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The assessment of drainage performance in the residential area using SWMM

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Abstract
Flood is a general issue that can lead to the life and safety of residents. One of the problems is the lack of capacity in the drainage system in a residential area. This paper will analyze the drainage system based on the capacity in one of the residential clusters. The method for the drainage system performance in hydrology analysis was carried out with Log Person, and the return period for rainfall duration is ten years (R_{10}) for hydraulic analysis using drainage system modeling with EPA – SWMM 5.1. The result based on hydrological is the precipitation for flood forecasting is 159.79 mm. It is found that the drainage capacity is filled in downstream of the main drain with a maximum discharge of 2.726 m^3/s and secondary drains with a maximum discharge of 0.624 m^3/s. Improvements were made to resolve the insufficiency of the existing channels by running two different scenarios: (1) Re-design the dimensions of the main and secondary channels, (2) Implement a detention pond, as well as re-design the dimensions of the secondary channels. Both scenarios could overcome the flood problem. Scenario 2 shows a higher reduction in the flow discharge at the downstream channel compared to scenario 1.

Keywords:
Discharge capacity;
Drainage system;
EPA – SWMM 5.1;
Flood;

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INTRODUCTION

In general, flooding or inundation is a condition where drainage channels can no longer accommodate water and lead it to overflow the surrounding area. The presence of flooding or inundation phenomena can occur due to very high rainfall and the inability of a drainage system to accommodate rainwater. Sometimes, external factors such as clogging drainage due to the presence of debris cause water to overflow the surface. A significant increase in rainwater in urban drainage can pose a threat to the life and safety of urban residents' property [1]. Previous research indicates that land-use changes increase an area's impervious value [2][3]. A significant increase in rainfall causes the channels to be unable to accommodate water at its existing capacity. Hence, with a higher impervious value of the area, it prevents the rainwater from infiltrating the soil. This land use changes because of a growth in the population, which increases the conversion of land use from open space to residential areas [4]. The development of residential areas not supported by the planning of drainage systems and good drainage infrastructure may cause inundation or flooding [5].

This research was conducted in a residential clustered area in Tangerang Regency, Banten Province, Indonesia. The development in this area includes infrastructure, residential, and industrial areas. There was a flood of around 5-15 cm high in the residential area in early 2020, and another flood is expected to occur every rainy season. The presence of flooding highlights the inability of the drainage capacity in the affected areas both inside and outside the cluster to accommodate the discharge of existing water. The drainage system analysis is done by checking the slope of the channel based on the channel characteristics, rain distribution calculations, and testing, followed by a simulation of the existing drainage system model of the area with the application of EPA-SWMM (Stormwater Management Modeling). SWMM is an effective tool for estimating floods in urban areas [6].

Suppose the drainage capacity is not able to accommodate the existing water discharge based on the results of model simulations. In that case, the improvement concepts were obtained by re – simulating the drainage system to accommodate the designed flood discharge [7]. The improvements can be in the form of re-designing the dimensions of drainage channels [8]. It can also be accomplished through water management planning in the form of detention ponds or retention ponds. This effort is carried out to ensure the smooth functioning of activities in this region in the future. Since hydraulic problems related to excess flow in drainage are quite common, a common solution is to increase the capacity of the system [9]. Drainage is a water management method that removes excess water from an area to enable optimal functioning. Efforts to control water quality in the soil associated with salinity are also defined as drainage [10]. Floods are an event that generally occurs due to heavy rains of long duration, which increases the volume of water and accelerates the accumulation of surface runoff at ground level [11]

A Detention pond is one approach of sustainable drainage systems, which has been used widely to prevent inundation or flooding [12] [13, 14, 15]. It is defined that a detention pond is a rainwater reservoir in a certain period. Its function is to reduce the peak of flooding in the body of water/river. Water that has been accommodated in the detention pond will flow back to the drainage channel when the drainage channel is no longer filled with water. Detention ponds are usually shaped like ponds or artificial lakes formed according to the condition of the area [16].

