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Comparative Analysis of River Capacity with Maximum Discharge in Ngotok Ring Canal

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Keywords:

Flood, flood damage, InaRisk, river normalization

ABSTRACT

Flooding in the Ngotok Ring Canal is a recurring problem, primarily caused by intense rainfall, elevated water levels of the Brantas River, and the limited capacity of the canal's flow. This issue is especially evident at the confluence points of the Ngotok Ring Canal with its tributaries, where backwater effects or puddling occur. The objective of this study is to analyze the flood dynamics in the Ngotok Ring Canal, specifically evaluating the rise in floodwater levels and necessary mitigation measures. The analysis was conducted using the HEC-RAS program to model existing river conditions and assess flood risks. The study identifies that the embankment height at the upstream section of the Ngotok River is insufficient to contain the flood discharge, leading to overflow into surrounding agricultural fields. The flood design for the Ngotok River, based on a 25-year return period, was determined to be 866.29 m^3/sec. The proposed solution involves an economical embankment design with a 1:1.25 slope, ensuring that the floodwater level remains below the average land elevation. This design approach addresses both floodwater containment and cost-efficiency in construction, providing a sustainable solution to reduce flooding risks in the area.

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INTRODUCTION

Flooding is one of the most frequent hydrometeorological disasters in Indonesia and has a significant impact on infrastructure damage, economic losses, and disruption of community activities, especially in areas close to river bodies. This phenomenon also occurs in Jombang Regency, specifically along the Ngotok Ring Canal River. Every year, this area experiences river overflows (overtopping) that cause inundation of settlements and public facilities, hampering the social and economic activities of the local community.

Flooding is quite disruptive for the community or residents who live in the area. This is because almost every year the river overflows (over topping) causing infrastructure facilities and houses to be flooded, thus disrupting community activities. Flooding that often occurs in Kali Ngotok Ring Kanal, Jombang Regency (Sembodo, 2024). Ngotok Ring Canal River has an important function as a collector river from several main tributaries in Jombang Regency, such as Tembelang, Sambong, Jombang Kulon, Jombang Wetan, Bening, Sewedang, Gunting, Balong, and Brangkal Rivers. The river then empties into the Brantas River in Mojokerto City (Jayaprana et al., 2021). Based on its morphology, the Ngotok Ring Canal River has relatively straight and flat characteristics (Surahman et al., 2022), which hydraulically contributes to the slow flow of water, especially during peak discharge. This condition is exacerbated by high rainfall and rising water levels in the Brantas River, which

often result in backwater phenomena along the tributary confluence (Roestamy & Fulazzaky, 2022). Water flow that is retained downstream is unable to flow effectively to the estuary, causing inundation, especially in low areas around the tributaries. In addition, the existence of drainage channels and syphon buildings that do not function optimally (bottle neck) is also one of the causes of flooding at several points (Arkananta et al., 2024).

A number of previous studies have discussed flood planning and management in watersheds. For example, Harsanto et al. (2021) used the HEC-RAS model to analyze channel capacity and embankment planning as a flood control solution in the Winongo River. Research by Muqaddas et al. (2021) also shows the importance of analyzing the combination of storage capacity and extreme rainfall in determining critical flood points in the Kamoning watershed of Sampang Regency, Madura. On the other hand, the National Disaster Management Agency (BNPB) through the InaRisk platform has developed a risk assessment system that can be used to map the level of losses due to disasters, including floods. Therefore, the use of a combined approach between hydraulic modeling, geographic information systems (GIS), and disaster risk mapping is very relevant in analyzing the potential and impact of flooding more comprehensively (Pinuji et al., 2019).

Based on the description above, it is necessary to analyze the flooding problems that occur in the Ngotok Ring Canal River to find out how high the flood water level rises in the river and what steps will be taken to overcome the flooding problem. In this case, the analysis of the increase in flood water level and the existing condition of the river will be carried out using the HEC-RAS (Hydrologic Engineering Center's - River Analysis System) program.

