Study of The Effectiveness of Bekasi Weir Gates Opening to Control Bekasi River Morphology

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Abstract. The Bekasi River flows through urban areas and frequently floods due to the river's capacity getting reduced by the channel depth due to sediment transport. The Bekasi River is currently under flood control works. However, because flood control focuses specifically on floodwater levels and ignores sediment parameters that affect the river's cross-section, it is necessary to investigate the sediment transport effects along the Bekasi river. Flood control is proposed in this study by evaluating changes in river morphology when river dynamics cannot flow naturally due to the Bekasi River's weir gates opening as a flow regulator. The following methods are used, hydrological analysis, sediment sampling, hydraulic analysis, and sediment transport analysis. Numerous scenarios are performed to analyze forecast changes in river morphology, with a 25-year return period for short-term being used to sediment flushing plan and a 2-year return period for long term being used to determine sediment transport rate. The results indicate the existence of a relationship between flow and sediment discharge, which can be used to forecast the amount of sediment accumulation, the distribution of potential erosion and sedimentation for river maintenance purposes and analysis of sediment transport capacity in Lane's balance to duration and discharge.

1. Introduction

Flood disasters frequently occur in Bekasi due to the Bekasi River's low flow capacity, which is unable to drain flood water, particularly during the rainy season [1]. Flood issues, in general, are inextricably linked to urbanization, which is generally followed by a rise in population, activity, and land requirements for settlements and economical operations. Due to the scarcity of land in urban areas, urban activities encroach on land designated for conservation and green open space. The dominant land cover change for period 2014-2019 was the increase in a built-up area and agricultural land, leading to a slightly increased surface runoff volume [2]. As a result, the water catchment area becomes increasingly constrained, increasing runoff and erosion. This affects the river sedimentation due to sediment input from the land and results in the narrowing of the river channel, reducing the river's capacity to drain the water discharge, causing the water to overflow and create flooding, particularly in regions along the Bekasi River. Floods in the Bekasi watershed are relatively large from year to year, owing to erosion conditions in the upstream portion of the watershed, resulting in increased flow and sedimentation in the Bekasi River. The sediment release ratio (SDR) for the Bekasi watershed, which covers approximately 39,045 ha, is 9.75 percent, which means that approximately 9.75 percent of the total eroded soil will become sediment [3].

Numerous studies have been conducted before on the concept of flood control schemes in the Bekasi River, spanning from technical handling issues to socioeconomic factors. The proposed handling solution incorporates integrated flood control by integrating all planning, implementation (construction), and operational/maintenance efforts required prior to, during, and after a flood event, including efforts to formulate and implement policies related to water management, land management, and risk management, with handling carried out through structural efforts, namely grey (rigid) structure, green (soft) structure, and hybrid structures [4]. The Cileungsi River's Narogong Reservoir has been suggested [5]. In order to control flooding in Upstream Bekasi River, based on the results of the analysis and discussion, it can be recommended that the construction of the dry dam in Cikeas River and the dry dam in the Cileungsi River can be recommended [6]. to overcome flooding in Bekasi City it is needed to do the revitalisation of drainage systems in micro and macro. Micro revitalization can be in the form of deepening and cleaning of drainage in the settlements so that it can accommodate a larger flow discharge, and for macro revitalization can be done by the government by monitoring and improving the closed city drainage system due to the development and land conversion function [7]. Non-structural techniques include continuous crop or plant cover, strip planting, crop rotation with green manure or ground cover crops, system agroforestry, residue management, and planting of vegetated waterways [3]. Community involvement in the planning process, policy formulation, implementation, and exploitation of watersheds is necessary to ensure the sustainability of watershed management [8] given the Kali Bekasi watershed's socioeconomic-institutional vulnerability. The need for land acquisition efforts around the Bekasi River so there is no current barrier to the meeting of the Three rivers. Need efforts from the government and local communities to realize times that are clean and environmentally friendly [9].

Several of these studies examined the causes and effects of flood control on the upstream portion. However, none examined the behavior of changes in river morphology on aspects related to the geometry, type, nature, behavior, and dynamics of the river in spatial and temporal dimensions and the environment that influences and influences it [10]. When the driving and resisting flow forces are balanced, as defined in Lane's (1967) scale, equilibrium is attained. In particular, riverbed roughness conditions, the flow regime, and the slope of the riverbed supply mechanical energy to convey the volume and size of sediment. When one parameter is altered, whether naturally or due to human intervention, one or more of the other parameters are altered to restore balance [4].

The suggested flood control in this study is to handle sediment control in the Bekasi River by evaluating changes in river morphology where the influence of river dynamics cannot occur naturally due to the Bekasi River's main weir acting as a flow regulator. While the highest change in bed morphology occurs when the gates are fully open during flooding. A scour hole appears behind the weir gates and sediment flushing from the upstream area near the gates may occur as well [11]. In addition, because this additional discharge is introduced when the flushing gates are fully opened and the water level is low, this discharge can be passed through the bottom outlets if its value is less than the maximum capacity of the outlets. Additional discharge has two major effects: first, it increases the induced bed shear stress and bed erosion and supplies an additional driving force to transport eroded sediments farther downstream in the reservoir and flush them out from the reservoir; second, it causes the water level to increase in the downstream river channel, which can be beneficial from an environmental point of view because it washes away fine materials from the downstream channel terraces (thereby preventing river channel clogging) [12]. Determining the exact position of the sediment accumulation will help to reduce the maintenance costs and efforts and will also help the stakeholders to decide on the best operation to meet the crop water requirements while simultaneously minimizing sediment problems [13]. Moreover, the operation of each individual gate will significantly impact the operation of the whole system as partial control of the system, compared with a fully controlled case, led to 17% increase in flood inundation. [14]. The effectiveness of the Bekasi weir gates opening on sediment transport will be used to calculate the sediment accumulation that occurs, both to maintain the river's balance upstream and downstream and to maintain the river's cross-sectional shape in draining the flood discharge that occurs, thereby reducing river maintenance costs and providing input into decision-making.