One of the popular applications in the implementation of drainage system analysis is EPA–SWMM. It is a program developed by the Environmental Protection Agency or EPA from the United States in 1971. EPA – SWMM can be used to run a simulation of water amount and quality for urban drainage systems [17] [18]. Both planning and analysis of the drainage system can be carried out using this application due to its function to estimate the performance of channels in accommodating runoff in a drainage system. Runoff in EPA-SWMM modeling can be reviewed on open channels [19], closed channels, detention ponds, and pumps [20][22]. EPA-SWMM delivers the quality and quantity of runoff affected by the catchment area, average flow, flow depth, water quality in each pipe, and open channel simulation time included in the addition of time. There are several components in modeling with EPA-SWMM applications, such as rain gauge, time series, sub-catchment, junction nodes, outfall nodes, flow divider nodes, storage units, conduits, and orifices.

METHOD

The initial step is to arrange the background and identify the drainage system problems in the residential cluster area in Tangerang Regency. The data was collected in the form of rainfall data, channel detail data, a topographic map of the area, a site plan, and photos of the site. Furthermore, the research was conducted by checking the safety of the channel slope by comparing the result of flow velocity calculations with the existing speed standards. With the data and the results of hydrological analysis, the simulation of the existing drainage system in residential cluster areas with EPA-SWMM can be performed [3, 22, 23]. Figure 1 shows the flowchart of this research.

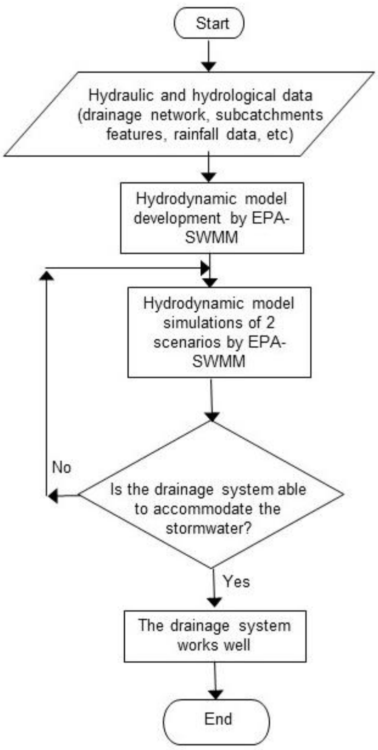

Figure 1. Research Methodology, modified from [24]

Hydraulic Analysis

Assessment of channel slope is performed based on channel characteristics such as channel slope, manning roughness value, and channel type. Safety checks are performed by comparing channel velocity calculation results using the manning formula and existing channel speed standards. For example, for manning value on the main channel is 0.035 for rough stone, while on a secondary channel is 0.018 for a concrete channel.

The minimum speed standard of the channel is with a value of 0.6 m/s, while the maximum speed standard is taken from the national regulation on urban drainage system management [24] with a value of 2 m/s for the stone channel and 3 m/s for the concrete channel.

Based on the checking of the channel slope, it was found that the flow velocity in the channel is within the permitted range, which is between 0.6 m/s to 2 m/s for stone channels and between 0.6 m/s to 3 m/s for concrete channels. Therefore, it can be concluded that the slope of the entire channel is in accordance with existing standards. It can be ensured that the problem does not arise from the slope of the channel.

Hydrology Analysis

Rain data that was used is rain data for 10 years, from 2008 – 2017 which are taken from 3 different rain stations. The results of rain data analysis by the algebraic method are as Table 1. From the hydrology analysis, the R10 value from Log Pearson III distribution is used as shown in Table 2.

Table 1. Rainfall Value

Year	Max (mm)
2009	181.00
2010	142.33
2017	138.67
2016	132.67
2008	115.67
2014	115.33
2015	107.67
2013	97.00
2011	95.00
2012	80.67

Table 2. Log Pearson III Design Rainfall

Rain Event	Design Rainfall (mm)
2 Years	116.51
5 Years	142.86
10 Years	159.79
20 Years	177.14
50 Years	196.30
100 Years	211.69

Drainage System Modeling

The channel data input is divided into two data input windows: junction and conduit. The junction data input includes an inverted elevation channel (upstream and downstream elevation of the channel), while conduit data input includes channel type, dimension, length, and manning roughness value. The junction and conduit data input windows in EPA-SWMM are shown in Figure 2.

In SWMM, the study area is divided into smaller computational units which have their own hydrological characteristics and independent rainfall-runoff processes, called sub-catchment [25]. The area reviewed, covering 18 Ha is divided into three areas. A schematic of the drainage system and its flow direction is shown in Figure 3.

