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Article

Effect of Wonokromo Sluice Gate Opening Variations on Water Surface Elevation in the Kali Mas River, Surabaya.

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Abstract

The Kali Mas River is one of the main drainage systems in Surabaya City that plays an important role in controlling water flow and flood risks in urban areas. The Wonokromo Water Gate serves as one of the flow-regulating structures that influences the hydraulic conditions of the Kali Mas River. This study aims to analyze the water surface profile and changes in flow conditions along the Kali Mas River under several Wonokromo Water Gate opening scenarios using the HEC-RAS 2D software. The hydraulic model covers a 16.3 km reach of the Kali Mas River, with the design flood discharge applied as the upstream boundary condition (flow hydrograph) and tidal data from Tanjung Perak applied as the downstream boundary condition. Simulations were conducted for gate openings of 100%, 50%, and the daily operating condition using an unsteady flow approach. The simulation results show that, for the 2-year return period design flood discharge of 257.5 m^3/s, none of the four scenarios resulted in significant inundation along the Kali Mas River reach. Variations in gate opening produced differences in water surface elevation between the upstream and downstream sections of the river. In the upstream section, the water surface elevations were 7.69 m for the 100% opening, 7.75 m for the 50% opening, 7.85 m for the daily condition, and 7.95 m for the 10% opening. Meanwhile, in the downstream section, the corresponding water surface elevations were 0.42 m, 0.40 m, 0.37 m, and 0.37 m, respectively. These results indicate that variations in the Wonokromo Water Gate opening affect flow conditions and the distribution of water surface elevations along the Kali Mas River, with more noticeable differences occurring in the upstream section than in the downstream section.

Keywords: Sluice Gate, Kali Mas, Flood Control, HEC-RAS, Operational Simulation.

1. Introduction

Flooding remains a major challenge in urban water management, particularly in densely developed areas where rainfall, river discharge, drainage capacity, and downstream water levels interact. Urban flooding can occur when the capacity of drainage and river systems is insufficient to accommodate incoming flows, resulting in increased water levels and inundation in surrounding areas. In Surabaya, flooding is influenced by both rainfall and the hydraulic conditions of its urban drainage system. A study of the drainage system in Pabean Cantikan, Surabaya, reported that inundation was associated with rainfall, limited drainage capacity, and high water levels in the Kali Mas River, with tidal conditions also contributing to the drainage response [1]. These conditions demonstrate the importance of understanding the interaction between river flow and hydraulic control structures in urban flood management.

The Kali Mas River is an important component of the urban river and drainage system in Surabaya and conveys flow through densely developed areas toward the downstream coastal zone. The Wonokromo Sluice Gate is one of the hydraulic structures used to regulate flow entering

the Kali Mas River. Changes in sluice-gate opening can affect the distribution of discharge and consequently influence water depth, flow velocity, and water surface elevation along the river. Therefore, gate operation needs to be considered as an important factor in evaluating the hydraulic response of an urban river system, particularly under high-flow conditions.

Previous studies have demonstrated the importance of evaluating sluice-gate operation through scenario-based hydraulic analysis. Muroi et al. [2] investigated different sluice-gate operating conditions and their effects on inland flood damage, showing that changes in gate operation can influence the resulting inundation conditions. In addition, Garcia et al. [3] demonstrated the application of HEC-RAS 2D to integrate hydraulic-structure operation with flood modeling. Their study showed that HEC-RAS 2D can simulate spatial variations in flood depth, water surface elevation, and flow velocity while incorporating gate-operation scenarios. These studies indicate that evaluating alternative gate-opening conditions through hydraulic modeling can provide a more detailed understanding of their effects on flood conditions.

Two-dimensional hydraulic modeling is particularly relevant for urban river systems because flow conditions may vary spatially due to complex channel geometry, surrounding topography, and hydraulic structures. Rangari et al. [4] applied HEC-RAS 2D to assess inundation risk in an urban area and demonstrated its capability to represent the spatial distribution of flood depth. Quiroga et al. [5] also evaluated two-dimensional hydraulic models for flood inundation mapping using water surface elevation and flood extent as assessment parameters. These studies support the use of two-dimensional modeling to examine spatial hydraulic responses rather than relying only on one-dimensional flow characteristics.