METHOD

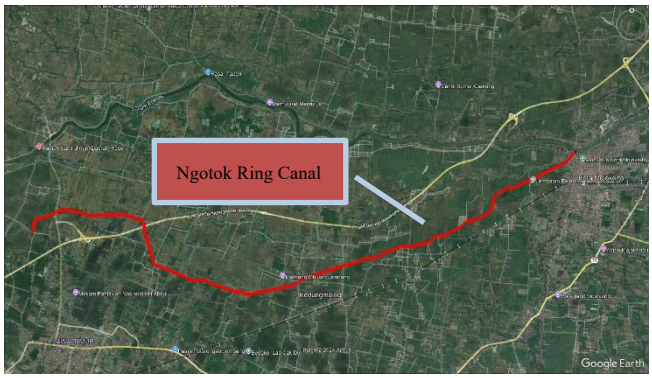


Figure 1. Study Location

The method in the study is primary data collection in the form of existing drainage channel dimension data, existing elevation data, and so on. Secondary data collection in the form of hydrological data, namely data from 14 rainfall stations that affect the Ngotok watershed, using annual maximum rainfall data for the last 32 years, map data including topographic maps, land use maps, and river system maps that describe the existing conditions of the planning area, hydraulics data in the form of Manning's roughness coefficient, riverbed slope, and river geometry data (long section and cross section). The next step is processing hydrological data and hydraulics data.

Processing of hydrological data by determining the maximum rainfall in the study area (Wiwoho & Astuti, 2022) after that calculating the average rainfall with the thiessen polygon

Comparative Analysis of River Capacity with Maximum Discharge in Ngotok Ring Canal method and then analyzing the design rainfall using the log pearson and Gumbel distribution approaches (Safitri & Zettyara, 2018). After calculating the design rainfall, it is continued with the distribution suitability test using the Chi Square and Smirnov Kolmogorov methods (Fiqri et al., 2023). After obtaining the right distribution, it is continued with the analysis of the planned flood discharge using the Gamma I and Snyder Synthetic Unit Hydrograph (HSS) method with a return period of 2, 5, 10, 25, 50, 100 and 1000 years (Id'fi, 2020). The selection of the HSS method that will be used for further calculations uses a flood approach that has occurred in the field. The next data processing is hydraulics analysis using the Hec-Ras application. The following in Figure 2 is a flow chart in this study.

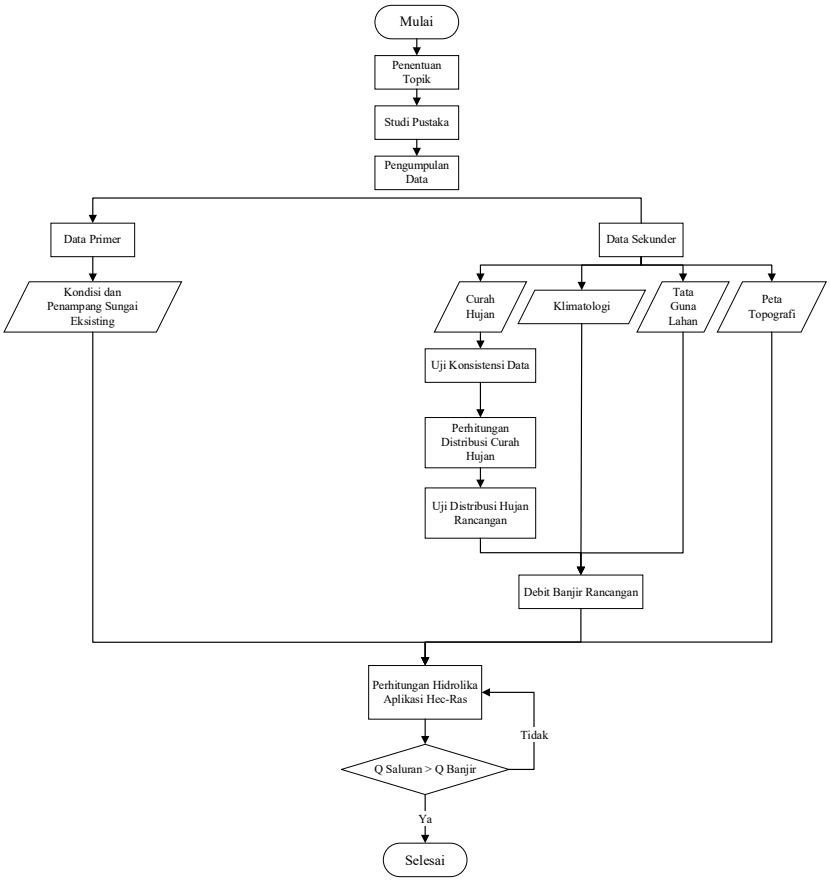
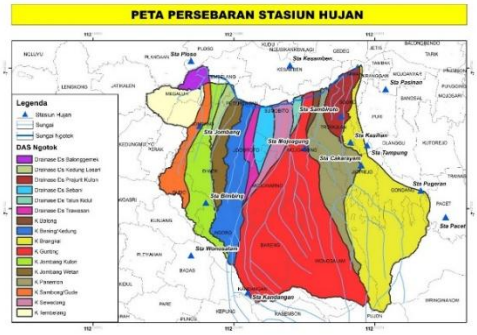


