Vol. 13, No. 2 (2024): 459 - 469 http://dx.doi.org/10.23960/jtep-l.v13i2.459-469

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Reassessment of the Dimensions and Layout of Roadside Canals

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Article History:

Received : 29 May 2023
Revised : 16 August 2023
Accepted : 15 September 2023

Keywords:

Reviewing,
Roadside channel,
Runoff

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ABSTRACT

Until now, there have been puddles on several sections of the Grand Depok City Boulevard road, which are located in the Sukmajaya and Cilodong Districts. This study aims to review the drainage system at three inundation locations (A, B, and C), which includes layout, runoff discharge, channel design discharge, channel dimensions, culverts, and cost estimation. The results showed that the drainage system was built inadequately, so an outlet channel was needed at location A and culverts at locations A and C. The calculated runoff discharge ranged from 0.16-0.73 m^3/second, with a planned channel discharge ranging from 0.38-1.10 m^3/sec. With this discharge value, it is necessary to deepen the canal at location A, which was originally 0.5 m to 0.7 m, and to reduce the slope of the canal bottom at location B, which was originally 3% to 2%. The culverts required at location A are 18.5 m long and 0.6 m in diameter, and there are 39 at location C, each 8 m long and 0.2 m in diameter. The estimated total cost is IDR 155,492,000. Construction of canals and culverts should use precast concrete materials and be done at night.

1. INTRODUCTION

The need for transportation access is directly proportional to the population size, so the higher the population density, the higher the need for transportation access in an area. The population of Depok City recorded by the Central Statistics Agency in 2020 was 2.4 million people (BPS, 2020), indicating a high demand for transportation in Depok City. There are important aspects in providing transportation access, both in terms of quantity and quality. One aspect to consider in ensuring the quality of roads is roadside drainage channels. The presence and condition of roadside drainage channels need to be ensured because they will collect and channel runoff water during rain towards the nearest water bodies. Flooding or excessive water runoff on roads will increase the risk of road damage, especially if the road has heavy daily traffic (Hatmoko *et al*., 2017). Without checking in long term, water ponding on road surfaces can loosen the bond between aggregates and asphalt, leading to road surface damage (Saputra & Fatmila, 2023).

Boulevard Grand Depok City Road, located in the Grand Depok City Area, falls into the category of collector road class with an average road width of 6 m. This road serves as access for residents of the Grand Depok City Area as well as a connector between the economic center of Depok City and the governmental area of Depok City. The total length of Boulevard Grand Depok City Road is 5.3 km with observed traffic conditions being quite busy. The drainage system condition of Boulevard Grand Depok City Road can be considered suboptimal at certain points. This is evidenced by significant water ponding at three locations, namely observation locations A, B, and C. Water ponding on road surfaces can be caused by various factors such as high rainfall, accumulation of trash, sediments, channel capacity, and topographical conditions (Muliawan, 2019).

The suboptimal drainage system condition on Boulevard Grand Depok City Road can hinder both traffic flow and environmental comfort. Ponding that occurs during rain often causes traffic congestion as road users reduce their speed, and in some instances, ponding spots become impassable, forcing road users to seek alternative routes. Based on these conditions, if left unaddressed, floodwater can have adverse effects on the surrounding environment. Thus, this study aims to reassess the drainage system at three ponding locations (A, B, and C) including layout, runoff discharge, planned channel discharge, channel dimensions, culverts, and cost estimation.

2. MATERIALS AND METHODS

2.1. Location and Research Time

This research was conducted during the period from March to May 2022, located at Boulevard Grand Depok City Road, Depok City. Data processing was carried out at the Department of Civil and Environmental Engineering, Faculty of Agricultural Technology, Bogor Agricultural University. The primary data collection locations referred to are three different observation locations on the same road, as indicated in Figure 1. These three locations, namely observation locations A, B, and C, are areas where water ponding occurs consistently during rain. Water ponding at these three locations is observed to last quite long, even up to 2 hours after rainfall events, indicating the need for further investigation regarding the roadside drainage system conditions. Observation location A is located at latitude -6.416501° and longitude 106.825273°, observation location B is located at latitude -6.418840° and longitude 106.826325°, and observation location C is located at latitude -6.438859° and longitude 106.825623°.

