HYDROLOGICAL AND HYDRAULIC ASSESSMENT OF RIVER NORMALIZATION FOR FLOOD MITIGATION IN THE BUNTUNG RIVER, SIDOARJO REGENCY, INDONESIA

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ABSTRACT

Buntung River is one of the rivers in Sidoarjo Regency that frequently experiences flooding due to insufficient channel capacity to convey flood discharge. This condition is mainly caused by sedimentation that reduces the effective cross-sectional capacity of the river, as well as inadequate channel dimensions. This study aims to assess the hydrological and hydraulic conditions of the Buntung River and evaluate river normalization as a flood mitigation measure. The hydrological analysis used rainfall data from six rainfall stations during the period 2016–2025. The analysis included rainfall consistency testing using the double mass curve method, areal rainfall estimation using the Thiessen Polygon method, rainfall frequency analysis using the Normal, Gumbel, Log-Normal, and Log-Pearson Type III distributions. The suitability of the distributions was evaluated using the Chi-Square and Smirnov–Kolmogorov goodness-of-fit tests. The Gumbel distribution, which produced the highest design rainfall values, was selected as a relatively conservative basis for subsequent analysis. Design flood discharges were estimated using the Mononobe method and the Nakayasu Synthetic Unit Hydrograph method. Hydraulic analysis was then performed using HEC-RAS 6.5 under steady-flow conditions to evaluate the existing and normalized channel conditions. The resulting design flood discharges were 74.04 m^3/s (Q_2), 97.91 m^3/s (Q_5), 113.71 m^3/s (Q_{10}), 133.67 m^3/s (Q_{25}), 148.48 m^3/s (Q_{50}), and 163.18 m^3/s (Q_{100}). The HEC-RAS simulation showed that the existing Buntung River channel experiences overtopping even under the 2-year return period flood discharge, indicating insufficient channel capacity. River normalization was proposed through sediment dredging and cross-sectional modification using precast concrete retaining walls. The normalized channel has a conveyance capacity of 284.48 m^3/s, enabling it to safely accommodate the 25-year and 50-year design flood discharges without overtopping.

Keyword: HEC-RAS 6.5, Nakayasu Synthetic Unit Hydrograph, design flood, sediment dredging, retaining wall

Introduction

Flooding is one of the most common problems in areas crossed by rivers, particularly during periods of high rainfall intensity. When river discharge exceeds the capacity of the channel, water may overflow into surrounding areas, causing environmental damage, infrastructure disruption, and disturbances to community socio-economic activities [1,2]. In addition to rainfall intensity, river conditions, sedimentation, and changes in land use within and around the watershed can further increase the risk of flooding [3–5]. Therefore, proper river management is essential for reducing flood risk and improving flood control.

Sidoarjo Regency, located in East Java Province, is one of the areas that is vulnerable to flooding, particularly during the rainy season. The region is crossed by several major rivers, including the Porong River and Buntung River. Several areas in Sidoarjo frequently experience inundation due to river overflows [6–8]. In this study, the Buntung River was selected as the research location because it is one of the major rivers crossing densely populated areas and has a history of frequent flooding, particularly in its downstream section. Furthermore, the Buntung River plays an important role in the drainage system of the surrounding area, making flood control along this river strategically important [9].

The Buntung River was selected as the focus of this study because it has relatively complex characteristics compared with other rivers in Sidoarjo. Compared with the Porong River and Pelayaran River, which generally have larger channel capacities, the Buntung River has more limited conveyance capacity and flows through densely populated residential areas. These conditions increase the potential flood risk when river discharge rises rapidly over a relatively short period, while the river's conveyance capacity has been reduced by sedimentation and inadequate channel dimensions [6]. Therefore, the Buntung River provides an appropriate case for a detailed assessment of flood control measures.

According to the Decree of the Minister of Public Works and Housing of the Republic of Indonesia No. 904/KPTS/M/2021 concerning the Water Resources Management Plan for the Brantas River Basin [10], the Buntung River watershed covers approximately 60.52 km² (6,052 ha), with an overall river length of approximately 34 km. Within this overall watershed, this study focuses on a contributing catchment area of approximately 23.28 km² that directly contributes runoff to the downstream section of the Buntung River under investigation, which extends for 6.15 km from cross-section B-390 to B-500. The study reach was selected because the downstream section is vulnerable to flooding due to reduced channel capacity associated with sedimentation and increasing urbanization in the surrounding area [6].

In this study, HEC-RAS 6.5 was employed to simulate the flow profile of the Buntung River. HEC-RAS (Hydrologic Engineering Center–River Analysis System) is a widely used hydraulic modeling software capable of simulating one-dimensional river flows, evaluating channel conveyance capacity, and assessing the effects of river normalization and channel improvements [11,12]. The application of HEC-RAS enables the evaluation of existing river conditions and the identification of appropriate technical measures for improving channel capacity and controlling flooding.

Therefore, this study aims to analyze the design flood discharges for return periods of 2, 5, 10, 25, 50, and 100 years in the Buntung River watershed; identify river cross-sections that are unable to accommodate the design flood discharges; and evaluate the effectiveness of river normalization as a flood control measure based on hydraulic simulations using HEC-RAS 6.5.

Methodology

Study Area Location

The study area focuses on the downstream section of the Buntung River Basin in Sidoarjo Regency, East Java, Indonesia. The analyzed section of the Buntung River is approximately 6.15 km long, with a catchment area of 23.28 km². The upstream section of the Buntung River is located in Tanjungsari Village, Taman District, Sidoarjo Regency, and the river flows downstream to the Java Sea [10].

