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Sengkang City Runoff Management in Primary Drainage Channels with One Dimensional SWMM model

M idris[1], R T Lopa[2], R Karamma[2] dan F Maricar[2]

[1]Magister Course, Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Indonesia.

[2]Department of Civil Engineering, Faculty of Engineering, Hasanuddin University, Indonesia.

E-mail: muhammad.idris.st@gmail.com

Abstract. The main problem in Sengkang City is the occurrence of flood with a height between 0,5 to 1 m in the city center which is an economic area, these is visually caused by the insufficient capacity of the drainage channel to drain runoff water. Topographically, the economic center of Sengkang city is a basin area which is the downstream part of 4 primary channels, namely channels A, B, C, and D. The purpose of this study was to analyze the existing conditions of inundation and volumes and to make modification plans to reduce the area and volume of flooding in Sengkang City. In this study, topographic measurements, data on channel cross-sectional conditions and elevations were carried out as well as data collection on rainfall and land use to be used as input data for the rainfall-runoff SWMM simulation that was appropriate and under existing conditions. Simulations were carried out using rainfall intensity 5-year and 10-year return periods and modifications were made to an additional storage capacity of 2.000 m3 in primary channel A. From the simulation results, the flood volume for 5-year return periods (R5) of 96.375m3 (11 inundation areas), 10-year return periods (R10) of 148.901 m3 (12 inundation areas), and modification of 10-year return periods (R10) of 43.990 m3 (9 inundation areas) with a percentage decrease of 70,46% and reduce of 3 inundation areas.

1. Introduction

Based on data from the BNPB 2022, within a period of 15 years for the South Sulawesi Province, natural disasters were dominated by floods and tornadoes with 463 and 469 incidents, respectively. Specifically, the incidence of flooding has increased in the last 10 years [1]

Flood is the process of inundation of residential land due to overflowing rivers, caused by heavy rains or flooding sent from other areas that are at higher altitudes. Indonesia has high rainfall, which ranges from 2000-3000 mm/year, so flooding is easy during the rainy season which is between October to January [2].

The phenomenon of flood in urban areas is a problem faced by almost all parts of Indonesia. This is due to the development of urban areas that are built in flood-prone plain areas close to rivers or beaches. The location is considered more strategic because it is close to transportation facilities and community economic routes.

The increasingly rapid development of urban areas, which is marked by the development of extensive urban facilities and infrastructure, attracts residents to move to urban areas and occupy settlements in water catchment areas. Changes in land use change which is quite drastic which is not accompanied by regional arrangement will increase the risk of flooding. This is due to increased surface runoff in urban areas.

In this study, Sengkang City, Tempe sub-district, Wajo district was used as the object of research. The population growth rate of the tempe sub-district reached an average of 0,91% per year, exceeding the district average of 0,33%. This has an impact on the level of population density in the sub-district and directly affects changes in land use in the Sengkang city area. The effect experienced by the population is an increase in the incidence of flooding 5 to 6 times a year in the central market area and Andi Paggaru road with inundation heights between 0,5 to 1 m.

Topographically, Sengkang City, Tempe District, Wajo Regency is characterized by a hilly area with valleys, with 4 primary channels that cross the city and end at the Walannae River. The river route crosses densely populated areas with inlets from secondary channels in residential areas.

The modeling of rainfall and runoff (RR) that occurs in the research area is used to analyze the condition of existing events in the primary canal. This model is used in various hydrological modeling applications to estimate the amount of runoff that occurs because of land-use changes. One application that uses a rainfall and runoff modeling system is the Storm Water Management Model (SWMM). SWMM is a software capable of analyzing water quantity and quality problems related to urban runoff. Storm Water Management was developed by the EPA (Environmental Protection Agency – US) since 1971 [3].

The use of SWMM has been used in various urban areas in hydrological and runoff models. Warwick and Tadepalli have calibrated and validated the SWMM to model a ± 10.000 km^2 urban watershed in Dallas State of Texas [4].

The purpose of this study was to obtain 5- and 10-year return flood volumes with SWMM modeling with primary channel modeling and alternative drainage network system modeling in reducing the impact of flood volume in the Sengkang City area.

2. Material and Methods

This research was conducted in Sengkang City. Sengkang City is the capital of the Wajo Regency. It is a small town located in South Sulawesi Province and is located between 30º39'01” – 40º16'01” South Latitude and 119º053'02” – 120º027'02” East Longitude. The total area of Sengkang city is 38,27 km^2, including one sub-district, Tempe District, which consists of 16 villages. The location of the research is shown in Figure 1.