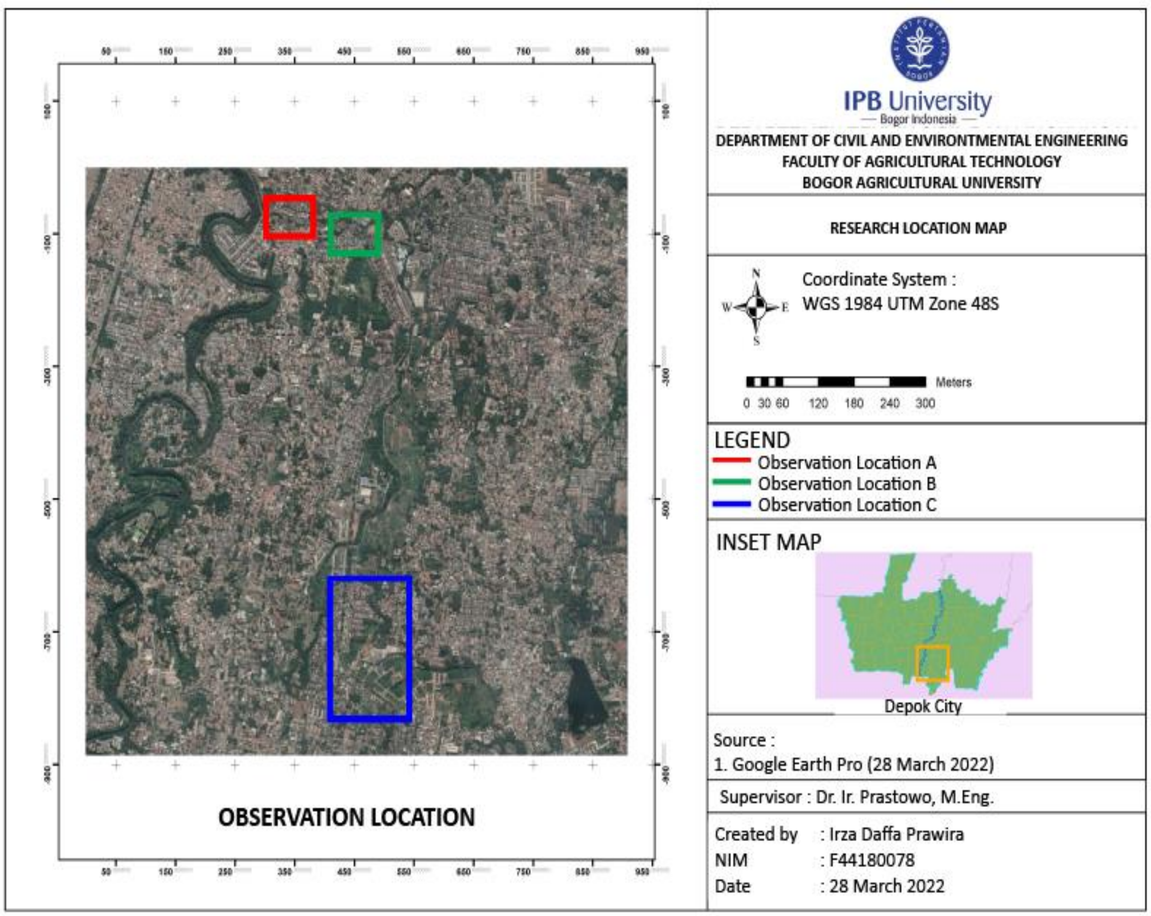

Figure 1. Map of the observation locations

2.2. Equipment and Materials

Materials used during the research consist of primary data obtained from field measurements and secondary data obtained from various reliable sources. The primary data include existing channel dimension data and site characteristic conditions. The secondary data utilized comprise maximum and minimum daily rainfall over the past 10 years measured by the nearest rain gauge station. The Bogor climatology station serves as the nearest rain measurement station, approximately 15 km away, while other rain gauge stations are located more than 20 km away. Daily rainfall data over the past 10 years can be obtained from the official BMKG online data website. Supporting maps required include research location maps, land use maps, and topographic maps. Tools used in the research data processing include a laptop, Google Earth Pro, ArcGIS, AutoCAD, and Microsoft Excel.

2.3. Research Framework

This research aims to reassess the built roadside drainage channels on Boulevard Grand Depok City Road based on the occurring runoff discharge. The reassessment is intended to determine the optimum dimensions and layout of roadside drainage channels to effectively manage the runoff. The research framework can be outlined in a flowchart as depicted in Figure 2.