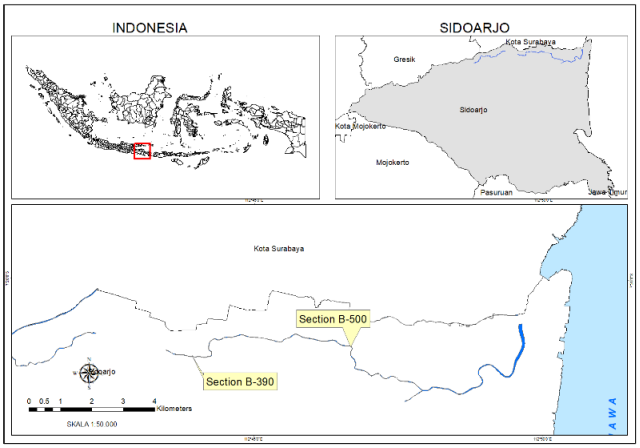


Figure 1. Location Map of the Buntung River Study Area

Supporting Data

The supporting data used in this study consisted of the Buntung River Basin map, rainfall data, river cross-sectional data, and 2025 land-cover data. The Buntung River Basin map was obtained from the Public Works and Water Resources Agency of Sidoarjo Regency and SIH3 East Java. Rainfall data covering a 10-year period from 2016 to 2025 were obtained from six rainfall stations, namely Ketegan, Botokan, Pelayaran, Bono, Seruni, and Ketawang. The rainfall data were provided by the Public Works and Water Resources Agency of Sidoarjo Regency and the Brantas River Basin Organization (BBWS Brantas). River cross-sectional and longitudinal profile data were obtained from BBWS Brantas and were used as input for the hydraulic analysis using HEC-RAS 6.5. In addition, 2025 land-cover data were obtained from ArcGIS Living Atlas of the World and were used to determine the runoff coefficient.

Hydrological Analysis

The hydrological analysis was conducted to determine the design flood discharges for return periods of 2, 5, 10, 25, 50, and 100 years. First, the consistency of the rainfall data was evaluated using the double mass curve method [13].

The annual maximum rainfall data were then used to calculate the maximum average areal rainfall using the Thiessen Polygon method. Design rainfall was determined using four probability distributions, namely the Normal, Gumbel, Log-Normal, and Log-Pearson Type III distributions. The suitability of the probability distributions was evaluated using the Chi-Square and Smirnov–Kolmogorov goodness-of-fit tests, and the distribution satisfying the statistical requirements was selected for the design rainfall calculation [14].

The runoff coefficient was subsequently determined based on the 2025 land-cover data. The selected design rainfall was then converted into hourly rainfall using the Mononobe method, followed by the determination of effective rainfall. The effective rainfall was transformed into flood hydrographs using the Nakayasu Synthetic Unit Hydrograph method [15]. The peak discharges obtained from the resulting hydrographs were taken as the design flood discharges for the 2-, 5-, 10-, 25-, 50-, and 100-year return periods. These discharges were subsequently used as flow inputs for the hydraulic analysis.

Hydraulic Analysis

The hydraulic analysis was performed using HEC-RAS version 6.5 to evaluate the existing conveyance capacity of the Buntung River [11,12]. The river geometry was developed using the cross-sectional and longitudinal profile data along the 6.15-km study reach from B-390 to B-500. The Manning roughness coefficient was assigned based on the existing channel characteristics, while the downstream boundary condition was defined using the normal depth method. Steady-flow simulations were performed for the design flood discharges corresponding to the 2-, 5-, 10-, 25-, 50-, and 100-year return periods.

The resulting water surface profiles were evaluated against the existing channel geometry and bank elevations. The comparison was used to determine the conveyance capacity of the existing river and identify critical cross-sections where the simulated water surface exceeded the available channel capacity. These locations were classified as sections experiencing overtopping and were subsequently considered in the evaluation of flood control measures.

River Normalization

River normalization was proposed for sections where the existing channel was unable to accommodate the design flood discharge. The proposed normalization consisted of sediment dredging and modification of the river cross-sectional dimensions using precast concrete retaining walls [16]. The modified cross-sectional geometry was incorporated into the HEC-RAS 6.5 model while maintaining the same design flood discharges used in the existing-condition simulation. The normalized channel was then re-simulated under steady-flow conditions to evaluate the resulting conveyance capacity and water surface profile.

The effectiveness of the normalization was evaluated by comparing the conveyance capacity of the normalized channel with the design flood discharges and by determining whether overtopping remained at the critical sections. This comparison was used to assess the ability of the proposed normalization to improve the flood conveyance capacity of the Buntung River.

Result and Discussion

Rainfall Data Consistency Test

The consistency of the rainfall data was evaluated using the double mass curve method for six rainfall stations, namely Bono, Ketawang, Pelayaran, Botokan, Seruni, and Ketegan. The analysis resulted in a coefficient of determination (R^2) of 0.99 for all six stations, indicating a very strong linear relationship between the cumulative rainfall at each station and the cumulative average rainfall of the surrounding stations. This result confirms that the rainfall data are consistent and can be considered reliable for subsequent hydrological analysis.

Areal Average Rainfall

The areal average rainfall of the Buntung River Basin was determined using the Thiessen Polygon method.

As shown in Figure 2, six rainfall stations influence the study catchment, namely Bono, Ketawang, Pelayaran, Botokan, Seruni, and Ketegan. The Thiessen weighting coefficients for each rainfall station are presented in Table 1. The differences in weighting coefficients indicate that each rainfall station has a different spatial influence on the estimation of areal rainfall, depending on its representative area within the catchment.