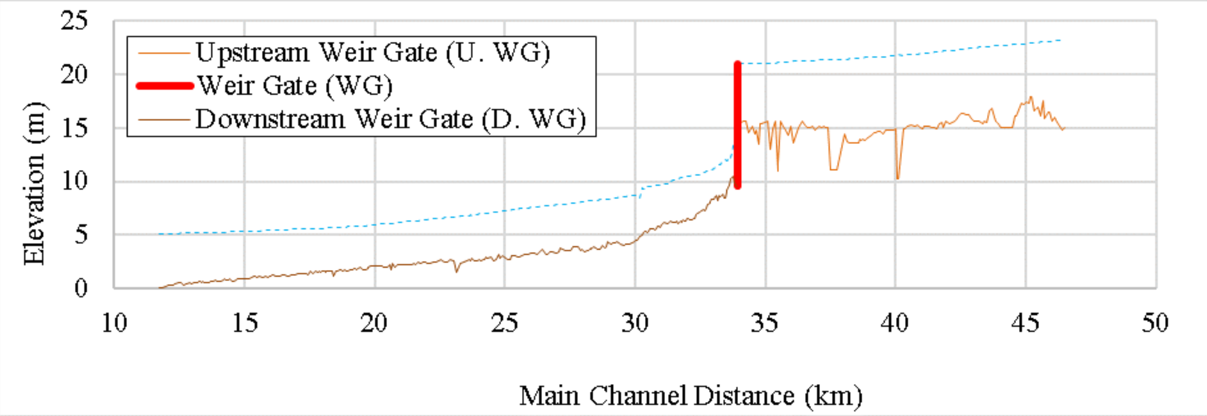

Figure 1. Long section profile of Bekasi River

2. Methodology

In general, the research methodology is divided into four categories, as described in the following:

a. Identification of existing conditions and sedimentation problems; at this stage, the researcher will examine the problems in the field by reviewing the research boundaries, tracing the river from upstream to downstream, and documenting the findings for use as a thesis topic on river morphology.

b. Data collection is classified as primary and secondary data collecting. Sediment sampling and instantaneous discharge measurements were used to acquire primary data in accordance with SNI [15]. Secondary data collection includes the following:
   1) Collecting spatial data from the website http://www.big.go.id;
   2) Collecting flood distribution map data in the Bekasi watershed from the Hydrology and Design Unit for Flood Control in the Lower Bekasi River;
   3) Collecting topographic data and river cross-sections as a result of the Lower Bekasi River Flood Control Design (2015) measurement; and
   4) Collecting data on the Bekasi Weir opening from the Operation and Maintenance Section of the BBWS Ciliwung Cisadane and PJT II Bekasi Weir Management;
   5) Collecting the latest rainfall data and hourly discharge from AWLR in the Bekasi watershed obtained from the Hydrology Unit of BBWS Ciliwung Cisadane.

c. Analyses conducted include hydrological and hydraulic analyses. Each of these analyses is as follows:
   1) Hydrological analysis is performed by converting rainfall data to unit hydrographs using the double mass-curve method, then analyzing the regional rainfall distribution, obtaining design rainfall, and creating Synthetic Unit Hydrographs (SUH) using the Nakayasu, Snyder, ITB-1B, and ITB-2B methods. The first step in recording discharge data at any point during a flood is to calculate the real unit hydrograph that will be used to forecast the anticipated flood discharge. The requirement for rainfall data with runoff discharge is determined by comparing the volume of SUH to the volume of the planned flood discharge from the actual hydrograph.
   2) Hydraulics analysis, which entails analyzing design flood discharge data and inputting it into the HEC-RAS programming to generate output on changes in river shape. The first step is to validate the flood discharge data by comparing it to the water level that happens as a result of the HEC-RAS steady flow 1D programming at the water guess post. The following step is to analyze sediment data in order to obtain information on sediment concentration and sediment

size gradation as a consequence of field sediment sampling. Following that, the HEC-RAS computer uses different ways to determine the most appropriate one based on the least Root Mean Square Error (RMSE) value.

3) The gate opening scenario is separated into two discharge scenarios: flood discharge using Q25 and dominant discharge using Q2. The purpose of using Q25 is to determine the amount of sediment that can be released from upstream to downstream during flood conditions as a basis for stabilizing the riverbed upstream. Simultaneously, the usage of Q2 aspires to be an effective discharge in terms of sediment transport in rivers and changes in river shape over time. Input Q25 to determine the quantity of sediment moved over a two-day flood period by opening the gate along the flood hydrograph. Inputting Q2 for a year is accomplished by opening the gate with an operation plan consisting of 1 month of operation – 1 week of maintenance/gate is opened according to the scenario – 1 month of operation – 1 week of maintenance/gate is opened according to the scenario – and so on. The main gate of the Bekasi weir is a double leaf gate, which is divided into two sections, with the top gate reaching a height of 5 meters (placed in the front) and the lower gate reaching a height of 5 meters (located at the rear). Both of them can be opened up and down independently of one another and are not obstructed by the gate in front of them.

