Potential Sedimentation in the Operation Ciliwung Diversion Tunnel

I.F.R. Silalahi[1], I. Soekarno[2], J. Nugroho[2], E. O. Nugroho[2], B. Heri[3]

[1]Water Resources Management Master Program, Civil Engineering Study Program, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology
[2]Water Resources Research Group, Civil Engineering Study Program, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Jl. Ganesa No. 10, Indonesia
[3]Ciliwung-Cisadane River Basin Organization, Jl Inspeksi Saluran Tarum Barat No.58, Indonesia

Abstract. The construction of the Ciliwung Diversion Tunnel is carried out in order to maximize the capacity of the main drainage channels such as the Eastern Flood Channel and reduce the flood water level in the Ciliwung River. This diversion is planned to be able to divert some of the flood discharge from the Ciliwung River to the Eastern Flood Channel through the Cipinang River at 60 m^3/second. One of the problems in this construction is sedimentation which can reduce the effectiveness of the diversion system. Sedimentation that occurs can be in the form of sedimentation on the river section where the inlet is located or sedimentation that occurs in the tunnel outlet pool. Therefore, this study will analyze the potential for sedimentation that occurs at the sediment trap when the system is finished operating. Sedimentation potential in the Ciliwung Diversion System was analyzed using a calibrated HEC-RAS model. The calibrations carried out are manning calibration and sediment model calibration. The sediment calibration model was carried out by comparing the modeling results of the Ciliwung River with the data from the geometry measurement of the Ciliwung River at the inlet of the diversion in 2021. From the results of the analysis, it is known that the bankfull discharge of the Ciliwung River before normalization is equivalent to the design flood of Q10 and after normalization is equivalent to the design flood of Q50. For the calibration of the sediment model, the invert elevation of the Ciliwung River 4 years after normalization was completed in 2017 was + 7.41 or a difference of 0.079 m from the 2021 measurement results. The amount of sediment carried into the tunnel before normalization was greater than after normalization in the small return period flood discharge like Q2 and Q5. After normalization, the amount of sediment that enters is approximately 48 tons at the design flood Q2, smaller than the sediment that enters the condition before normalization which is 104 tons. To prevent sedimentation in the tunnel, it is necessary to pump immediately after the flood flow in diversion tunnel is being stopped.

1. Introduction

One of the Jakarta flood control projects is the construction of a diversion tunnel from the Ciliwung to the Cipinang River, this tunnel is planned to be able to divert some of the flood discharge from the Ciliwung River to the Eastern Flood Channel (KBT) through the Cipinang River at 60 m^3/s (Figure 1). Construction of the Ciliwung – KBT diversion system is designed using 2 micro tunnels, each with a diameter of 3.5 m and length ± 1,260 m [1]. Based on the physical model carried out in 2014 it is known that the designed diversion discharge is achieved when there is a 10-year return period (Q10) flood in Ciliwung River and a maximum 2-year return period flood (Q2) in Cipinang River. In addition, 1-D numerical hydraulic based on a proposed design has been done to assess the performance of the diversion system in any combination of upstream and downstream boundary condition [2]. The operation of this system is regulated by sluice gates located at the inlet and outlet of the tunnel [3]. The diversion system, such as the Ciliwung Diversion Tunnel, by using a micro tunnel that connects two rivers, is not widely known.

Figure 1. Layout of Ciliwung - KBT diversion system

Some examples of flood diversion system using micro tunnels are the Thalwil Diversion Tunnel in Austria [4] and the Bisagno Diversion Tunnel in Italy [5]. However, these two diversion tunnels have different system with the Ciliwung Diversion Tunnel.

The Bisagno Diversion Tunnel has 4 intakes, namely the Bisagno intake, the Feraggiano intake, the Rovare intake, and the Noce intake. The Bisagno intake system consists of a weir on the river with 3 radial gates and a side spillway to drain some of the discharge of the Bisagno River to the main diversion tunnel. While the other three intakes are vortex shaft intakes equipped with vertical drop shafts and outlet structures. The outlet of the Bisagno Diversion Tunnel is in the Tirreno Sea and is designed with coastal protection. With a diversion tunnel slope of 0.61% upstream, a 0.9% shortly in the middle and 0.4% downstream and an outlet system that directly drains the flood into the sea so that residual flooding that has the potential to deposit sediment in the tunnel can be minimized.

The Thalwil Diversion Tunnel diverts flooding from the Sihl River to Lake Zurich. The intake tunnel structure is a side spillway with 2 sills placed downstream of the intake structure. These thresholds (Sills) will ensure a certain water level along the intake structure and thus a certain discharge into the tunnel. The outlet structure of the Thalwil diversion tunnel is the same as the Bisagno Diversion Tunnel in the form of an open outlet, this outlet structure directly drains the flood into Lake Zurich and the flood which causes a fairly high retention effect will be diverted by Lake Zurich to the Limmat River. Because the intake structure has been optimized in relation to the flow of the open outlet system, the potential for sediment deposition in the tunnel is also minimal.

At the Ciliwung diversion, there is a sediment trap/outlet pool at the outlet that serves to accommodate sediment that settles when the diversion tunnel is operated and when the remaining flood water is emptied in the tunnel. Sediment in the sediment trap will be pumped using a sludge pump. Therefore, this study will analyze the potential for sedimentation that occurs at the sediment trap when the system is finished operating.

2. Literature Study

The importance of a general understanding of sediment transport in rivers in the construction of water structures desuch as dams, power plants, bridge piers, culverts, bridges, etc described by Iwuoha *et al.* [6]. The lifetime of this building depends on the amount of sediment carried by the river. The high flow of sediment that enters the river affects the efficiency of these water structures. In the tunnel itself, sedimentation that occurs can be in the form of sedimentation on the river section where the inlet is located [4] or sedimentation that occurs in the tunnel.

In principle, the analysis of the potential for sedimentation that occurs in the flood diversion tunnel is estimated based on the tunnel operation pattern. Where flood diversion tunnels are generally designed to only flow certain flood discharges to maintain the morphological balance of the diverted river. If sediment control is not carried out properly, the load of sediment entering the receiving river can cause sedimentation or scouring. If the amount of sediment supply from the supply river and receiving river exceeds the carrying capacity of the new regime flow in the receiving river, then deposition will occur and in the long term it can cause flooding problems in the receiving river. On the other hand, if the amount of sediment load is too low compared to the carrying capacity of the new flow regime, the bottom and banks of the receiving river will be eroded and this condition can cause banks slides along the receiving river. The same impact can occur in the downstream section of the supplier river [7].

