CIVED Journal of Civil Engineering and Vocational Education

EISSN: 2622-6774
Vol 11 No.1 March 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

# The Effect of Changes in Flood Discharge on Sedimentation Rates in Middle Segment of Batang Kuranji Check Dam using HEC-RAS 6.0.0

**Septi Wila Zarinda[1*], Darwizal Daoed[2], Nurhamidah[3]**
[1,2,3] Civil Engineering, Faculty of Engineering, Universitas Andalas, Indonesia
[*] Corresponding author, e-mail: septiwilazarinda@gmail.com

Received 17th Jan 2024; Revision 28th Feb 2024; Accepted 6th March 2024

## ABSTRACT

*The magnitude of the longitudinal slope of river gratly determines the magnitude of sediment transport. This is due to the large flow velocity. This shape causes gradation of the river bed, especially upstream of the river. This phenomenon is seen in the middle segment of Batang Kuranji. where a sediment control buildg or check dam has been built. However, sediment transport and changes in river cross-section upstream still occur. Based on this phenomenon, a simulation of changes in flood discharge on sediment rate was carried out. This simulation was carried out using the Meyer Peter Muller method found in HEC-RAS 6.0.0. The simulation was carried out using 25 year planned flood discharge with smaller variations in discharge changes, namely Q1, Q2 and Q3. In general, the simulation results show that changes in flood discharge determine the magnitude of changes in sediment rates, the greater the flow discharge, the higher the sediment rate, both with and without check dams. The simulation results also show that the sediment rate in conditions with a check dam has decreased compared to conditions without a check dam, this shows that the presence of a check dam can reduce the sediment rate that occurred before the check dam was built.*

**Keywords:** *Check dam; Middle Segment of Batang Kuranji; Sedimentation Rate; Planned Flood Discharge.*

Copyright © Septi Wila Zarinda, Darwizal Daoed, Nurhamidah
This is an open access article under the: https://creativecommons.org/licenses/by/4.0/

## INTRODUCTION

Sedimentation is the process of deposition of material transported by flows from upstream, which occurs through process of erosion, transport, deposition and compaction of the sediment itself. Sediment transport that occurs from upstream to downstream can be expressed in volume per unit time which is called sediment rate [1], [2]. Sediment rate at high river bed slopes can cause scouring in the river which can make the water flow unstable, thus causing a buildup of sediment. The rate of sediment in the river cannot stop, so if it is allowed to continue continously it will cause the river flow to be disrupted. One effort to control sediment is to build the check dam.

The middle segment of Batang Kuranji is one of the rivers in the Batang Kuranji River Basin which has a very high river slope, causing sediment movement in the river bed [3]. Based on a report from BWSS V in 2011, it was found that the sediment rate occuring in the middle segment of Batang Kuranji was quite large, namely around ± 566.81 ton/day, so a sediment control building (check dam) was built.
The sediment rate will not occur without the presence of water flow (discharge), in this case is the planned flood discharge. Based on this, research was carried out regarding the effect of

changes in planned flood discharge on the sedimentation rate in the middle segment of the Batang Kuranji check dam.

### Location of Study

The study location is in the middle segment of Batang Kuranji check dam at latitude 0°55'31.44" S and longitude 100°25'51.79" E, located around ± 420.2 meters from Gunung Nago Kuranji weir. The location can be seen in Figure 1.


Figure 1. The study location is in the middle segment of Batang Kuranji

## MATERIALS AND METHODS

### Sediment

Sediment is a product of rock disintegration and decomposition. Disintegration is the entire process in which rocks are damaged or broken into small grains without changing the chemical substance, while decomposition refers to the breakdown of rock mineral components by chemical reactions in the form of carbonation, hydration, oxidation and solutions processes [4]. The charatectistics of sediment particles include size, shape, volume weight, specific gravity and falling speed of the sediment particles themselves.