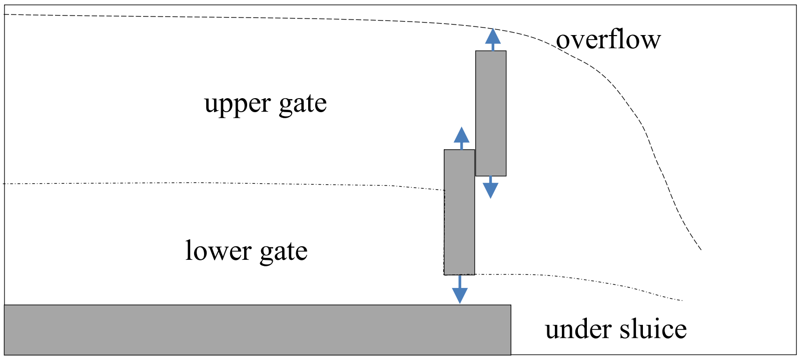

Figure 3. Weir gates opening system

4) For HEC-RAS programming, the quasi-unsteady flow 1D approach is used. This method is used to simulate the effect of changes in river morphology on sediment transport by taking into account the opening of the Bekasi Weir gates.

d. Conclusions are the outcome of an investigation and serve as a reference material for future research on sediment transport and river morphology in the Bekasi River.

The graphic below illustrates the framework for doing the data analysis and the interrelationships between the various research methodologies.

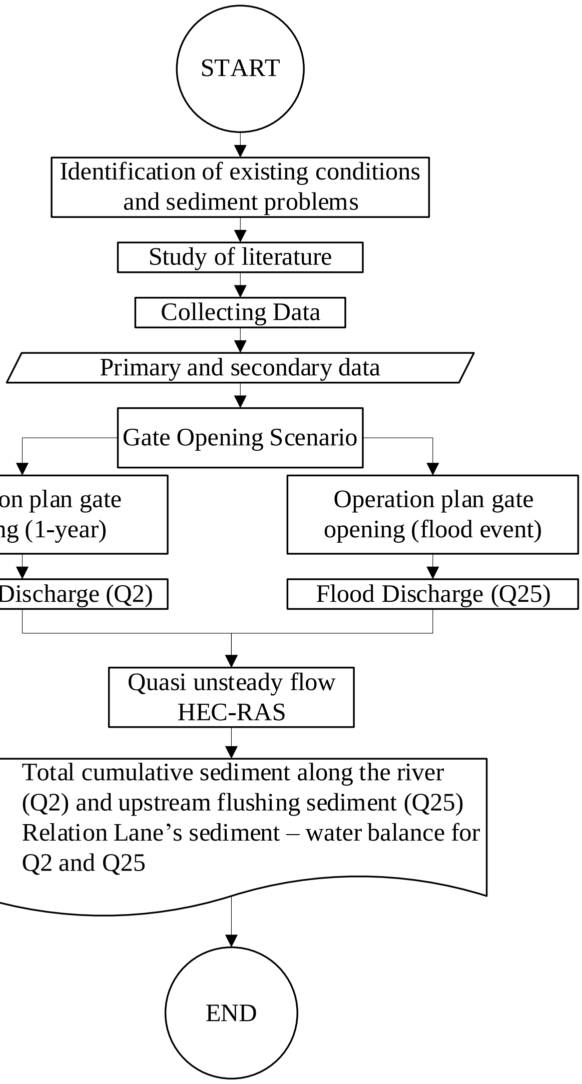

Figure 4. Methodology flowchart

3. Analysis

3.1. Hidrological Analysis

This analysis calculates the planned flood hydrograph and dominant discharge recording data from the AWLR near the Bekasi Weir.

3.1.1. Calculation of the Planned and Dominant Flood Discharge Hydrograph. The study of planned flood discharge is necessary to determine the necessity for planned flood discharge data, specifically discharge data with a 25-year return period and dominant discharge data with a 2-year return period as the basis for the discharge of bankfull capacity in the Bekasi River.

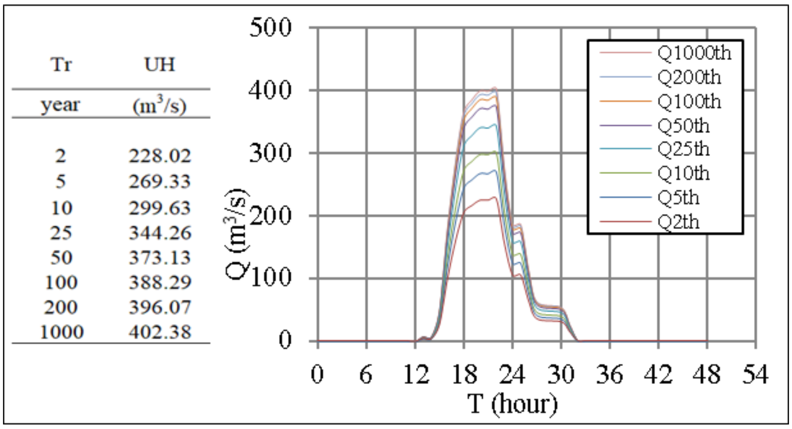

Figure 5. Flood hydrographs of Bekasi River

3.1.2. Rainfall Data Volume Calibration Using Runoff Discharge. Calibration of the runoff discharge data obtained from the AWLR observation at Bekasi Weir requires comparing the hydrograph volume of the runoff discharge with hydrograph volume of the effective rainfall. This is done to ensure that the certainty of runoff discharge may be used in conjunction with the actual rainfall data. The hydrograph volume of the watershed effective rainfall is calculated using several methods, including SCS-Snyder, Nakayasu, ITB-1B, and ITB-2B, whereas the hydrograph volume of the runoff discharge unit is derived from the hydrograph volume of the planned flood unit calculated from the actual discharge in the preceding discussion. The following table and picture illustrate the volume calculation findings.