Many studies have been carried out on the topic of river morphology in the upstream Ciliwung watershed. One of erosion and sedimentation research in the upstream Ciliwung watershed using the ArcSWAT model was conducted by Razianto, M. Z *et al.* [8]. Land erosion that occurs in the upstream Ciliwung watershed is one of the causes of sedimentation in the downstream. From this research, it is known that the average runoff in the existing conditions is 140.84 mm/year, the average erosion is 66.28 tons/ha/year and the sedimentation is an average of 43,143.41 m^3. This condition shows the criticality level of land in the Upper Ciliwung watershed with semi-critical criteria covering an area of 925.47 ha (6.31% of the watershed area), critical area of 8,662.5 ha (57.37% of the watershed area) and super critical area of 5,510.88 ha (36.5% of the watershed area).

Still related to land erosion and sediment control, research by Putra, S.S *et al.* related to the Mini Sabodam Placement Planning by Sediment Balance Method in the Upstream Area of the Proposed Ciawi Reservoir, Ciliwung watershed, provides an alternative to land erosion management in the upstream Ciliwung with the construction of a mini sabodam [9].

Regarding river morphology research in the downstream, it can be seen in research by Murniningsih and Mustafa which analyzed the Impact of River Normalization on Erosion and Sedimentation in Urban Areas [10]. This research on the Pesanggrahan River was carried out using the HEC-RAS model and gave simulation results that the amount of sediment transport increased at the upstream point which was reviewed by 155.11 tons/year, at the midpoint it increased 89.64 tons/year and the downstream point decreased by 0.28 tons/year.

The sediment transport capacity function in HEC-RAS has the capability of predicting transport capacity for non-cohesive sediment at one or more cross sections based on existing hydraulic parameters and known bed material properties. It does not take into account sediment inflow, erosion, or deposition in the computations. Classically, the sediment transport capacity is comprised of both bed load and suspended load, both of which can be accounted for in the various sediment transport predictors available in model.

2.1. Sediment Continuity

Sediment tracing in the HEC-RAS program with the sediment continuity equation, namely the Exner equation [11], is as follows:

$$\left(1 - \lambda_p\right) = B\,\frac{\delta\eta}{\delta t} = -\frac{\delta Q_S}{\delta x} \tag{1}$$

Where:

B	= channel width (ft)
η	= channel elevation (ft)
λ_p	= active layer porosity (-)
t	= time (s)
x	= distance (ft)
Q_s	= transported sediment load (ft^2/s)

This equation states that the change in sediment volume in the control volume is equal to the difference between the inflow load and outflow load as shown in its manual [12]. The sediment continuity equation is solved by calculating the sediment transport capacity through the control volume at any given cross section. The load capacity of sediment leaving the control volume is compared with the sediment supply entering the control volume. If the outgoing sediment capacity is greater than the incoming sediment load then erosion occurs, if the outgoing sediment capacity is greater than the supply then there is a surplus of sediment which causes sedimentation.

2.2. Sediment Transport Capacity

Sediment transport capacity is how much material of a certain sediment size can be transported by water. Sediment transport capacity is calculated by using one of several sediment transport formulas in the model. Most of these sediment transport equations are calculated with single grain sizes such as d50 or d90 only. There are seven equations of sediment carrying capacity in the software. In this study, the Ackers White equation was chosen. This equation is a function of total load which was developed based on the assumption that fine sediment transport is related to turbulent water fluctuations and coarse sediment transport is closely related to shear force or in a variable called the average velocity. The fine sediments in question are silt measuring less than 0.04 mm and coarse sediments measuring more than 2.5 mm.

$$X = \frac{G_{gr} s d_s}{D.\left(\frac{u_*}{v}\right)^n} \quad \text{and} \quad G_{gr} = C\left(\frac{F_{gr}}{A} - 1\right) \tag{2}$$

Where:

X	= sediment flux
G_{gr}	= transport potential parameter (-)
s	= sediment specific gravity (-)
d_s	= median particle size (ft)
D	= effective depth (ft)
u*	= shear velocity (-)
V	= average channel velocity (ft/s)
n	= transition exponent (based on sediment size) (-)
C	= coefficient (-)
F_{gr}	= sediment mobility parameter (-)
A	= threshold mobility (-)

2.3. Settling Velocity

Settling velocity has a big influence on the sediment transport process. A sediment will continue to float or not settle as long as the vertical flow velocity is greater than the settling velocity. In the model, there are seven methods of calculating settling velocity, namely Rubey (1933), Toffaleti (1968), Van Rijn (1993), Report 12 (Default method in HEC-6), Dietrich (1982), Soulsby (1997) and Wu and Wang (2006).

Wu and Wang (2016) re-evaluated the graph of the relationship between depositional velocity and particle size and shape recommended by the Subcommittee on Sedimentation of the U.S. Interagency Committee on Water Resources 1957 in the form of mathematical equations [13]. The equation given by Wu and Wang is as follows:

$$\omega_s = \frac{M\upsilon}{Nd}\left[\sqrt{\frac{1}{4}+\left(\frac{4N}{3M^2}D_*{}^3\right)^{1/n}}-\frac{1}{2}\right]^n \tag{3}$$

Where:

ω	= particle settling velocity (cm/s)
ν	= kinematic viscosity (ft^2/s)
D*	= dimensionless particle diameter (-)
d	= nominal diameter of sediment particles (mm)
M, N, n	= coefficient (-)

3. Ciliwung Diversion System and Methodology

3.1. Ciliwung Diversion System

In the Ciliwung diversion tunnel, the diversion system from the inlet to the outlet consists of a garbage barrier pole, a rotary trash rack, side weir, open channel, intake gate, micro tunnels, sediment trap/outlet pool, outlet weir, outlet gate, pump, and the disposal area as illustrated in Figure 2. The elevation data of this diversion system are as follows: Ciliwung riverbed normalization +6.07, side weir +9.50, upstream open channel +9.07, downstream open channel 9.15, bottom elevation of intake gate +9.50, upstream micro tunnel +8.00, downstream micro tunnel + 0.14, sediment trap -0.50, outlet side weir +7.00, outlet gate +7.00, Cipinang river bed normalization +6.00 [1].

