THE IMPACT OF UPPER CITARUM DIVERSION CHANNELS ON SEDIMENT TRANSPORT AND RIVER MORPHOLOGY

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Abstract . Flood control infrastructures such as diversion channels or generally called "sudetan", levees, retention ponds, and others have been built in South Bandung area to control the flood, especially in affected areas such as Dayeuhkolot, Sapan, and Baleendah. Flood in those areas occurred due to the overflow of water from the Upper Citarum River. The diversion channels have been done on several points along the Upper Citarum River to increase the water flow velocity, so the water flows as quickly as possible to the downstream. The diversion channels give an impact on increasing the river slope, as well as the water flow velocity. The increment of the water flow velocity affects the sediment transport along the river. On the other hand, diversion channels also affect the morphology of Upper Citarum River and causing the reduction of its capacity. The capacity of Upper Citarum after the diversion channels construction has increased by approximately 25%. This capacity is decreasing because of the river morphological changes caused by erosion and sedimentation along the river. The existing river capacity is possible to accommodate design discharge for return period 10 years (Q_{10}). The HEC-RAS simulation model of sediment transport showed that the sediment transport within 1 year was 118,040 tons/year. The largest erosion was 1 meter and the largest sedimentation was 1.4 meters. The results of the analysis of meander' radius growth and stability showed that those radius are not stable and still growing, therefore the diversion channels' walls need reinforcement, so the river flow does not moving to its natural form (meandering). There are a lot of oxbows along the Upper Citarum River that potential to be used as retention ponds with total storage capacity of 2.9 million m^3.

1. Introduction

Upper Citarum River Flood Control in certain eras, before 1990 to early 2000 was done by building diversion channels in the bend/ meander of the river flow. More than a dozen diversion channels have been made along the Upper Citarum River. The diversion channels' performance in flood control is not completed thoroughly, so there are still annual floods in permanently affected areas such as Sapan, Dayeuhkolot, Baleendah, and surrounding areas. Furthermore, the diversion channels even cause a follow-up effect on the acceleration of sediment transport and morphological changes, both in diversion channels and inlet and outlet of diversion channels. The affected areas and the example of the diversion channel are shown in **Figure 1** and **Figure 2** below.

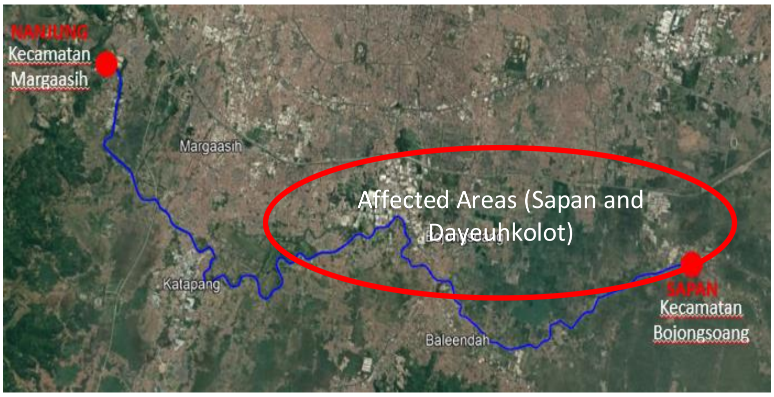

Figure 1. Upper Citarum River Flow

Figure 2. Diversion Channel at Sapan Area

2. Solution Approach

2.1 Design Rainfall for Flood Control

Flood control of Upper Citarum River is based on design rainfall by Gumbel Method with the equation as below:

Diversion Channel

$$R_T = R_{ave} + SD \cdot K_T$$

where:

R_T = Maximum Daily Rainfall
R_{ave} = Average Rainfall
SD = Standard Deviation
K_T = Correction Factor
so:

$$R_T = 82.9 + 12.2 \cdot K_T$$

with design rainfall for return period 25yr (R_{25}), the value of K_T is obtained = 3.199, so

$$R_{25} = 82.9 + 12.2 \cdot 3.199 = 121.9 \text{ mm}$$

The location of the rainfall stations in the watershed is presented in the **Figure 3** below. Each color represented the affected area of each the rainfall station.