Figure 1 Sengkang city

The data used in this study include:

a. Rainfall data in the form of TRMM (1998 to 2021) from the National Institute of Aeronautics and Space (LAPAN).
b. Sengkang city channel elevation measurement data and primary channel cross-section with geodetic and manual measurements.
c. Map of the type of soil in Sengkang City from the Balitbangda government office Wajo City.
d. Sengkang city elevation data is in the form of the National Digital Elevation Model (DEMNAS) from the Geospatial Information Agency and a map of the layout Sengkang City.

Rainfall data from TRMM were analyzed to obtain rainfall intensity with 5-year and 10-year return periods. Mononobe rainfall intensity formula is as follows:

$$R_t = \frac{R_{24}}{t}\left(\frac{t}{T}\right)^{2/3} \quad (1)$$

For Indonesia t = time of rain concentration used 6 hours

The curve number data used uses references from Urban Hydrology for Small Watersheds (TR-55) [4], with the following table:

Table 1 Curve Number

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (previous areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (townhouses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (Previous areas only, no vegetation) [5]		77	86	91	94

The Soil group as follows:

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0,30 in/hr).

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Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0,15- 0,30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0,05-0,15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high-water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0,05 in/hr).
These formulations for the rainfall-runoff simulation uses the SWMM program:

a. The height of inundation or rain runoff D (mm) in each sub-watershed is as follows:
$$D_1 = D_t + R_t \quad (2)$$
b. The outflow discharge from sub-watershed runoff is calculated by the Manning equation:
$$v = \frac{1}{n} {D_2}^{2/3} S^{1/2} \quad (3)$$
$$Q = vBD_2 \quad (4)$$
c. The water level of the sub-watershed from rain, infiltration and outflow is obtained through the following equation:
$$D_{t+\Delta t} = D_2 - (\frac{Q}{A})\Delta_t \quad (5)$$
d. Process number 1 to 4 is repeated until all sub-das calculations are complete.
e. The discharge entering the channel is calculated by adding the discharge from the land (Q_{oi}) with the discharge from the upstream channel (Q_{gi}).
$$Q_{in} = \sum Q_{oi} + \sum Q_{gi} \quad (6)$$
f. Changes in water level due to increased discharge in a channel are:
$$Y_1 = Y_t + (Q_{in}/A_g)\ \Delta_t \quad (7)$$
g. Manning's equation is used to calculate the channel outflow discharge.
$$v = \frac{1}{n} R^{2/3} S^{1/2} \quad (8)$$
$$Q_g = vA_c \quad (9)$$
h. The results of the water depth in the channel from the inflow and outflow are calculated by the continuity equation as follows:
$$Y_t + \Delta_t = Y_1 + (Q_{in} - Q_g)\Delta_t / A_g \quad (10)$$
i. Steps 6 to 9 are repeated until all channels have been counted. [5]

3. Result and discussion

The land use conditions Sengkang City are based on the results of LAPAN information processing with the results of the mapping in Figure 2

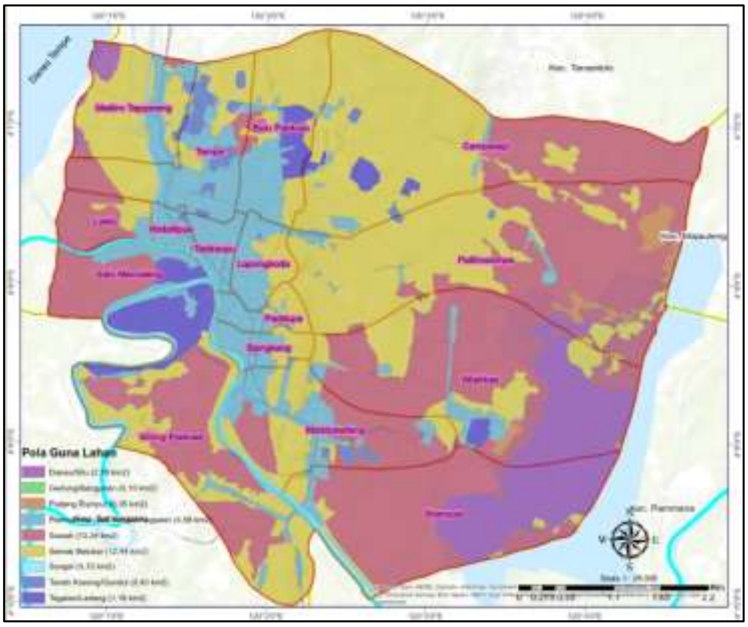

Figure 2 Land map use of Tempe city

Digitizing the sub-catchment area of each catchment that affects the junction of the primary canal, there are 47 sub-catchments accompanied by the area, soil type, and average slope of the sub-catchment shown in figure 3