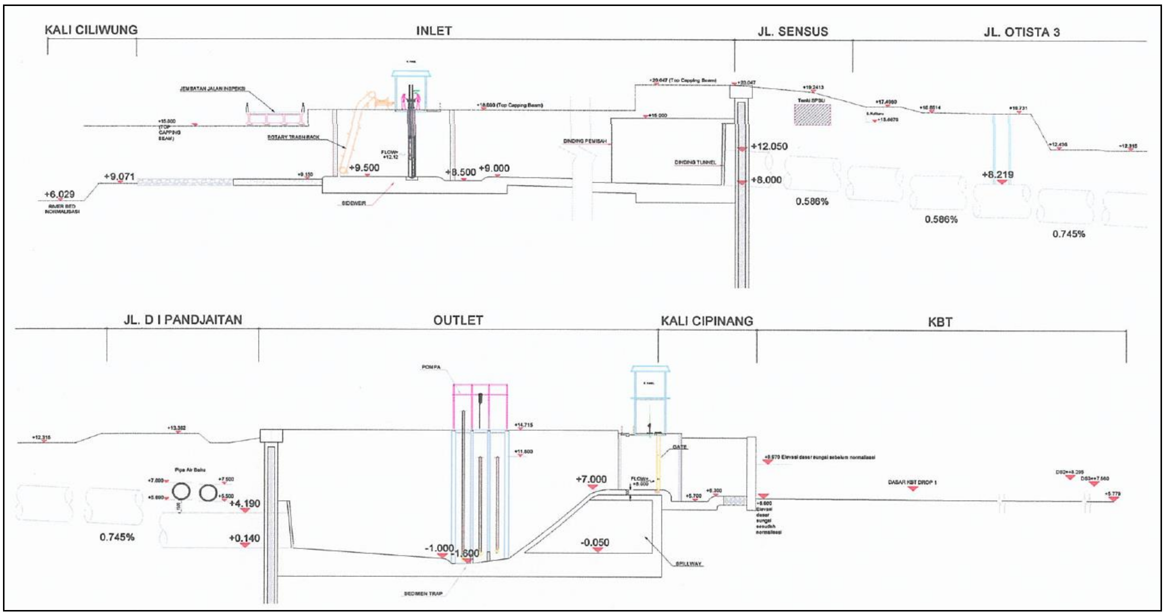


Figure 2. Ciliwung Diversion System to the Eastern Flood Channel

3.2. Methodology

The implementation stages in this study consist of data collecting, hydrological analysis, hydrodynamic modeling (unsteady flow), and sedimentation modelling (quasy-unsteady flow) using the model to analyze the transport of sediment carried by flooding in the tunnel.

The design flood analysis carried out on the Ciliwung and Cipinang River is require as input for the boundary conditions in the model. The method used is the ITB Synthetic Unit Hydrograph (SUH). The data held is in the form of daily rainfall at 7 (seven) rain gauges stations that are spread fairly evenly both inside and outside the Ciliwung watershed with a data series recording length of 11 years from 2008 - 2018. Rainfall data will be analyzed using the frequency analysis method to get design rainfall. The design rainfall required in calculating the design flood using the synthetic unit hydrograph method is the design rainfall which is distributed in hourly rains. The method used to obtain the rain distribution from the planned rain is the PSA 007 distribution model.

Prior to sediment modeling, steady flow hydrodynamic modeling will be performed for manning calibration on the geometry of the Ciliwung River. The manning to be used is the manning value from the measurement results in the field. After that, to obtain a rating curve for the Ciliwung River and diversion inlet, a hydrodynamic (unsteady flow) model of the diversion system will be made with a bankfull capacity scenario in the Ciliwung River conditions before and after normalization.

The sediment model calibration will use the 2013 Ciliwung River normalized design data with geometric measurements of the 2021 Ciliwung River at the intake inlet location. For this reason, as an upstream boundary condition, daily discharge data will be used which is sourced from the AWLR MT Haryono recording from 2017 – 2020. The calibration was carried out by comparing the base elevation of the Ciliwung River 4 years after normalization was completed in 2017 from the model results with the 2021 measurement results.

The calibration of the Ciliwung River sediment model resulted in the calibration of the Ciliwung River's HEC-RAS sediment model parameters. These parameters will be used in the sediment model of the diversion system consisting of Ciliwung River – Diversion Tunnel – Cipinang River. The boundary conditions used are the design flood of the Ciliwung and the Cipinang River. From this diversion system model, the amount of sediment entering the tunnel will be generated at the combined design flood of the Ciliwung and Cipinang River for various return periods. The stages of this research can be seen in the following flow chart:

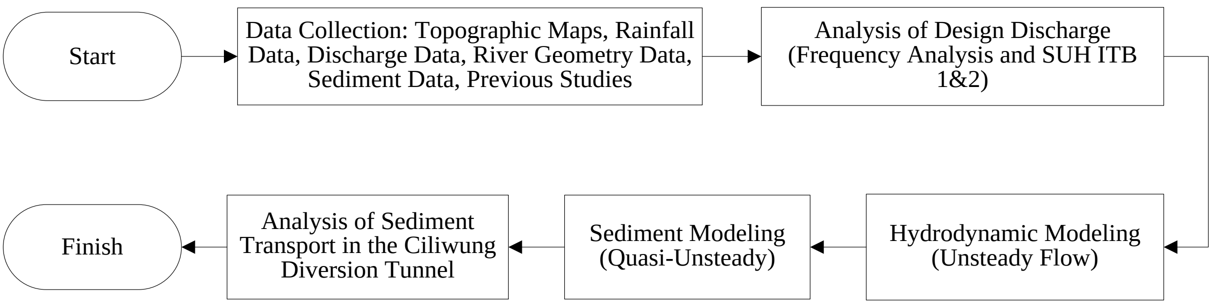


Figure 3. Flowchart of Methodology

4. Result and Discussion

4.1. Analysis of the Design Flood of Ciliwung and Cipinang River

Analysis of design flood was carried out on Ciliwung and Cipinang River to be used as boundary conditions in sediment modeling. The data required in this hydrological analysis are watershed boundaries and rainfall data. In determining the watershed boundaries, starts with delineating watersheds using GIS software and DEMNAS data from the Geospatial Information Agency (BIG). From the results of the watershed delineation, the area of the Ciliwung watershed to the inlet of the river is 329.02 km^2 with a river length of 101.89 km and 49.91 km^2 with a river length of 27.3 km for Cipinang River.

Determining mean areal rainfall can be done by 3 methods, namely: Arithmetic, Thiessen Polygon, and Isohyetal method. This study was conducted based on the Thiessen Polygon method. The available rainfall data is daily rainfall data from 7 rain gauge stations in and around the Ciliwung and Cipinang watersheds with the recording year from 2008 – 2018 (11 years) as shown in Figure 4 and Figure 5.