Figure 2. Flow Chart

RESULTS AND DISCUSSION

Rainfall

Daily maximum rainfall used as many as 14 rainfall stations that affect the Ngotok watershed (Figure 3). The maximum daily rainfall data used for the analysis was from 1992 to 2023.



No	Nama Stasiun Hujan	No	Nama Stasiun Hujan
1	Ploso	8	Sambiroto
2	Jombang	9	Pasinan
3	Blimbing	10	Tampung
4	Kandangan	11	Kasian
5	Mojoagung	12	Pugeran
6	Kesamben	13	Pacet
7	Wonosalam	14	Cakarayam

Figure 3. Rainfall Stations

From the calculation of the Thiessen polygon, the watershed area is obtained as shown in Table 2 below.

Table 2. Watershed Area of Thiessen Polygon Calculation Results

No	Watershed Name	Main River Length (km)	Watershed Area (km²)
1	Tembelang	6.20	14.85
2	Kali Gude/Sambong	17.24	30.12
3	Balonggemek	2.40	2.13
4	Jombang Kulon	14.26	25.78
5	Kedung Losari	3.76	2.68
6	Jombang Wetan	13.80	23.18
7	Kali Bening	15.60	29.59
8	Trawasan	16.40	25.60
9	Sebani	8.80	9.71
10	Sewedang	14.60	19.94
11	Talun Kidul	3.10	3.46
12	Kali Gunting	32.20	239.96
13	Kali Balong	7.80	8.13
14	Panemon	13.90	17.20
15	Prajurit Kulon	3.60	8.00
16	Kali Brangkal	31.20	250.27

From the results of the calculation of log Pearson and Gumbel and after being tested Chi square and Smirnov Kolmogorov found that the distribution of log Pearson that meets the requirements of both. So the next calculation uses the log pearson method.

Table 3. Smirnov Kolomogov and Chi Square Test Results

Smirnov-Kolmogorov Test

Distribution	Rainfall Data	Dmax	Dcritical	Conclusion
Gumbel	Max Daily Rainfall	0.238	0.102	Dmax > Dcritical, not acceptable
Log Pearson Type III	Max Daily Rainfall	0.072	0.102	Dmax < Dcritical, acceptable

Chi-Square Test

Distribution	Rainfall Data	X^2 Hit	X^2 Critical	Conclusion
Gumbel	Max Daily Rainfall	4.361	5.991	X^2 Hit < X^2 Critical, acceptable
Log Pearson Type III	Max Daily Rainfall	1.190	5.991	X^2 Hit < X^2 Critical, acceptable

So the following is the maximum rainfall using the Log Pearson method.

Table 4. Recap of Rainfall Plan for Ngotok Watershed

No.	Name of watershed	Recurrence Period Design Rainfall (mm)				
		5 th	10 th	25 th	50 th	100 th
1	Tembelang	71.55	82.99	96.64	106.29	115.51
2	Kali Gude/Sambong	84.97	102.15	124.19	140.98	159.61
3	Balonggemek	83.67	102.59	126.32	143.78	160.92
4	Jombang Kulon	76.10	91.31	110.77	125.64	141.78
5	Kedung Losari	91.10	108.81	131.02	147.38	163.55
6	Jombanng Wetan	63.14	70.71	79.30	85.13	90.52
7	Kali Bening	80.33	85.86	91.29	93.78	96.47
8	Trawasan	59.57	65.41	71.10	74.44	77.17
9	Sebani	63.99	67.59	70.24	71.38	72.11
10	Sewedang	92.54	98.51	105.30	108.02	112.20
11	Talun Kidul	91.68	97.59	104.33	107.02	111.16
12	Scissors River	45.16	49.07	53.13	55.67	57.89
13	Balong River	54.90	57.20	58.57	58.99	59.18
14	Panemon	44.50	49.80	55.53	59.24	62.56
15	Prajurit Kulon	50.50	55.90	59.66	62.11	62.62
16	Brangkal River	51.26	57.15	63.12	66.76	69.85

Furthermore, using the design rainfall with a return period of 25 years because the Ngotok watershed is River order 2 so that the return period discharge used is 25 years.