### Sedimentation Rate

The rate of sedimentation or sediment transport is the volume of sediment lifted per unit area per unit time. The speed of sediment to be deposition is influenced by several factors, namely current speed, river discharge, tides and other hydrooceanographic factors [5]. Sediment transport in rivers occurs continously without stopping. The critical speed is influenced by variable flow depth, channel slope and channel roughness [6].

Sediment transport is grouped based on 2 methods, namely sediment transport as basic material and sediment transport as wash load. Sediment transport as basic material consist of bed load and suspended load. Sediment transport as wash load is sediment that has a very fine grain size. Several sediment transport methods that can be used to analyze the behavior of sedimentation rates using HEC-RAS software are the Ackers-White, Engelund-Hansen, Laursen (Copeland), Meyer Peter Muller, Toffaleti, Yang, dan Wilcock-Crowe [7].

**Estimation Formula of Sedimentation Rate**
The rate of sediment is based on diameter of the material and velocity of the flow which the flow is in unsteady flow conditions, this is estimated based on several formulas that have been issued by previous researchers [8].

Einstein method (1942) and Brown (1950) stated :

$$\Phi = 40\,(1/\psi)^3 \quad (1)$$

$$\Psi = \frac{(\rho_s - \rho)\,D}{\rho R' S_0} \quad (2)$$

$$\Phi = q_s \sqrt{\frac{\rho}{(\rho_s - \rho)\,g D^3}} \quad (3)$$

Meyer Peter Muller method gives the following equation [9] :

$$\left(\frac{K_s}{K_r}\right)^{3/2} .\gamma.\mathrm{R}\,.\,\mathrm{S} = 0{,}0407(\gamma_s - \gamma)d_m + 0{,}25\left(\frac{\gamma}{g}\right)^{1/3}\left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{2/3} {q_b}^{2/3} \quad (4)$$

Where, qs = qb = sedimen discharge per unit width, D = sediment diameter, ρs = mass density, Ks = roughness coefficient, Kr = grain roughness coefficient, d90 = grain diameter 90, γs = sediment specific gravity, γ = specific gravity of water, g = gravity.

**Sediment Control Building (*Check dam*)**
Check dam is a sediment control structure that is created due to the presence of a flow with a fairly large concentration of sediment, the sediment come from soil erosion in the upstream part of the river [10]. Check dam building is a debris or lava flow control structure, which built across a river channel has the working principle of controlling sediment by holding, accommodate and flow material/sand carried by the flow and releasing water downstream [11]. In the body of check dam building, flow holes (drop holes / drain holes) are made.
Various type of check dam based on shape, layout and function of view [12].

1. Type of check dam based on shape, namely close type and open type.
2. Type of check dam based on layout, namely single type, continuous type, and level type.
3. Type of check dam based on function, namely control type, consolidation type, and support type.

This research using HEC-RAS 6.0.0 software which has 3 elements that must be fulfilled, namely imitation of river data geometry, sediment data and quasy-unsteady flow data [13].

1. River geometry data was obtained along 1939 m with a cross section extending from river sta. +0.00 (downstream) to river sta. +39.00 (upstream).
2. Data of sediment is sediment discharge and grain gradation. Sediment discharge was obtained from the 2011 BWSS V report. Grain gradation was obtained from sieve analysis with sediment samples taken directly from the river. The sieve analysis test is based on ASTM D 422 – 63 [14]. In sediment data input using the 25 year planned flood discharge which has been calculated from hydrologic analysis.
3. Input quasy-unsteady flow data use downstream and upstream boundary condition. Use "normal depth condition" in the downstream section. In the upstream section, "flow series" condition are used, is hydrograph. In this research, Nakayasu"s synthetic unit hydrograph method was used [15].

The sediment rate simulation use Meyer Peter Muller method in HEC-RAS 6.0.0 with two condition, it's with check dam and without check dam condition. The sedimentation discharge prediction approach use unsteady flow condition using Meyer Peter Muller method [8].