The calculation of design rainfall is perform using frequency distribution analysis. The method used in this study is the Normal frequency distribution, Log Normal, Log Pearson III and Gumbel. In this study, analysis was carried out with several return periods (Tr), namely 2 years, 5 years, 10 years, 20 years, 25 years, 50 years, and 100 years. The distribution of the design rainfall was tested by the Smirnov-Kolmogorov Test and the Chi-Square Test. From the test results, it is concluded to choose the Gumbel distribution as the selected rainfall distribution for the design rainfall in the two watersheds. Next, the design rainfall is multiplied by the ARF coefficient to reduce the maximum annual rainfall value. The determination of the ARF formula is determined based on SNI 2415: 2016. With the Ciliwung watershed area of 329.02 km^2, the ARF value is 0.8416. For the Cipinang watershed with a watershed area of 49.91 km^2, the ARF value is 0.9426

The design rainfall data require in calculating the design flood using the hydrograph method is the design rainfall which is distributed in hourly. The method used to obtain the rainfall distribution from the design rainfall in this study is the PSA 007 distribution model. The SUH is obtained by multiplying the unit hydrograph by the effective rainfall factor and the hourly rainfall distribution. The results of the HSS analysis with various return periods are given in Table 1.

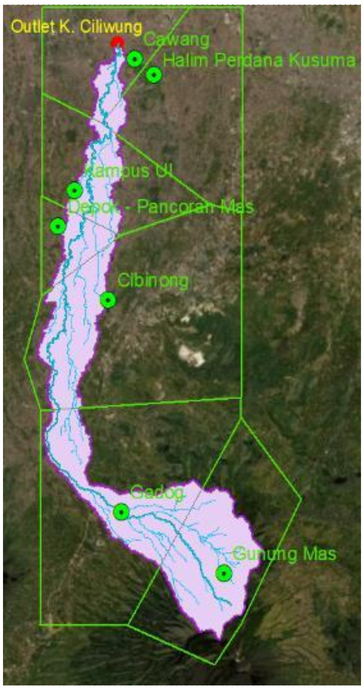


Figure 4. Thiessen polygon analysis in Ciliwung watershed with ArcGis.

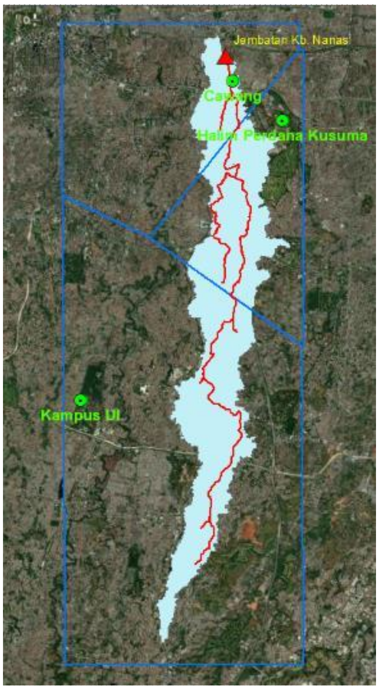


Figure 5. Thiessen polygon analysis in Cipinang watershed with ArcGis.

Table 1. Ciliwung and Cipinang River Design Flood on various return periods

Tr	Ciliwung River (m^3/s)	Cipinang River (m^3/s)
2	327	97
5	400	114
10	451	125
25	515	140
50	563	151
100	611	161
200	659	172

4.2. Hydrodynamic Modeling (Unsteady Flow)

During sediment sampling, flow velocity measurements and water level observations were also execute. Based on these data, the manning coefficient analysis can be performed which can be used as input for the calibrated parameters in the model. From the measurement results, it is known that the bed slope and discharge, with the chezy velocity formula and the relationship formula between the manning coefficient and chezy, the manning coefficient is 0.0268. Analysis was performed on each measurement series. Each manning coefficient from the 3 series of measurements is used in the HEC-RAS steady flow hydrodynamic model to prove whether the calculated manning coefficient corresponds to the discharge and water level elevation generated by the model. From the simulation results, it can be seen that the manning coefficient and the flow data obtained from the measurement results show that the water level is in accordance with the results of the measurements. Therefore, it can be concluded that from the three manning coefficients the results of each measurement are taken the average value of 0.026.

The analysis of the rating curve and the diversion inflows rate was carried out on the diversion system that consisting geometry model of the Ciliwung River, Diversion Tunnel, and Cipinang River. The Ciliwung River itself consists of two geometries, namely before and after normalization. The model will be simulated with unsteady flow and design flood according to the bankfull capacity of each geometry. For the geometry before normalization will use Q10 on the Ciliwung River and Q2 on the Cipinang River and the geometry after normalization will use the design flood of Q50 on the Ciliwung River and Q2 on the Cipinang River. The rating curve modeling results will still be processed with Ms Excel with non-linear regression equations to get a smoother rating curve graph.

From the processing of the modeling results, the rating curve for the Ciliwung River and the intake inlet before and after normalization is obtained with the following formula:

- Ciliwung River before normalization : $Q = 1.58(H - 6)^{\wedge 2.58}$
- Inlet Tunnel before normalization : $Q = 2.5(H - 9)^{\wedge 1.91}$
- Ciliwung River after normalization : $Q = 10(H - 6)^{\wedge 1.97}$
- Inlet Tunnel after normalization : $Q = 4(H - 9)^{\wedge 1.93}$

The Ciliwung River's Curve Rating and the flow rate diversion results from the analysis of the HEC-RAS model can be seen in Figures 6 and 7.