In addition to upstream flow conditions, downstream water levels may influence hydraulic behavior in rivers connected to coastal areas. In Surabaya, a drainage-system study in the Pabean Cantikan area identified tidal conditions and elevated water levels in the Kali Mas as factors associated with inundation and backwater conditions [1]. This indicates that the hydraulic response of the Kali Mas River cannot be evaluated solely from the incoming discharge; downstream water-level conditions also need to be considered. Accordingly, an unsteady-flow simulation incorporating a tidal downstream boundary condition can provide a more representative description of the hydraulic response under varying gate-opening conditions.

Although previous studies have examined sluice-gate operation, urban flood modeling, and the application of HEC-RAS 2D, the hydraulic response of the Kali Mas River to specific Wonokromo Gate 1 opening configurations requires further assessment. The present study focuses specifically on the response of the Kali Mas River to alternative operating conditions of Wonokromo Gate 1 using an unsteady HEC-RAS 2D model with a downstream tidal boundary condition. The novelty of this study lies in the scenario-based comparison of gate-opening configurations by evaluating three hydraulic indicators, namely water depth, flow velocity, and water surface elevation, along the modeled river reach. This approach allows the hydraulic effects of different gate-opening conditions to be compared spatially under the same design-flood conditions.

Therefore, this study aims to analyze the hydraulic response of the Kali Mas River to variations in Wonokromo Gate 1 opening under the 25-year return-period design flood discharge (Q25). Four operating scenarios are considered, consisting of the daily operating condition and gate-opening configurations of 10%, 50%, and 100%. The hydraulic response of each scenario is evaluated based on water depth, flow velocity, and water surface elevation at selected locations along the modeled river reach. The results are intended to provide a comparative assessment of the hydraulic conditions associated with different gate-opening configurations and contribute to a better understanding of sluice-gate operation in the Kali Mas River.

2. Material and Method

This study was conducted to analyze the hydraulic response of the Kali Mas River to variations in the Wonokromo Sluice Gate opening using an unsteady HEC-RAS 2D model. The data consisted of primary and secondary data. Primary data were obtained through field observations

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of the physical condition of the Wonokromo Sluice Gate, its mechanical system, and gate operating procedures. Secondary data included rainfall data, tidal data, topographic and terrain data, river cross-sectional data, and technical data related to the sluice gate obtained from relevant agencies.

Rainfall data from the Wiyung, Porong, Ngareskidul, and Tapen rainfall stations were used for the hydrological analysis. The rainfall data covered the period of 2015 - 2026. Tidal data at Tanjung Perak covering 2025 were used to define the downstream water-level boundary condition. Topographic and terrain data were obtained from DEMNAS, while river geometry and cross-sectional data were obtained from PJT 1. Sluice-gate operational data, including the daily operating condition and prescribed gate-opening configurations, were obtained from PJT 1.

The analysis consisted of hydrological analysis, hydraulic modeling using HEC-RAS 2D, simulation of different sluice-gate opening scenarios, and comparative analysis of the resulting hydraulic parameters.

2.1 Hydrological Analysis

Hydrological analysis was conducted to obtain the design flood discharge used as input for hydraulic modeling. The analysis began with delineation of the watershed using ArcGIS. The delineation resulted in a watershed area of 391 km², which was subsequently used as one of the parameters for generating the flood hydrograph.

2.2 Regional Average Rainfall Analysis

Regional average rainfall was calculated using the Thiessen Polygon Method based on the rainfall stations influencing the delineated watershed. The rainfall stations used were Wiyung, Porong, Ngareskidul, and Tapen. The area of influence of each station was delineated using ArcGIS based on the watershed boundary.
The resulting areas of influence are presented in Table 1.

Table 1. Areas of Influence

Wiyung (km²)	Porong (km²)	Ngareskidul (km²)	Tapen (km²)
134	140	74	43

2.3 Design Rainfall Analysis

Design rainfall analysis was conducted to obtain rainfall depths corresponding to the selected return periods. The probability distribution was determined by evaluating the statistical characteristics of the annual maximum rainfall series and testing several candidate probability distributions. The Log Pearson Type III distribution was selected based on its suitability for representing the statistical characteristics of the annual maximum rainfall data and the results of the goodness-of-fit tests.
The Log Pearson Type III parameters included the logarithmic mean, standard deviation, and coefficient of skewness. The coefficient of skewness obtained from the rainfall data was **0,54**. The goodness-of-fit tests were conducted to verify the suitability of the selected distribution. The calculated test statistics were compared with the corresponding critical values at the selected significance level. The distribution was considered acceptable when the calculated statistic satisfied the acceptance criterion.