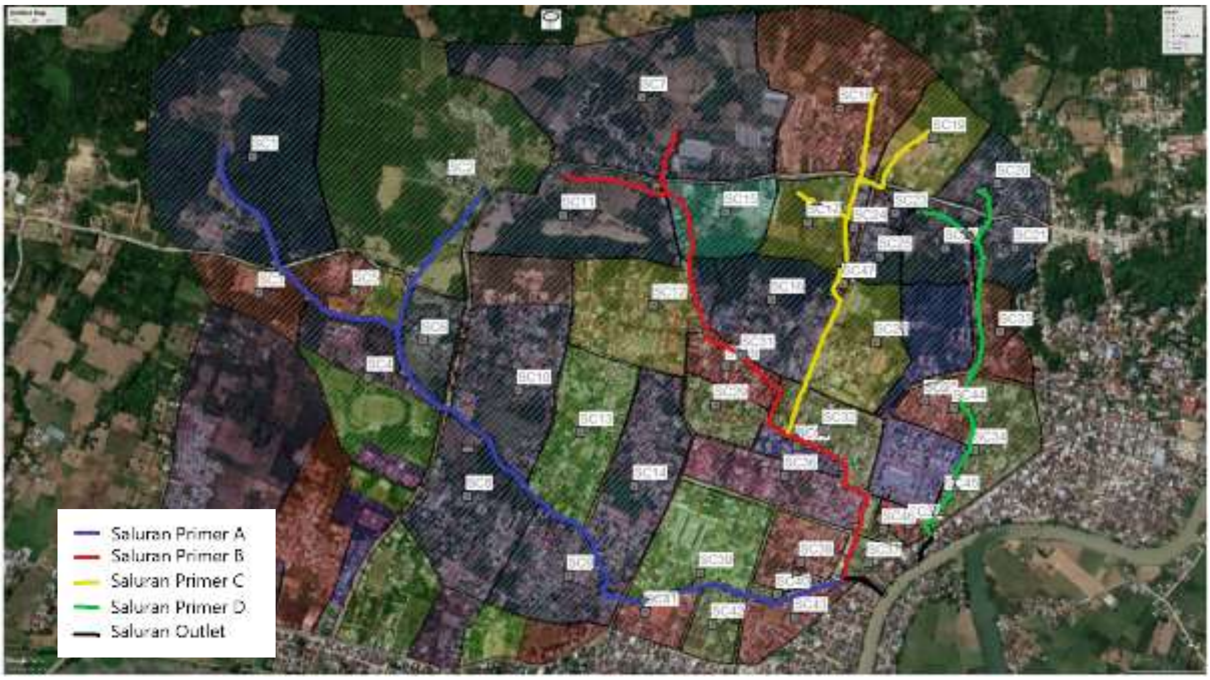

Figure 3 sub-catchment Map

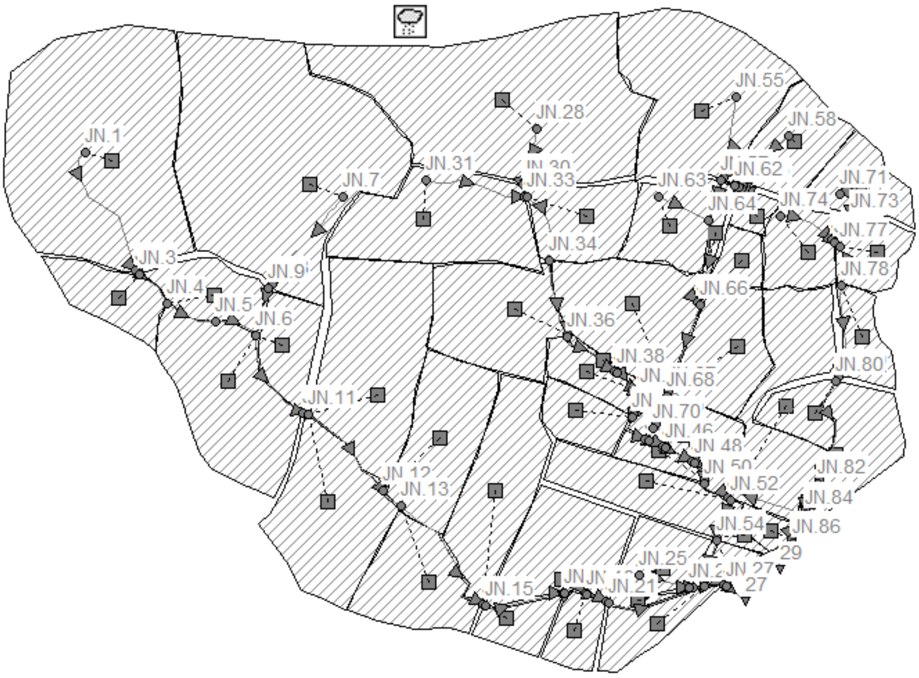

Figure 4 SWMM Modelling Map

Mononobe rainfall intensity for Sengkang city

Table 2 Mononobe rainfall intensity

t	Rt	Rainfall net (Rn, mm) with Repeat Time (Year)	
		R5	R10
		116,115	139,038
(Hour)	(%)	Rainfall Net = Rn x Rt	
1	55,032%	63,900	76,515
2	14,304%	16,609	19,888
3	10,034%	11,651	13,951
4	7,988%	9,275	11,106
5	6,746%	7,833	9,379
6	5,896%	6,847	8,198