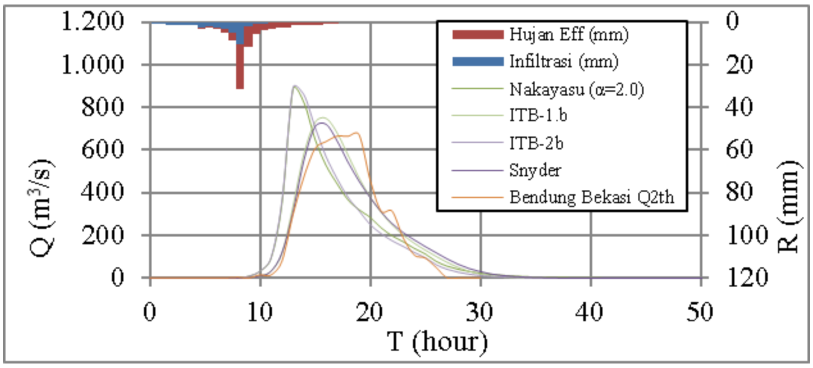

Figure 6. Comparasion between of runoff and rainfall discharge hydrographs

Table 1. The results of the hydrograph volume of runoff and rainfall discharge calculations

Description	Nakayasu (α=2.0)	SCS-Snyder	ITB-1B	ITB-2B
Vol. Rainfall Hydrograph	21,529,627.82	21,673,911.01	21,661,064.21	21,300,652.65
Vol. Runoff Hydrograph	20,303,053.64	20,303,053.64	20,303,053.64	20,303,053.64
difference	**1,226,574.18**	**1,370,857.37**	**1,358,010.57**	**997,599.01**
Ratio	**1.06**	**1.07**	**1.07**	**1.05**
% conformity	**94.30%**	**93.68%**	**93.73%**	**95.32%**

From the table above, it can be seen that there is a match between the volume of SUH effective rainfall in the watershed and the hydrograph volume of the runoff discharge unit ranging from 93.68 to 95.32% with the rainfall volume closest to the HSS ITB-2B.

3.2. Hydraulic Analysis
Several models were developed in this investigation utilizing HEC-RAS with 1D steady flow and quasi-unsteady flow approaches. The following explanation will analyze each of these strategies.

3.1.3. Design Flood Discharge Data Validation Using HEC-RAS 1D Steady Flow Modeling. The water level was determined in this analysis by modeling with HEC-RAS and the steady flow approach in order to confirm the planned flood discharge data on the water level recorded at the AWLR in the Upper Bekasi River (Villa Nusa Indah) and the Bekasi Weir. The method for validating in order to approach the results of the water level prediction AWLR in the modeling is to substitute the n-manning value for the cross-sectional flow discharge capacity function. The following figure illustrates the results of the HEC-RAS modeling used to validate each observation discharge.

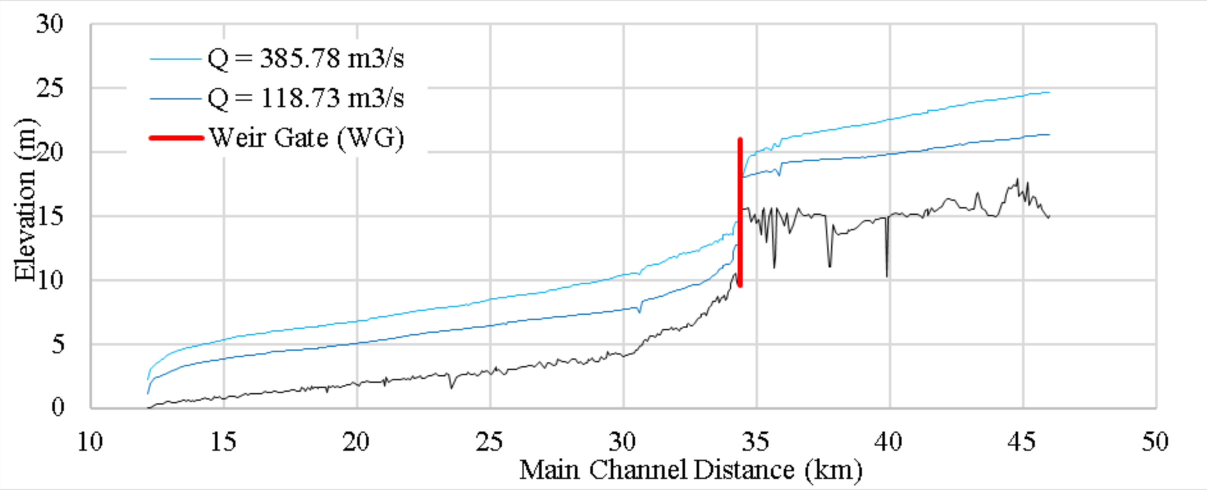

Figure 7. Model validation with observation discharge data

As shown in the table above, the modeling findings for the upstream Bekasi River are 24.66 m for Q=385.78 m^3/s and 21.36 m for Q=118.73 m^3/s. These results are consistent with the elevation profile measured at the AWLR upstream of the Bekasi River at the Villa Nusa Indah elevation AWLR of 24.2 m for Q=385.78 m^3/s and 21.4 m for Q=118.73 m^3/s, and at the Bekasi Weir elevation AWLR of 17 m for Q=385.78 m^3/s and 17.9 m for Q=118.73 m^3/s, with (can be seen in the following figure).

Table 2. The Bekasi River's water level and observation discharge were utilized to validate the data

Station / Time	Cileungsi (m)	Cikeas-Nagrak (m)	Villa Nusa Indah (m)	Bekasi Weir	
				Elevation (m)	Discharge (m^3/s)
20:00	6	1.18	19.6	18.5	38.603
21:00	5.1	1.18	21.4	18.3	35.922
22:00	1.5	1.26	24.2	17.9	118.728
23:00	1.4	2	25.2	17	385.777
00:00	1.3	2.6	25.4	17.3	584.27
01:00	1.15	3.04	25.5	17.5	723.706

3.1.4. Analysis of Sediment Data. The following results are obtained from sediment data collected at the three discharge conditions mentioned previously and data processing at the Bekasi Irrigation Engineering Unit Laboratory.