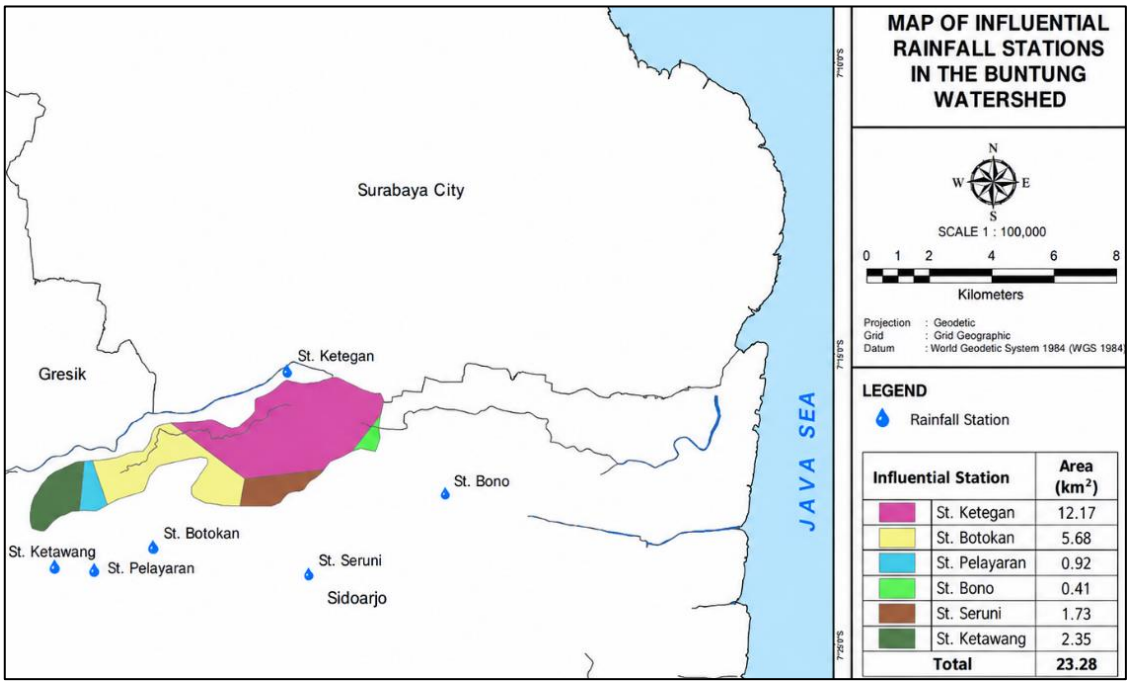


Figure 2. Thiessen Polygon of the Buntung River Basin

Table 1. Thiessen Weighting Coefficients

Rainfall Stations	Area (km²)	Percentage (%)	Thiessen Coeff. (C)
Bono	0.41	1.78	0.02
Ketawang	2.35	10.10	0.10
Pelayaran	0.92	3.97	0.04
Botokan	5.68	24.41	0.24
Seruni	1.73	7.45	0.07
Ketegan	12.17	52.29	0.52
Jumlah	**23.28**	**100.00**	**1.00**

Table 2. Areal Average Rainfall Calculation

Year	Thiessen Coefficient						Max Rainfall (mm)
	Bono	Ketawang	Pelayaran	Botokan	Seruni	Ketegan	
	0.02	0.10	0.04	0.24	0.07	0.52	
2016	85	136	111	170	150	189	171.14
2017	48	55	33	100	103	137	111.64
2018	25	43	51	54	49	114	83.51
2019	201	71	54	118	178	92	102.84
2020	7	23	0	46	50	166	104.20
2021	88	31	46	39	60	122	84.56
2022	87	47	72	57	53	93	75.64
2023	28	48	35	103	15	82	75.88
2024	171	18	3	69	59	140	99.42
2025	55	78	54	91	113	130	109.61

The areal average rainfall was subsequently calculated by applying the Thiessen weighting coefficients to the rainfall recorded at each station. The resulting annual areal rainfall values are presented in Table 2. The Thiessen-weighted rainfall accounts for the spatial distribution of rainfall across the catchment and therefore provides a representative rainfall value for the Buntung River Basin. These areal rainfall values were subsequently used as input for the rainfall frequency analysis to determine the design rainfall.

Design Rainfall

The design rainfall was calculated using four probability distributions, namely the Gumbel, Normal, Log-Normal, and Log-Pearson Type III distributions, to estimate rainfall depths for different return periods. The results of the design rainfall calculations for each probability distribution are presented in Table 3. The results show differences in the estimated design rainfall values among the four probability distributions due to their different statistical characteristics in representing the observed rainfall data.

Table 3. Design Rainfall for Different Probability Distributions

Tr (year)	Design Rainfall (mm)			
	Normal	Gumbel	Log Normal	Log Pearson Type III
2	101.84	98.07	99.00	94.52
5	125.27	131.28	121.34	118.23
10	137.51	153.26	134.95	137.05
25	149.80	181.03	150.15	163.74
50	158.07	201.64	161.33	186.33
100	166.55	222.09	173.67	211.21

Among the four probability distributions, the Gumbel distribution generally produced relatively higher design rainfall values, particularly for the longer return periods. The results of the design rainfall calculations were then evaluated using goodness-of-fit tests to determine the suitability of each probability distribution for representing the observed rainfall data. The Chi-Square and Smirnov–Kolmogorov tests were used for this evaluation.

Goodness-of-Fit Test

The goodness-of-fit of the Normal, Gumbel, Log-Normal, and Log-Pearson Type III distributions was evaluated using the Chi-Square and Smirnov–Kolmogorov tests. The results of the goodness-of-fit tests are presented in Table 4.

Based on the Chi-Square test, the calculated values for all distributions, namely the Normal, Gumbel, Log-Normal, and Log-Pearson Type III distributions, were lower than the critical value ($X^2 < X_{cr}^2$), indicating that all distributions satisfied the acceptance criterion of the test. Similarly, the Smirnov–Kolmogorov test showed that the calculated deviations were lower than the critical value ($\Delta P_i < \Delta P_{cr}$), indicating that all distributions satisfied the allowable critical limit. Therefore, both goodness-of-fit tests indicated that the four distributions were suitable for representing the rainfall data used in this study.

Since the goodness-of-fit tests did not indicate any significant difference in suitability among the four distributions, the Gumbel distribution was subsequently selected based on the consideration that it generally produced relatively higher design rainfall values, particularly for longer return periods, thereby providing a more conservative basis for the design flood discharge calculation.

