resources by promoting the natural replenishment of aquifers, which is particularly significant in regions experiencing rapid urbanization and increasing impervious surface coverage (Neukum et al., 2022; Wang et al., 2024)

4. CONCLUSION

Based on the analysis results, the flow rate in the primary channel in the Old Market Area, Serang City, is recorded at 0.24724 m^3/second (planned Q), while the channel capacity reaches 0.74996 m^3/second (channel Q). In the secondary channel II, the planned flow rate is 0.43004 m^3/second, and in the secondary channel III, it is 0.42744 m^3/second, with the channel capacity for both remaining at 0.74996 m^3/second. The comparison between the planned discharge and the channel capacity shows that the existing drainage channels are still adequate to carry the water discharge without causing overflow. However, the topographical characteristics of the area need special attention. The Pasar Lama area has a flat yet naturally concave landform, causing rainwater that falls in the area to tend to flow and accumulate in the lowest part, right at the research location. This condition causes water accumulation that has the potential to trigger flooding. Therefore, efforts are needed to redesign the channel dimensions to improve the effectiveness of rainwater drainage. The newly planned channel has a square cross-section with a depth (h) of 0.94 meters and a base width (b) of 0.94 meters. The flow velocity in this new channel is estimated to reach 5.014 meters per second. In addition to enlarging the channel dimensions, the design also includes the construction of infiltration wells on the side of the channel. These infiltration wells function to capture runoff water, enhance groundwater recharge, and reduce the amount of surface water that could potentially flow into the surrounding areas. With the implementation of this strategy, the drainage system is expected to become more adaptive and capable of supporting sustainable rainwater management.

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