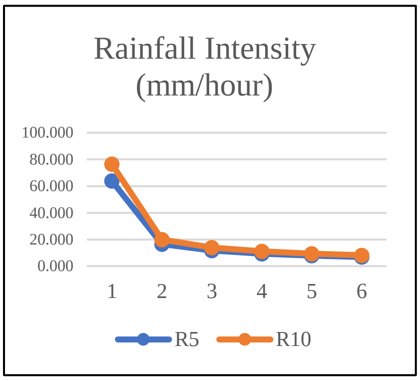

Figure 5 rainfall intensity

3.1. Calibration Model

Model calibration is to ensure that the results of the field survey are the same as the results of the SWMM modeling, by comparing the water level. The water level used from field survey data was taken on June 10, 2022.

Table 3 SWMM model calibration recapitulation

Junction	Water Level Observation (cm)	Model Water Level (cm)	% Error
JN 18	10	9	0,11
JN 22	11	10	0,10
JN 65	15	12	0,25

The calibration value is acceptable if the resulting error value is less than 10% [3]. Based on the table above, the % error obtained is less than 10% so that the model can be accepted.

3.2. Running modelling with R5

Running modelling SWMM one dimension with R5 shown in table 4 and figure 6

Table 4 Junction that is flooding R5

Node	Maximum Rate CMS	Total Flood Volume 10^6 ltr	Total Flood Volume m3
JN.12	0,319	0,01	5,00
JN.14	20,605	55,77	55.768,00
JN.15	1,832	0,02	18,00
JN.16	4,194	18,28	18.277,00
JN.45	1,949	2,11	2.108,00
JN.50	0,804	1,04	1.042,00
JN.55	2,33	5,54	5.538,00
JN.58	0,661	1,39	1.392,00
JN.66	1,72	3,46	3.457,00
JN.67	0,957	0,84	840,00
JN.68	2,231	7,93	7.930,00
	Total		96.375,00

Running model R5 there is an excess of channel capacity on the primary channel path, resulting in flood events with a total flood volume of 96.375 m^3 (11 inundation areas).