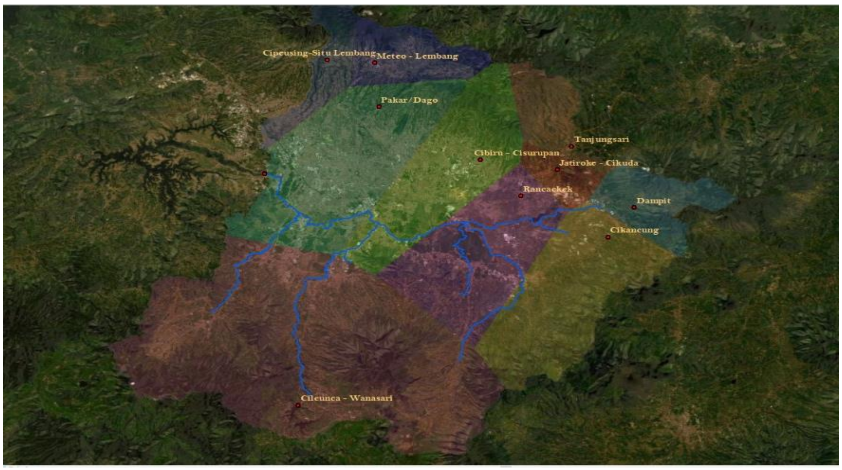

Figure 3. Rainfall Station

For various return periods, the value of Rt is given as **Table 1** below.

Table 1. Design Rainfall (Gumbel Method)

Design Rainfall (Year)	Gumbel Distribution (mm)
2	87.4
5	101.3
10	110.3
25	121.9
50	130.4
100	139.0
200	147.4
1000	167.0

2.2 Design Discharge of 25 Year (Q_{25})

Design discharge was calculated with *Soil Conservation Service* (SCS) method. The total area of the catchment area/ watershed is 1,829 km^2 with the river length 62.5 km. The outlet of the Upper Citarum catchment area is at Nanjung. The catchment area of Upper Citarum River is shown in **Figure 4 and Figure 5** below.

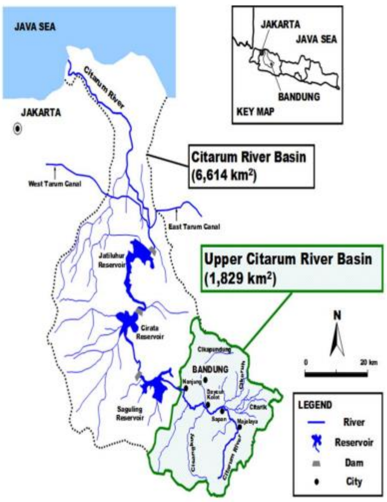

Figure 4. Upper Citarum Catchment Area Location (source: Dayeuhkolot Feasibility Study)

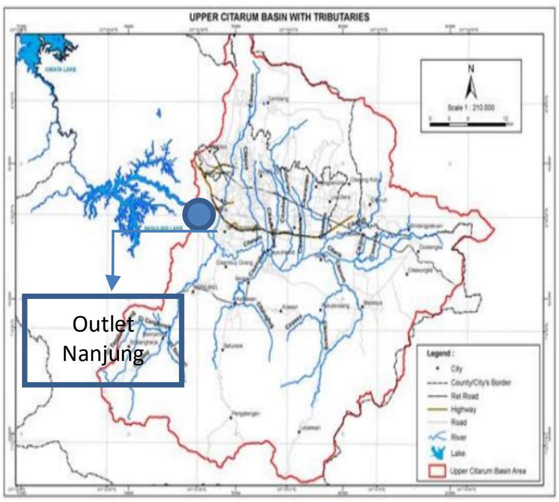

Figure 5. Upper Citarum Catchment Area (source: Dayeuhkolot Feasibility Study)

The design discharge for Upper Citarum Hulu is for return period 25 years. The hydrograph of design discharge for return period 25 years is shown in **Figure 6.** below. The peak discharge (Qp) is 689.8 m^3/s and time peak (Tp) is 19 hours.