Table 3. Suspended load data at each observation point

Obervation Point	Segment	Suspended Load (Qs) (tonnes/day)			Discharge (Q) (m^3/s)		
		Test-1 (28-03-21)	Test-2 (29-08-21)	Test-3 (04-09-21)	Test-1 (28-03-21)	Test-2 (29-08-21)	Test-3 (04-09-21)
Point A (Upstream)	A1	0.147	0.026	0.040	12.43	1.39	2.05
	A2	0.127	0.060	0.088	12.20	3.04	4.46
	A3	0.383	0.064	0.076	15.86	3.66	4.38
Cumulative		**0.657**	**0.150**	**0.204**	**40.49**	**8.09**	**10.89**
Point B (Middle)	B1	0.054	NA	NA	6.82	NA	NA
	B2	0.138	NA	NA	14.21	NA	NA
	B3	0.093	NA	NA	14.84	NA	NA
Cumulative		**0.286**	**-**	**-**	**35.87**	**-**	**-**
Point C (Downstream)	C1	0.104	NA	NA	8.57	NA	NA
	C2	0.114	NA	NA	10.01	NA	NA
	C3	0.096	NA	NA	6.46	NA	NA
Cumulative		**0.314**	**-**	**-**	**25.04**	**-**	**-**

Note: NA is no data sampling

Due to research constraints, the periodic collection of suspended load of sediment data from the Bekasi River is limited to the river's upper reaches. As can be seen from the table above, the middle and lower reaches of the Bekasi River do not have periodic observations.

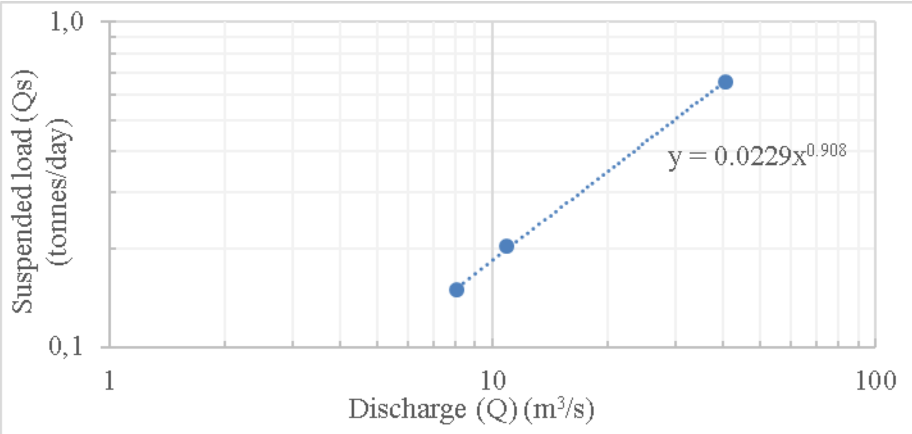

Figure 9. Rating curve of sediment in upstream Bekasi River

As shown in the graph above, the sediment rating curve for the Bekasi River in the upper reaches of the power regression line equation is:

$Qs = 0.0229 * Q^{0.908}$ (1)

with:

Qs = suspended load (ton/day)
Q = discharge (m^3/s)
a = 0.0229
b = 0.908

The rating curve equation's results can be used to forecast the sediment load in the Bekasi river for a given discharge, allowing for the utilization of material accumulated over time in river maintenance.

3.1.5. HEC-RAS 1D Quasi-Unsteady Flow Modeling. The purpose of this analysis is to determine the profile of changes in river morphology caused by river sediment transport along the Bekasi River from upstream to downstream using the Bekasi Weir gates as a basis for regulating sediment transport from upstream to the lower reaches of the Bekasi River. The modeling scenario is run utilizing both the dominant and design flood discharges. According to the results of modeling with HEC-RAS and a quasi-unsteady flow approach, numerous analyses in a single river system include the following.

a. In the Q2 simulation, the most significant degradation occurred along the river, precisely when the top gate was opened as high as 4 m, resulting in an average degradation of the riverbed as deep as 0.361 m carrying a sediment mass of 694.69 kilotons, while riverbed degradation decreased with a gate opening of 5 m. Meanwhile, the most significant degradation occurred when the bottom gate was opened to a height of 3 m, resulting in an average degradation of the riverbed of 0.359 m carrying a sediment mass of 690.57 kilotons, while the riverbed degradation decreased when the bottom gate was opened to a height of 3 to 5 m.
b. In the Q25 simulation, the highest degradation occurred upstream of the weir, namely when the top gate was opened to a height of 5 meters, resulting in an average degradation of the riverbed of 0.047 meters carrying a sediment mass of 13.06 kilotons. Meanwhile, the highest deterioration occurred when the bottom gate was opened to a height of 2 m, with an average degradation of the riverbed of 0.051 m carrying a sediment mass of 13.71 kilotons, and for gate openings of 3 to 5 m, there was no noticeable decrease in riverbed degradation. consistent/significant.