The catchment area value is obtained based on AutoCAD measurements, while the C coefficient value is calculated based on land use. For example, for cluster residential area used 0.70, the coefficient for roads with the flexible pavement is 0.95, and the coefficient for unused land is 0.3. The C coefficient and land slope are included in the sub-catchment data input window for the catchment area as Figure 4.

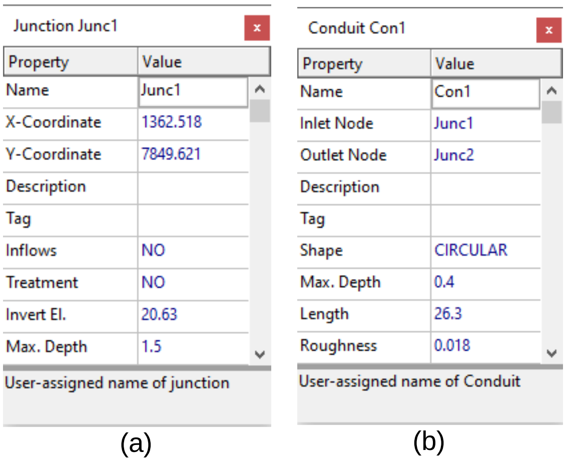

Figure 2. Input Data for (a) Junction and (b) Conduit

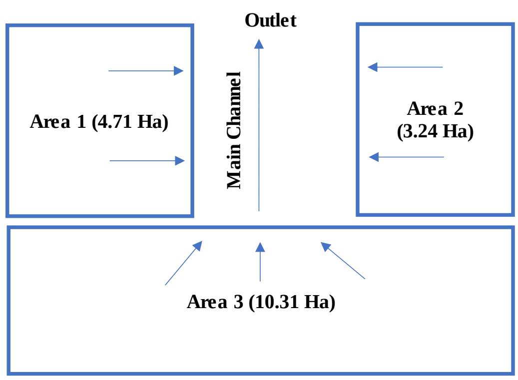

Figure 3. Flow Direction of Drainage System

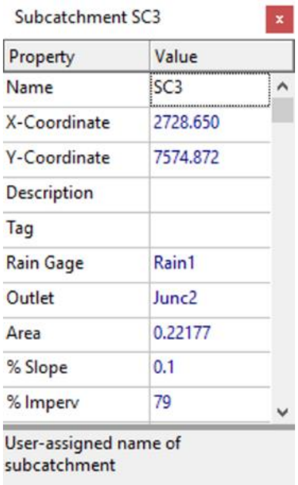

Figure 4. Sub Catchment Input Data

To determine hourly rain data value for EPA - SWMM, calculations can be performed using the Mononobe formula. With ten years of rainfall events of 159.79 mm and a rain duration of 6 hours, it can be determined the time series data input required by EPA – SWMM. The calculation results can be seen in Table 3, whereas the data input in EPA – SWMM is shown in Figure 5.

Table 3. Time Series Calculation Result

T (hr)	I (mm/hr)	I (T) (mm)	ΔP (mm)	Δ (%)	P (mm)
1	55.40	55.40	55.40	55.03	87.94
2	34.90	69.79	14.40	14.30	22.86
3	26.63	79.89	10.10	10.03	16.03
4	21.98	87.94	8.04	7.99	12.76
5	18.95	94.73	6.79	6.75	10.78
6	16.78	100.66	5.94	5.90	9.42
Total				100	159.79

Where:
I : intensity
P : precipitation

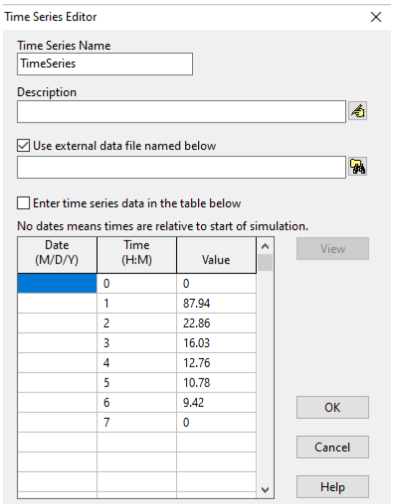

Figure 5. Time Series Input Data

RESULTS AND DISCUSSION

Existing Drainage System

From the simulation of the existing drainage system at the time of maximum discharge, which is 2nd hour of rain, a map is obtained showing the condition of the channel capacity, as shown in Figure 6.