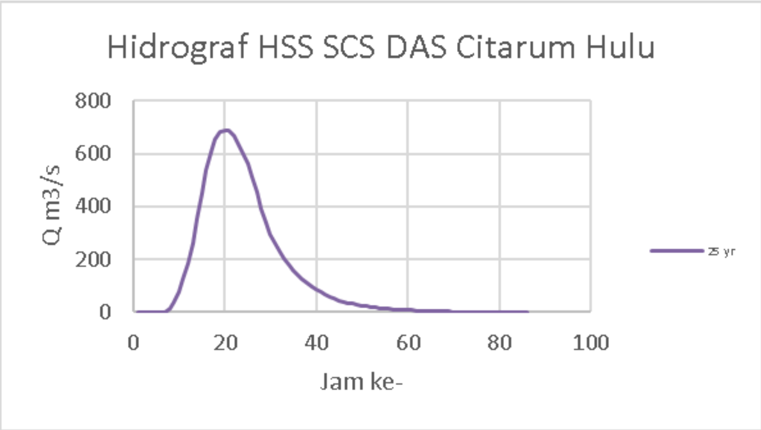

Figure 6. Hydrograph Q25

2.3 Upper Citarum River Capacity

2.3.1 Capacity Before and After the Diversion Channels Construction

Analysis was done for the river capacity before and after the diversion channels exist. Both capacities formed an equation of capacity after the diversion channels exist (Qsdh) and capacity before the diversion channels exist (Qsbl). The river capacity was calculated using Chezy formula with 3 n-values that were obtained from factual method (comparison of field condition with book's reference), geological method (Cowan's formula), and empirical method (Kutter's formula). The equations are shown on **Table 2.** below.

Table 2 . The Equation of River Capacity Before and After Diversion Channels

n-Method	Equation
n-Factual	Qsdh = 1,225 Qsbl + 429.67
n-Geologist	Qsdh = 1.25 Qsbl + 325.34
n-Empiric	Qsdh = 1.2411 Qsbl + 341.54

River capacity after the diversion channels exist is increased by approximately 25%.

2.3.2 Existing Upper Citarum River Capacity

The existing river capacity was analyzed using HEC-RAS simulation model. Analysis was done using steady flow for design discharge with return period 10 years (Q_{10}) and 25 years (Q_{25}). Simulation model results showed that the existing capacity is Q_{10}. The simulation results are shown in **Figure 7** and **Figure 8** below.

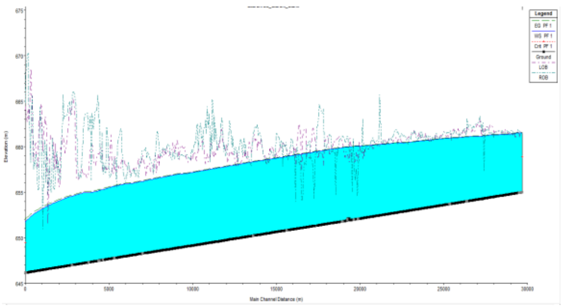

Figure 7. Simulation of Q_{10}

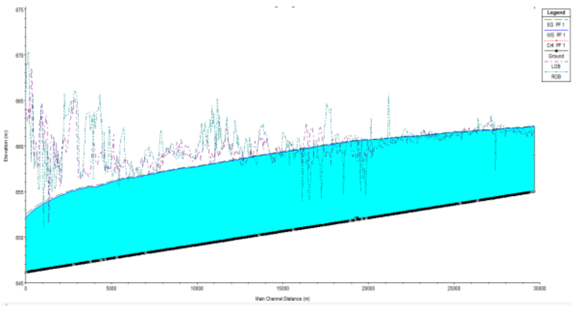

Figure 8. Simulation of Q_{25}

2.4 Meander Growth and Stability

Analysis of meander growth at Upper Citarum River was carried out with comparation between the measurement of meander radius using Google Earth imagery (as **Figure 9** below) and calculations of stable radius using Ripley's formula (1927). The calculation was using bankful discharge. The results are the stable outer radiuses have range from 600 – 1,300 meters, whereas existing outer radiuses have range from 80-300 meters. The stable inner radiuses have range from 190 – 700 meters, whereas the existing inner radiuses have range 70 – 250 meters. The outer radiuses have grown 8.2 - 24% and the inner radiuses have grown 15.8 – 78.6%. That means the meanders are not stable and still growing. It is possible that diversion channels will move towards the original bends/ meanders, within tens to hundreds of years. To prevent the shifting of those channels, it is necessary to protect the walls using retaining walls, such as a reinforced concrete slab. Cliff reinforcement on the walls of the diversion channel's inlets and outlets are also recommended.