1. Design Flood Discharge

Analysis of the design flood discharge requires the calculation of the watershed runoff coefficient obtained from the analysis results of 0.672. After that, calculate HSS Gamma and Snyder. From the calculation results, it is found that by using HSS Gamma, the discharge calculation results are close to the results of existing flood measurements with a return period of 25 years.

Table 5. Recap of Flood Calculation Results

No	Sub-Watershed Name	Discharge (m^3/s) Measurement	Discharge (m^3/s) Calculation 2024
1	Kali Tembelang	52.81	48.18
2	Kali Balonggemek	16.29	21.36
3	Kali Gude/Sambong	85.31	88.54
4	Kali Jombang Kulon	73.27	80.77
5	Kedung Losari	19.99	29.44
6	Kali Jombang Wetan	49.39	56.06
7	Kali Bening	79.99	80.81
8	Kali Trawasan	26.41	43.10
9	Sebani	34.36	40.22
10	Sewedang	62.13	68.33
11	Talun Kidul	22.90	30.79
12	Kali Gunting	210.94	213.30
13	Balong	26.58	28.00
14	Kali Panemon	23.46	35.04
15	Prajurit Kulon	20.30	30.36
16	Kali Brangkal	296.01	311.33

Comparative Analysis of River Capacity with Maximum Discharge in Ngotok Ring Canal

So that the existing river scheme in the Ngotok watershed as shown in Figure 5 is divided into 6 river pias with the discharge of each pias, namely Pias 6 (upstream) of 48.18 m^3/dt which comes from the Tembelang River, pias 5 of 158.08 m3 /dt which comes from the Balonggemek River, pias 4 of 238.25 m^3/dt which consists of the Gude / Sambong River, Kali Jombang Kulon, Kali Kedung Losari, and kali jombang wetan, pias 3 of 396.44 m^3/dt which consists of Bening Kedung, Trawasan River, Sebani Drainage Channel, Sawedang River and Talun Kidul Drainage Channel, Pias 2 of 785.52 m^3/dt consisting of Gunting River, Balong River, Panemon River and Prajurit Kulon Drainage Channel, and Pias 1 (hiilir) of 866.19 m^3/dt originating from Brangkal River.

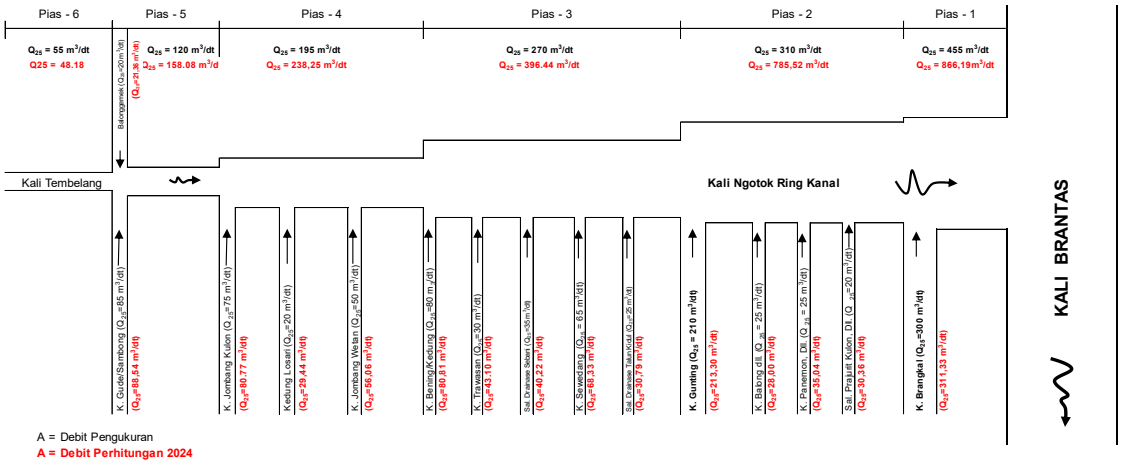


Figure 4. Comparison of Flood Discharge Distribution Schemes of the Ngotok River Ring Canal Watershed Plan (Q 25 Years)