Table 4. Cumulative mass change results for Q2

Criteria	Unit	0 m	1 m	2 m	3 m	4 m	5 m
Upper Gate Opening							
D. WG	Kilo Tonnes	-416.56	-412.23	-394.75	-405.05	-409.19	-406.85
U. WG	Kilo Tonnes	-275.82	-281.97	-295.80	-288.22	-285.50	-284.23
Total	Kilo Tonnes	-692.38	-694.21	-690.55	-693.27	-694.69	-691.08
Lower Gate Opening							
D. WG	Kilo Tonnes	-362.71	-405.50	-405.22	-406.52	-405.93	-405.14
U. WG	Kilo Tonnes	-214.63	-284.05	-284.13	-284.05	-284.13	-284.13
Total	Kilo Tonnes	-577.34	-689.55	-689.35	-690.57	-690.07	-689.27

Note: (-) is cumulative mass change of degradation

Table 5. Cumulative mass change results for Q25

Criteria	Unit	0 m	1 m	2 m	3 m	4 m	5 m
Upper Gate Opening							
D. WG	Kilo Tonnes	-21.92	-21.24	-20.01	-17.29	-15.98	-15.50
U. WG	Kilo Tonnes	-3.81	-4.84	-6.87	-10.10	-11.60	-13.06
Total	Kilo Tonnes	-25.73	-26.08	-26.88	-27.38	-27.58	-28.56
Lower Gate Opening							
D. WG	Kilo Tonnes	-21.97	-16.35	-15.16	-15.03	-15.01	-15.19
U. WG	Kilo Tonnes	-3.64	-12.81	-13.71	-13.71	-13.71	-13.71
Total	Kilo Tonnes	-25.61	-29.16	-28.87	-28.74	-28.72	-28.90

Note: (-) is cumulative mass change of degradation

1. In the Q2 simulation, the type of sediment transport changed from degradation to aggradation at a distance of 30 kilometers downstream of the Bekasi River as the slope changed from steep (S = 0.00151) to sloping (S = 0.00023). The decrease in sediment size diameter (d50) also correlates with the change in slope, which was originally derived from downstream sample at km 30. (point

B, see sediment size gradation graph above) When it reached the end of the downstream Bekasi River, its d50 of 0.08 mm changed to 0.055 mm, indicating that the balance represented by the Lane's Diagram remained valid on the Bekasi River, despite the influence of the Bekasi Weir opening gate.

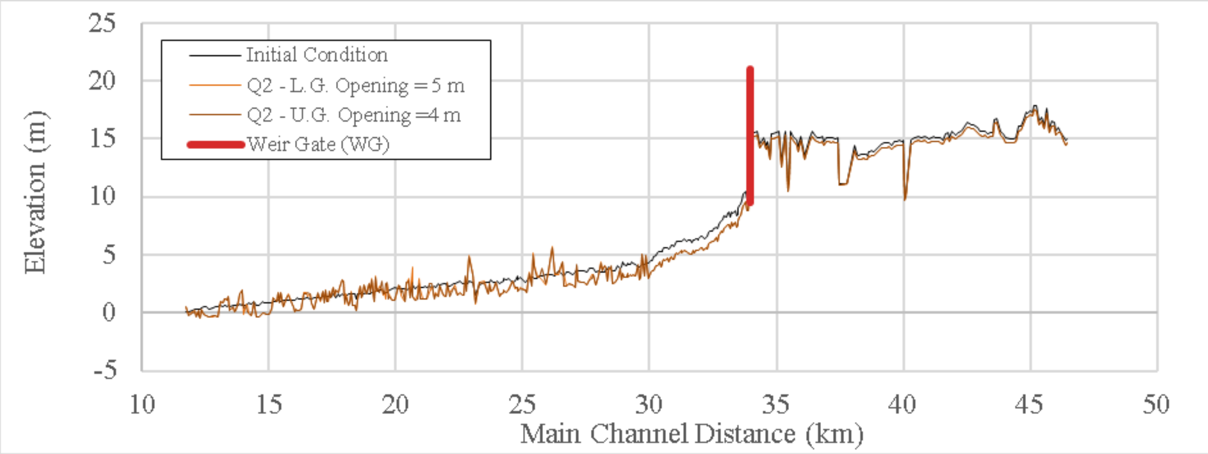

Figure 10. Elevation Aggradation and Degradation Simulation Results for Q2

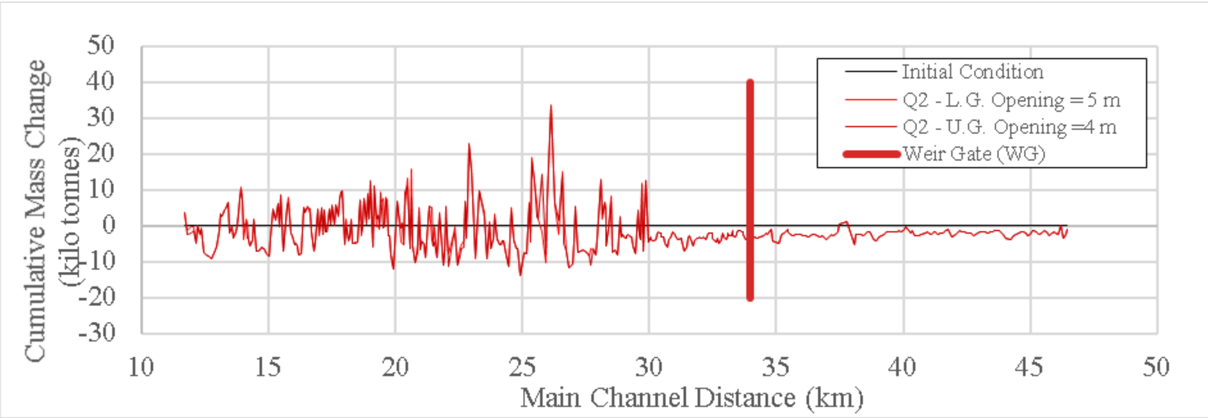

Figure 11. Cumulative mass change results along the river for Q2

2. In the Q25 simulation, the type of sediment transport changed from degradation to aggradation following the opening of the Bekasi weir due to the slope changing from steep (S = 0.00005) to steep (S = 0.00151). The change in sediment size diameter (d50) does not match to the change in slope, which was originally derived from downstream sampling at km 30. (point B, see sediment size gradation graph above) Because the balance represented by the Lane's Diagram is meaningless on the Bekasi River due to the presence of a temporary flood discharge, d50 was 0.055 mm.