Table 4. Goodness-of-Fit Test Results for the Gumbel Distribution

Distribution	Chi-Square Test		Smirnov-Kolmogorov Test	
	X^2	X_{cr}^2	ΔP_i	ΔP_{cr}
Normal	1	5.991	0.14	0.41
Gumbel	5	5.991	0.17	0.41
Log Norma	1	5.991	0.11	0.41
Log Pearson Type III	1	5.991	0.11	0.41

Runoff Coefficient

The runoff coefficient was determined by identifying the land-cover types within the Buntung River Basin and calculating the area occupied by each land-cover category. The 2025 land-cover data were obtained from ArcGIS Living Atlas of the World. The area, runoff coefficient, and weighted runoff coefficient for each land-cover type are presented in Table 5.

Table 5. Runoff Coefficient Calculation

Land Cover	Area (A) (km^2)	C Value	C x A
Water Body	0.01	0.05	0.001
Forest/Trees	0.05	0.05	0.002
Vegetation	0.01	0.15	0.002
Agricultural Land	1.71	0.10	0.17
Built-up Area	20.51	0.60	12.31
Shrubland	0.98	0.07	0.07
Total	**23.28**		**12.55**

Based on the results presented in Table 5, the Buntung River Basin is predominantly covered by Built-up Area, with a runoff coefficient of 0.60, followed by other land-cover types with lower coefficients. Therefore, the average runoff coefficient was calculated as

$$C\ average = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} = \frac{12.55}{23.28} = 0.54$$

The resulting average runoff coefficient of 0.54 indicates that approximately 54% of the rainfall

contributing to the catchment can be considered as runoff under the adopted land-cover conditions. This coefficient was subsequently used in the determination of effective rainfall and design flood discharge.

Effective Rainfall

The effective rainfall was determined by multiplying the design rainfall by the runoff coefficient obtained from the land-cover analysis. The calculation was performed for return periods of 2, 5, 10, 25, 50, and 100 years using an average runoff coefficient of 0.54. The resulting effective rainfall values are presented in Table 6.

Table 6. Effective Rainfall Calculation

Tr	R (mm)	C	R_{eff} (mm)
2	98.07	0.54	52.90
5	131.28	0.54	70.81
10	153.26	0.54	82.66
25	181.03	0.54	97.64
50	201.64	0.54	108.76
100	222.09	0.54	119.79

Hourly Rainfall Distribution

The hourly rainfall distribution was determined based on the observed rainfall pattern in Indonesia. Since the observed rainfall concentration period does not exceed 7 hours, a maximum rainfall concentration duration of 6 hours was adopted in this study [17]. The hourly rainfall distribution was calculated using the Mononobe method, with the resulting rainfall distribution ratios presented in Table 7.

Table 7. Hourly Rainfall Distribution Ratios

Hour (t)	Rainfall Intensity (I)	Rainfall Distribution Ratio (Rt)
1	0.55	0.55
2	0.35	0.14
3	0.26	0.10
4	0.22	0.08
5	0.19	0.07
6	0.17	0.06

The rainfall distribution ratios were then applied to the design rainfall for the 2-, 5-, 10-, 25-, 50-, and 100-year return periods. The resulting hourly rainfall distributions are presented in Table 8. The calculated hourly rainfall values provide the temporal rainfall input required for the subsequent Nakayasu Synthetic Unit Hydrograph analysis to estimate the design flood discharge.

Table 8. Hourly Rainfall Distribution for Different Return Periods

Hour (t)	Rt	Effective Rainfall (1-hr) (mm)					
		2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
1	0.55	29.11	38.97	45.49	53.74	59.85	65.92
2	0.14	7.57	10.13	11.82	13.97	15.56	17.13
3	0.10	5.31	7.10	8.29	9.80	10.91	12.02
4	0.08	4.23	5.66	6.60	7.80	8.69	9.57
5	0.07	3.57	4.78	5.58	6.59	7.34	8.08
6	0.06	3.12	4.18	4.87	5.76	6.41	7.06

Design Flood Discharge

The design flood discharge was calculated using the Nakayasu Synthetic Unit Hydrograph method based on the characteristics of the Buntung River Basin. The parameters used in the calculation consisted of a catchment area of 23.28 km², a main river length of 22.83 km, and a base flow of 3.55 m³/s. The calculation of the time intervals and discharge ordinates for the Nakayasu synthetic unit hydrograph is presented in Table 9.

Table 9. Time Intervals of the Nakayasu Synthetic Unit Hydrograph

Characteristic	Nota-tion	Start Time		End Time	
		Nota-tion	Hour	Nota-tion	Hour
Rising Limb	Qa	0	0	Tp	2.76
Falling Limb Stage 1	Qd1	Tp	2.76	Tp+T0.3	5.02
Falling Limb Stage 2	Qd2	Tp+T0.3	5.02	Tp+T0.3+1.5T0.3	8.40
Falling Limb Stage 3	Qd3	Tp+T0.3+1.5T0.3	8.40	~	~