2.4 Hourly Rainfall Distribution

Hourly rainfall distribution was determined using the Alternating Block Method (ABM). This method was used to transform design rainfall into a time-based rainfall distribution required for developing the flood hydrograph. The resulting hourly rainfall distribution was subsequently used as input for the Nakayasu Synthetic Unit Hydrograph analysis.

2.5 Nakayasu Synthetic Unit Hydrograph

The design flood hydrograph was generated using the Nakayasu Synthetic Unit Hydrograph (SUH) method. The design rainfall distribution

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obtained from the Alternating Block Method (ABM) was transformed into a flood hydrograph based on the characteristics of the delineated watershed. Based on the hydrological analysis, the 2-year return period (Q2) was selected as the design flood condition for the hydraulic simulation. The selection of Q2 was intended to represent the design flood condition considered in this study, while higher return periods produced substantially greater design discharges. The resulting Q2 hydrograph had a peak discharge of 257.5 m^3/s and was subsequently used as the inflow hydrograph at the upstream boundary of the HEC-RAS 2D model.

2.6 Hydraulic Modeling Using HEC-RAS

Hydraulic modeling was conducted using HEC-RAS version 6.7 with unsteady flow analysis using the HEC-RAS 2D model. The model was developed based on river geometry data, cross sections, topographic data, terrain, Manning's roughness coefficient, 2D Flow Area, and control structures within the Kali Mas system. The upstream boundary condition used the flow hydrograph obtained from the design flood discharge analysis, while the downstream boundary condition used a stage hydrograph [3].

2.7 Sluice Gate Operating Scenarios

Operational simulations were conducted using the 2-year return period design flood discharge (Q2) of 257.5 m^3/s for all scenarios. Four operating scenarios were considered for the Wonokromo Sluice Gate, consisting of 100% opening, 50% opening, 10% opening, and the daily operating condition. The 100% opening scenario represented the fully opened gate condition, while the 50% and 10% scenarios represented reduced gate-opening conditions. The daily operating condition represented the actual gate operation, with gate openings of 0.6 m and 0.4 m, respectively.

For each scenario, the river geometry, terrain data, Manning's roughness coefficient, boundary conditions, computational mesh, and other model parameters were maintained consistently. The only parameter varied between the scenarios was the sluice-gate opening condition. The simulation results were subsequently compared based on maximum water depth, maximum flow velocity, and maximum water surface elevation (WSE) to evaluate the hydraulic response of the Kali Mas River under different Wonokromo Sluice Gate operating conditions.

2.8 Simulation Results Analysis

The simulation results for each scenario were analyzed at several points representing flow conditions from the upstream to the downstream sections of the Kali Mas River. The evaluation parameters included Maximum Depth, Maximum Velocity, and Maximum Water Surface Elevation (WSE). These three parameters were used to identify changes in flow depth, flow velocity, and water surface elevation resulting from variations in the Wonokromo Sluice Gate opening. The results of the three scenarios were then compared to determine the operating condition that provided the most effective performance for flood control.

3. Results and Discussion

The results were obtained through a series of hydrological and hydraulic analyses to evaluate the hydraulic response of the Kali Mas River to variations in Wonokromo Sluice Gate operation. The hydrological analysis was conducted to determine the design flood hydrograph based on the watershed characteristics and rainfall data. The resulting hydrograph was then used as the upstream boundary condition for the HEC-RAS 2D hydraulic model. The hydraulic simulations were conducted using the 2-year return period design flood discharge (Q2) of 257.5 m^3/s under four Wonokromo Sluice Gate operating scenarios: 100% opening, 50% opening, 10% opening, and daily operating condition. The resulting maximum water depth, flow velocity, and water surface elevation (WSE) were compared to evaluate the hydraulic response of the river under each gate-opening condition..