2. Hydraulics Analysis

To determine the fluctuation of the water level during flooding and the influence of tides, a hydraulics analysis is carried out, so that it is known which part of the river section has a flood risk (Tunas & Herman, 2019). Making this scheme is the beginning of inputting geometry data before entering river cross-section data, which is needed to define each section (reach) of the river that is built (Faisal et al., 2021). To determine the capacity of the river, it is necessary to analyze the hydraulics of the water level profile in the river. Following the Ngotok River system scheme, the river flows from the large numbered station number (River Sta) (348) to the small numbered station number (River Sta) (1), because in the HEC-RAS program the large numbered station number (River Sta) is identified as the upstream area, and the small numbered one is identified as the downstream/muara area (Ogras & Onen, 2020).

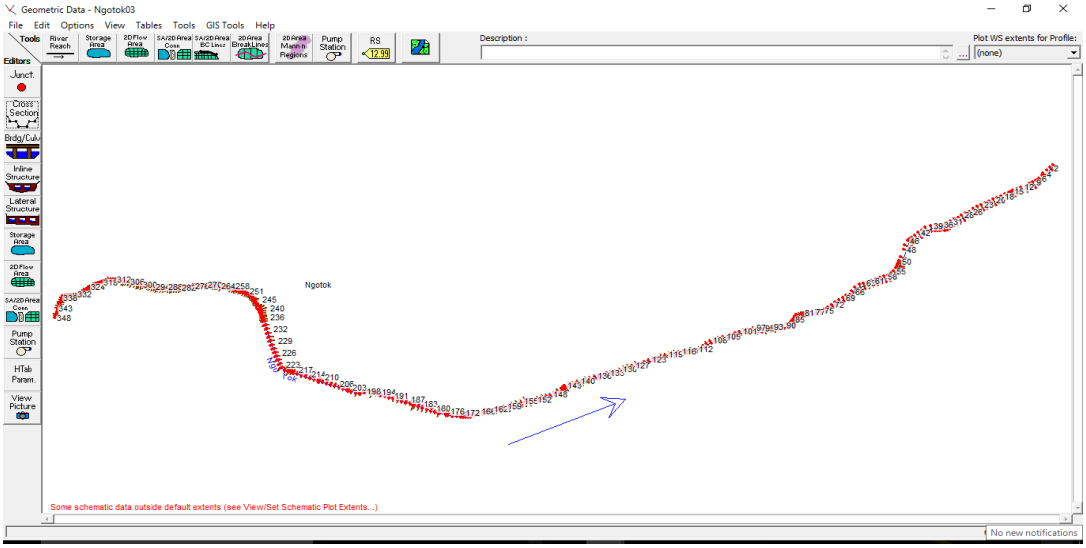


Figure 5. Schematic of Ngotok River in HEC-RAS program

In this study, the Q25th plan discharge was used, because the work location is in the Regency area and close to residential areas. The following is a picture of the HEC-RAS running results for various flow conditions.

Because the work site is located in the Brantas river, it is also necessary to consider the effect of the water level on the Brantas river. Based on elevation data at Mlirip weir, which is about 2 km downstream from Ngotok, it is known that the highest elevation for the Ngotok river downstream is +19.4 m.