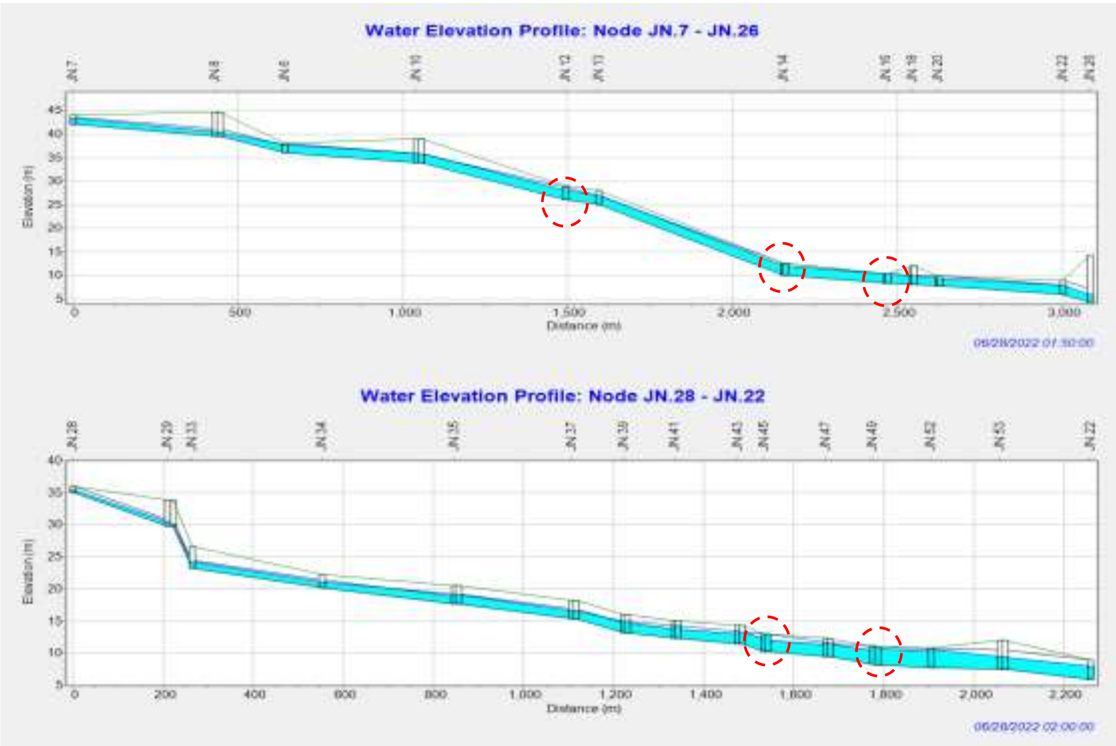

Figure 6 Primary channel water evaluation A,dan B with R5

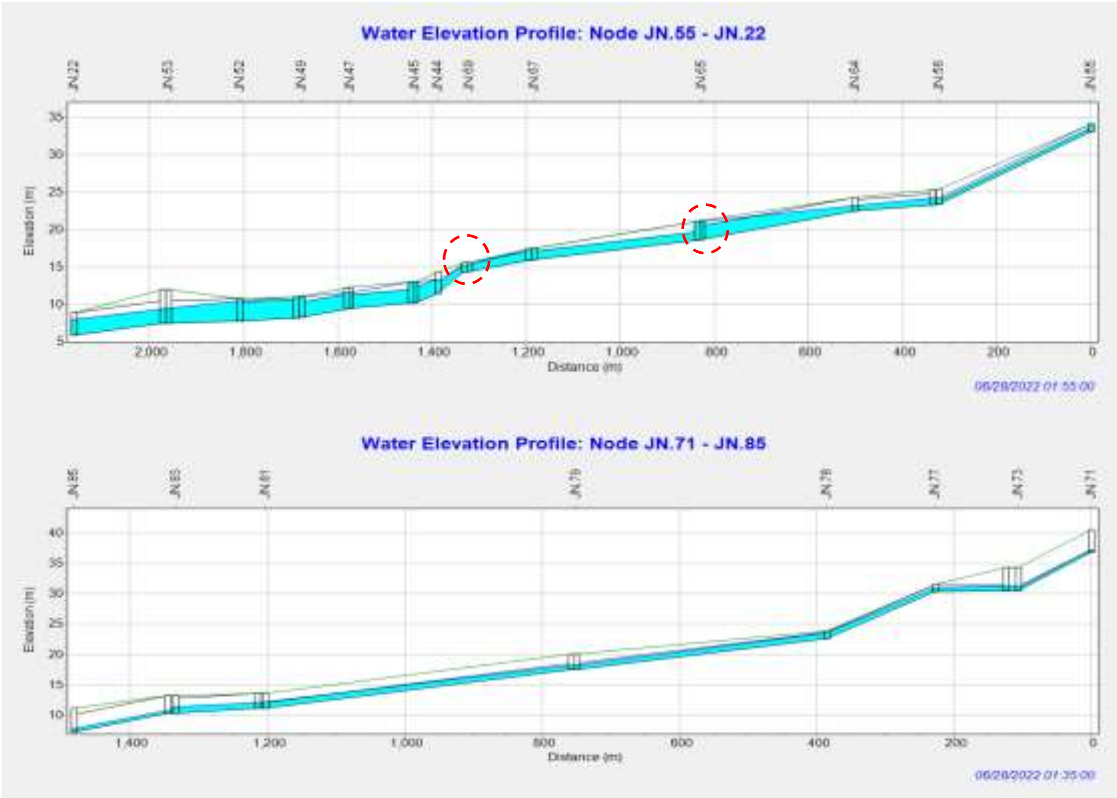

Figure 7 Primary channel water evaluation C dan D with R5

3.3. Running modelling with R10

Running modelling SWMM one dimension with R10 shown in table 5 and figure 7

Table 5 Junction that is flooding R10

Node	Maximum Rate CMS	Total Flood Volume 10^6 ltr	Total Flood Volume m3
JN.12	4,22	5,617	5.617,00
JN.14	22,203	77,511	77.511,00
JN.15	2,282	0,027	27,00
JN.16	4,814	23,883	23.883,00
JN.45	4,146	7,812	7.812,00
JN.50	1,658	3,538	3.538,00
JN.55	3,298	8,692	8.692,00
JN.58	0,991	2,339	2.339,00
JN.66	2,312	5,453	5.453,00
JN.67	1,977	2,773	2.773,00
JN.68	2,243	10,852	10.852,00
JN.78	0,51	0,404	404,00
	Total		148.901,00