## RESULTS AND DISCUSSION

Data of river geometry obtained is 1,939 km with cross section stretching from river sta. +0.00 to river sta. +39.00, where the check dam is located on river sta. +30.00. This simulation use planned flood discharge for 25 year with smaller variation in discharge changes, namely Q1 with value 343.81 m$^3$/s, Q2 with value 171.91 m$^3$/s and Q3 with value 85.95 m$^3$/s. The result of the sedimentation rate with check dam can be seen in Table 1 below.

Table 1. Simulation results of sedimentation rate values with check dam

| No. | River Sta. | River Width (m) | Sedimentation Rate (ton/day/m) | | |
|---|---|---|---|---|---|
| | | | Q1 = 343.81 m$^3$/s | Q2 = 171.91 m$^3$/s | Q1 = 85.95 m$^3$/s |
| 1 | 34 | 123.30 | 56.69 | 33.73 | 18.57 |
| 2 | 33 | 129.60 | 42.35 | 16.76 | 7.56 |
| 3 | 32 | 119.31 | 59.48 | 8.93 | 5.53 |
| 4 | 31 | 144.62 | 5.39 | 3.68 | 3.23 |
| 5 | ***30*** | 133.80 | 3.11 | 2.81 | 2.14 |
| 6 | 29 | 139.20 | 18.75 | 18.87 | 10.38 |
| 7 | 28 | 138.74 | 20.61 | 7.52 | 11.22 |
| 8 | 27 | 123.39 | 4.42 | 22.39 | 14.53 |
| 9 | 26 | 105.32 | 41.00 | 25.42 | 16.33 |
| 10 | 25 | 169.60 | 3.92 | 2.13 | 1.14 |

The result of the sedimentation rate without check dam can be seen in Table 2 below.

Table 2. Simulation results of sedimentation rate values without check dam

| No. | River Sta. | River Width (m) | Sedimentation Rate (ton/day/m) | | |
|---|---|---|---|---|---|
| | | | Q1 = 343.81 m$^3$/s | Q2 = 171.91 m$^3$/s | Q1 = 85.95 m$^3$/s |
| 1 | 34 | 123.30 | 56.69 | 33.73 | 18.57 |
| 2 | 33 | 129.60 | 42.27 | 16.90 | 7.55 |
| 3 | 32 | 119.31 | 59.64 | 11.30 | 5.62 |
| 4 | 31 | 144.62 | 6.93 | 4.64 | 6.07 |
| 5 | ***30*** | 133.80 | 6.27 | 4.16 | 3.28 |
| 6 | 29 | 139.20 | 28.50 | 23.76 | 13.27 |
| 7 | 28 | 138.74 | 40.81 | 9.13 | 11.31 |
| 8 | 27 | 123.39 | 24.74 | 22.95 | 14.54 |
| 9 | 26 | 105.32 | 39.02 | 25.91 | 16.41 |
| 10 | 25 | 169.60 | 4.06 | 2.21 | 1.17 |

Based on a report from BWSS V in 2011, it was found that sediment rate in the middle segment of Batang Kuranji was quite large, it's ± 566.81 ton/day. In Table 3 below, the sedimentation rate value in 2011 per cross section unit.

Table 3. Sedimentation rate values in 2011

| No. | River Sta. | River Width (m) | Sedimentation Rate in 2011 | |
|---|---|---|---|---|
| | | | (ton/day) | (ton/day/m) |
| 1 | 34 | 123.30 | 566.81 | 4.60 |
| 2 | 33 | 129.60 | 566.81 | 4.37 |
| 3 | 32 | 119.31 | 566.81 | 4.75 |
| 4 | 31 | 144.62 | 566.81 | 3.92 |
| 5 | ***30*** | 133.80 | 566.81 | 4.24 |
| 6 | 29 | 139.20 | 566.81 | 4.07 |
| 7 | 28 | 138.74 | 566.81 | 4.09 |
| 8 | 27 | 123.39 | 566.81 | 4.59 |
| 9 | 26 | 105.32 | 566.81 | 5.38 |
| 10 | 25 | 169.60 | 566.81 | 3.34 |

The result of simulation in this research it's sedimentation rate with check dam and without check dam, with variation of discharge, namely Q1, Q2, and Q3.