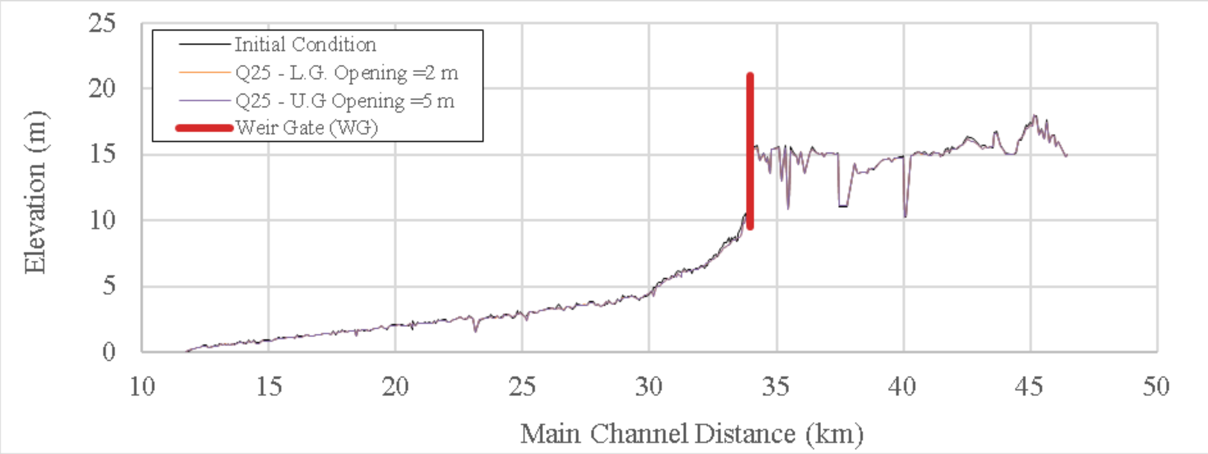

Figure 12. Elevation Aggradation and Degradation Simulation Results for Q25

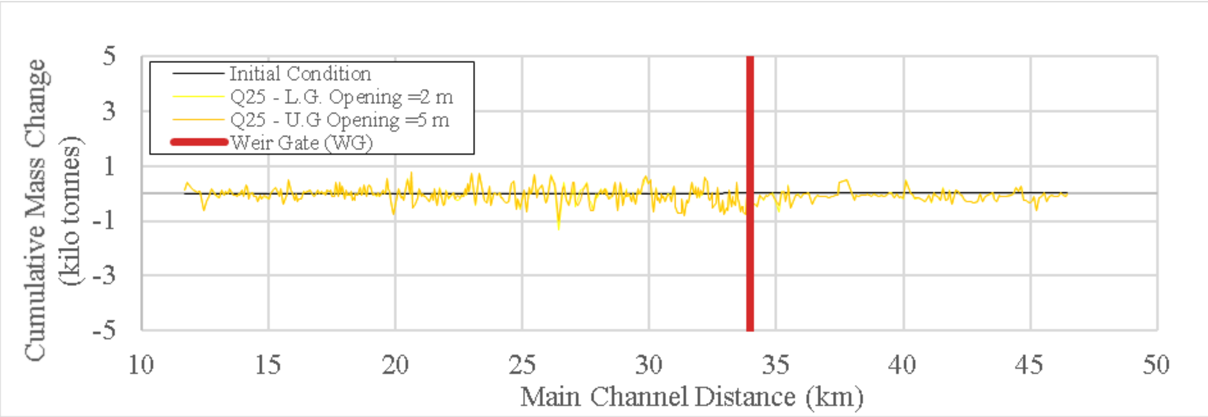

Figure 13. Cumulative mass change results along the river for Q25

3. There are disparities in sedimentation aggradation and degradation downstream of the weir (km-33) to km-30 in the Q2 and Q25 models. Whereas Q2 is degraded at this distance, Q25 is aggrading. In actual situations, adding sediment from Q25 can improve the supply of material at that distance, hence reducing degradation.

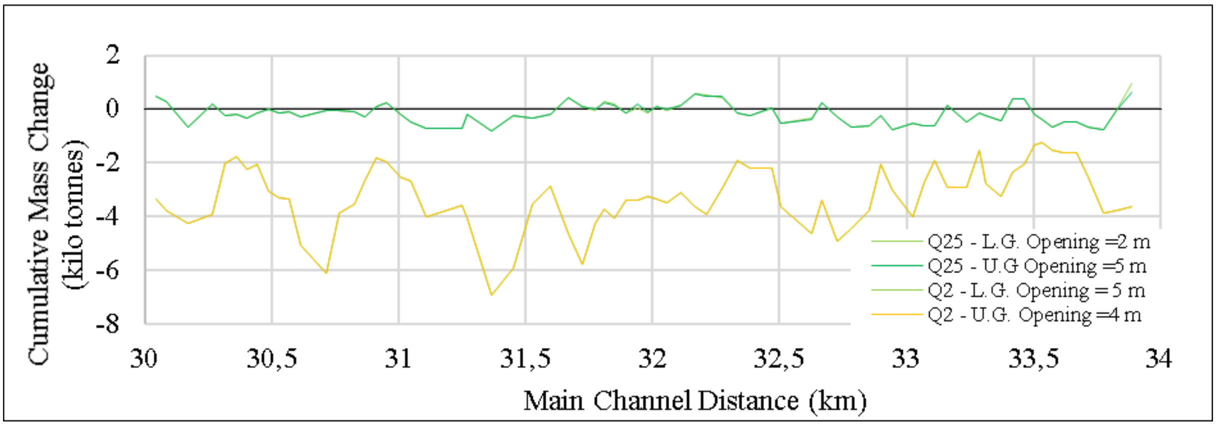

Figure 14. Cumulative mass change at km-30 to km-33

The analysis produces the result of simulating a single gate opening, not a combination of both because the HEC-RAS program is incapable of modeling a combination gate for quasi-unsteady flow modeling.