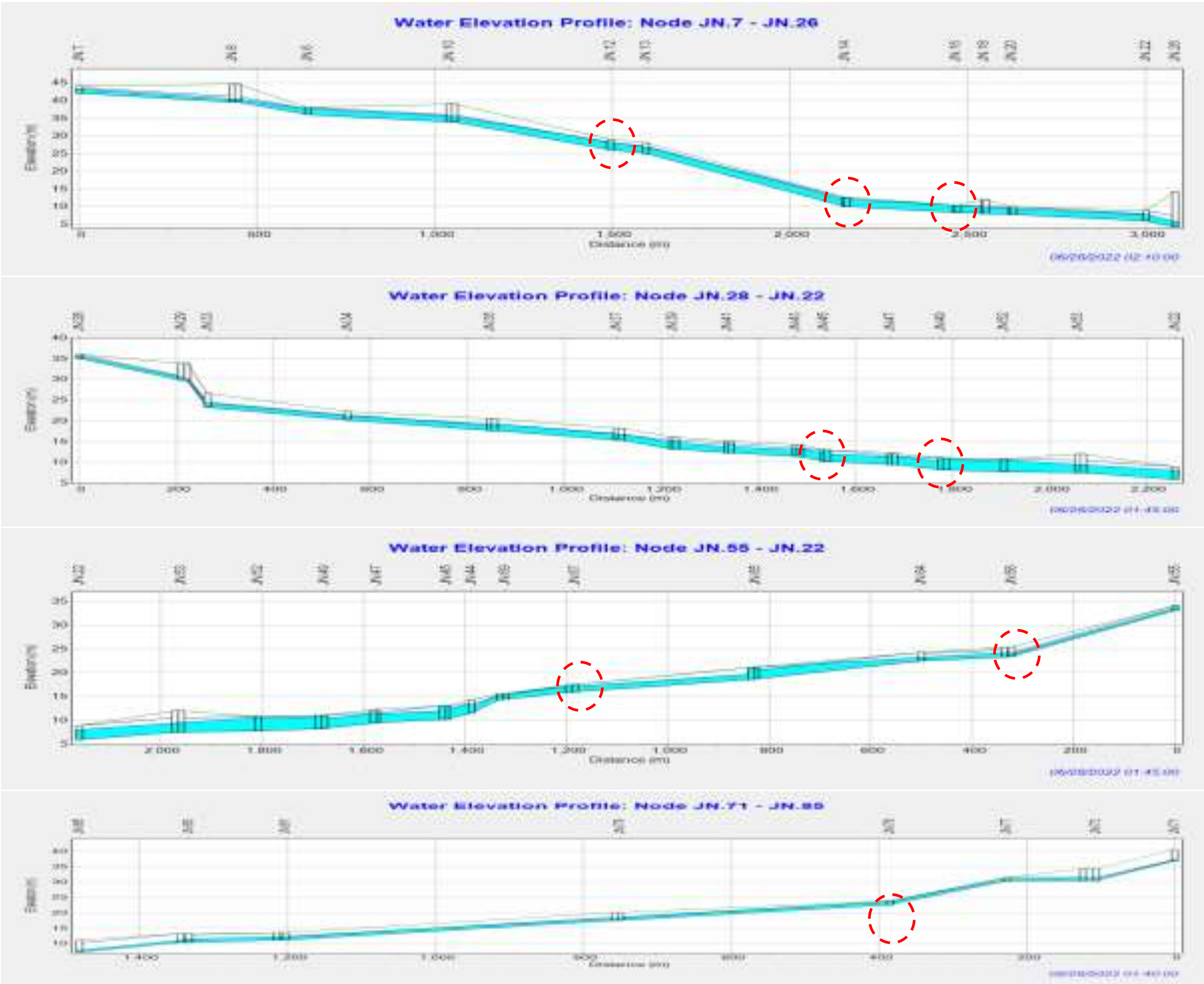

Figure 8 Primary channel water evaluation A, B, C dan D with R10

In the R10 run model, there is excess channel capacity in the primary channel path, which results in flooding events in the table with a total flood volume of 148.901 m^3 (12 inundation areas) in Figure 7

If a comparison is between R5 and R10, there is an increase in the total flood volume by 54,5%. based on field analysis of flood events with R10 approaching the incidence of flood conditions at the research location. The results of the calculation of the Coeff runoff are in the interval of 0,73 to 0,93 (figure 8).