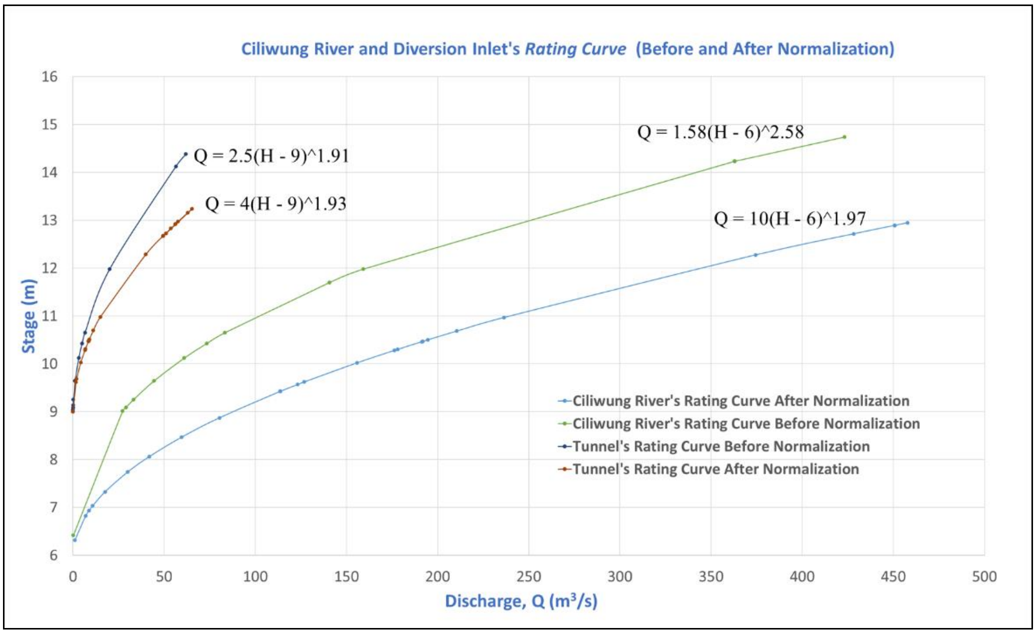


Figure 6. Rating Curve of Ciliwung River and Diversion Tunnel

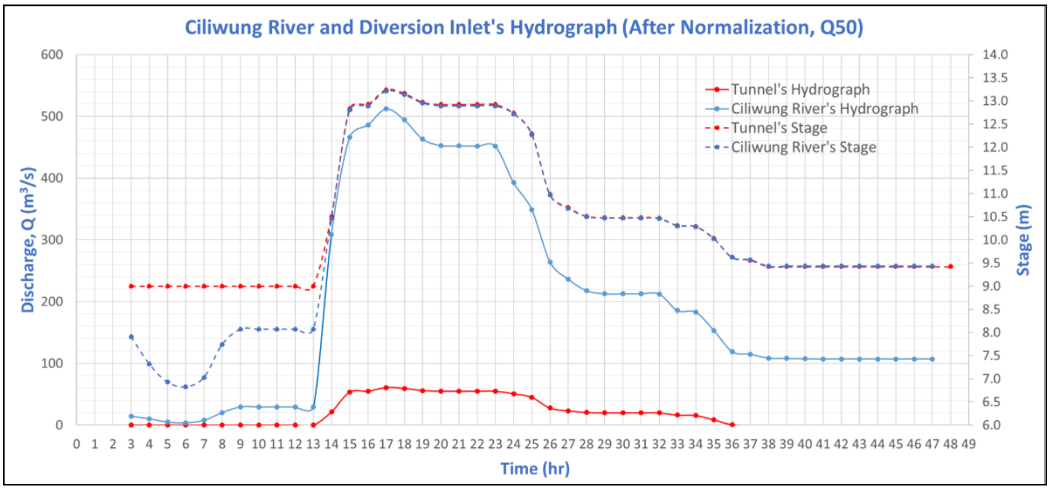


Figure 7. Hydrograph of Ciliwung River and Diversion Tunnel

4.3. Sedimen Modelling

4.3.1. Sediment Model Calibration. The calibration of the sediment model was carried out by comparing the modeling results of the Ciliwung River with the geometry measurement data of the Ciliwung River at the 2021 inlet's location. The measurement results can be seen in Figure 8. From this cross section, it is known that the invert elevation of the Ciliwung River in 2021 is +7.327. The geometric data used in the calibration model is the 2013 Ciliwung River normalization design data which was completed in 2017. The results of the geometric input of the Ciliwung River at the completion of normalization in 2017 can be seen in Figure 9. The invert elevation of the Ciliwung River in 2017 is +6.320. The geometric parameters require to build the model are long profiles, cross-section profiles, riverbed roughness (calibrated maning) and daily discharge.

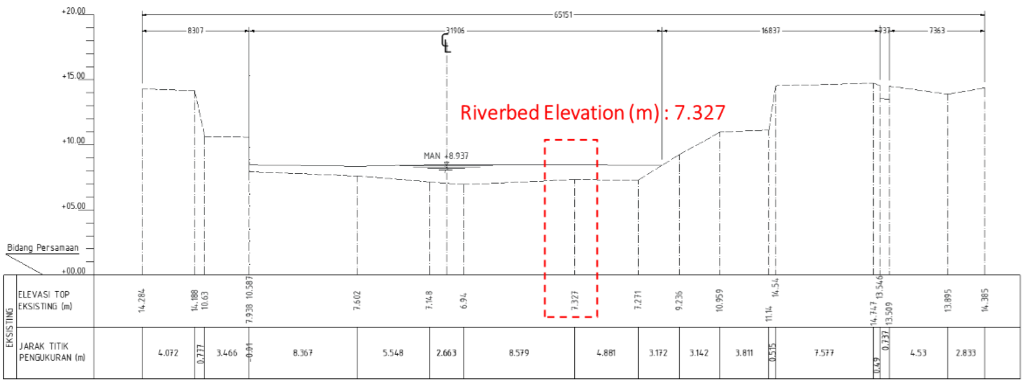


Figure 8. Cross section of the Ciliwung River at the tunnel's inlet location

Sediment measurements were carried out 3 times, in September and November 2021. These hydrometric measurements included river cross-section, flow velocity, suspended sediment sampling, bedload sediment sampling, river bed material sampling, and river water level slope measurements.

The Total Sediment Rating Curve used as the boundary condition at the upstream of Ciliwung can be seen in Figure 10.