3.1. Hydrological Analysis Results

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The watershed delineation results used in the study indicate a catchment area of 391 km². This watershed area was used as the basis for hydrological analysis to obtain the design flood discharge, which was subsequently used as input for the HEC-RAS model. Regional average rainfall analysis was conducted using four rainfall stations, namely Wiyung, Porong, Ngareskidul, and Tapen. Based on the calculations, the highest regional average rainfall occurred in 2015 at 101.39 mm.

Several probability distributions were evaluated to determine the distribution that best represented the annual maximum regional rainfall data. The distributions considered were Normal, Log-Normal, Gumbel, and Log Pearson Type III. The selection of the appropriate distribution was based on the goodness-of-fit test by comparing the calculated statistical parameters with the corresponding critical values. The results of the goodness-of-fit analysis are presented in Table 3.

Table 2. Goodness of Fit Test Result

Distribution	Critical Value	Calculated Value	Result
Normal	Cs = 0	Cs = 0,35	Rejected
	Ck = 3	Ck = 3,33	
Log-Normal	Cs = 3 Cv + Cv^2	≠	Rejected
	Ck = 5,383	≠	
Gumbel	Cs ≤ 1,1396	≠	Rejected
	Ck ≤ 5,4002	≠	
Log-Pearson III	Cs ≠ 0	Cs = 0,54	Accepted

The goodness-of-fit test results show that the Normal, Log-Normal, and Gumbel distributions did not satisfy the specified statistical criteria and were therefore rejected. In contrast, the Log Pearson Type III distribution satisfied the required criteria and was accepted as the probability distribution for the annual maximum regional rainfall data. Therefore, the Log Pearson Type III distribution was selected to estimate the design rainfall for the selected return periods.

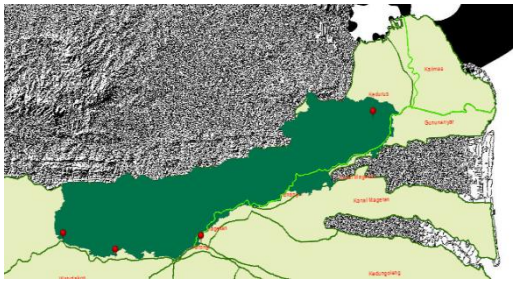

Fig. 1. Study Watershed Delineation

Table 3. Recapitulation of Average Regional Rainfall in 2015–2025

No.	Year	Regional Average Rainfall (mm)
1	2015	101.39
2	2016	101.17
3	2017	38.86
4	2018	68.50
5	2019	72.41
6	2020	66.60
7	2021	44.07
8	2022	57.39
9	2023	71.31
10	2024	34.99
11	2025	47.21

The probability distribution analysis indicates that the Log Pearson Type III Distribution meets the requirements for use in determining design rainfall. Based on this distribution, the 2-year return period design rainfall was obtained as 83.42 mm. The rainfall was subsequently distributed into hourly rainfall using the Alternating Block Method (ABM) and then used to generate the flood hydrograph using the Nakayasu Synthetic Unit Hydrograph.

Table 4. Maximum Daily Rainfall Using the Log Pearson III Method

Return Period (T)	Probability (P)	Cs Log	K	Log Xt	Maximum Daily Rainfall (mm/hour)
2	0.5	-0.156	-0.05	1.78	59.92
5	0.2	-0.156	0.82	1.84	69.71
10	0.1	-0.156	1.30	1.88	75.91
25	0.04	-0.156	1.84	1.92	83.42
50	0.02	-0.156	2.20	1.95	88.85
100	0.01	-0.156	2.53	1.97	94.17

Table 5. Rainfall Distribution for the 2-Year Return Period

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t (hour)	Rainfall intensity (mm/jam)	P Cumulative (mm)	P hourly (mm)	Distributed ABM (mm)	%	Distribusi ABM P2t (mm)
1	20.77	20.8	20.8	2.5	6.7	4.0
2	13.09	26.2	5.4	3.8	10.0	6.0
3	9.99	30.0	3.8	20.8	55.0	33.0
4	8.24	33.0	3.0	5.4	14.3	8.6
5	7.10	35.5	2.5	3.0	8.0	4.8
6	6.29	37.7	2.2	2.2	5.9	3.5
				37.7	100.0	59.9

The flood hydrograph generated using the Nakayasu Synthetic Unit Hydrograph shows that the discharge increased until reaching a peak discharge of 257,5 m³/s at the 9th hour, followed by a gradual decrease. The peak discharge was used as the inflow hydrograph at the upstream boundary of the HEC-RAS model. Thus, the Q5 discharge of 257,5 m³/s served as the same hydrological condition for all simulation scenarios, so the differences in hydraulic response were primarily caused by changes in the Wonokromo Sluice Gate opening condition.