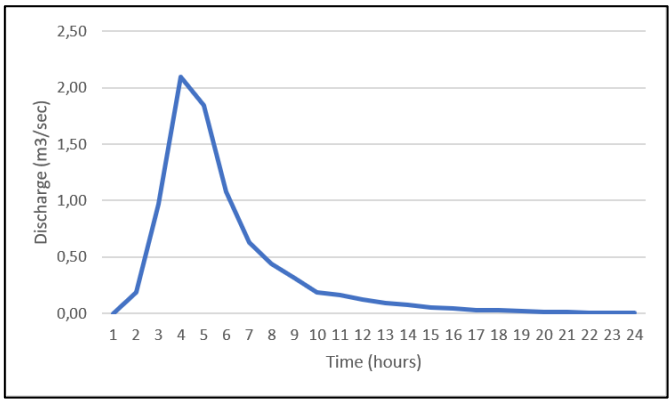


Figure 3. Nakayasu Synthetic Unit Hydrograph

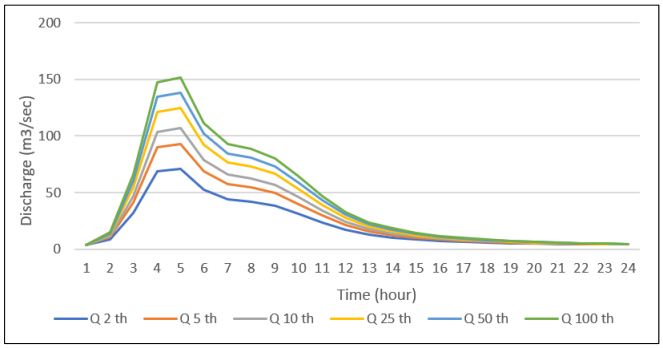


Figure 4. Design Flood Hydrographs for 2-, 5-, 10-, 25-, 50-, and 100-Year Return Periods

The resulting synthetic unit hydrograph was subsequently used to calculate the design flood hydrographs for the 2-, 5-, 10-, 25-, 50-, and 100-year return periods. The resulting design flood hydrographs are presented in Figure 4. The peak discharge occurs at approximately the third hour for all return periods. The peak discharge increases as the return period increases, corresponding to the increase in design rainfall.

The complete recapitulation of the design flood discharges is presented in Table 10.

Table 10. Recapitulation of Design Flood Discharges

Return Period (Years)	Design Flood Discharge (m^3/s)
2	74.04
5	97.91
10	113.71
25	133.67
50	148.48
100	163.18

The peak design flood discharges were subsequently used as input discharges for the hydraulic analysis using HEC-RAS 6.5 under steady-flow conditions to evaluate the existing hydraulic capacity of the Buntung River and identify critical sections where overtopping may occur.

Existing River Hydraulic Analysis

The hydraulic analysis was conducted to evaluate the capacity of the Buntung River to convey flood discharges for return periods of 2, 10, 25, 50, and 100 years. The results of the hydraulic analysis using HEC-RAS 6.5 are presented below.

Table 11. HEC-RAS 6.5 Output for the 2-Year Peak Flood Discharge under Existing River Conditions

Station	Bank Elevation (m)		Water Surface Elv. (m)	Description
	Right	Left		
B-391	6.53	6.31	8.16	Overtopping
B-401	5.92	6.58	7.94	Overtopping
B-411	6.03	6.37	7.76	Overtopping
B-421	6.03	6.37	7.54	Overtopping
B-431	5.21	5.65	7.41	Overtopping
B-441	6.31	6.50	7.28	Overtopping
B-451	5.44	5.42	7.10	Overtopping
B-461	5.00	4.96	6.92	Overtopping
B-471	4.82	4.19	6.77	Overtopping
B-481	5.20	4.56	6.63	Overtopping
B-491	5.19	5.36	6.50	Overtopping
B-500	5.23	5.50	6.37	Overtopping