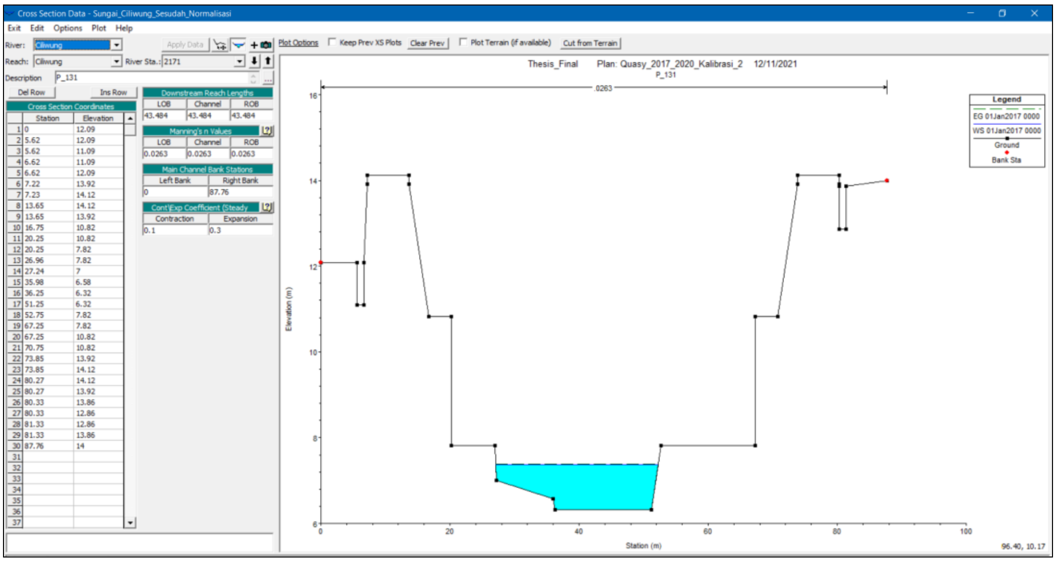


Figure 9. Geometry display of Ciliwung River model calibration scenario

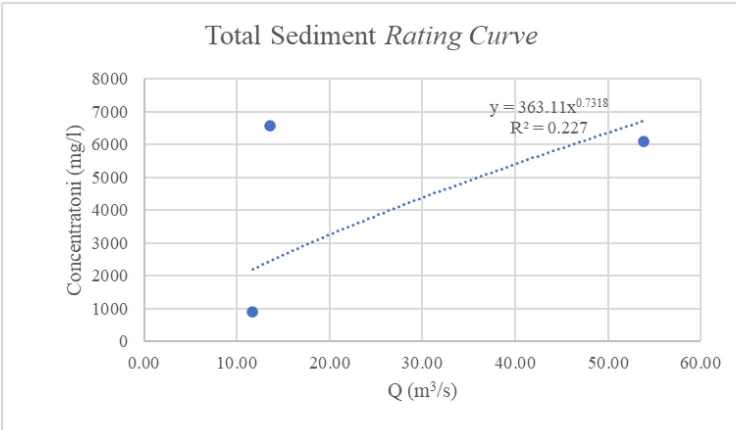


Figure 10. Total Sediment Rating Curve

The condition of the upstream boundary uses daily discharge data recorded by AWLR MT. Haryono from 2017 – 2020. The condition of the downstream boundary uses the normal depth option which is filled with the bed slope 0.000449.

4.3.2. Calibrated Sediment Parameters. From the modeling results, the invert elevation of the Ciliwung River 4 years after normalization was completed in 2017 is + 7.41 or a difference of 0.079 m from the 2021 measurement results. The modeling results can be seen in Figure 11. Based on these results, it can be concluded that the parameters used in the calibration's scenario can already be used in sediment modeling scenarios for diversion system. These parameters include:

- Transport Function Scaling Factor and Critical Mobility Scaling Factor in the Transport Function Calibration and Modification section are 0.85 and 0.9, respectively.
- Transport Function used is Ackers-White
- The selected sorting method is Copeland (Exner 7)
- Fall Velocity Method used is Wu and Wang.

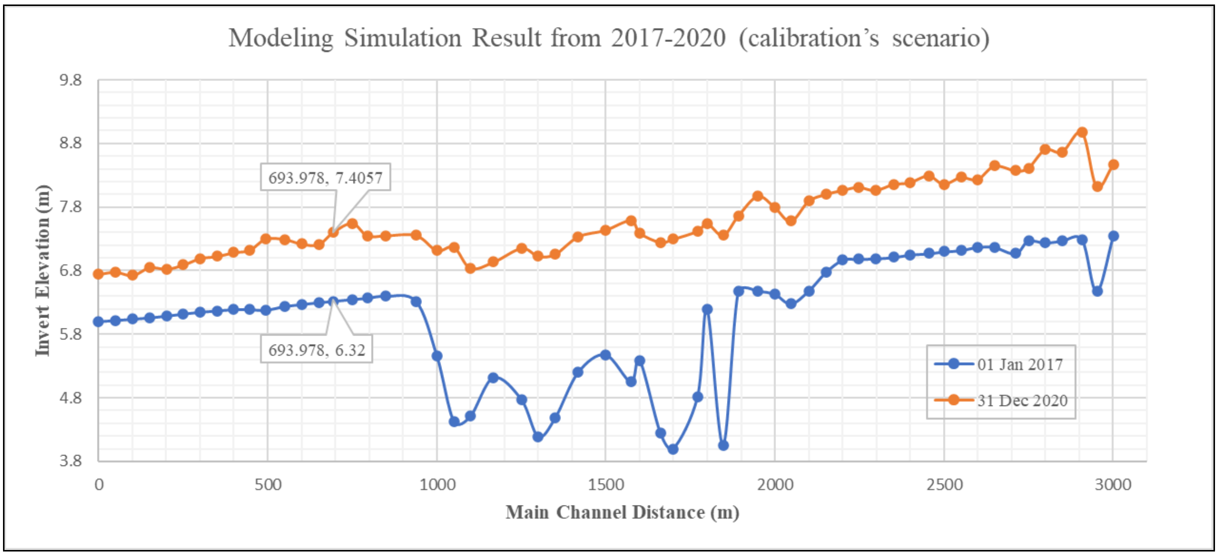
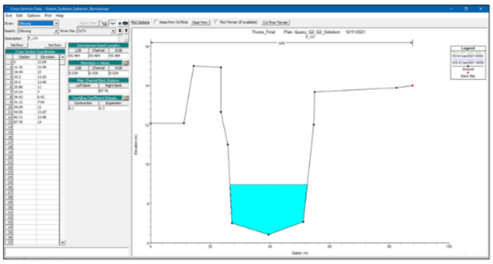


Figure 11. The Ciliwung's invert elevation at the inlet location, modeling simulation result from the 2017-2020

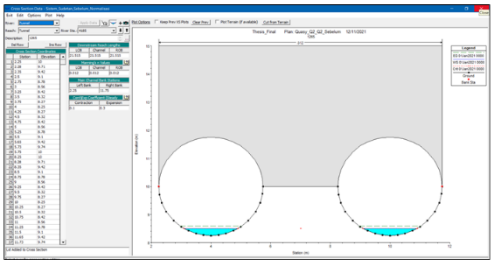
4.4. Analysis of Sediment Transport in the Ciliwung Diversion Tunnel

4.4.1. Geometry Data. The diversion system consists of the Ciliwung River, the diversion tunnel, and the Cipinang River. For the geometry of the Ciliwung River itself, there are 2 types of geometry, namely before and after the design normalization. The results of the input geometry of the diversion system before normalization can be seen in Figure 13.

