Analysis of The Effect Of Sediment Transport on River Bed Changes of Cengkareng Floodway

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Abstract. The city of Jakarta, especially in the northern part, is located in a low-lying area and densely populated. This area is prone to flooding, either from rivers or the sea, which is commonly known as a tidal flood. In Jakarta, various flood control structures have been constructed, one of which being the Cengkareng Floodway. Cengkareng Floodway is a 7.8-kilometer-long artificial river/canal located in the administrative areas of West Jakarta and North Jakarta. It was created in 1983. The upstream is located at the confluence of Angke River and Pasanggrahan River and the estuary is located at Jakarta Bay. It is part of the flood control system for the western region of DKI Jakarta Province. Sedimentation is one of the causes of river capacity reduction, which can affect its performance as flood control. This study was conducted to analyze the sedimentation rate in Cengkareng Floodway and its effect on river bed changes. In this study, primary data collection was done by collecting bed material and suspended load samples and measuring the discharge along the Cengkareng Floodway and its tributaries (Angke River, Pesanggrahan River, and Mookervart River). The results of the bed material test show that the type of sediment is dominated by cohesive material with a percentage of 58 – 98%. The sediment transport simulation has been done using a Quasi-Unsteady Flow model on the HEC-RAS 1D with upstream boundary condition of 2 (two) scenarios in the form of daily discharge and flow duration curve, where the downstream boundary condition is tides for 5 years (2016 – 2020). The results of the sediment transport analysis show that the daily discharge scenario is closest to the measurement results, where there is sedimentation along the Cengkareng Drain with an average river bed change of 1.04 m from the simulation results, while the average channel river bed change from the measurement result is 1.08 m.

1. Introduction

The city of Jakarta, especially in the northern part, is located in the lowlands and densely populated, is an area that is prone to flooding, either from rivers or from the sea, which is commonly known as tidal flooding. Flooding can be caused by several factors, one of which is sediment deposition. The problems associated with sediment deposition are varied. Sediments deposited in stream channels reduce flood-carrying capacity, resulting in more frequent overflows and greater floodwater damage to adjacent properties [1].

Cengkareng floodway is an artificial river/canal located in the administrative area of West Jakarta and North Jakarta which was built in 1983 along a length of 7.8 km as a part of the flood control system for the western region of DKI Jakarta Province. As a flood controller, the capacity of the Cengkareng floodway is very important to maintain so that it can continue to function optimally. However, in the field, there is sedimentation in the Cengkareng floodway which results in a reduction in the capacity of the canal. Thus, from 2013 to 2015, the Cengkareng floodway became one of the work locations for the Jakarta Urban Flood Mitigation Package 2A, where one of the scopes of work was dredging from upstream to the estuary to increase the capacity of the Cengkareng floodway as a flood control channel. This study aims to analyze the rate of sediment transport that occurs in the Cengkareng floodway and its impact on changes in the riverbed.

2. Study Area

Cengkareng floodway is an artificial river/canal located in the administrative area of West Jakarta and North Jakarta which was built in 1983 along 7.8 km with an average river width of 40-80 m and a very gentle slope of the riverbed, which is average riverbed slope of 0.00045 – 0.0005. Cengkareng floodway upstream is located at the confluence of the Angke River and River Pasanggrahan, and empties into Jakarta Bay, as part of the flood control system in the western region of DKI Jakarta Province. Cengkareng floodway drains water from rivers in the Angke Watershed to Jakarta Bay with a total catchment area of 462.67 km^2. Three main rivers rises to the Cengkareng floodway namely Angke River, Pasanggrahan River, and Mookervart River.

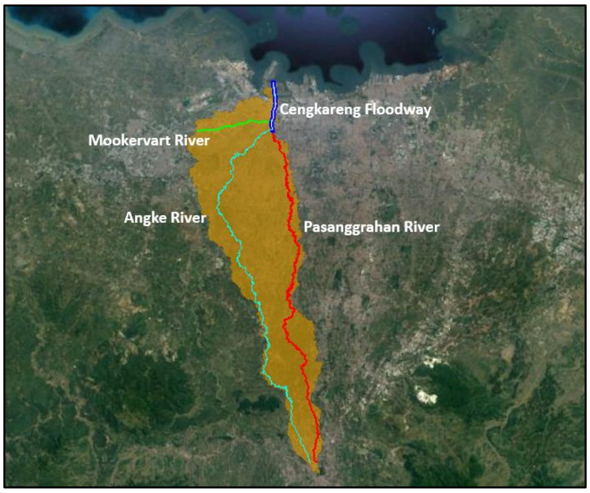


Figure 1. Angke Watershed

3. Data and Methodology

In this study, the method used to obtain riverbed changes is to simulate a numerical model of sediment transport using the one-dimensional HEC-RAS 6.1 software using hydrodynamic approach *Quasi-Unsteady Flow*. To obtain the required input in the simulation, it is necessary to analyze some data, both secondary data and primary data.