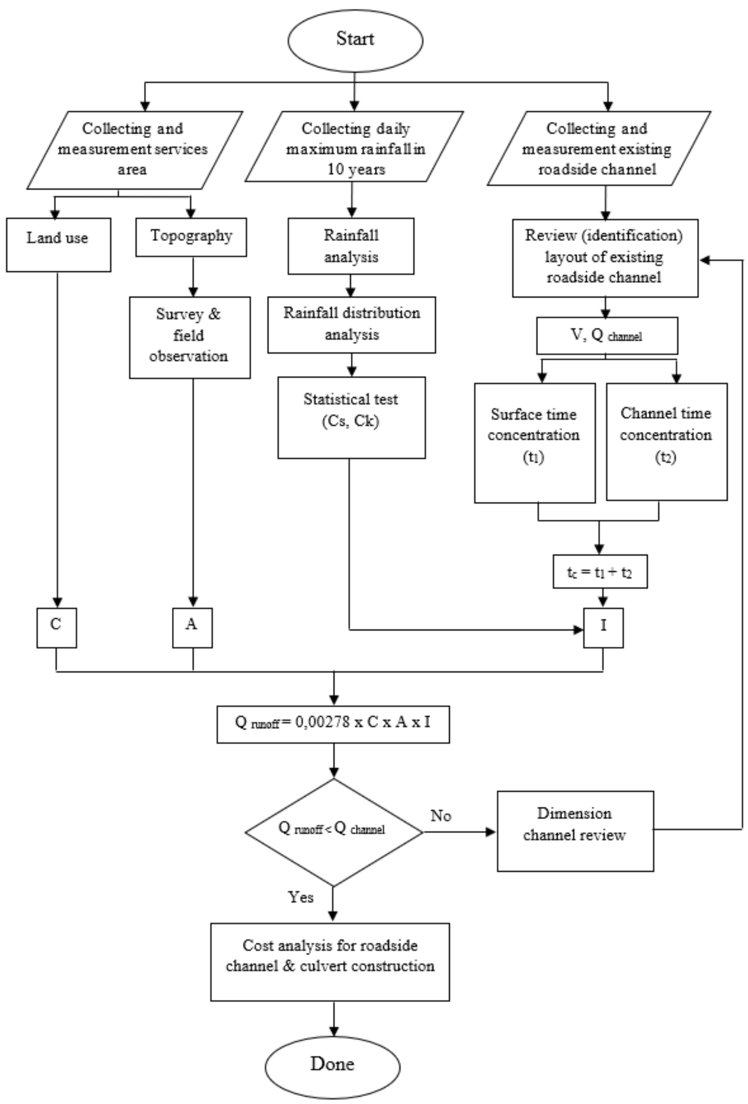

Figure 2. Flowchart of research activities

In general, the analysis conducted includes runoff analysis, reassessment of channel dimensions and layout, and analysis of construction action costs. Runoff analysis utilizes the rational method in Equation (1). This runoff analysis requires the rainfall intensity value, which can be calculated using the Mononobe equation in Equation (2). The calculation of rainfall intensity requires the concentration time, which can be calculated using Equations (3), (4), and (5) (KemenPU, 2006).

$$Q = 0.00278\ \times C\ \times I\ \times A \tag{1}$$

where Q is runoff discharge (m^3/s), C is runoff coefficient, I is rainfall intensity during concentration time (mm/h), and A is area (ha).

$$I = \frac{R_t}{24} \times \left[\frac{24}{t_c}\right]^{\frac{2}{3}} \tag{2}$$

where R_t is design rainfall for various return periods (mm), and t_c is concentration time (h).

$$t_c = t_1 + t_2 \tag{3}$$

$$t_1 = \left(\frac{2}{3} \times 3.28\ \times l_0 \times \frac{nd}{\sqrt{is}}\right)^{0.167} \tag{4}$$

$$t_2 = \frac{L}{60 \times V} \tag{5}$$

where t_1 is time to reach the inlet of the channel from the farthest location (min), t_2 is flow time in the channel along length L from the end of the channel (min), l_0 is distance from the farthest location to the drainage facility (m), L is channel length (m), nd is resistance coefficient, is is lope of the longitudinal channel, and V is average water velocity in the drainage channel (m/second)

3. RESULTS AND DISCUSSION

3.1. Topography and Land Use

Based on observations on Boulevard Grand Depok City Road, several factors suspected of causing runoff at certain points include construction activities, road contour conditions, and environmental land cover conditions. To clarify these conditions, the contour conditions at observation location A, B, and C can be seen in Figure 3. The Road contour conditions located in depressions or with lower elevations compared to the surrounding environment will cause runoff to accumulate in these depressions, as observed at observation location A. Figure 3 shows ponding occurring in relatively low contour areas, around 99 - 100 meters above sea level, compared to the surroundings reaching 104 meters above sea level. Contour maps can also depict a slope or land gradient. The higher the land gradient, the larger the coefficient value possessed (Saputro *et al*., 2018).