**Comparison of Sedimentation Rates in 2011 with Simulations without Check dam**

Rate of sedimentation in 2011 is data when the check dam in the middle segment of Batang Kuranji has not yet been built. The data is compared with simulation of sedimentation rate without check dam. In Figure 2, it can be seen that sedimentation rate simulation result is closest to the sediment rate data in 2011, namely the sediment rate with discharge variation Q3. If seen the result of simulation in this research, it can be said that the data of sediment rate in 2011 is not obtained under maximum planned flood discharge condition.

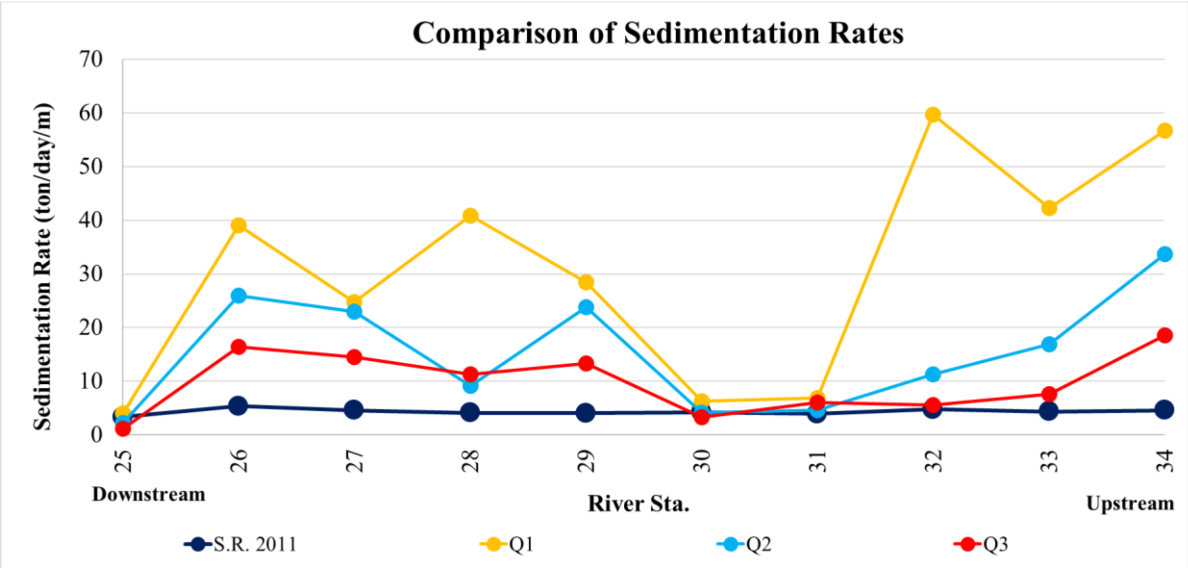

Figure 2. Sedimentation rate graph without check dam at Sta. +25 to Sta. +34

CIVED Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.1 March 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

**Comparison of Sedimentation Rates in 2011 with Simulations with a Check dam**

In Figure 3, it can be seen that the value of sediment rate with check dam in three discharge variation is smaller than the sediment rate in 2011, which can be seen in river sta. +30 where the check dam is located. where Simulasi laju sedimen dengan *check dam* dibandingkan dengan data laju sedimen tahun 2011. This explain that existence of the check dam is able to reduce the rate of sedimentation in the middle segment of Batang Kuranji.