Secondary data used in the analysis included river geometry data, Digital Elevation Model (DEM) maps obtained from the Geospatial Information Agency (BIG), land use maps obtained from the Ministry of Environment and Forestry, soil type maps based on *Harmonized World Soil Database* (HWSD) obtained from the *Food and Agriculture Organization of the United Nation* (FAO), daily discharge data at the Rawa Buaya Water Level Station (2007-2020) and Kebon Jeruk Air Water Level Station (2001-2020), rainfall data in 3 (three) Rain Stations, namely Bedahan Sawangan Station (2009-2020), South Tangerang Station (2001-2020), and Cengkareng floodway Station (2003-2020), as well as tidal data obtained from previous studies. The general methodology of this study can be seen in the figure below.

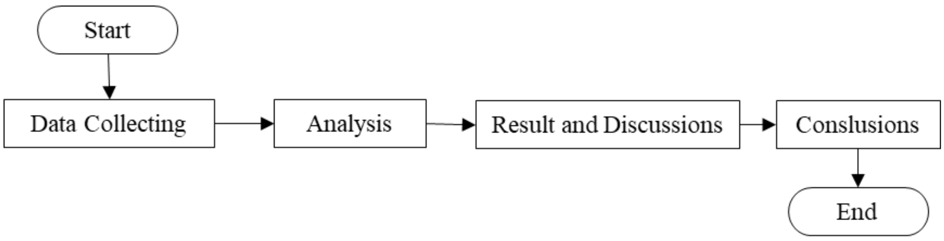
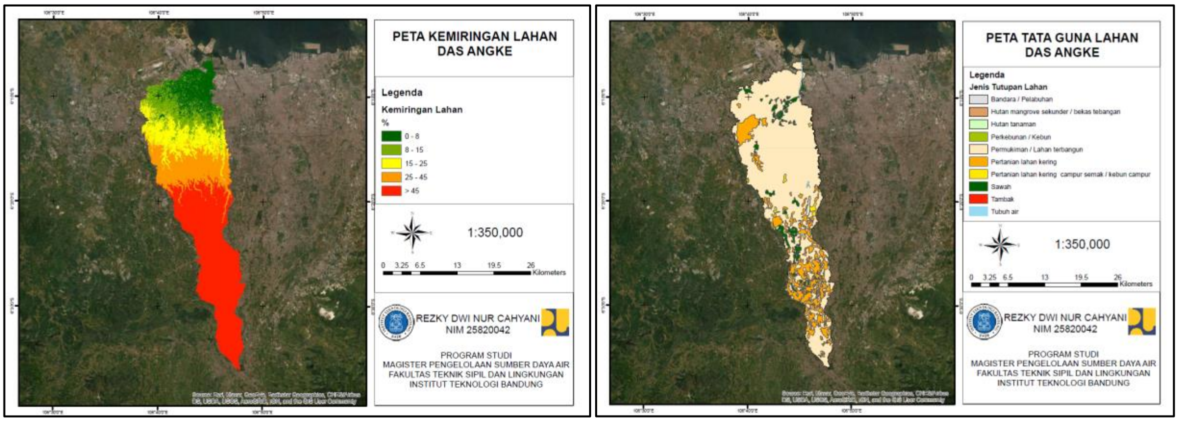


Figure 2. Flowchart of Methodology

In carrying out the analysis of the calculation of the rate of sediment transport, several data are needed, including land slope, land use maps, and maps of soil types that are processed using software based on Geographic Information Systems. These maps can be seen in the figure below:



(a) (b)

Figure 3. (a) Land Slope Map (b) Land Use Map

Based on the land slope map that has been analyzed, it can be seen that the upstream area of the Angke watershed has a fairly steep slope of more than 45%, the middle part ranges from 15-45%, and it is relatively flat in the downstream part of the watershed with a slope of around 0-8%. Based on the land cover map that has been processed using geographic information system software, it is found that the land cover in the Angke watershed is dominated by residential/built-up land with a percentage of 77.68%.

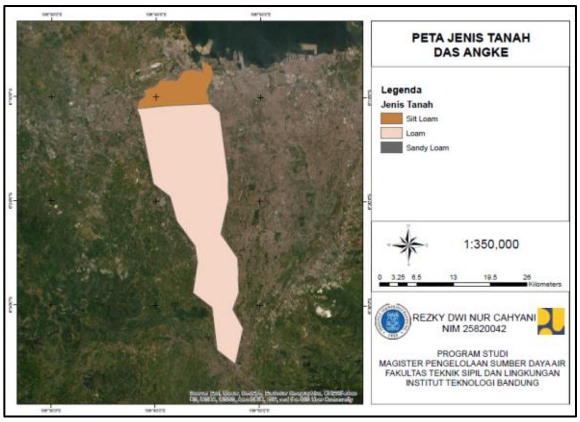


Figure 4. HWSD Soil Texture Map

Based on the soil type map based on HWSD that has been processed using geographic information system software, it is found that the soil types in the Angke watershed consist of Loam which dominates most of the watershed, Silt Loam in the downstream area, and Sandy Loam in the upstream area.