Table 6. 2-Year Return Period Design Flood

T (jam)	U(t,1)	Hourly Rainfall (mm)						Q
		R1	R2	R3	R4	R5	R6	
	m3/det/mm	4.04	6.01	32.98	8.57	4.79	3.53	m3/det
0.00	0.00000							0.0
1.00	0.01301	0.05						0.1
2.00	0.06869	0.28	0.08					0.4
3.00	0.18176	0.73	0.41	0.43				1.6
4.00	0.36255	1.47	1.09	2.27	0.11			4.9
5.00	0.61937	2.50	2.18	5.99	0.59	0.06		11.3
6.00	0.95936	3.88	3.72	11.96	1.56	0.33	0.05	21.5
7.00	6.69173	27.05	5.77	20.42	3.11	0.87	0.24	57.5
8.00	3.21859	13.01	40.23	31.64	5.31	1.74	0.64	92.6
9.00	1.24857	5.05	19.35	220.67	8.22	2.96	1.28	257.5
10.00	0.81202	3.28	7.51	106.14	57.36	4.59	2.19	181.1
11.00	0.39914	1.61	4.88	41.17	27.59	32.03	3.39	110.7
12.00	0.19619	0.79	2.40	26.78	10.70	15.41	23.64	79.7
13.00	0.09644	0.39	1.18	13.16	6.96	5.98	11.37	39.0
14.00	0.04740	0.19	0.58	6.47	3.42	3.89	4.41	19.0
15.00	0.02330	0.09	0.29	3.18	1.68	1.91	2.87	10.0
16.00	0.01145	0.05	0.14	1.56	0.83	0.94	1.41	4.9
17.00	0.00563	0.02	0.07	0.77	0.41	0.46	0.69	2.4
18.00	0.00277	0.01	0.03	0.38	0.20	0.23	0.34	1.2
19.00	0.00136	0.01	0.02	0.19	0.10	0.11	0.17	0.6
20.00	0.00067	0.00	0.01	0.09	0.05	0.05	0.08	0.3
21.00	0.00033	0.00	0.00	0.04	0.02	0.03	0.04	0.1
22.00	0.00016	0.00	0.00	0.02	0.01	0.01	0.02	0.1
23.00	0.00008	0.00	0.00	0.01	0.01	0.01	0.01	0.0
24.00	0.00004	0.00	0.00	0.01	0.00	0.00	0.00	0.0
				Debit Banjir Rancangan (m3/det)				257.5

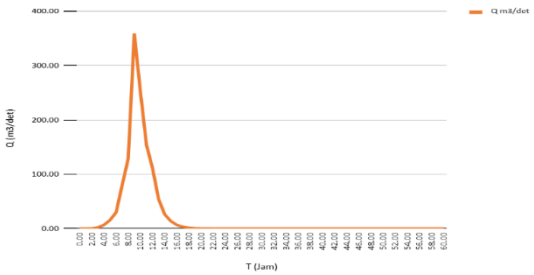

Fig. 2. Q2 Design Flood Hydrograph

3.2. Hydraulic Simulation Scenarios

Hydraulic modeling was conducted using four operating scenarios for the Wonokromo Sluice Gate, namely 100% opening, 50% opening, 10% opening, and daily condition. All scenarios used the same inflow discharge, namely Q2 of 257,5 m³/s, as well as the same geometry, terrain, Manning's roughness coefficient, and computational settings. With this approach, differences in the simulation results can be used to examine the direct influence of gate opening variations on the hydraulic conditions of the Kali Mas River. In this model, the opening variation was applied only to Wonokromo Gate 1, while Wonokromo Gate 2 was kept closed under all scenarios.