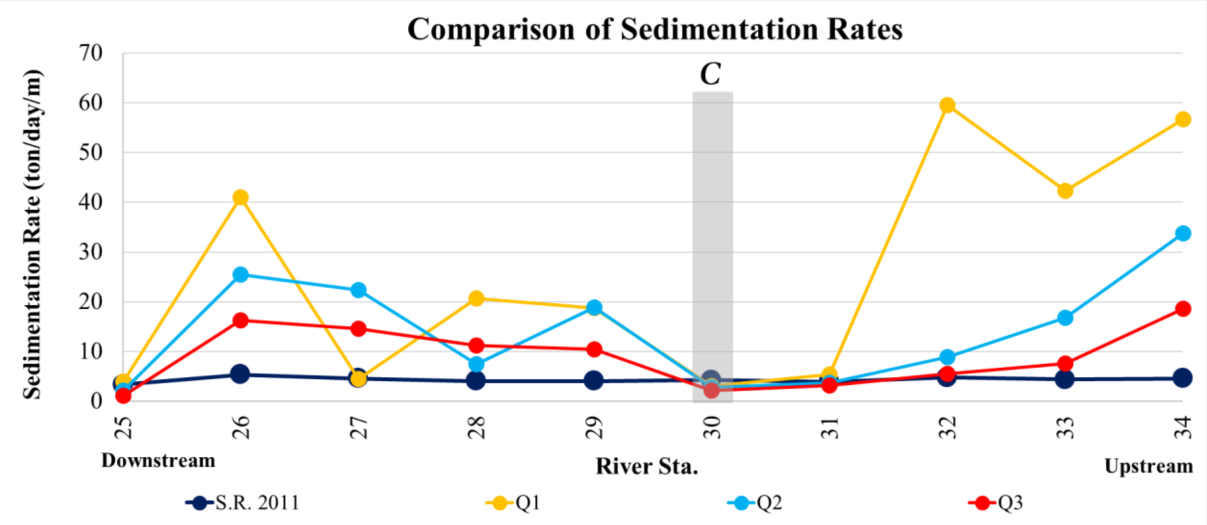


Figure 3. Sedimentation rate graph with check dam at Sta. +25 to Sta. +34

**Changes in Flood Discharge on Sedimentation Rate Sta. +31**

The result of changes in flood discharge variation Q1, Q2, and Q3 on changes in sediment rate at sta. +31 can be seen in Figure 4 below.

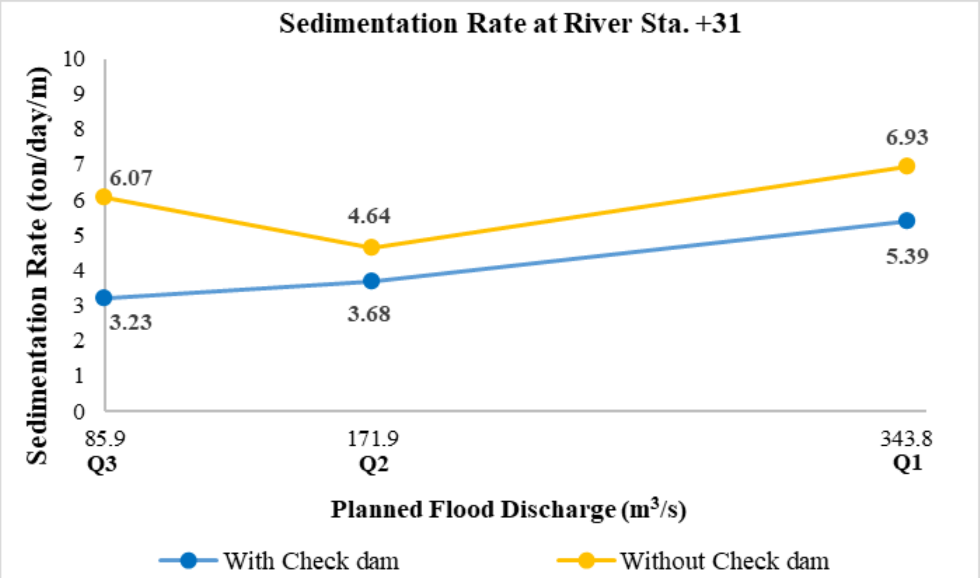


Figure 4. Changes in flood discharge on sedimentation rate at Sta. +31

In Figure 4, it can be seen that there are 2 sediment rate condition, it's condition with check dam and without check dam.