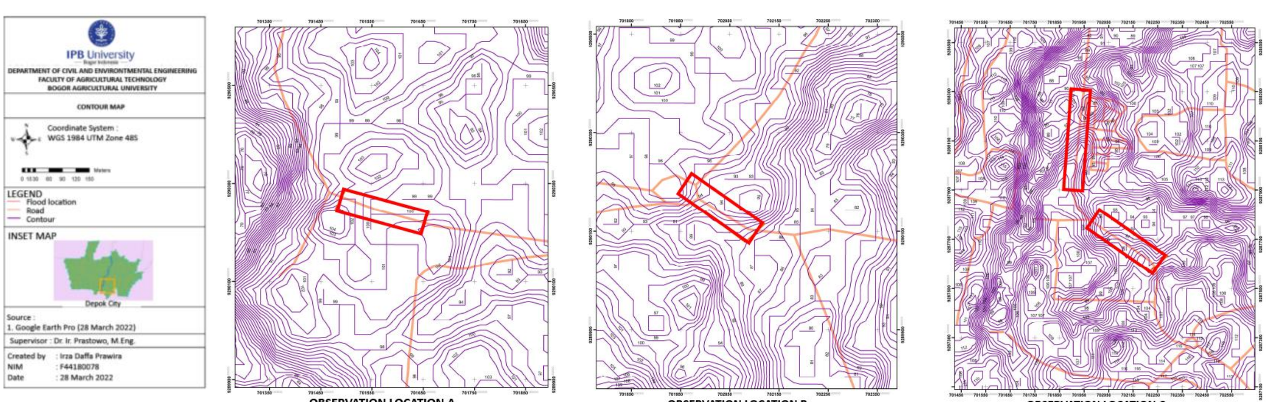

Figure 3. Topographic map of observation location A, B, and C

The land use conditions at observation locations A and B can be depicted on a single map due to their proximity, as shown in Figure 4. The land use conditions at observation location C can be seen in Figure 5. The puIDR ose of creating land use maps is for calculating the runoff coefficient, as different land use conditions will have different runoff coefficient values (Asdak, 2002). Land use conditions with certain slopes can also affect the runoff coefficient value later on. Steeper land cover tends to have higher coefficient values (Paramitha *et al*., 2018). In Figure 4, residential areas dominate the land use around the ponding location, while in Figure 5, land use is still dominated by vegetation or green open spaces. Changes in land use over time from green open spaces to residential areas can lead to increased flood discharge (Hutagaol & Hardwinarto, 2011).

Figure 4. Land use map of observation locations A and B

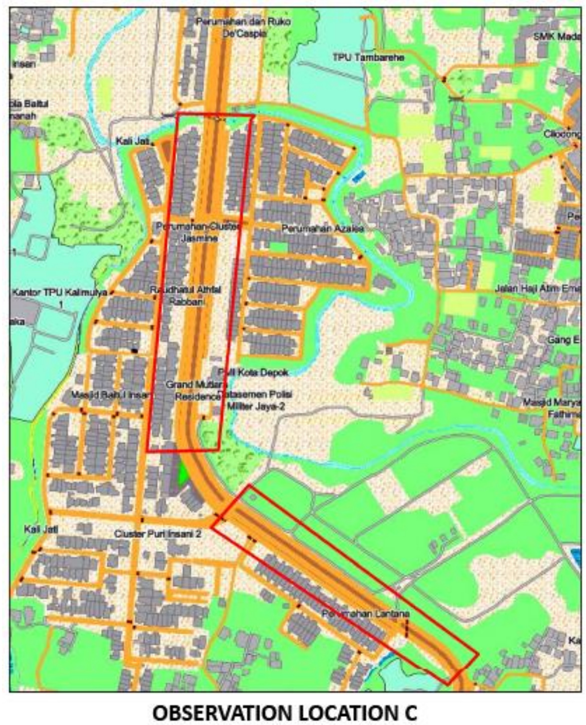

Figure 5. Land use map of observation location C

3.2. Drainage Flow Patterns

The layout and flow patterns of channels rely on gravity as the energy to convey water, thus, these flow patterns originate from higher areas to lower areas. There are 6 different types of drainage flow patterns, namely elbow, parallel, grid iron, natural, radial, and mesh (Sidharta, 1997). The suitable drainage flow pattern for roads is mesh with the aim to follow the road contour (Hasmar, 2001). The mesh drainage flow pattern itself is divided into 4 types based on their functions, namely perpendicular, interceptor, fan, and radial patterns (Patang & Ashari, 2018). The drainage flow patterns constructed in the three research locations are in line with the road contour (Figure 6). The flow patterns are essential to ensure that surface water flows are directed promptly towards the nearest water bodies to prevent pooling and inconvenience to the surrounding residents (Suripin, 2004).