Figure 9. Meander's Radius (at Sapan Area)

2.5 Sediment Transport Analysis

Sediment transport analysis was carried out by taking primary data of suspended load and bed material. The analysis results showed the equation of flow discharge (Q) , the suspended load discharge (Qs), bed load discharge (Qb), and total sediment discharge (Qt), as shown in **Figure 10**, **Figure 11**, and **Figure 12** below. Bed load has a big influence in the total sediment.

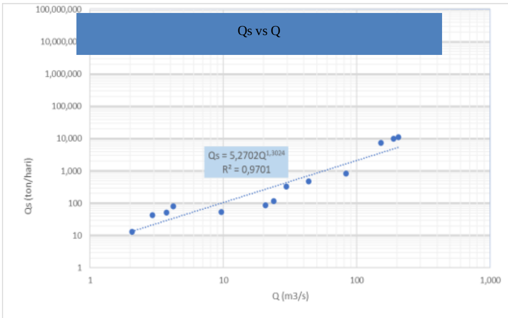

Figure 10. Equation of Suspended Load Discharge vs Flow Discharge

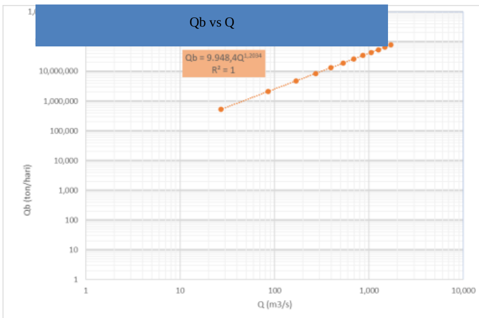

Figure 11. Equation of Bed Load Discharge vs Flow Discharge

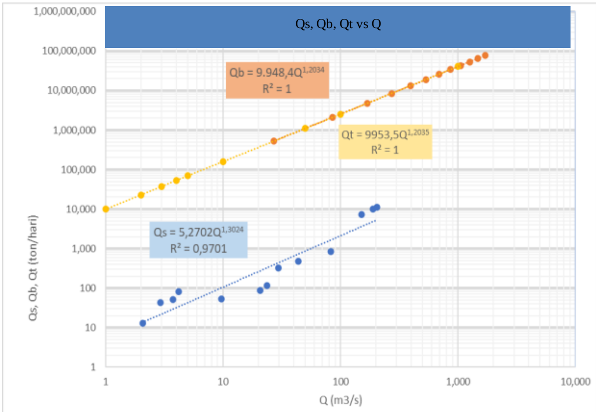

Figure 12. Equation of Total Sediment Discharge vs Flow Discharge

2.6 *River Bed Changes*

The analysis of river bed changes was done by simulation model using HEC-RAS software. The simulation's boundary was daily discharge for 1 year. The results showed that there is erosion and sedimentation along the Upper Citarum River from Sapan to Nanjung with the largest erosion is 1 meter and the largest sedimentation is 1.4 meters. The erosion and sedimentation give impact to river bed changes as shown in **Figure 13.** below. The black straight line is the initial river bed, whereas the blue line is the simulation results of bed changes.