Meanwhile, the primary data obtained directly in the field are gradation data of river bed material, floating sediment concentration data, and discharge data as many as 3 (three) locations spread over the upstream, middle, and downstream Cengkareng floodway, as well as 1 (one) each -respectively on the Angke River, Pasanggrahan River, and Mookervart River.

Figure 5. Sampling Survey Location

4. Result and Discussions

4.1 Bed Material

One of the inputs needed in the sediment transport simulation is the grain gradation of the bed sediment material. The riverbed sediment data was obtained from the results of the grain gradation analysis in the laboratory on samples taken in the field. A summary of the basic sediment characteristics at the study site can be seen in the following table.

Table 1. Bed Material Data

Sample	Location	D50 (mm)	Sand (%)	Silt (%)	Clay (%)
01	Cengkareng floodway – Upstream	0.045	8	77	15
02	Cengkareng floodway – Middle	0.05	28	63	9
03	Cengkareng floodway - Upstram	0.035	13	72	15
04	Mookervart	0.062	42	49	9
05	Angke	0.045	28	63	9
06	Pasanggrahan	0.015	2	75	23

Based on the data in the table above, it can be concluded that the type of bed material at the location of the study is dominated by cohesive sediments [2], namely Silt and Clay with a total percentage of 58 – 98%, while the percentage of non-cohesive sediments, namely Sand, is 2 – 42%.

4.2 Sediment Concentration and Measure Discharge

Sediment concentration was obtained from *Total Suspended Solid* (TSS) testing in the laboratory on suspended sediment samples that had been taken in the field along with 3 (three) instantaneous discharge measurements in September 2021, October 2021 and January 2022. Due to the limitations of the measurement data, to obtain curved curve sediment to discharge, sediment transport analysis was carried out by multiplying the factor *Sediment Delivery Ratio* obtained from the Ministry of Environment and

Forestry and monthly average land erosion rate obtained using the method *Universal Soil Loss Equation* (USLE) by Wischemeier & Smith (1978) [3] based on the following equation:

$$A = R \times K \times Ls \times CP \qquad (1)$$

Where :

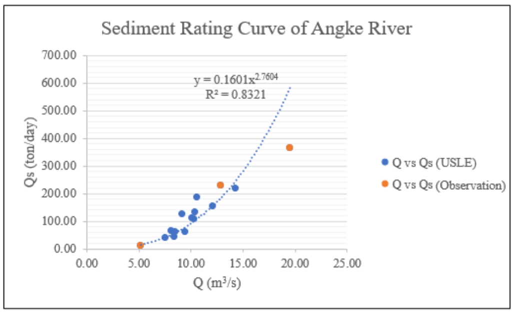
A : Total soil loss (tonnes/ha/year)
R : Erosivity of average annual rainfall
K : Soil erodibility index
LS : Index of slope length and slope
C : Land use index
P : Soil conservation effort index

Table 2. Relation of Catchment Area and Sediment Delivery Ratio

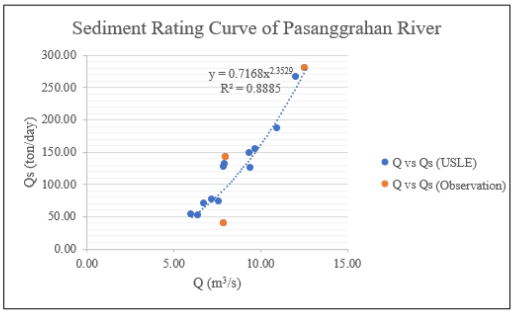
Number	Watershed Area (ha)	Sediment Delivery Ratio (%)
1	10	53
2	50	39
3	100	35
4	500	27
5	1,000	24
6	5,000	15
7	10,000	13
8	20,000	11
9	50,000	0.85
10	2,600,000	0.49

(Reference : SK No. 346/Menhut-V/2005 (Watershed Priority Sequencing Criteria)

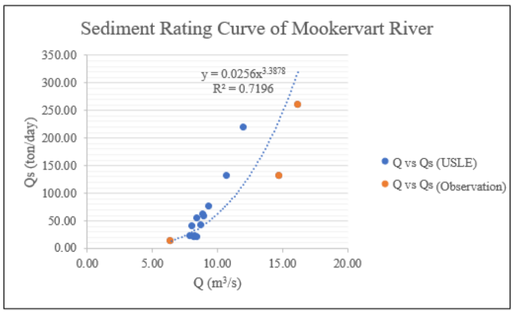
Based on the results of the transportation analysis carried out using the USLE x SDR method and the results of measurements in the field, the sediment rating curve for the discharge on the Angke River, Pasanggrahan River, and Mookervart River is obtained as shown in the figure below.