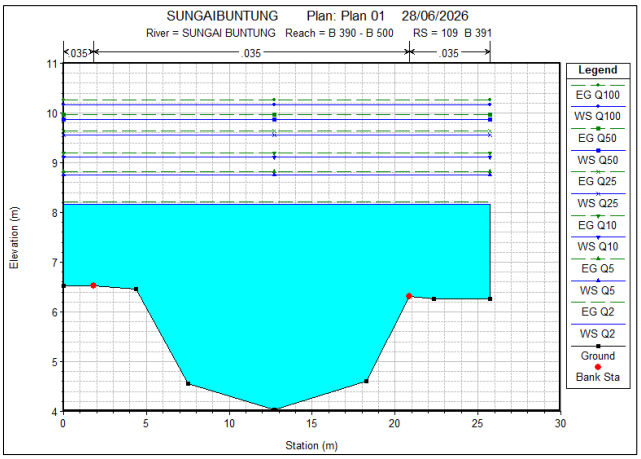


Figure 5. Existing Cross Section of the Buntung River at Station B-391

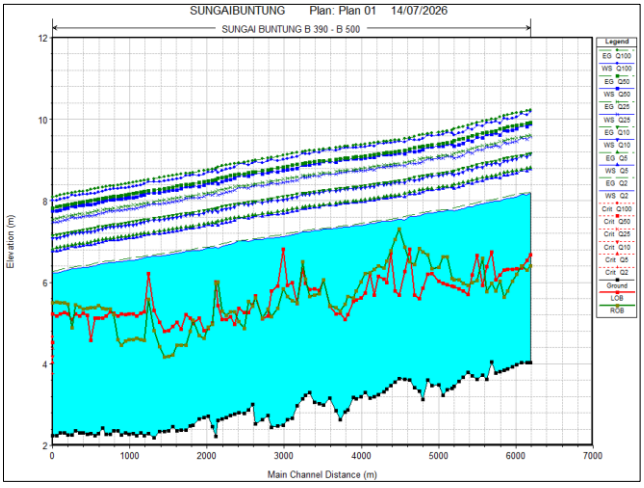


Figure 6. Existing Longitudinal Profile of the Buntung River

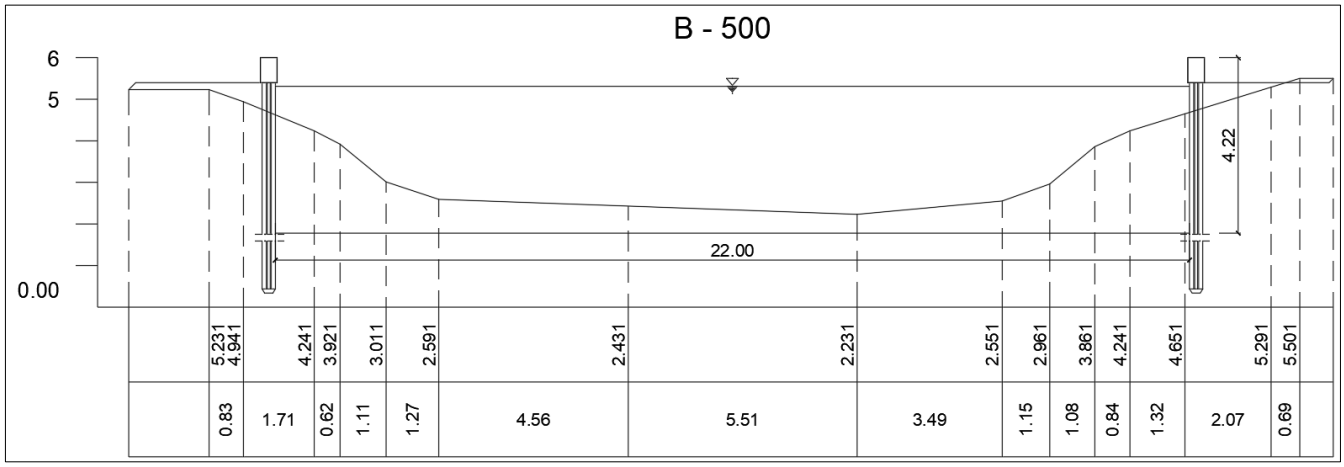


Figure 7. Design of Buntung River Normalization with Precast Concrete Retaining Walls

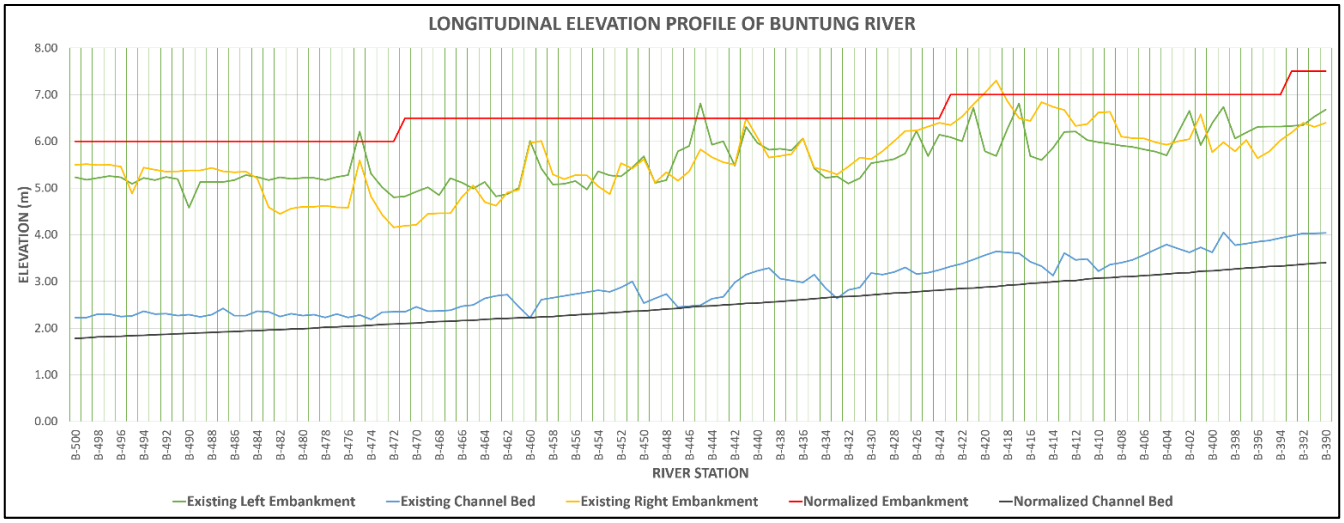


Figure 8. Comparison of Riverbed and Bank Elevations Before and After Normalization

Based on Figures 6 and 7 and Table 11, the water surface elevation was found to be higher than the riverbank elevation along the study reach, particularly from station B-491 to B-500. This condition indicates that the existing river cross-sectional capacity is insufficient to accommodate the flood discharge, resulting in overtopping.

The identification results indicate that the occurrence of overtopping is influenced by high sedimentation, which reduces the effective channel cross-sectional area, as well as variations in riverbank conditions that further reduce the flow conveyance capacity. Even under the 2-year return period flood discharge, the Buntung River experiences overtopping, indicating that the existing hydraulic capacity of the river is inadequate.

Flood Control Alternative

River normalization was designed for the Buntung River by dredging sediment and modifying the channel dimensions using precast concrete retaining walls with a rectangular channel concept. The channel dimensions were determined using a trial-and-error method to meet the capacity requirements for the 25- and 50-year design flood discharges. The 100-year design flood discharge was not adopted as a design criterion, as the proposed normalization was intended to provide hydraulic protection up to the 50-year return period. An example of the proposed normalized channel at station B-500 is presented in Figure 7.

The conveyance capacity of the normalized channel can be determined using the Manning equation, as follows:

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

$$Q = \frac{1}{0.011} \times 92.48 \times (3.04)^{\frac{2}{3}} \times (0.00026)^{\frac{1}{2}}$$

$$Q = 284.48\, m^3/sec$$

Based on the calculation results, the normalized Buntung River channel has a conveyance capacity of

284.48 m³/s. This capacity is greater than the 25-year design flood discharge of 133.67 m³/s and the 50-year design flood discharge of 148.48 m³/s. Therefore, the normalized channel has sufficient capacity to accommodate the design flood discharges for both return periods.

The comparison of the riverbed elevation and the right and left bank elevations before and after normalization is presented in Figure 8. The figure shows that the existing river condition is highly irregular, both in terms of riverbed elevation and bank elevations. In contrast, the normalized condition exhibits a more uniform riverbed profile and more regular right and left bank elevations.