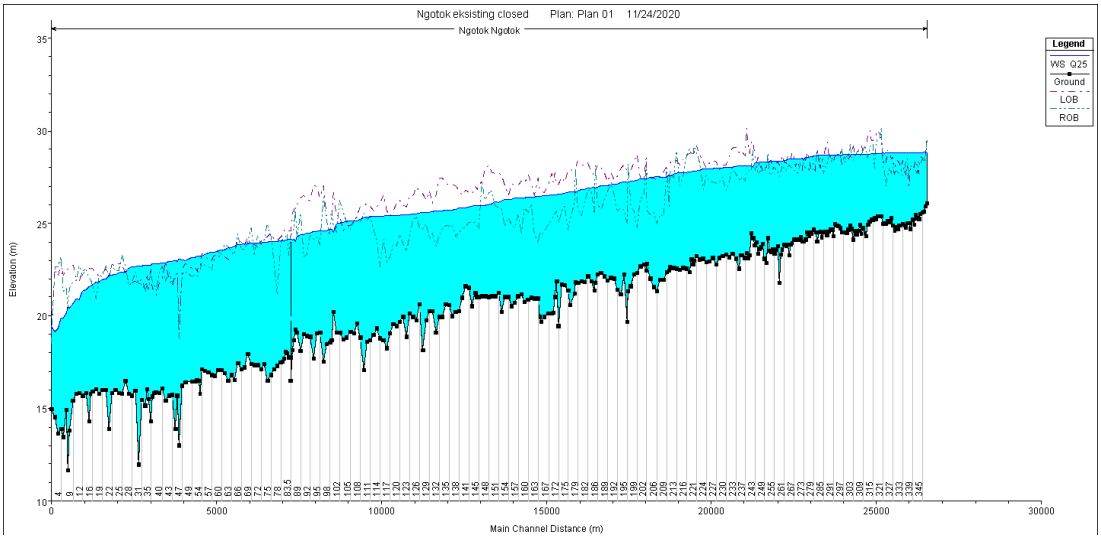


Figure 6. Longitudinal section of Ngotok river in existing condition hecras (Yani Dam Door Open)

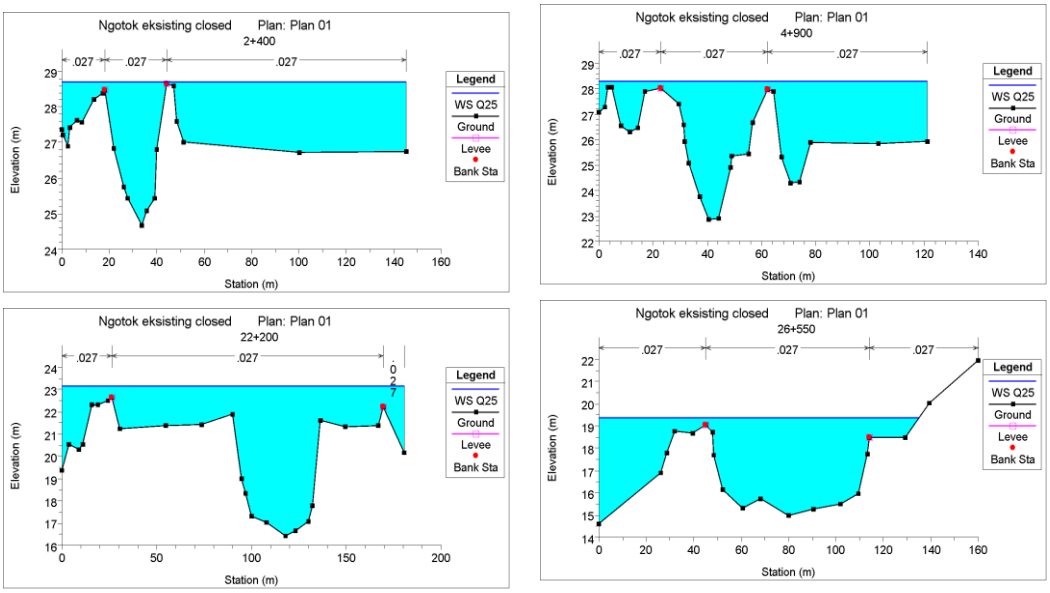


Figure 7. Several Cross Section Results of Running HEC-RAS Section of Ngotok River in Existing Condition (Dam Yani Door Open)

According to the results of the analysis, the Ngotok River in its existing condition has an irregular cross-section, with some sections narrowing and silting up due to erosion, sedimentation and sand mining. In the existing condition with the occurrence of flood discharge Q25 of 804.49 m3 / s, flood overflow occurs in most river sections, especially in areas that have not been embanked. To overcome the occurrence of overflows in several river sections, it is necessary to normalize and raise embankments in several sections where flood overflows occur (Nurdianyoto et al., 2024). For this reason, hecrass analysis with normalization conditions will be carried out again, which will determine the condition of the flood water level after normalization and other technical treatments.