In condition with check dam:

1. The result of sediment rate using Q1 is 5.39 ton/day/m.

CIVED Journal of Civil Engineering and Vocational Education
EISSN: 2622-6774
Vol 11 No.1 March 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

2. The result of sediment rate using Q2 is 3.68 ton/day/m, this value is smaller than using Q1. Sediment rate using Q2 is decreased by 31.81% from Q1.
3. The result of sediment rate using Q3 is 3.23 ton/day/m, this value is smaller than using Q1 and Q2. Sedimen rate using Q3 is decreased 40.17% from Q1.

In condition without check dam:

1. The result of sediment rate using Q1 is 6.93 ton/day/m.
2. The result of sediment rate using Q2 is 4.64 ton/day/m, this value is smaller than using Q1. Sediment rate using Q2 is decreased by 33.07% from Q1.
3. The result of sediment rate using Q3 is 6.07 ton/day/m, this value is greater than using Q2 and smaller than using Q1. Sediment rate using Q3 is increased by 30.98% than Q2 and decreased by 33.07% than Q1.

Comparison of sediment rate in condition with check dam and without check dam :

1. In Q1, it show that the sediment rate with check dam is decreased by 1.54 ton/day/m or 22.20 %.
2. In Q2, it show that the sediment rate with check dam is decreased by 0.96 ton/day/m or 20.74 %.
3. In Q3, it show that the sediment rate with check dam is decreased by 2.85 ton/day/m or 46.90 %.

**Changes in Flood Discharge on Sedimentation Rate Sta. +30**

The result of changes in flood discharge variation Q1, Q2, and Q3 on changes in sediment rate at sata. +30 can be seen in Figure 5 below.

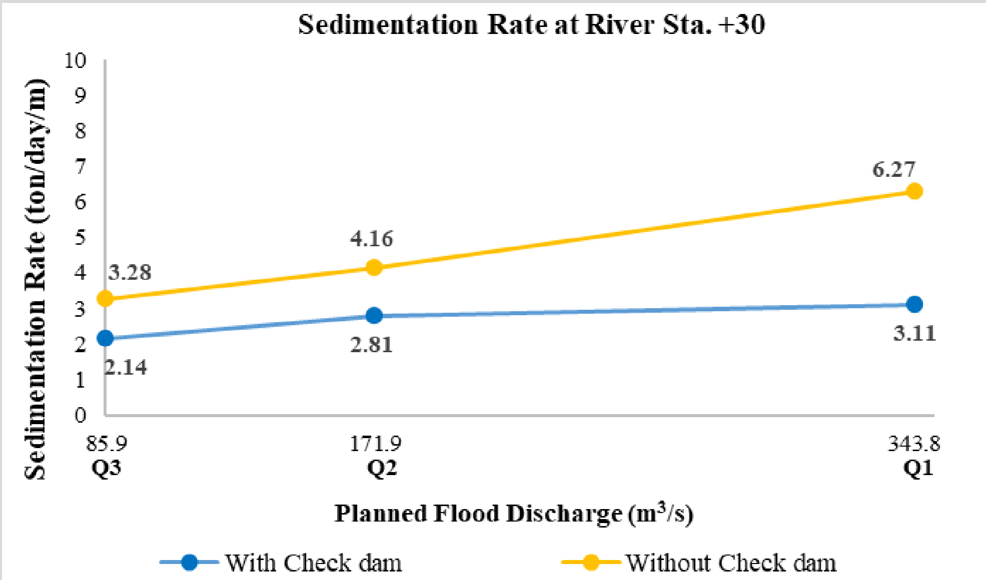


Figure 5. Changes in flood discharge on sedimentation rate at Sta. +30

In Figure 5, it can be seen that there are 2 sediment rate condition,it's condition with check dam and without check dam.

In condition with check dam:

1. The result of sediment rate using Q1 is 3.11 ton/day/m.
2. The result of sediment rate using Q2 is 2.81 ton/day/m, this value is smaller than using Q1. Sediment rate using Q2 is decreased by 9.68% from Q1.