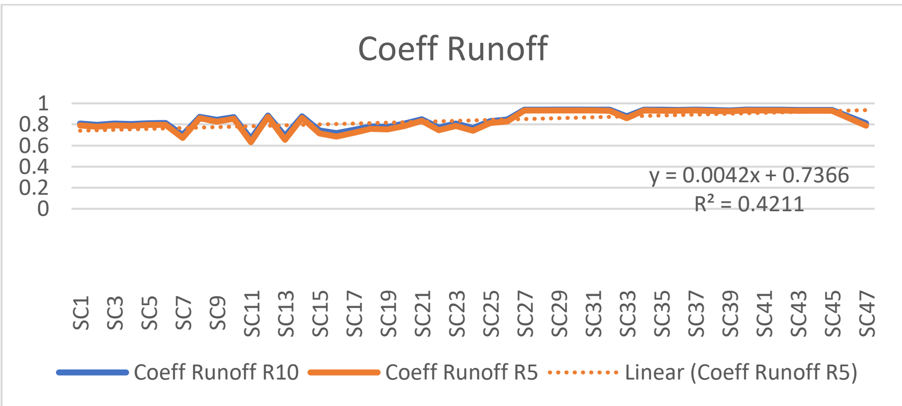

Figure 9 Coeff Runoff

3.4. Running model R10 Modification

Flood disaster mitigation efforts were carried out by modifying the primary channel network model with the addition of 2.000 m^3 storage capacity at the Rusa Street. This was because the largest total volume of water flowed in primary channel A.

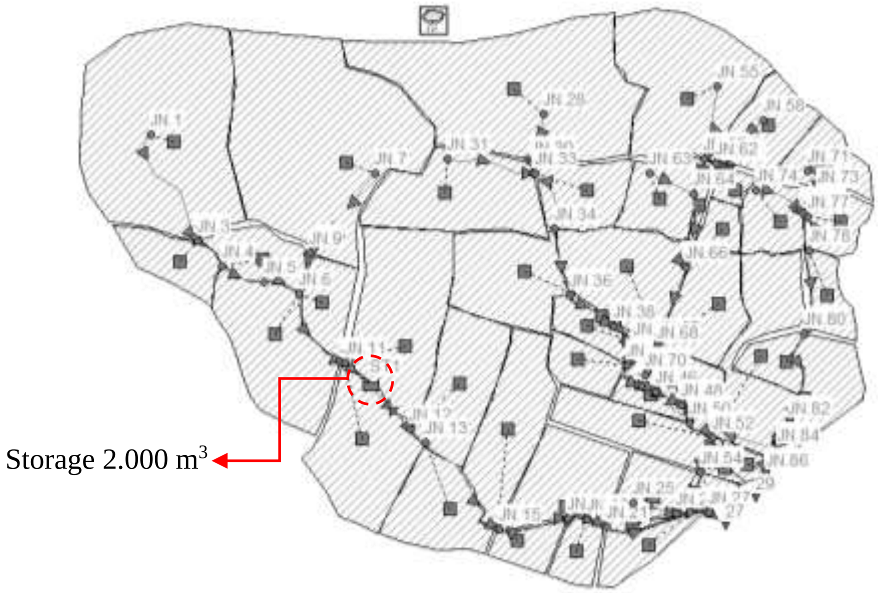

Figure 10 Storage Site Plan

Running modelling SWMM one dimension with R10 modification shown in table 6 and figure 10

Table 6 Junction that is flooding R10 modification

Node	Maximum Rate CMS	Total Flood Volume 10^6 ltr	Total Flood Volume m3
JN.16	2,111	2,135	2.135,00
JN.45	4,141	7,808	7.808,00
JN.50	1,659	3,532	3.532,00
JN.55	3,298	8,692	8.692,00
JN.58	0,991	2,339	2.339,00
JN.66	2,297	5,454	5.454,00
JN.67	1,976	2,773	2.773,00
JN.68	2,243	10,852	10.852,00
JN.78	0,51	0,405	405,00
	Total		43.990,00