(a)



(b)



(c)

Figure 6. (a) Sediment Rating Curve of Angke River (b) Sediment Rating Curve of Pasanggrahan (c) River Sediment Rating Curve of Mookervart River

4.3 Simulation Transport Sediment

Sediment transport simulations were carried out using HEC-RAS 6.1 software to obtain the pattern of river bed changes. The data used as the basis for the simulation calibration of riverbed changes are the 2015 Cengkareng floodway geometry data along the 7 km obtained As-Built Drawing of the Jakarta Urban Flood Mitigation Work Package 2A [4] and the 2020 Cengkareng floodway geometry data along the 0.950 km downstream which were obtained from the work preparation of the Detail Designed for the Integrated Coastal Development of the State Capital Phase 2 by Ministry of Public Works and Housing and direct measurements in the field at 3 (three) cross-section points in the upstream, middle and downstream areas.

In general, the sediment transport simulation scheme is as follows.

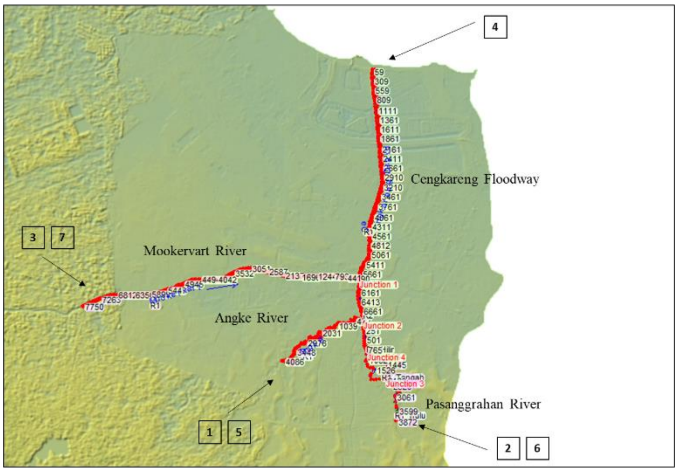


Figure 7. Transport Sediment Simulation Boundary Conditions

Table 3. Descriptions of Boundary Conditions

Data	Boundary	Description
Quasi Unsteady Data	1	Flow Series of Angke River
	2	Flow Series of Pasanggrahan River
	3	Flow Series of Mookervart River
	4	Stage Series
Sediment Data	5	Rating Curve of Angke River
	6	Rating Curve of Pasanggrahan River
	7	Rating Curve of Mookervart River

To achieve simulation results that are by the conditions in the field, 2 (two) scenarios were carried out as follows: 1. Simulation using upstream boundary conditions in the form of daily discharge inflow series and rating curve on sediment data, and downstream boundary conditions in the form of daily tidal water level at stage series. 2. Simulation using upstream boundary conditions in the form of Flow Duration Curve inflow series and rating curve on sediment data, and downstream boundary conditions in the form of daily tidal water level in stage series.

Because the type of riverbed sediment materials at the study site is mostly cohesive sediment, the sediment transport simulation in HEC-RAS 6.1 uses the cohesive method with the Krone and Partheniades equations[5]. The value of the cohesive parameter can be specifically determined based on the material bed data used in the simulation. Equation Krone to analyze the rate of sedimentation and Parthiniades Equations to analyze the level of erosion taking into account the four parameters [6] : Particle Shear Threshold(τ c) in units of N / m^{2,} Particle Erosion Rate (Kd) in units of N / m^2/ hr, Mass Erosion Rate Threshold(τ M_W) in N/m^2, and Mass Erosion Rate (KdM_W) in N/m^2.

Krone Equation :

$$\left(\frac{dC}{dt}\right) = -\left(1 - \frac{\tau b}{\tau c}\right)\frac{Vc\ C}{y} \tag{2}$$

Where :
C : sediment concentration
t : time
τ_c : bed shear stress
τ_b : critical shear stress for deposition

Partheniades Equation :

$$\left(\frac{dm}{dt}\right) = M\left(\frac{\tau b}{\tau c} - 1\right) \tag{3}$$

Where :
M : mass of material in the water column
T : time
M : empirical erosion rate for particle scour

4.4 Simulation 1

In simulation 1, as a condition for the upstream flow series limit, daily discharge data is used for rivers that enter the Cengkareng floodway, namely the Angke River, Pasanggrahan River, and Mookervart River for 5 years (2016 - 2020), the conditions for the upstream sediment data limit are rating curve, the condition for the downstream stage series 2016-2020. The following is the daily debit data input used in simulation 1.