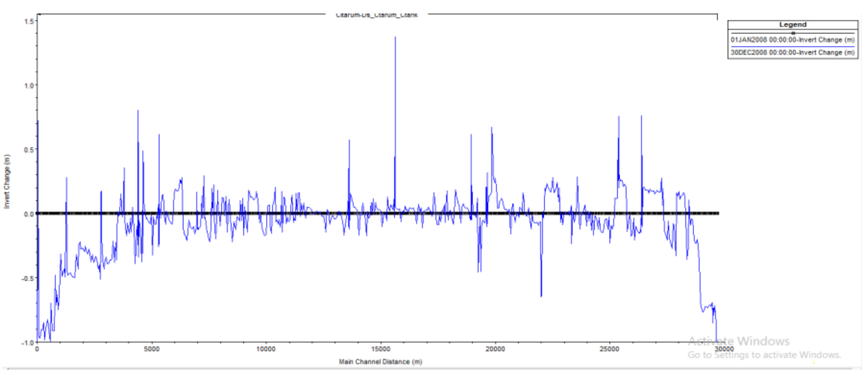

Figure 13. River Bed Changes

Analysis of sediment transport from the effect of accelerated flow in the diversion channels modeled with HEC-RAS showed that sediment transport rates of 118,040 tons/year.

2.7 Potential Retention Ponds

Diversion channels leave the land between meander and the diversion channels or known as oxbows. Several oxbows are not well managed. Those oxbows are potential to be used as local drainage retention ponds and groundwater conservation. If the retention ponds are constructed with 6 (six) meters depth, similar as the Andir Retention Pond (the latest retention pond in Bandung), it will have a storage capacity of 45,000 – 645,000 m^3, with a total storage of 2.9 million m^3. Furthermore, the water can be used as raw water locally with the local Water Treatment Plant (WTP). Retention ponds also serve as an artificial recharge of groundwater. It was analyzed from the changes on the coefficient of surface soil permeability from 10^{-6} - 10^{-5} cm/s to 10^{-5} - 10^{-3} cm/s, equivalent to a recharge value of 86.4 mm/day that exceeds normal rainfall (>60 mm/day). The potential oxbows are listed in **Table 3** below.

Table 3. Potential Oxbows

No.	Oxbow	Location	Total Area (m^2)	Effective Area (m^2)	Percentage of Effective Area (%)	Depth (m)	Volume (m^3)
1	Sapan	6°59'11.2"S 107°42'02.8"E	22,000	22,000	100	6	132,000
2	Haurcucuk	6 ° 59'18.5 "S 107 ° 41'41.8" E	13,700	8,500	62	6	51,000
3	Haurcucuk	6 ° 59'22 "S 107 ° 41'34 "E	27,400	15,100	55	6	90,600
4	Babakan Patrol	6 ° 59'25 "S 107 ° 41'20 "E	49,200	49,200	100	6	295,200
5	Tegalluar	6 ° 59'38 "S 107 ° 40'50 "E	45,200	32,200	71	6	193,200
6	Jelengkong	6 ° 59'59.7 "S 107 ° 40'09.7" E	70,700	70,700	100	6	424,200
7	Mahanggang	7 ° 00'30.1 "S 107 ° 38'46.2" E	44,200	44,200	100	6	265,200
8	Bojongsoang	6 ° 59'28.2 "S 107 ° 37'58.8" E	130,900	61,300	47	6	367,800
9	Cisangkuy	6 ° 59'37.6 "S 107 ° 37'27.9" E	31,800	7,500	24	6	45,000
10	Solomon	6 ° 59'24 "S 107 ° 34'14 "E	14,300	14,300	100	6	85,800
11	Gref	6 ° 58'54 "S 107 ° 33'29" E	56,000	56,000	100	6	336,000
12	praised	6°58'22"S 107°32'27"E	200,900	107,600	54	6	645,600

3. Conclusion

- The river capacity after the diversion channels exist increased by approximately 25%.
- Meander's radius are not stable and still growing, so it is possible that diversion channels will move towards the original bends/ meanders, within tens to hundreds of years. To prevent the shifting of those channels, it is necessary to protect the walls by retaining walls or cliff reinforcement.
- Analysis of sediment transport from the effect of accelerated flow in the diversion channels that modeled with HEC-RAS provided sediment transport rates of 118,040 tons/year, causing

morphological changes such as erosion and sedimentation. The largest erosion was 1 meter and the largest sedimentation was 1.4 meters.

- Oxbows are potential to be used as retention ponds with storage capacity of 45,000 – 645,000 m^3 and total storage capacity of 2.9 million m^3.

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