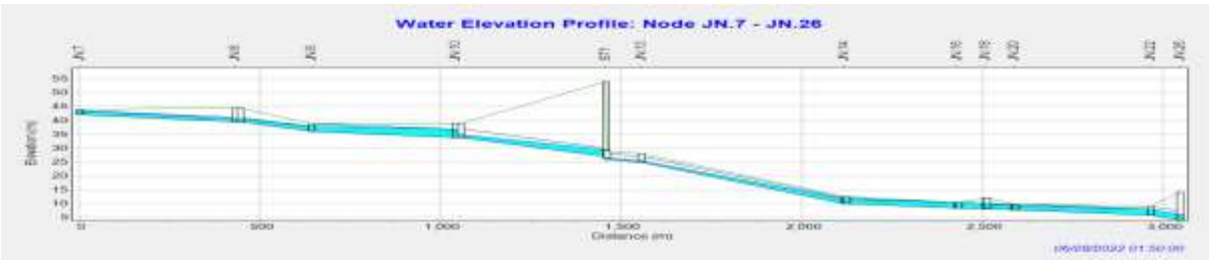

Figure 11 Primary channel water evaluation A with R10 modification

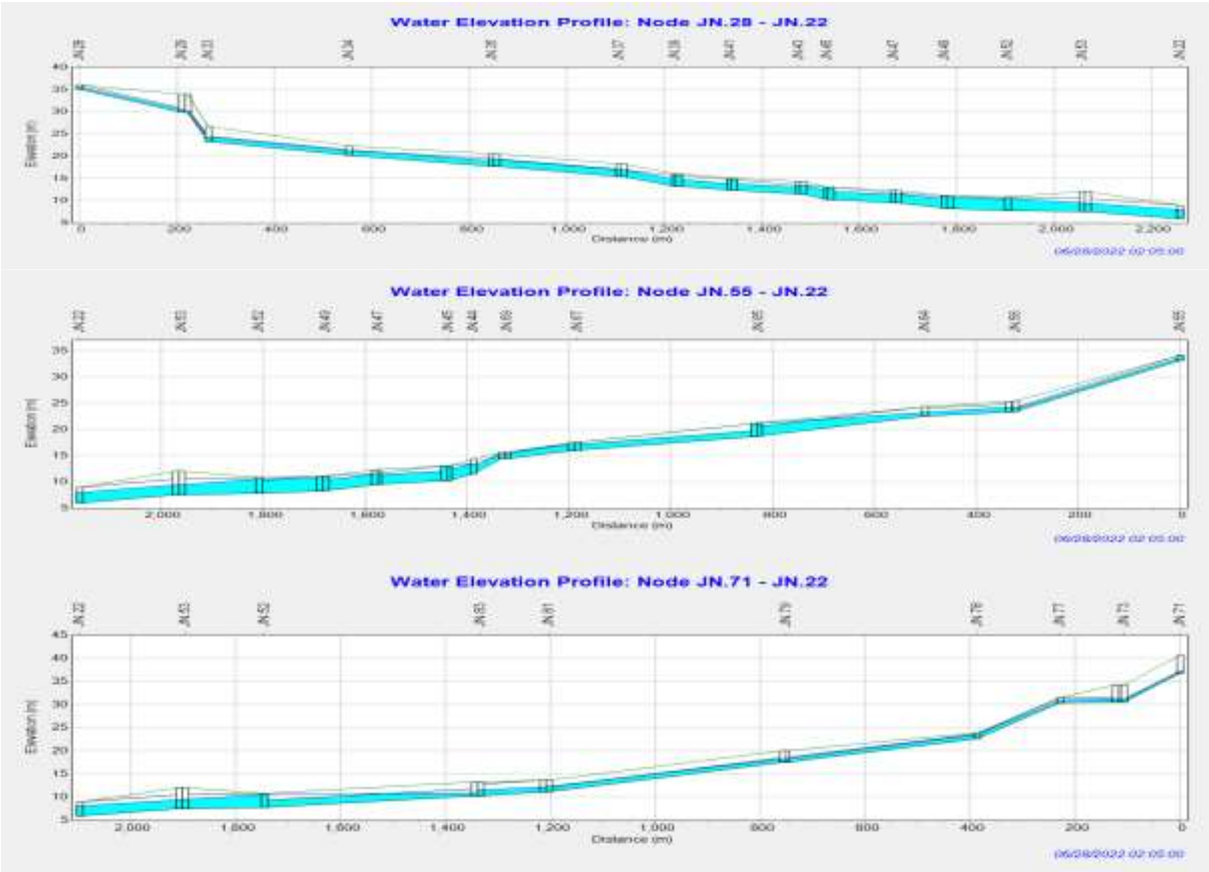

Figure 12 Primary channel water evaluation B, C dan D with R10 modification

Based on the results of running the modified R10 model, the total flood volume is 43.990 m^3 (9 inundation areas).
The evaluation results show that disaster mitigation by modifying primary channel A with the addition of a storage capacity of 2.000 m^3 can reduce the flood potential of R10 by 70,46% and reduce the inundation area by 3 areas (Junction: JN12, JN14 and JN15).

4. Conclusions

- The flood event at the research location was confirmed according to the flood location using the SWMM rainfall-runoff modelling method, total flood volume of 5-year return periods (R5) 96.375 m^3 (11 inundation areas) and 10-year return periods (R10) 148.798 m^3 (12 inundation areas) with Coeff runoff 0,73 – 0,93.
- Modification of the primary channel by installing a storage capacity of 2.000 m^3 reduces the flood potential of 10-year return periods (R10) by 70,46% and reduces 3 inundation areas (JN12, JN14 and JN15).

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