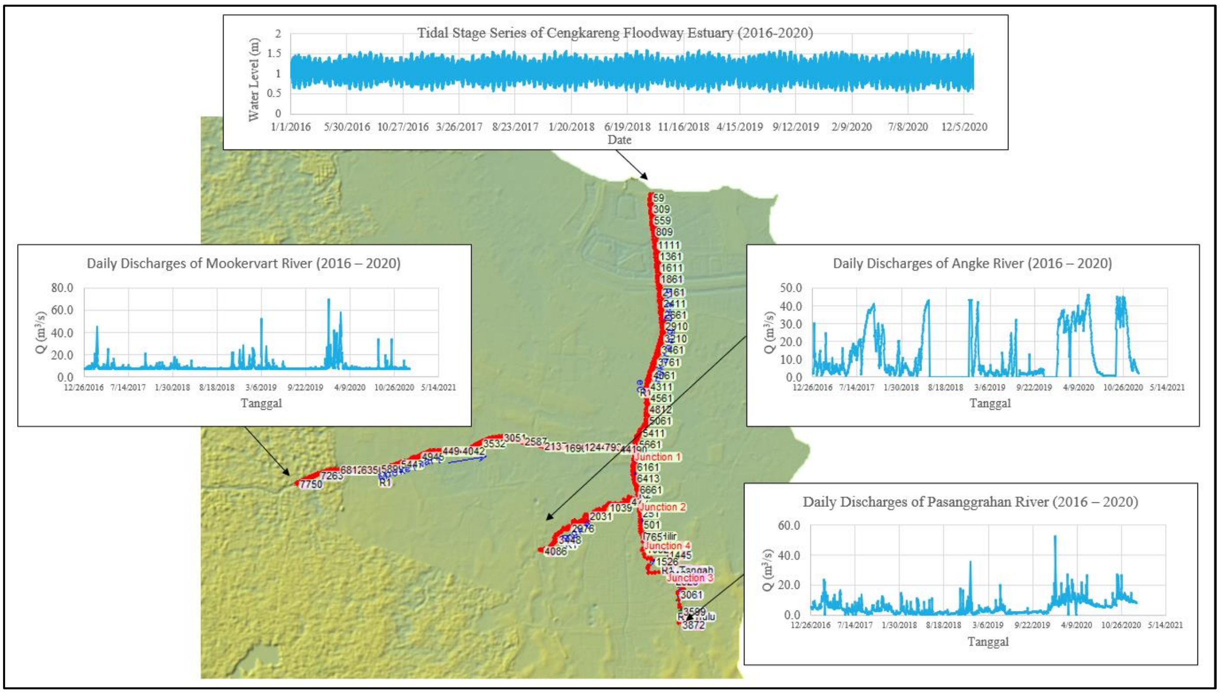


Figure 8. Flow Series Boundary Condition on Simulation 1

Due to the lack of cohesive parameter data, sediment transport simulation is carried out by adjusting the cohesive parameter namely Particle Shear Threshold (τc) in N/m2 units, Particle Erosion Rate (Kd) in N/m2/hr units, Mass Erosion Rate Threshold (τ_{MW}) in units of N/m2, and Mass Erosion Rate (Kd_{MW}) until the change in the channel riverbed is closest to the riverbed elevation of the Cengkareng Floodway in 2020. The cohesive parameters obtained can be seen in the following figure.