3. The result of sediment rate using Q3 is 2.14 ton/day/m, this value is smaller than using Q1 and Q2. Sediment rate using Q3 is decreased by 31.12% from Q1.

In condition without check dam:

1. The result of sediment rate using Q1 is 6.27 ton/day/m.
2. The result of sediment rate using Q2 is 4.16 ton/day/m, this value is smaller than using Q1. Sediment rate using Q2 is decreased by 33.71% from Q1.
3. The result of sediment rate using Q3 is 3.28 ton/day/m, this value is smaller than using Q1 and Q2. Sediment rate using Q3 is decreased by 47.78% from Q1.

Comparison of sediment rate in condition with check dam and without check dam :

1. In Q1, it show that the sediment rate with check dam is decreased by 3.17 ton/day/m or 50.47 %.
2. In Q2, it show that the sediment rate with check dam is decreased by 1.35 ton/day/m or 32.52 %.
3. In Q3, it show that the sediment rate with check dam is decreased by 1.14 ton/day/m or 34.67 %.

**Changes in Flood Discharge on Sedimentation Rate Sta. +29**

The result of changes in flood discharge variation Q1, Q2, and Q3 on changes in sediment rate at sta. +29 can be seen in Figure 6 below.

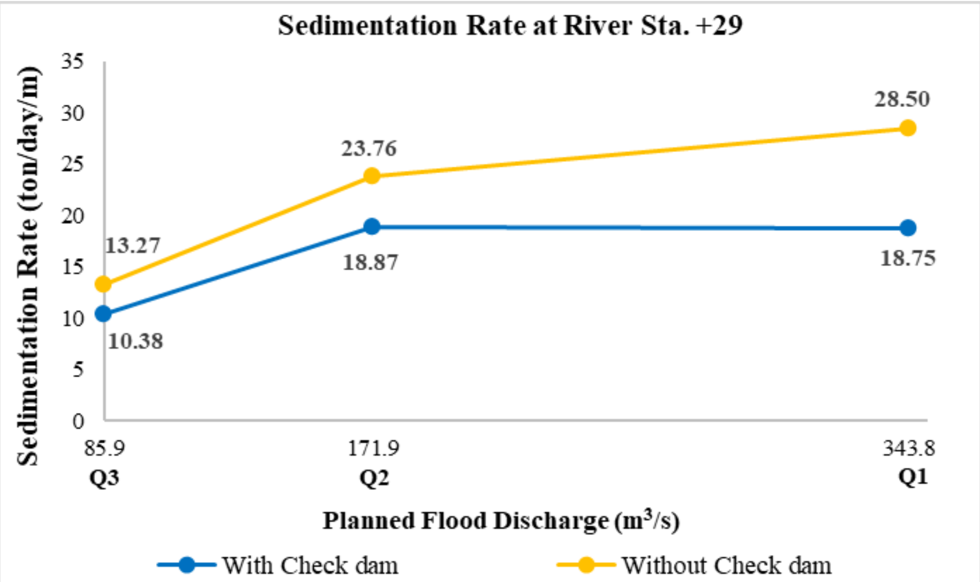


Figure 6. Changes in flood discharge on sedimentation rate at Sta. +29

In Figure 5, it an be seen that there are 2 sediment rate condition, it's condition with check dam and without check dam.

In condition with check dam:

1. The result of sediment rate using Q1 is 18.75 ton/day/m.
2. The result of sediment rate using Q2 is 18.87 ton/day/m, this value is smaller than using Q1. Sediment rate using Q2 is increased by 0.65% from Q1.
3. The result of sediment rate using Q3 is 10.38 ton/day/m, this value is smaller than using Q1 and Q2. Sediment rate using Q3 is decreased by 44.66% from Q1.

In condition without check dam:
1. The result of sediment rate using Q1 is 28.50 ton/day/m.
2. The result of sediment rate using Q2 is 23.76 ton/day/m, this value is smaller than using Q1. Sediment rate using Q2 is decreased by 16.64% from Q1.
3. The result of sediment rate using Q3 is 13.27 ton/day/m, this value is smaller than using Q1 and Q2. Sediment rate using Q3 is decreased by 53.44% from Q1.