4. Conclusion

Several significant conclusions can be drawn from the results of the research of changes in river morphology in the Bekasi River, including the following:

a. Morphological changes in the Bekasi River are significantly influenced by the Bekasi Weir's gate operation, particularly the efficacy of the river's most prominent gate opening, namely the upper gate opening. The bottom gate opening enables it to function effectively, but opening the enormous gate does not increase sediment transport. This is because the flow rate decreases as the bottom gate are opened, and for weir operation and maintaining the weir's function as a barrier to water that is a runoff to drain the irrigation area, opening the bottom gate maintains the river balance.
b. Flush sediment from the upstream section of the Bekasi Weir during a flood can be accomplished by opening the lower gate following the Bekasi Weir's Standard Operation Procedure, which states that when a flood discharge occurs, the lower gate must be opened to dispose of the maximum discharge downstream weir.
c. Lane's diagrams work well for changing river morphology over a long period but fail to work correctly when a large discharge flows through a river in a short period, resulting in faster sediment transport.
d. In river maintenance, by recording actual daily discharge, it is possible to predict the amount of sediment transported by using a sediment rating curve formed upstream of the Bekasi River as a reference.

References

[1] Purbaningsih, E I, *et al* 2006 kajian sistem mitigasi bencana banjir kali bekasi (study of the flood disaster mitigation system of the Bekasi River) (Yogyakarta: Sekolah Pascasarjana UGM) p 1

[2] Yusuf S M, *et al* 2021 *Surface runoff of Bekasi River subwatershed* (IOP Conf. Ser.: Earth Environ. Sci.) p 7

[3] Kadri T 2019 *analysis of bekasi watershed erosion and sedimentation problem* (IOP Conf. Ser.: Mater. Sci. Eng.) **620** pp 1-9

[4] Cahyono, *et al* 2020 *kajian pengelolaan banjir dki dan sekitarnya bagi pembangunan infrastruktur berkelanjutan (study of flood management in dki and its surroundings for sustainable infrastructure development)* Indonesia pp 5–23

[5] Nugraha M R R, *et al* 2020 *Waduk di Sungai Citeureup dan Pilot Channel di Hilir Siphon Kalimalang untuk Pengendalian Banjir di Wilayah Bekasi (Reservoir on the Citeureup River and Pilot Channel in Downstream Siphon Kalimalang for Flood Control in the Bekasi Region)* (Indonesia: Proc. Pertemuan Ilmiah Tahunan HATHI XXXVII Vol I) p 199

[6] Sriyono E, *et al* 2020 *Control of Upstream Bekasi River Floods by Building a Dry Dam Series in Cikeas River and Cileungsi River, West Java* (International Seminar of Science and Applied Technology (ISSAT 2020) vol 198) p 6

[7] Damayanti A and Dwiputra N A 2018 *Flood Exposure of Settlement Areas in Bekasi City* (Int. Conf. on SMART CITY Innovation) p 5

[8] Prasetyo, *et al* 2019 *kerentanan das kali bekasi ditinjau dari aspek sosial-ekonomi-kelembagaan (the vulnerability of the Bekasi River Basin in terms of socio-economic-institutional aspects)* (Bogor:Journal of Environmental Sustainability Management) p 576

[9] Nandiasa J E, *et al* 2021 *Analysis of Bekasi River to Flood in Pondok Gede Permai Housing* (Proceeding of World Conference vol 3) p 216

[10] BSN – National Standardization Agency of Indonesia 2015 SNI 1724:2015 *Analisis Hidrologi,*

Hidraulik, dan Kriteria Desain Bangunan di Sungai (Analysis of Hydrology, Hydraulics, and Building Design Criteria on the River) (Indonesia:BSN) p 9

[11] Nguyen V T, *et al* 2014 *Numerical Simulation of Sediment Transport and Bedmorphology around Gangjeong Weir on Nakdong River* (Korea: Springer - KSCE Journal of Civil Engineering) pp 1-7

[12] Esmaeili T, *et al* 2017 *Three-Dimensional Numerical Study of Free-Flow Sediment Flushing to Increase the Flushing Efficiency: A Case-Study Reservoir in Japan* (The Netherlands:Water vol 9) p 19

[13] Theol S A, *et al* 2019 *The Role Of Gate Operation In Reducing Problems With Cohesive And Non-Cohesive Sediments In Irrigation Canals* (The Netherlands:Water vol 11) p 20

[14] Jafari F, *et al* 2019 *investigating the role of gate operation in real-time flood control of urban drainage systems* (Singapore: Springer Nature Singapore vol 741) p 10

[15] BSN – National Standardization Agency of Indonesia 2008 SNI 3414:2008 *Tata Cara Pengambilan Contoh Muatan Sedimen Melayang di Sungai dengan Cara Integrasi Kedalaman Berdasarkan Pembagian Debit (Procedure for Sampling of Suspended Sediment Loads in the River by Depth Integration Based on Discharge Distribution)* (Indonesia:BSN) pp 4–8

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