From the simulation results at the 2nd hour, it can be known that the main channel and ten secondary channels that cannot accommodate the water are marked in red with a capacity value of 1. A value of 0 indicates the unallocated water in the channel, while 1 is a filled channel with water. The colors of dark blue, cyan, green, yellow, and red respectively indicate 0 %, 25 %, 50 %, 75 %, and 100 % filled channels with water. The results of the channel performance of the main channel (trapezoidal type) are shown in Table 4 dan Figure 7, and the secondary channels are as follows in Table 5 and Figure 8.

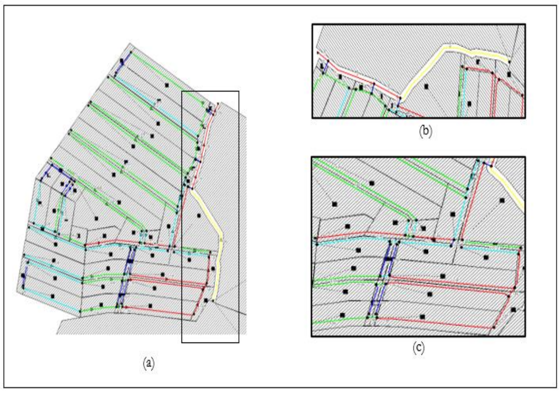

Figure 6. (a) Existing Drainage Modeling, (b) Drainage System Scheme Main Drain and (c) Secondary Drain

Table 4. Main Drain Capacity Performance

No	Dimension (m)	Water level (m)	Q (m^3/s)	Capacity (0 – 1)
1	Width = 2	0.89	2.402	0.90
2	Height= 1	1	2.697	1
3		1	2.707	1
4		1	2.726	1

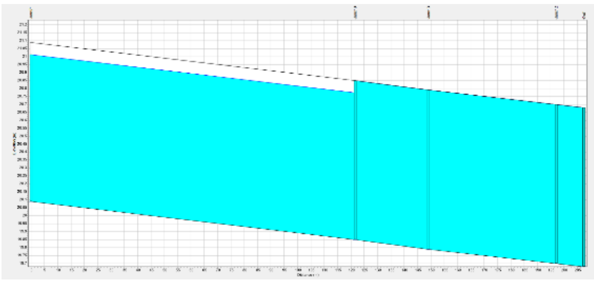

Figure 7. Cross Section of Height Level Main Drain

Table 5. Secondary Drain Capacity Performance

Sec	Type	Height (m)	Water Level (m)	Q (m^3/s)	Capacity (0 – 1)
21	RCP*	0.5	0.5	0.147	1
36	RCP	0.4	0.4	0.082	1
48	RCP	0.4	0.4	0.082	1
49	RCP	0.6	0.6	0.264	1
51	RCP	0.5	0.6	0.281	1
53	BC	0.8	0.8	0.304	1
58	RCP	0.4	0.4	0.084	1
59	BC**	0.5	0.5	0.177	1
65	RCP	0.4	0.4	0.088	1
66	RCP	0.4	0.4	0.093	1

*Reinforced concrete pipe
** Box Culvert

The channels are currently unable to accommodate the discharge of water during the 2nd hour of rain, indicated by the capacity value of 1, which indicates that the channel's capacity was fully filled, and the existing water overflowed to the surface.

Scenario 1 and Scenario 2 Modeling

Based on the simulation results above with the EPA – SWMM application, it can be known that the existing drainage system in the cluster area experiences insufficiency in accommodating water in the main channel and some secondary channels at the time of maximum discharge. This is characterized by the red output on some channels that identifies that the channel is fully filled with water and has a risk of flooding. Related to this, there need to be certain efforts to change the condition to reduce the risk of flooding in the area. There are 2 scenarios that are planned as an effort to improve the existing flood problem. In scenario 1, there is a dimensional change in the main channel, as shown in Figure 8 and secondary channel while in scenario 2, there is a dimensional change in the secondary channel and the addition of storage on the main channel.

The simulation result of scenario 1 at the time of maximum discharge generates the map in Figure 8. The results of drainage simulation based on the picture above show that there are channels that can accommodate the water and characterize with no more red color in the channels. This indicates that the channels can accommodate the water discharge. These changes include the dimensional change shown in Figure 8 and the result of the main drain capacity can be shown in Table 6 and Figure 9, and the result of the secondary drain can be shown in Table 7.