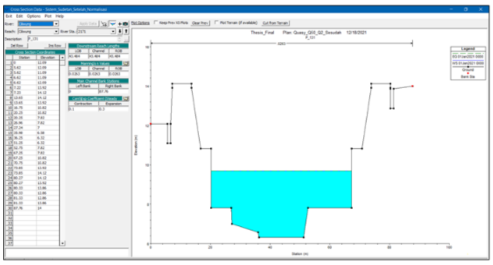
Figure 12. Schematic of the Ciliwung River – Diversion Tunnel – Cipinang River – KBT, with a Google Map background



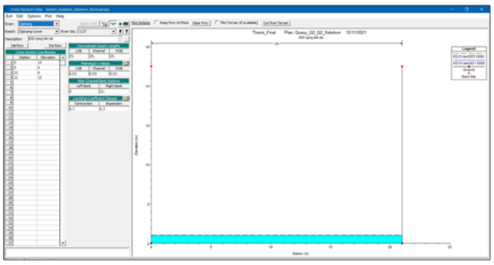
Cross Sections Ciliwung River before Normalization



Cross Sections Tunnel Diversion



Cross Sections Ciliwung River after Normalization



Cross Sections Tunnel Diversion, Cipinang River

Figure 13. Geometric data of Ciliwung Diversion System

4.4.2. Model Boundary Condition. The boundary conditions for sediment modeling in this diversion system consist of design flood data for Ciliwung and Cipinang River (Figure 12), sediment data for Ciliwung and Cipinang River, sediment rating curve for Ciliwung River and equilibrium load for Cipinang River (Figures 14 and 15), as well as calibrated model parameters.

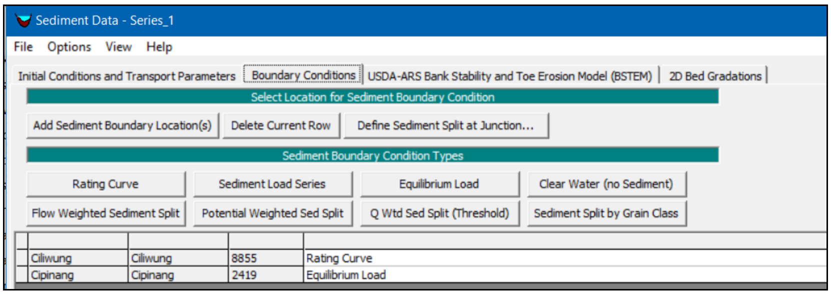
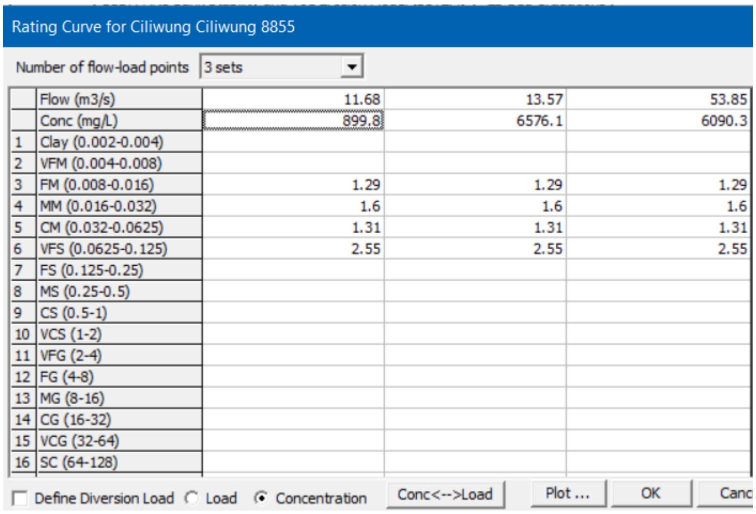


Figure 14. Sediment boundary conditions for diversion system model



Rating Curve for Ciliwung Ciliwung 8855

Number of flow-load points 3 sets

	Flow (m3/s)	11.68	13.57	53.85
	Conc (mg/L)	899.8	6576.1	6090.3
1	Clay (0.002-0.004)			
2	VFM (0.004-0.008)			
3	FM (0.008-0.016)	1.29	1.29	1.29
4	MM (0.016-0.032)	1.6	1.6	1.6
5	CM (0.032-0.0625)	1.31	1.31	1.31
6	VFS (0.0625-0.125)	2.55	2.55	2.55
7	FS (0.125-0.25)			
8	MS (0.25-0.5)			
9	CS (0.5-1)			
10	VCS (1-2)			
11	VFG (2-4)			
12	FG (4-8)			
13	MG (8-16)			
14	CG (16-32)			
15	VCG (32-64)			
16	SC (64-128)			

Define Diversion Load   Load   Concentration   Conc<-->Load   Plot ...   OK   Canc

Figure 15. Rating Curve used as sediment boundary condition

4.4.3. Results of the Analysis of Sediment Transport in the Ciliwung River. In principle, the potential for sedimentation that occurs in the flood diversion tunnel is estimated based on the analysis of the tunnel operation pattern. This sediment model does not accommodate the inlet and outlet gates, but the analysis results obtained can be used as an approximation of the amount of sediment deposited in the tunnel after the flood has pass over. The model is simulated based on a combination of design flood discharges for Ciliwung and Cipinang River that may occur. Based on the design flood hydrograph, it is known that the peak flood discharge occurs at the 16th hour and the duration of the flood until it recedes is approximately 72 hours and the model is run for 120 hours (5 days). The results of the analysis of the amount of sediment (mass in) that entered the outlet pool (xs-349) after 48 hours of flood diversion (flood conditions began to drawdown) can be seen in Table 2 for Ciliwung River conditions before normalization and Table 3 for Ciliwung River after normalization.

Table 2. Amount of sediment carried (mass in) to diversion outlet (xs-349) after 48 hours flood diversion (tons) at various Tr – before normalization

		Cipinang						
	Tr (year)	**Normal**	**2**	**5**	**10**	**25**	**50**	**100**
Ciliwung	**2**	104	104	104	104	104	104	104
	5	149	149	148	148	148	148	148
	10	181	181	181	181	181	180	181
	25	225	225	225	226	226	225	225
	50	257	257	257	257	257	257	259
	100	290	290	290	290	290	290	290

Table 3. Amount of sediment carried (mass in) to diversion outlet (xs-349) After 48 hours flood diversion (tons) at various Tr – after normalization

		Cipinang						
	Tr (year)	**Normal**	**2**	**5**	**10**	**25**	**50**	**100**
Ciliwung	**2**	48	48	48	48	48	48	48
	5	75	75	75	75	75	75	76
	10	252	252	252	252	252	252	252
	25	307	307	307	307	252	306	308
	50	348	348	348	348	348	347	348
	100	383	383	383	383	383	383	383

It can be seen that the amount of sediment that enters the tunnel at various combinations of the design flood of the Cipinang River produces an almost constant amount of sediment. For example, in the Q2 flood discharge of the Ciliwung River and Q2 of the Cipinang River, the amount of sediment that enters is 48 tons, and the result is the same as the combination of the other Cipinang River flood discharges. This means that the flow that occurs in this diversion system is a modular flow, i.e. the flow from the Ciliwung River is not affected by the flow in the Cipinang River. Changes in the amount of sediment only occur in extreme events, namely when the Cipinang River is in flood discharge conditions for a return period of 100 years.