3.3. Runoff Analysis

The analysis of runoff using rational method in Equation (1) requires a design rainfall that can be computed using four different methods: normal method, lognormal method, log Pearson III method, and Gumbel method (Harto, 1993). These four methods utilize maximum rainfall data occurring over the past 10 years to calculate design rainfall with various return periods, presenting the calculation results in Table 1. Among the six different return periods, a 5-year return period is utilized for road drainage system planning (KemenPU, 2006).

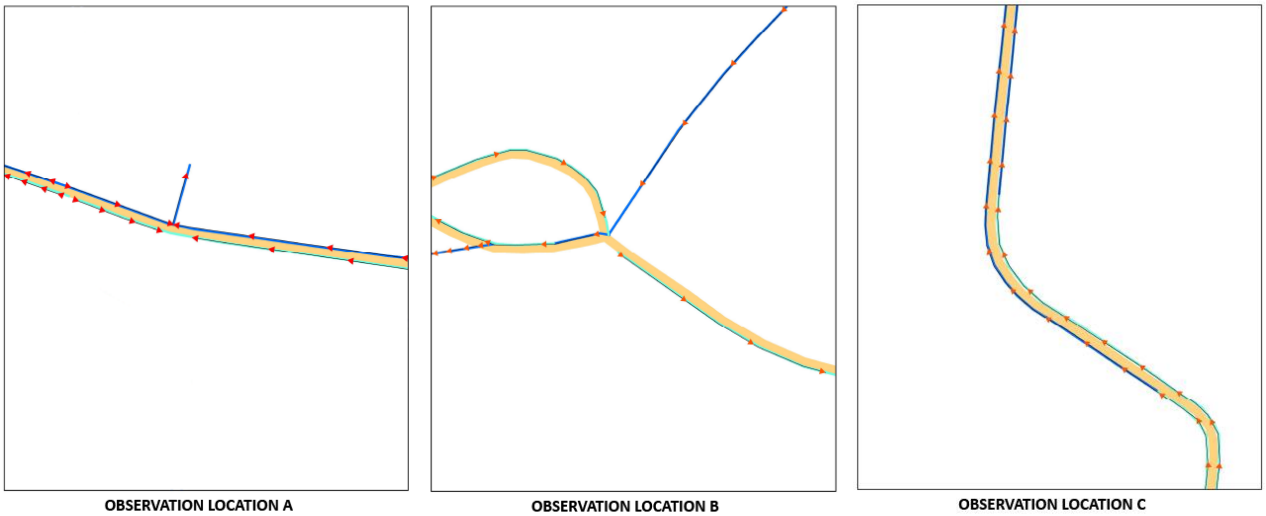

Figure 6. Drainage flow pattern at observation location A, B, and C

Table 1. Calculation results of design rainfall

Return Period (years)	Design Rainfall (mm)			
	Log Pearson III	Gumbel	Log normal	Normal
2	123.09	122.61	120.57	125.88
5	144.87	151.43	141.34	146.17
10	158.34	170.52	156.31	156.79
25	174.57	194.63	176.60	167.18
50	186.18	212.52	192.30	175.39
100	197.51	230.28	209.20	182.15

Table 2. Calculation Results of Time of Concentration and Rainfall Intensity

Observation Location	Maximum Daily Rainfall (mm)	Time of Concentration (hours)	Rainfall Intensity (mm/hour)
Location A	144.87	0.08	271.58
Location B	144.87	0.06	351.59
Location C	144.87	0.16	175.20

The calculation methods for design rainfall entail their respective constants. The calculations for log Pearson III and lognormal distributions involve a frequency factor *K* based on the skewness coefficient (*Cs*) (Soewarno, 1995). Meanwhile, the Gumbel distribution calculation requires several constants in its computation (Soemarto, 1999). The normal distribution method calculation utilizes various Gaussian variables depending on the rainfall return period (Bonnier, 1980). The selection of the design rainfall calculation method involves examining the *Cs* and kurtosis coefficient (*Ck*) of each method since each calculation method has characteristic values of *Cs* and *Ck* (Widyawati *et al*., 2020). The characteristic values of *Cs* and *Ck* can be observed in SNI 2415:2016 regarding flood discharge calculation procedures. Based on the analysis results of *Cs* and *Ck* values approaching their respective characteristics, the Log Pearson III method is chosen, resulting in a selected design rainfall of 144.87 mm.