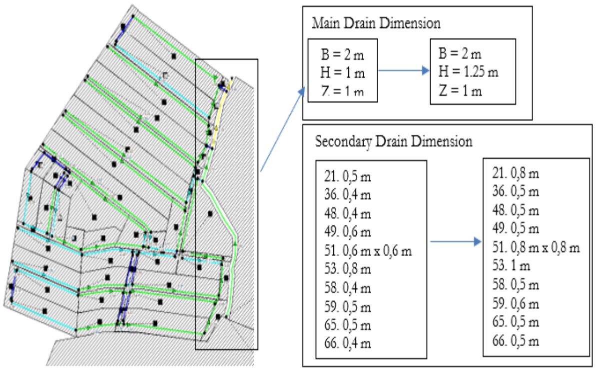

Figure 8. Scenario 1 of Drainage System

Table 6. The Capacity Main Drain of Scenario 1

No	Type	D* (m)	Water level (m)	Q (m^3/s)	C**** (0 – 1)
1	Trapezoidal	W** = 2	0.85	2.302	0.60
2	Trapezoidal	H*** =	0.98	3.107	0.72
3	Trapezoidal	1.25	1.04	3.217	0.78
4	Trapezoidal		1.06	3.328	0.80

*Dimension
** Width
***Height
****Capacity

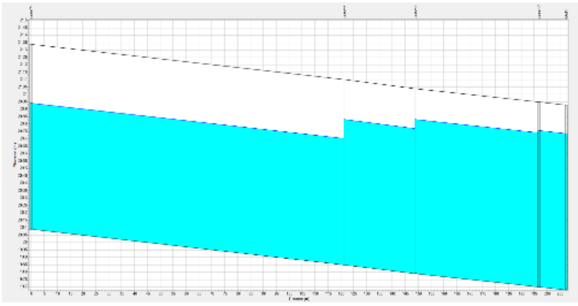

Figure 9. Cross Section Main Drain of Scenario 1

Table 7. Scenario 1 Secondary Channel Simulation Result

Sec	Type	Height (m)	Water Level (m)	Q (m^3/s)	Capacity (0 – 1)
21	RCP*	0.8	0.5	0.147	1
36	RCP	0.5	0.4	0.082	1
48	RCP	0.5	0.4	0.082	1
49	RCP	0.8	0.6	0.264	1
51	BC**	0.8	0.6	0.281	1
53	RCP	0.8	0.8	0.304	1
58	RCP	0.5	0.4	0.084	1
59	BC	0.6	0.5	0.177	1
65	RCP	0.5	0.4	0.088	1
66	RCP	0.5	0.4	0.093	1

*Reinforced concrete pipe
** Box Culvert

From Table 8, the previously filled channels in the existing condition are no longer fully filled with water after the dimensional change. In the downstream of the main channel, the capacity of the main channel previously filled by 100 % can be reduced to 80 %. This indicates that changing dimensions in the main and secondary channels can increase the capacity of the channel and reduce the risk of flood in the area [27]. The simulation result of scenario two at the time of maximum discharge generates the following map.

The results in Table 8 are obtained after the addition of the detention pond and dimensional change in the secondary channels, as shown in Figure 10. The addition of storage reduces the discharge load received by the main channel at one time by temporarily accommodating the water runoff from area 3 before being reflowed through the main channel. The 6 hours simulation produced a graph of the water level in the storage, as presented in Figure 11.

From the water level graph of the storage above, the water reaches its peak discharge during the 2 hours of the rainfall event, but the orifice is able to control the water level in the storage to make the water remains constant at the height of 2.5 m.