Table 7. Simulation Scenarios

Scenario	Gate Opening
100% Opening	Gate 1 : 4,00 m Gate 2 : 4,00 m
50% Opening	Gate 1 : 2,00 m Gate 2 : 2,00 m.
10% Opening	Gate 1 : 0,4 m Gate2 : 0,4 m
Daily Operating Condition	Gate 1 : 0,60 m Gate 2 : 0,40 m

3.3. Boundary Condition

Boundary conditions were used to define the flow conditions at the upstream and downstream boundaries of the Kali Mas River hydraulic model. The boundary conditions were established based on the flow characteristics at the modeled locations and were kept identical for all simulation scenarios so that changes in the results could be

attributed to variations in the Wonokromo Sluice Gate opening.

At the upstream boundary, the boundary condition was defined using the 2-year return period design flood discharge (Q2) of 257,5 m^3/s. This discharge was used as the inflow for all simulation scenarios. At the downstream boundary, a Stage Hydrograph was used to represent water surface fluctuations caused by tidal effects. Tidal data were entered as changes in water surface elevation over time at the downstream boundary of the model. The use of a Stage Hydrograph was intended to account for the influence of tidal conditions on the downstream section of the Kali Mas River, which is connected to the coastal area.

By using the same boundary conditions for all scenarios, the simulations were performed under consistent boundary conditions. Therefore, differences in water surface elevation, flow depth, flow velocity, and potential inundation among the scenarios were primarily used to evaluate the influence of variations in the opening of Gate 1 on the hydraulic conditions of the Kali Mas River..

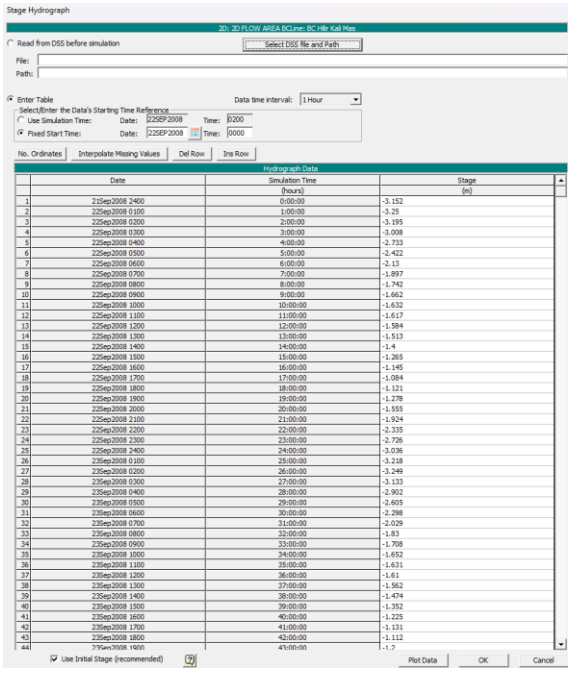

Fig. 3. Stage Hydrograph

3.4. Hydraulic Simulation Results

Based on the established simulation scenarios, hydraulic modeling was conducted using HEC-RAS to determine the effect of variations in sluice gate opening on the flow conditions of the Kali Mas River. All scenarios used the 25-year return period design flood discharge (Q25) of 257,5 m^3/s with the same geometric parameters, terrain, Manning's roughness coefficient, and computational settings. Differences in the simulation results for each scenario were used to evaluate changes in water surface conditions caused by variations in gate opening.

The hydraulic simulation results for each scenario were analyzed based on Water Surface Elevation (WSE) values at several analysis points along the Kali Mas River. The analysis points included the downstream section of the Wonokromo Sluice Gate, upstream of the Rubber Weir, downstream of the Rubber Weir, Kota Tua Surabaya, and Perak (downstream of the Kali Mas River). A comparison of WSE values for each scenario is presented in Table 7.

Table 7. Simulation Result

Station	WSE (m)			
	Gate 100%	Gate 50%	Daily	Gate 10%
108.91	7.69	7.75	7.85	7.95
279.1	7.42	7.44	7.37	7.49
4164.85	5.45	5.41	5.4	5.46
5087.46	4.18	4.07	4.01	4.06
11681.64	0.43	0.41	0.37	0.37
13073.97	0.42	0.4	0.37	0.37

Based on Table 7, the simulation results show differences in water surface elevation (WSE) under the four sluice-gate operating scenarios, namely 100% opening, 50% opening, daily operating condition, and 10% opening. At the Hulu Pintu Kali Mas location, the WSE was 7.69 m under the 100% opening scenario, increasing to 7.75 m under the 50% opening scenario, 7.85 m under the daily operating condition, and 7.95 m under the 10% opening scenario. These results indicate that a smaller gate opening resulted in a higher upstream water surface elevation. This condition is associated with the restriction of the

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flow passage through the gate, which causes greater water accumulation upstream of the control structure.