The rational method calculation requires rainfall intensity data. which can be computed using the Mononobe formula in Equation (2). The utilization of the Mononobe formula necessitates the selected design rainfall data and the time of concentration (Tc) calculated using Equations (3), (4), and (5). The calculation results of rainfall intensity at each observation location can be seen in Table 2. The runoff coefficient values at each observation location vary depending on the land use type and the area coverage of the location. The runoff coefficient values need to be determined as they are one of the crucial factors in determining runoff discharge (Rahman, 2013). The final calculation results of runoff coefficients are indicated in Table 3. Location A has a runoff coefficient of 0.86, Location

B has 0.91, and Location C has 0.64. The runoff coefficient value is directly proportional to the runoff discharge that occurs, so the greater the value of the runoff coefficient, the greater the runoff discharge (Negoro, 2018). The runoff coefficient values listed in the Kemen PU guidelines fall within a certain range. The runoff coefficient for road surfaces with asphalt or concrete material has a range of 0.70-0.95. There is a difference in the runoff coefficient value of road surfaces at Location B because this location has steeply sloping terrain, thus the coefficient value within the high range of 0.95 is used. A similar situation occurs in the area coverage (A3) at Locations B and C due to the residential area at Location B having land with a relatively high slope.

Table 3. Calculation Results of Runoff Coefficient Values

Observation Location	Service Area	Land Use	Area (ha)	Runoff Coefficient (*C*)	Final Runoff Coefficient (*C*)
Location A	Road Surface (A1)	Asphalt	0.04	0.70	0.86
	Road Shoulder (A2)	-	0	0.00	
	Surroundings (A3)	Commercial Area around the city	0.20	0.60	
	Total		0.24		
Location B	Road Surface (A1)	Asphalt	0.05	0.95	0.91
	Road Shoulder (A2)	-	0	0.00	
	Surroundings (A3)	Residential	0.30	0.60	
	Total		0.35		
Location C	Road Surface (A1)	Concrete	0.48	0.70	0.64
	Road Shoulder (A2)	Asphalt	0.47	0.70	
	Surroundings (A3)	Residential	1.38	0.40	
	Total		2.33		

3.4. Channel Dimensions

The built channels at the research sites have various dimensions with different cross-sectional shapes. At observation Location A, the channel cross-section is trapezoidal, while at Locations B and C, square cross-sections are utilized. Therefore, the existing channel dimensions are presented in Table 4.

Table 4. Measurement Results of Built Channel Dimensions

Observation Location	B (m)	T (m)	A (m^2)	H (m)	Slope (%)	Cross-Section Shape
Location A	0.70	1.40	0.10	0.50	1.31	Trapezoid
Location B	0.50	0.50	0.40	0.80	3.01	Square
Location C	0.65	0.65	0.55	0.85	0.90	Square

Note: B = bottom width of the channel, T = top width of the channel, H = channel height, A = cross-sectional area of the channel

Table 5. Calculation Results of Runoff Discharge

Observation Point	Runoff Coefficient (C)	Rainfall Intensity (mm/hour)	Service Area (Ha)	Runoff Discharge (m^3/second)
Location A	0.86	271.58	0.24	0.16
Location B	0.91	351.59	0.35	0.31
Location C	0.64	175.20	2.33	0.73

3.5. Planned Channel Discharge

The determination of planned channel discharge is adjusted according to the magnitude of runoff discharge that occurs. The magnitude of runoff discharge can be calculated using the rational method formula in Equation (1). The calculation results of runoff discharge at the three observation locations can be seen in Table 5. This runoff discharge represents the amount of water flowing on the surface due to exceeding the rate of water infiltration into the soil

(Dunne & Leopold, 1978). The determination of planned channel discharge is carried out by trial and error method on the channel dimensions following the provisions stated in the KemenPU Guidelines number T-02-2006-B, resulting in planned discharge as shown in Table 6.

Table 6. Determination of Planned Channel Discharge

Observation Location	Runoff Discharge (m^3/second)	Planned Channel Discharge (m^3/second)
Location A	0.16	0.38
Location B	0.31	0.86
Location C	0.73	1.10

3.6. Flood Phenomena and Mitigation

The flood phenomena encountered vary considerably and have different characteristics at each observation location. Figure 7 depicts a relatively high flood phenomenon reaching 35 cm found at Observation Location A. The floods at Location B range from 5 to 10 cm. At location C the flood depth is around 3-5 cm, but it has a runoff length of up to 400 m. Based on the observations of flood phenomena, a rainfall height of 14.2 mm can cause these flood phenomena. If there is more rainfall, then there is a possibility of higher flooding, especially at Observation Location A.