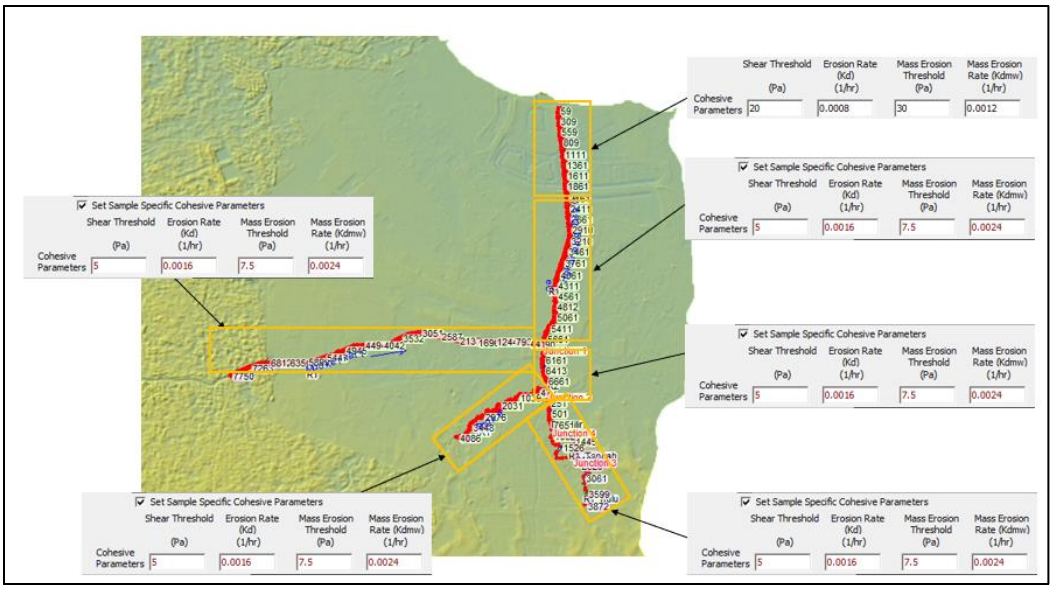


Figure 9. Cohesive Parameters

Based on the picture above, it can be obtained the value of the cohesive parameters in the downstream part of Cengkareng Floodway are Particle Shear Threshold (τc) 20 N/m^2, Particle Erosion Rate (Kd) 0.0008 N/m^2/hr, Mass Erosion Rate Threshold (τ_{MW}) 30 N/m^2, and Mass Erosion Rate (Kd_{MW}) 0.0012 N/m^2/hr. Whereas, the cohesive parameters in the middle and upstream of Cengkareng Floodway, Angke River, Pasanggrahan River, and Mookervart River are Particle Shear Threshold (τc) 5 N/m2, Particle Erosion Rate (Kd) 0.0016 N/m2/hr, Mass Erosion Rate Threshold (τ_{MW}) 7.5 N/m2, and Mass Erosion Rate (Kd_{MW}) 0.0024 N/m2/hr. Using these parameters, a sediment transport simulation was carried out for five years (2016 – 2020), to obtain a change in the riverbed of the Cengkareng Floodway from downstream (Station 0) to upstream (Station 6911) as shown in the figure below.

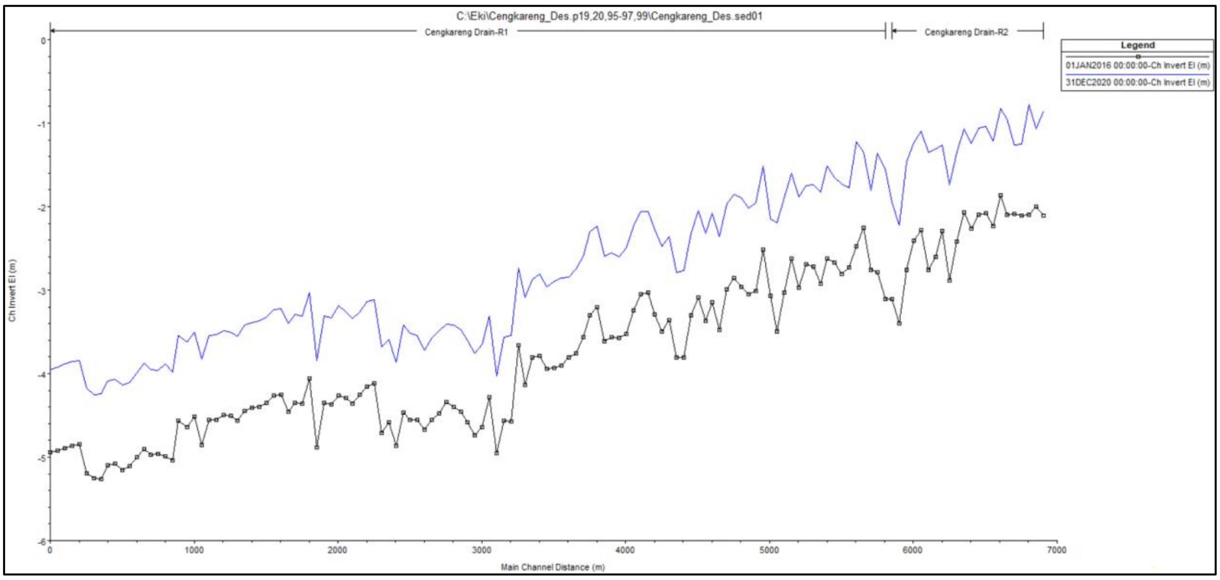


Figure 10. River Bed Change of Cengkareng Floodway based on Simulation 1 Result

From the results of the sediment transport simulation carried out, the average river bed change of the Cengkareng Floodway is 1.04 m, where the maximum bed change of 1.55 m occurs at Station 5812, while the minimum channel bed change is 0.82 m at Station 6711.