At the Perak (downstream of Kali Mas) location, the WSE values were 0.42 m for the 100% opening, 0.40 m for the 50% opening, 0.37 m for the daily operating condition, and 0.37 m for the 10% opening. The relatively small differences between scenarios at the downstream location indicate that the effect of gate-opening variations becomes less pronounced toward the downstream section. The downstream water level is also influenced by the hydraulic conditions at the river outlet and the downstream boundary condition.

Overall, the four operating scenarios produced different WSE patterns along the Kali Mas River. The differences were more pronounced in the upstream section of the sluice gate, with the highest WSE occurring under the 10% opening scenario. In contrast, the differences between scenarios became smaller at locations farther downstream. At Kota Tua Surabaya and Perak, the WSE values under the four scenarios were relatively close to one another. This spatial pattern indicates that the influence of sluice-gate opening variations is strongest in the upstream section and gradually decreases toward the downstream reach.

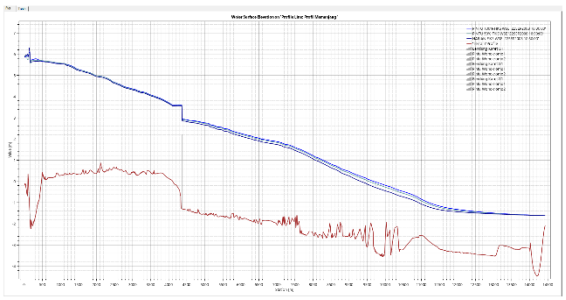

Fig. 4. Longitudinal WSE Profile of the Kali Mas River, Surabaya

Figure 4 shows the water surface elevation under the four scenarios generally decreases from the upstream toward the downstream section of the Kali Mas River. In the initial section up to approximately station 4,000 m, the water surface elevation profiles for the respective scenarios remain relatively close to one another. At approximately station 4,200 m, a relatively sharp change in water surface elevation occurs due to the presence of a hydraulic structure along the river reach. After this point, the water surface elevation gradually decreases toward the downstream section.

After station 4,500 m, the differences between the scenarios become more apparent. The water surface elevation profile under the 100% gate-opening scenario tends to remain higher, whereas the 10% gate-opening scenario generally shows a lower water surface elevation. These differences remain visible toward the downstream section but gradually become smaller around station 12,000 m and toward the end of the profile, where the four water surface elevation profiles converge and become relatively close to one another.

Table 8. Scenario Comparison

Evaluation Parameter	100%	50%	Daily	10%
WSE	Reference condition	Higher upstream and lower downstream than the 100% opening condition	Higher upstream and lower downstream than the 100% and 50% opening conditions	Higher upstream and relatively lower downstream than the 100%, 50%, and daily operating conditions
Genangan	Inundation occurs in the upstream section	Inundation occurs in the upstream section	Inundation occurs in the upstream section	Inundation occurs in the upstream section

4. Conclusions

Based on the series of hydrological analyses and hydraulic modeling using HEC-RAS 2D on the Kali Mas River, the following conclusions were obtained.

a. Based on the simulation results of the 2-year return period design flood discharge (Q2) of 257.5 m^3/s, the four Wonokromo Sluice Gate operating scenarios show no significant inundation in the downstream section of the Kali Mas River. However, inundation still

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occurs in the upstream section, indicating that the river is not yet fully capable of conveying the simulated discharge.

b. Variations in Wonokromo Sluice Gate opening affect the water surface elevation (WSE) of the Kali Mas River. A smaller gate opening results in a higher WSE in the upstream section, while the differences in the downstream section are relatively small.
c. Based on the comparison of WSE, flow depth, flow velocity, and inundation

conditions, the 10% gate-opening scenario provides the most favorable hydraulic response among the simulated scenarios, particularly in the downstream section. The effects of gate-opening variations are more pronounced in the upstream section and tend to decrease toward the downstream section.

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