Figure 7. Flood Phenomenon at observation location A, B, and C

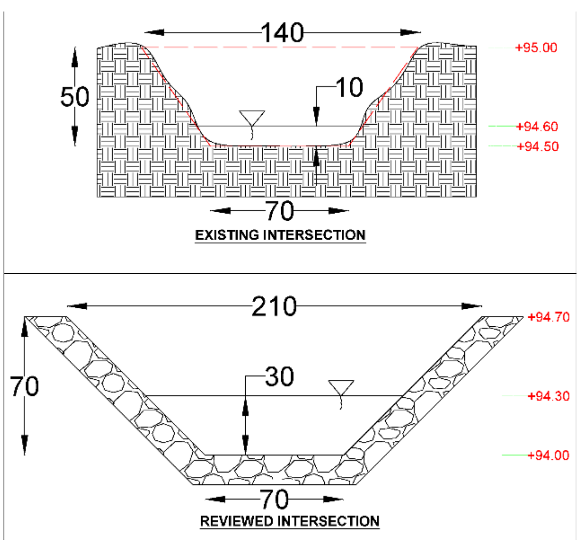

Figure 8. Comparison of existing channel cross-section and reassessment at observation location A

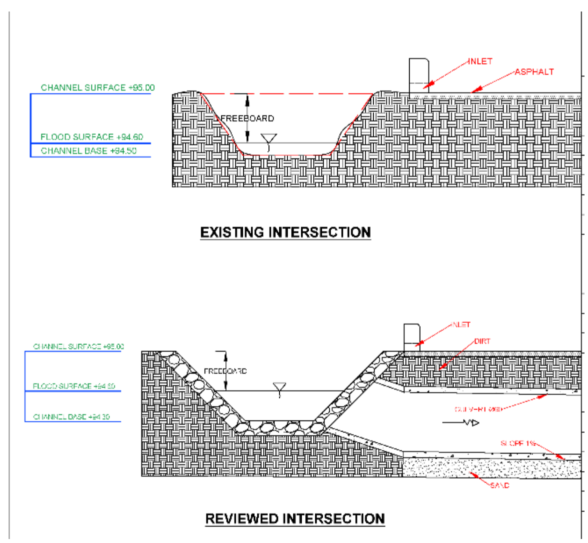

Figure 9. Elevation scheme and channel cross-section at observation location A

The constructed channel conditions at Observation Location A have a flow velocity of 0.71 m/second. This velocity exceeds the limit set by the Ministry of Public Works, which is 0.7 m/second, considering the channel material is grassy soil. There is no drainage or outlet found at Observation Location A, resulting in rainwater pooling in the road segment's depression. This situation is critical as there are two different flow directions at this location. Without drainage outlets, water will overflow and inundate the road surface. Therefore, flood mitigation recommended at Observation Point A involves dimension alterations and additional culverts as depicted in Figures 8 and 9. According to Figure 8, the existing channel width is 1.4 m and depth is 0.5 m. The channel is widened to 2.1 m with a depth of 0.7 m. These dimension changes adhere to the planning criteria stipulated by the Ministry of Public Works. Figure 9 illustrates outlet recommendations in the form of culverts positioned lower than the channel to minimize water re-emergence onto the surface when the outlet reaches its maximum capacity (Aziz *et al*., 2018). The culverts required as outlets have a total length of 18.5 m with a diameter of 60 cm and a 1% slope.