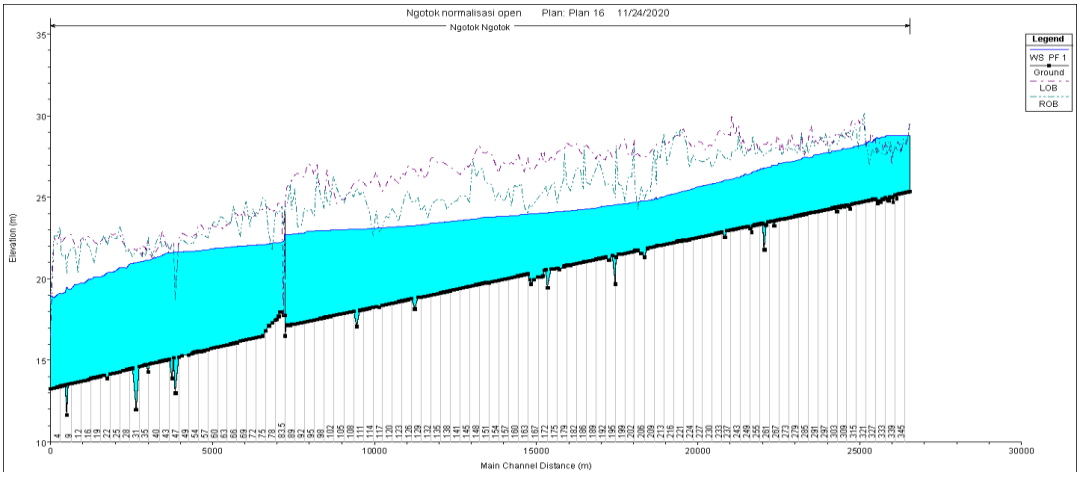


Figure 8. Longitudinal section of Ngotok River in HEC-RAS normalization condition (Yani Dam Door Open)

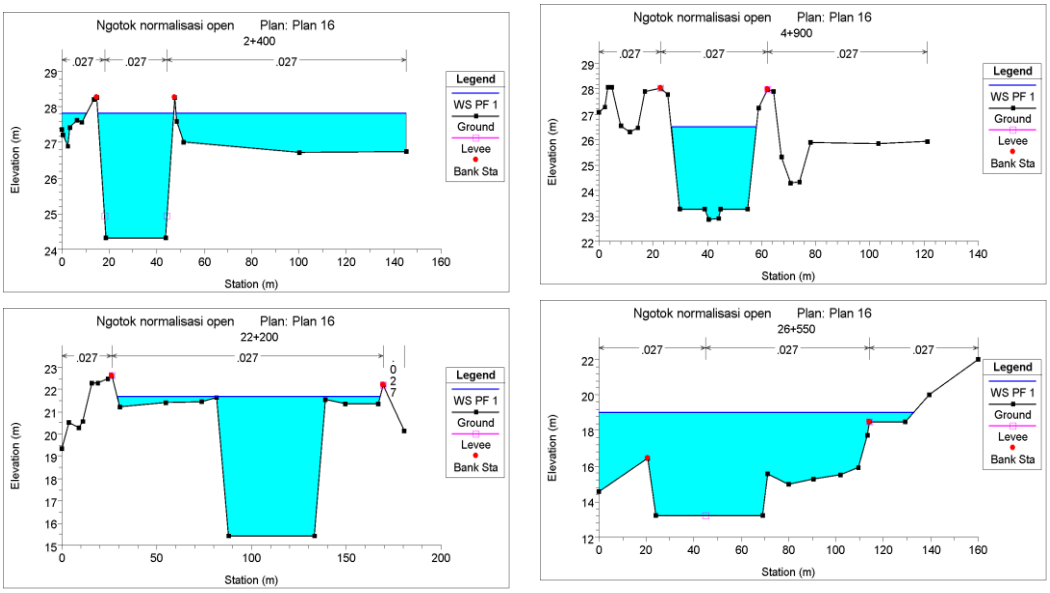


Figure 9. Several Cross Section Results of Running HEC-RAS Section Ngotok River normalization conditions (Dam Yani Door Open)

According to the results of the analysis, the Ngotok River design conditions, namely with normalization, there has been a reduction in flood overflow areas. Meanwhile, areas where overflow still occurs will be handled by increasing the embankment, especially in section 0+050 to section 1+400.

CONCLUSION

The design flood discharge calculation for a 25-year return period indicates that the peak flow in the downstream section of the Ngotok Ring Canal reaches 866.19 m^3/sec, surpassing the limited flow capacity of its six main segments. This hydraulic imbalance leads to overflow and flooding, adversely affecting communities near the river. To address this, comprehensive technical interventions are necessary, including river normalization to improve flow, raising embankments to contain high water levels, and installing parapets along the canal banks for added protection. These measures aim to mitigate flooding risks and enhance sustainable flood management in the region. For future research, it is recommended to explore the integration of real-time monitoring and early warning systems, as well as the assessment of ecological impacts of structural modifications, to optimize flood resilience and environmental sustainability.

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