The hydraulic analysis of the normalized Buntung River was subsequently performed using steady-flow simulations in HEC-RAS 6.5 for the 25- and 50-year return periods, which are considered representative design periods for the proposed river normalization.

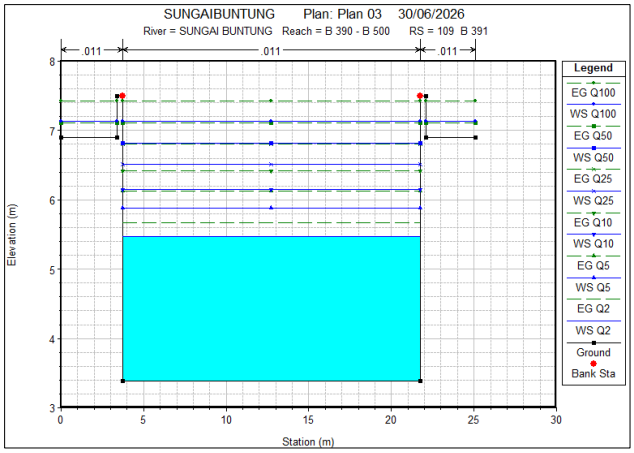


Figure 9. Cross Section of the Normalized Buntung River at Station B-391

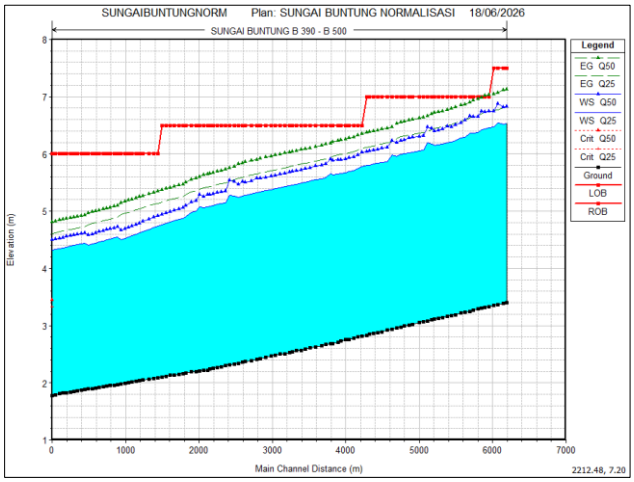


Figure 10. Longitudinal Profile of the Normalized Buntung River under the 25- and 50-Year Peak Flood Discharges

Table 12. HEC-RAS 6.5 Output for the Normalized Buntung River under the 25- and 50-Year Peak Flood Discharges

Station	Bank Elevation (m)		Water Surface Elv. (m)		Description
	Right	Left	Q_{25}	Q_{50}	
B-391	7.50	7.50	6.53	6.83	No Overtopping
B-401	7.00	7.00	6.28	6.55	No Overtopping
B-411	7.00	7.00	6.05	6.31	No Overtopping
B-421	7.00	7.00	5.82	6.06	No Overtopping
B-431	6.50	6.50	5.63	5.88	No Overtopping
B-441	6.50	6.50	5.45	5.68	No Overtopping
B-451	6.50	6.50	5.27	5.52	No Overtopping
B-461	6.50	6.50	5.06	5.26	No Overtopping
B-471	6.50	6.50	4.76	4.94	No Overtopping
B-481	6.00	6.00	4.50	4.67	No Overtopping
B-491	6.00	6.00	4.44	4.62	No Overtopping
B-500	6.00	6.00	4.32	4.50	No Overtopping

Table 13. Comparison of Water Surface Elevation Before and After River Normalization for the 50-Year Design Flood

Station	Water Surface Q_{50} (m)		Difference (m)	Reduction (%)
	Eksisting	After Normalization		
B-391	9.60	6.83	2.77	28.85
B-401	9.35	6.55	2.80	29.95
B-411	9.14	6.31	2.83	30.96
B-421	8.94	6.06	2.88	32.21
B-431	8.81	5.88	2.93	33.26
B-441	8.68	5.68	3.00	34.56
B-451	8.45	5.52	2.93	34.67
B-461	8.24	5.26	2.98	36.17
B-471	8.05	4.94	3.11	38.63
B-481	7.87	4.67	3.20	40.66
B-491	7.72	4.62	3.10	40.16
B-500	7.57	4.5	3.07	40.55
Average			**2.97**	**35.05**

Based on Figures 9 and 10 and Tables 12, the normalized Buntung River channel is capable of conveying the design flood discharges for the 25- and 50-year return periods. This indicates that the conveyance capacity of the normalized channel meets the design requirements. As shown in Table 13, the comparison of water surface elevation under the 50-year design flood discharge shows an average reduction of 2.97 m, corresponding to an average reduction of 35.05% across the evaluated cross-sections after river normalization.

At all evaluated cross-sections, from station B-491 to B-500, no overtopping occurred because the water surface profile remained below the available freeboard limit. Therefore, the normalized channel is considered capable of safely conveying the design flood discharges.

Conclusion

The hydrological analysis using the Nakayasu Synthetic Unit Hydrograph (SUH) method resulted in design flood discharges of 74.04 m^3/s (Q_2), 97.91 m^3/s (Q_5), 113.71 m^3/s (Q_{10}), 133.67 m^3/s (Q_{25}), 148.48 m^3/s (Q_{50}), and 163.18 m^3/s (Q_{100}).

The hydraulic analysis using HEC-RAS 6.5 under existing conditions showed that the Buntung River was unable to accommodate the design flood discharge, even for the 2-year return period. The steady-flow simulation indicated overtopping along the entire investigated river reach, from station B-390 to B-500, covering a total of 111 cross-sections. This condition demonstrates that the existing channel capacity is inadequate and may cause flooding if no mitigation measures are implemented.