The result table shows that the amount of sediment carried into the tunnel after normalization is smaller than before normalization in the design flood of the Ciliwung River for the Q2 and Q5 return periods. This is because the normalization of the Ciliwung River resulted in a decrease in the water level so that the discharge entering the drain during the return period was smaller than before normalization. However, for the design flood Q10 to Q100, the amount of sediment entering the drain is larger after normalization. This can be seen in Figure 16 which contains a comparison graph of sediment transport entering the tunnel at xs-4475 (inlet tunnel) and xs-349 (outlet tunnel) in the design flood of Ciliwung River Q50 before and after normalization. Both at the inlet and at the outlet tunnel sediment transport before normalization was greater than after normalization at the beginning of the flood and as the peak of flooding decreased, sediment transport occurred the opposite.

But cumulatively, it can be concluded that the volume of sediment transport before normalization that enters the tunnel is greater than after normalization but with a difference that is not too significant (Figure 17).

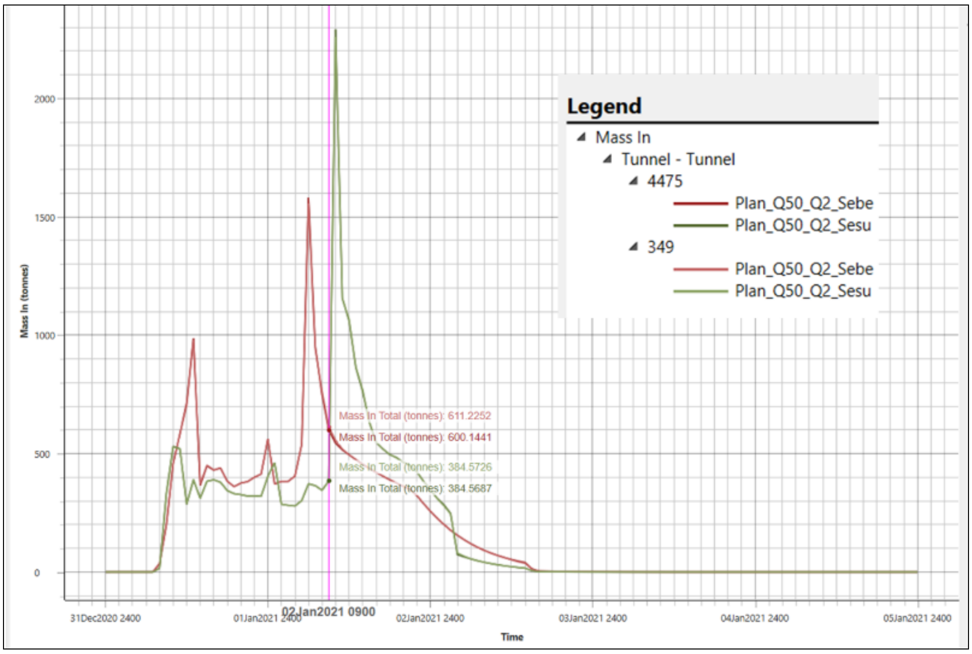


Figure 16. Comparison of the amount of sediment transport (tons) entering the inlet and tunnel outlets in the design flood conditions of Q50, before and after normalization

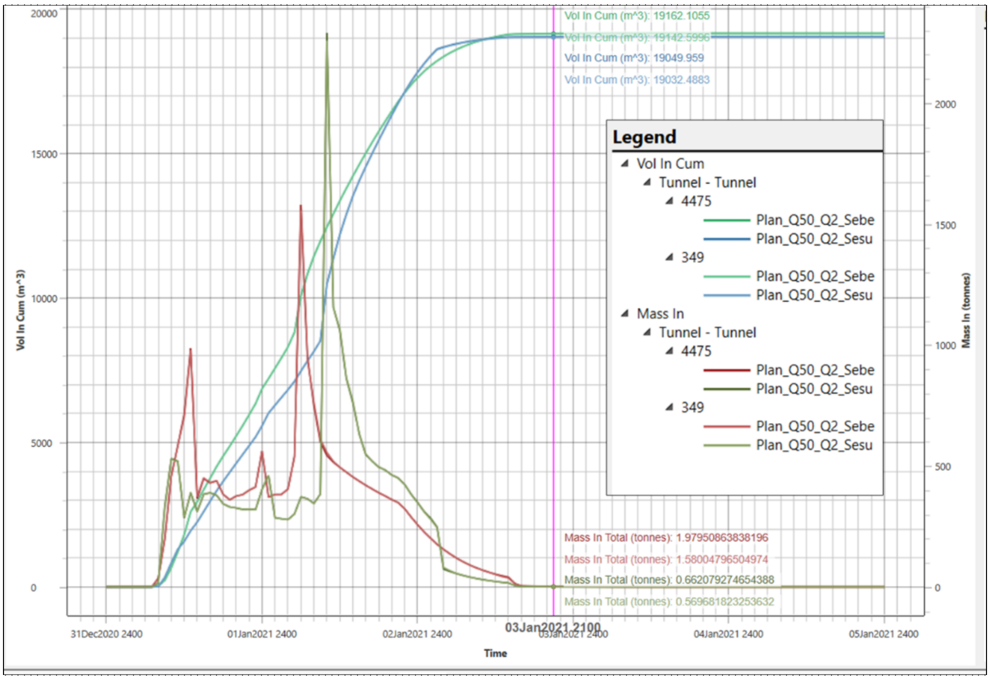


Figure 17. Graph of the comparison of the mass of incoming sediment with its cumulative volume at the inlet and outlet of the drain, before and after normalization

5. Conclusion

The results of the analysis of the amount of sediment (mass in) in the outlet pool (xs-349) after 48 hours of flood diversion is known to be approximately 48 tons at the design flood discharge of Q2 Ciliwung River after normalization and Cipinang River under normal conditions, smaller than the amount of incoming sediment in conditions before normalization obtained by 104 tons. In the design flood Q10 – Q100 which occurred on the other hand, the sediment transport that came in the condition after normalization was greater than before normalization. For example, in Q10 Ciliwung River after normalization it was 252 tons when compared to before normalization the result was smaller, namely 181 tons.

The start time of deposition in the outlet pool varies depending on the amount of flooding that is passed. The cumulative amount of sediment transport in the outlet pool began to increase at 33 hours after the drain began to divert the flood. To prevent sedimentation in the tunnel, it is necessary to pump immediately after the flood flow in diversion channel is being stopped.

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