4.5 Simulation 2

In simulation 2, as a condition for the upstream flow series, debit duration curve data is used for rivers that enter the Cengkareng floodway, namely the Angke River, Pasanggrahan River, and Mookervart River for 5 years (2016 - 2020), the conditions for the upstream sediment data limit is the rating curve, the condition for the downstream stage series limit is used daily tidal water level at stage series in 2016-2020. The geometry data and cohesive parameters used are the same as the simulation 1.

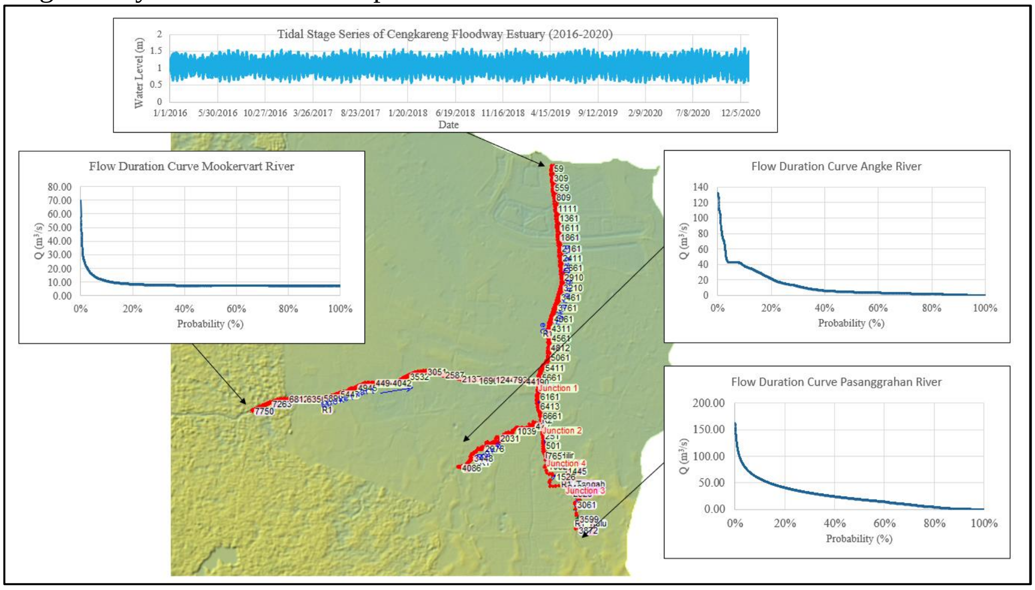


Figure 11. Flow Series Boundary Condition on Simulation 2

The riverbed changes of the Cengkareng Floodway from downstream (Station 0) to upstream (Station 6911) from simulation 2 as shown in the figure below.

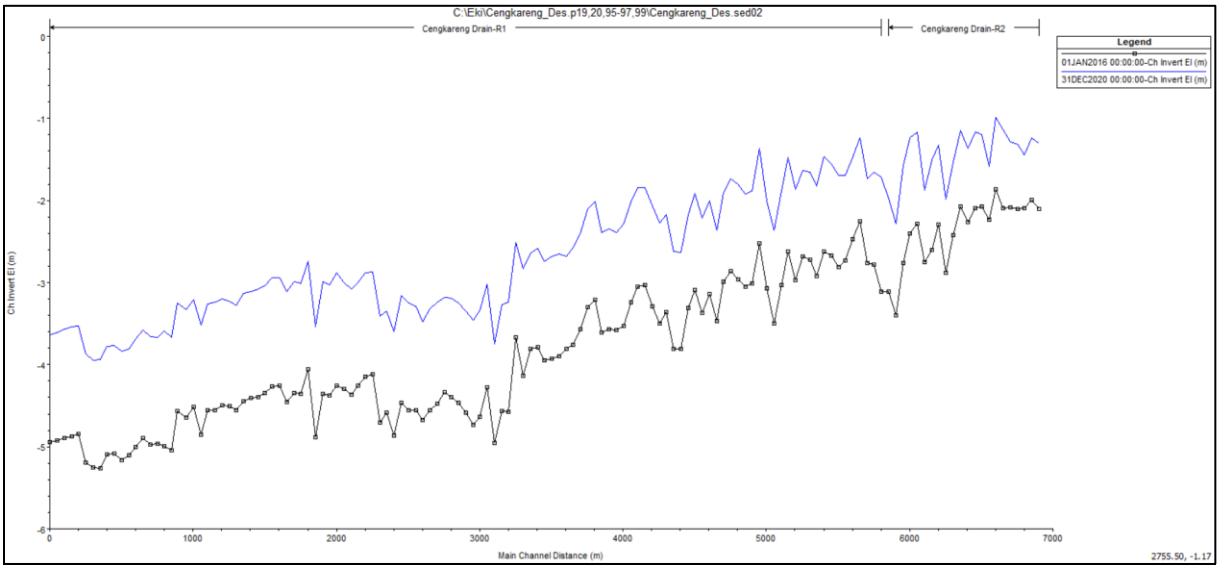


Figure 12. River Bed Change of Cengkareng Floodway based on Simulation 2 Result

From the results of the sediment transport simulation 2 above, the average river bed change of the Cengkareng Floodway is 1.19 m, where the maximum bed change of 1.41 m occurs at Station 809, while the minimum channel bed change is 0.65 m at Station 6561.