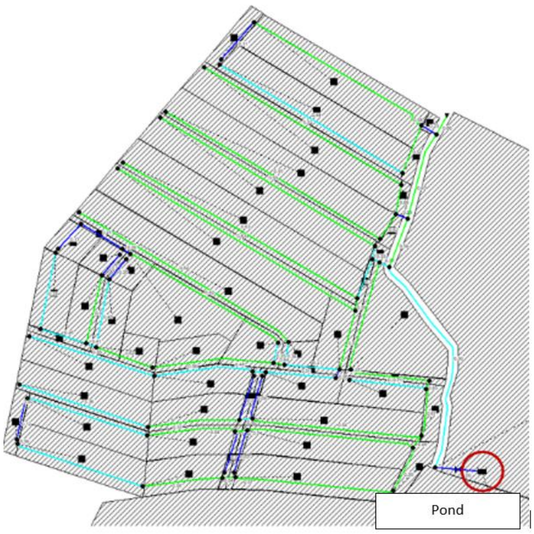

Figure 10. Scenario 2 Drainage Simulation Map

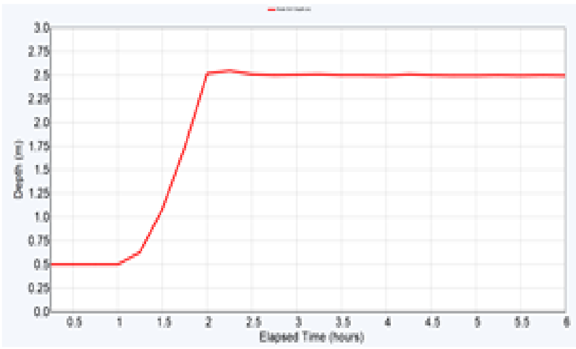

Figure 11 Storage Water Level during 6 Hours Graph

This addition of storage influences the simulation results on the main channel. Here are the main and secondary channel simulation results, as presented in Table 8 and Figure 12.

From Table 9, adding a detention pond without any changes in the main channel's dimensions and dimensional change for several secondary channels can reduce the risk of flood in the area. This is indicated by the capacity that is no longer fully filled. This result is in alignment with Lin et al. [28] and Sahoo et al. [3]. The downstream capacity of the main channel was successfully reduced to 66 % only. The presence of a detention pond effectively reduces the flow of water in the main channel simultaneously.

Table 8. The Capacity of Main Drain Simulation Result

No	Type	D* (m)	Water level (m)	Q (m^3/s)	C**** (0 – 1)
1	Trapezoidal	W** = 2 H*** = 1.0	0.38	1.166	0.30
2	Trapezoidal		0.63	1.909	0.56
3	Trapezoidal		0.69	2.012	0.63
4	Trapezoidal		0.72	2.116	0.66

*Dimension
** Width
***Height
****Capacity

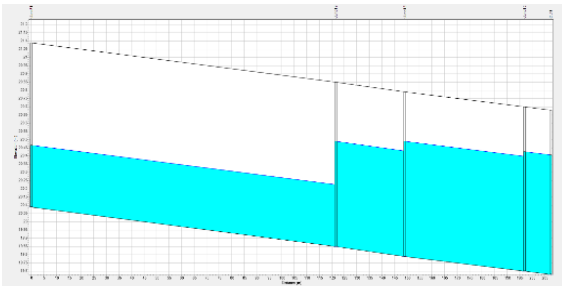

Figure 12. Cross Section Main Channel of Scenario 2

Table 9 Scenario 2 Secondary Channel Simulation Result

Sec	Type	Height (m)	Water Level (m)	Q (m^3/s)	Capacity (0 – 1)
21	RCP*	0.8	0.38	0.238	0.46
36	RCP	0.5	0.27	0.086	0.58
48	RCP	0.5	0.26	0.082	0.55
49	RCP	0.8	0.51	0.264	0.73
51	BC**	0.8	0.52	0.281	0.70
53	RCP	0.8	0.56	0.329	0.60
58	RCP	0.5	0.26	0.084	0.55
59	BC	0.6	0.26	0.177	0.76
65	RCP	0.5	0.28	0.088	0.59
66	RCP	0.5	0.29	0.093	0.63

*Reinforced concrete pipe
** Box Culvert

CONCLUSION

Several conclusions were accomplished from this research. First, the existing drainage system design shows that the channel cannot accommodate rainwater during 2 hours of the rainfall event. In order to overcome this problem, two scenarios were proposed and simulated using the EPA-SWMM program. In scenario 1, the re-design of the main channel dimension and ten secondary channels has reduced the flood in the residential cluster area. As a result, the capacity of the main channel in the downstream area is filled by 80 % with a discharge of 3.328 m^3/s. In scenario 2, both the re-design of the dimensions of ten secondary channels and the addition of storage in the main channel are simulated. The results show that the capacity of the main channel in the downstream area is filled by only 66% with a discharge of 2.116 m^3/s.

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