The proposed river normalization was designed and evaluated using the Q_{25} and Q_{50} design flood discharges as the design criteria for the study reach. Q100 was not adopted as a design criterion because the proposed normalization was intended to provide hydraulic protection up to a 50-year return period. Nevertheless, the Q_{100} discharge was calculated as part of the hydrological analysis to characterize a higher-return-period flood condition, but it was not used as the basis for determining the dimensions of the normalized channel. The evaluation results showed that the normalized channel at station B-500 has a conveyance capacity of 284.48 m^3/s, which is greater than Q_{25} of 133.67 m^3/s and Q_{50} of 148.48 m^3/s. HEC-RAS simulations showed that the normalized channel was capable of conveying both design flood discharges without overtopping. In addition, under the Q_{50} condition, the water surface elevation decreased by an average of 2.97 m, corresponding to a 35.05% reduction, across the evaluated cross-sections. Therefore, the hydraulic performance of the proposed normalization demonstrated in this study is applicable up to the Q_{50} design flood discharge within the investigated section of the Buntung River.

References

1. A.B. Saputra, D.A.D. Nusantara, Kajian normalisasi terhadap kapasitas Sungai Gude Desa Pulolor berbasis HEC-RAS, *J. Tek. Sipil* **2** (2021) 17–22. DOI: 10.31284/j.jts.2021.v2i1.1766.
2. A. Andriawan, Kajian hidrologi pada sistem pengendalian banjir, *J. Tek. Sipil Ranc. Bangun* **7** (2021) 35–41. DOI: 10.33506/rb.v7i1.1228.
3. H.C. Maddi, R. Musa, H. Ashad, Kajian pengendalian banjir dengan menggunakan waduk regulasi (studi kasus: DAS Wanggu Kota Kendari), *J. Flyover* **1** (2021) 21–32. DOI: 10.52103/jfo.v1i1.658.
4. M. Yatsrib, A.N. Harman, S.R. Taufik, T.N.A. Kesuma, D. Saputra, M.S.B. Kusuma, M. Farid, A.A. Kuntoro, Study on the contribution of normalization to reducing flood risk in the Ciliwung River, Tebet District, Jakarta, *IOP Conf. Ser. Earth Environ. Sci.* **933** (2021) 012032. DOI: 10.1088/1755-1315/933/1/012032.
5. [5] M.D.N. Syamsuddin, M.A. Maulana, Hydraulic modeling study of alternative flood control strategies for the Rejoso River Pasuruan, *Journal of Marine-Earth Science and Technology* **6** (2025). DOI: 10.12962/j27745449.v6i1.8781.
6. N.I.E. Nanda, Y.R. Savitri, M.A. Maulana, 2D rain–discharge and inundation modeling for flood analysis in Buntung watershed, Sidoarjo regency, *AGREGAT* **11** (2026) 14526–14535. DOI: 10.30651/ag.v11i1.31715.
7. R.A. Sulhan, M. Efendi, R.I. Hapsari, Analisis debit banjir pada Sungai Buntung di Kabupaten Sidoarjo, *J. Online Skripsi Manaj. Rekayasa Konstr. Polinema* **1** (2020) 79–84. DOI: 10.55404/jos-mrk.2020.01.03.79-84.
8. R.R.R. Alam, I. Saud, F.N. Ansori, D.F. Ralindra, A.F.H. Prajitno, Pemodelan perubahan morfologi sungai akibat pembuangan lumpur Sidoarjo pada Kali Porong, *J. Apl. Tek. Sipil* **22** (2024) 199–206. DOI: 10.12962/j2579-891X.v22i2.19613.
9. M. Rohmaniyah, L.D. Rohmadiani, Bentuk dan tingkat partisipasi masyarakat terhadap banjir Sungai Buntung di Kecamatan Waru, *J. Tek. Waktu* **18** (2020) 15–25. DOI: 10.36456/waktu.v18i1.2347.
10. Kementerian Pekerjaan Umum dan Perumahan Rakyat, *Rencana Pengelolaan Sumber Daya Air Wilayah Sungai Brantas*, Keputusan Menteri Pekerjaan Umum dan Perumahan Rakyat No. 904/KPTS/M/2021, 2021.

11. F. Desromi, Y.E. Putri, O.E. Wijaya, H. Hermawati, Penggunaan program HEC-RAS dalam pengendalian banjir sungai, *J. Deform.* **7** (2022) 117–126. DOI: 10.31851/deformasi.v7i2.9646.
12. S. Ogras, F. Onen, Flood analysis with HEC-RAS: A case study of Tigris River, *Adv. Civ. Eng.* **2020** (2020) 6131982. DOI: 10.1155/2020/6131982.
13. A. Khalil, Inhomogeneity detection in the rainfall series for the Mae Klong River Basin, Thailand, *Appl. Water Sci.* **11** (2021) 147. DOI: 10.1007/s13201-021-01474-6.
14. S.L.S. Yong, J.L. Ng, Y.F. Huang, C.K. Ang, Assessment of the best probability distribution method in rainfall frequency analysis for a tropical region, *Malaysian J. Civ. Eng.* **33** (2021) 35–44. DOI: 10.11113/mjce.v33.16253.
15. A.M. Takeleb, M.A. Ximenes, A.F. Godinho, C.A. de J. da Costa, Q.R. Fajriani, Design of flood discharge with synthetic unit hydrograph in Comoro Watershed, Timor Leste, *Timor-Leste J. Eng. Sci.* **4** (2023) 1–9.
16. M. Harits, A. Sapei, N.H. Pandjaitan, Avoiding flood by improving cross-sectional capacity through river normalization, *J. Tek. Pertan. Lampung* **13** (2024) 1023–1035. DOI: 10.23960/jtep-l.v13i4.1023-1035.
17. S. Sosrodarsono, K. Takeda, *Hidrologi untuk Pengairan*, PT Pradnya Paramita, Jakarta, 2006.