The comparison of river bed change of Cengkareng Floodway between simulation 1 and simulation 2 from downstream (Station 0) to upstream (Station 6911) is shown in the figure below.

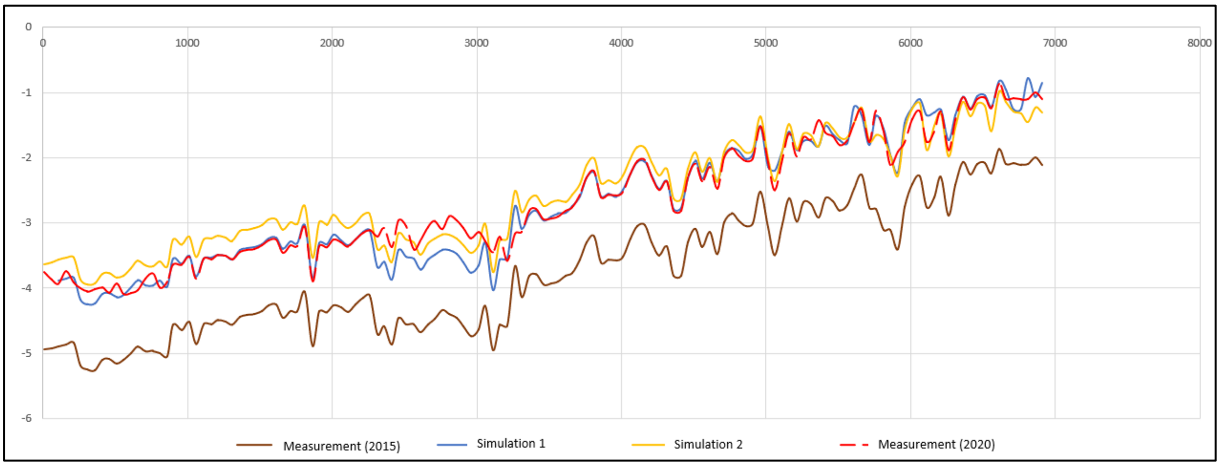


Figure 13. Comparison of River Bed Change based on Simulation 1 dan Simulation 2

Based on the results of the sediment transport simulation analysis that has been carried out, it can be seen that the *simulation* results of river bed changes that are closest to the riverbed change data in the field are Simulation 1 with the average riverbed changes of 1.04 m and 1.08 m.

Table 4. Comparison of River Bed Change based on Simulation and Measurement Data

No	River Bed Change 2016 - 2020	Simulation 1 (m)	Simulation 2 (m)	2015 – 2020 Data (m)
1	Maximum	1.55	1.41	1.50
2	Minimum	0.82	0.65	0.50
3	Average	1.04	1.19	1.08

5. Conclusions

Based on the results of the sediment transport simulation analysis that has been carried out, both simulation 1 and simulation 2 give the same trend from upstream to downstream. The result of simulation 1 shows that sedimentation occurs along the Cengkareng Floodway with the highest sedimentation height of 1.55 meters for 5 years (2016-2020). The result of simulation 2 shows that the maximum sedimentation at the riverbed of Cengkareng Floodway is 1.41 meters. The simulation results of river bed changes that are closest to the riverbed changes data in the field are Simulation 1. Further studies are required to find the most suitable cohesive parameter to be applied at this location.

6. References

[1] Pierre Y. Julien 2010 *Erosion and Sedimentation* (United States of America Cambridge University Press)
[2] Van Rijn L 2020 *Literature Review Of Critical Bed-Shear Stresses For Mud-Sand Mixtures*.
[3] Wishmeier W H and Smith D D United States Department of Agriculture 1978 *Predicting Rainfall Erosion Losses* (United States of America : United States Department of Agriculture)
[4] Ciliwung Cisadane River Basin Organization 2013 Jakarta Urgent Flood Mitigation Project Package 2A Report
[5] US Army Corps of Engineers 2021 *HEC-RAS River Analysis System Reference Manual Version 6.0*.
[6] Partheniades E 2009 *Cohesive Sediment in Open Channel* (United States of America : Elsevier Inc)