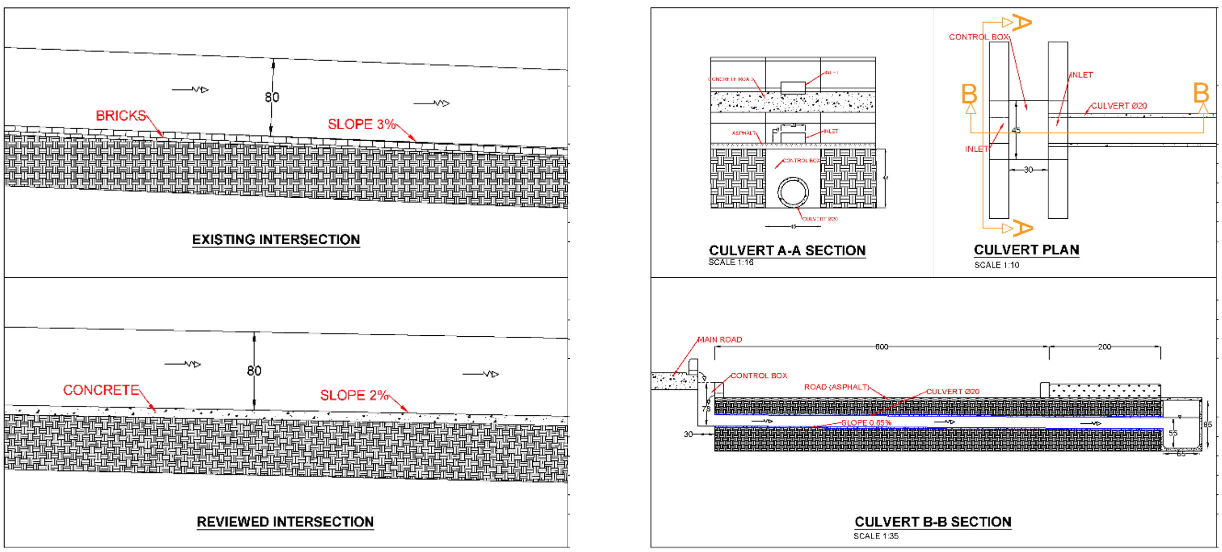

Figure 10. Recommended channel slope at observation location B (left) and C (right)

The constructed channel conditions at Observation Location B have a channel slope of 3%. Although this slope is permissible according to the Ministry of Public Works guidelines, the resulting flow velocity exceeds the established standard. The existing flow velocity in the channel is 3.62 m/second, while only 3 m/second is permitted. Therefore, the recommended action involves adjusting the channel slope to 2%, as depicted in Figure 10. At Observation Location C, the issue of water retention due to suboptimal channel inlets can be addressed by modifying the inlets. These modifications involve creating control basins equipped with culverts to allow water to flow into the channel without disrupting road users on both main roads and residential streets. Recommendations for inlets, control basins, and culverts can be seen in Figure 11. The recommended inlets have dimensions of 20 cm in length and 8 cm in height, placed at intervals of 20 meters along the road. The spacing of these inlets is determined by the maximum runoff discharge and the area of the channel's service area (Suharyanto, 2013). Water entering through the inlets will flow into culverts with a diameter of 20 cm and a slope of 0.65%, directing it towards the roadside channel. A total of 39 culverts are required, each with a length of 8 m.

The construction actions recommended at each observation point incur certain costs. The total cost required for construction actions at Observation Location A is IDR 37,164,126. The cost for channel improvement at Observation Location B is IDR 50,467,025. Observation Location C requires IDR 67,861,560 for culvert and inlet construction. Detailed cost breakdowns of these construction actions are provided in Table 7.

Table 7: Construction action cost requirements

Observation Location	Construction Action	Type of Work	Unit Price (IDR)	Volume	Total Cost (IDR)
A	Repair	Stone Channel (m^3)	610,600.00	33.66	20,552,796.00
		Ordinary Earth Excavation (m^3)	42,700.00	54.32	2,319,464.00
	New Construction	60 cm Culvert	868,000.00	15.00	13,020,000.00
		Earth Backfill (m^3)	18,400.00	8.09	148,856.00
		Ordinary Earth Excavation (m^3)	42,700.00	26.30	1,123,010.00
		Sub-total			37,164,126.00
B	Improvement	Precast (U-ditch 50x80)	667,000.00	56.00	37,352,000.00
		Channel Demolition (m^2)	58,800.00	50.25	2,954,700.00
		Precast U-ditch Cover	174,000.00	56.00	9,744,000.00
		Ordinary Earth Excavation (m^3)	42,700.00	9.75	416,325.00
		Sub-total			50,467,025.00
C	New Construction	20 cm Culvert	229,000.00	273.00	62,517,000.00
		Earth Fill (m^3)	18,400.00	37.05	681,720.00
		Ordinary Earth Excavation (m^3)	42,700.00	109.20	4,662,840.00
		Sub-total			67,861,560.00
		Total			155,492,711.00

CONCLUSIONS

A reassessment of roadside channel layouts has been conducted at two locations: Observation Location A, involving the addition of outlet channels, and Observation Location C, involving the addition of culverts to connect inlets and channels. The runoff discharge rates at Location A, Location B, and Location C are 0.16 m^3/second, 0.31 m^3/second, and 0.73 m^3/second, respectively. The planned runoff discharge rates for roadside channels at Location A, Location B, and Location C are 0.38 m^3/second, 0.86 m^3/second, and 1.10 m^3/second, respectively. A reassessment of roadside channel dimensions has been conducted, necessitating changes in channel depth at Location A from 0.5 m to 0.7 m and the channel slope at Location B from 3% to 2%. The required culverts at Location A are one unit measuring 18.5 m in length with a diameter of 0.6 m, while at Location C, 39 culverts are needed, each measuring 8 m in length with a diameter of 0.2 m. The total estimated budget for the construction actions of roadside channels and culverts amounts to IDR 155,492,711.

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