Comparison of sediment rate in condition with check dam and without check dam :
1. In Q1, it show that the sediment rate with check dam is decreased by 9.76 ton/day/m or 34.22 %.
2. In Q2, it show that the sediment rate with check dam is decreased by 4.89 ton/day/m or 20.57 %.
3. In Q3, it show that the sediment rate with check dam is decreased by 2.90 ton/day/m or 21.83 %.

**Effect of Changes in Discharge on Sedimentation Rate**

The effect of changes in discharge Q1, Q2 and Q3 onnsediment rate at sta. +31, sta. +30 dan sta. +29 can be seen in Table 4 below.

Table 4. Effect of changes in discharge on sedimentation rate

| **Discharge** | **Sedimentation Rate (ton/day/m)** | | | | | |
|---|---|---|---|---|---|---|
| | **With Check dam** | | | **Without Check dam** | | |
| | **Sta. +31** | **Sta. +30** | **Sta. +29** | **Sta. +31** | **Sta. +30** | **Sta. +29** |
| Q1 | 5.39 | 3.11 | 18.75 | 6.93 | 6.27 | 28.50 |
| Q2 | 3.68 | 2.81 | 18.87 | 4.64 | 4.16 | 23.76 |
| Q3 | 3.23 | 2.14 | 10.38 | 6.07 | 3.28 | 13.27 |

In Table 4, can be seen that the rate of sediment using Q1 at sta.+30 has the smallest value between all the sta. (cross section), both condition with check dam or without check dam. The same thing also happened in sediment rate using Q2 and Q3.

The difference in sediment rate at sta. +31 and sta. +30 :
1. In Q1, the sediment rate condition with check dam at sta. +30 is decreased by 2.28 ton/day/m from sta. +31. Sediment rate without check dam at sta. +30 is decreased by 0.66 ton/day/m from Sta. +31.
2. In Q2, the sediment rate condition with check dam at sta. +30 is decreased by 0.87 ton/day/m from sta. +31. Sediment rate without check dam at Sta. +30 is decreased by 0.48 ton/day/m from sta. +31.
3. In Q3, the sediment rate condition with check dam at sta. +30 is decreased by 1.09 ton/day/m from sta. +31. Sediment rate without check dam at sta. +30 is decreased by 2.79 ton/day/m from sta. +31.

The decrease in sediment rate condition with check dam at sta. +30 has greater value than condition without check dam. This is cause the effect of presence the check dam at sta. +30, it's cause value the rate of sediment is experienced a greater decline than the decrease of rate sediment without check dam condition. Rate of sediment with check dam is smaller than without check dam condition, it's make the decrease in sediment rate with check dam is greater than without check dam condition

The difference in sediment rate at sta. +30 and sta. +29:

1. In Q1, the sediment rate condition with check dam at Sta. +29 is decreased by 15.64 ton/day/m from Sta. +30. Sediment rate without check dam at Sta. +30 is increased by 22.23 ton/day/m from Sta. +30.
2. In Q2, the sediment rate condition with check dam at Sta. +29 is increased by 16.06 ton/day/m from Sta. +30. Sediment rate without check dam at Sta. +30 is increased by 19.6 ton/day/m from Sta. +30.
3. In Q3, the sediment rate condition with check dam at Sta. +29 is incerased by 8.24 ton/day/m from Sta. +30. Sediment rate without check dam at Sta. +30 is increased by 9.99 ton/day/m from Sta. +30.

The rate of sediment at sta. +29 is greater that sediment rate at sta. +30, due to high slope of the river bed at sta. +29. The increase in sediment rate with check dam is smaller than the sediment rate without check dam, this is due to the effect of the presence of the check dam.

## CONCLUSION

In general, changes in flood discharge can affect sediment rate, the greater the flood discharge, the greater sediment rate. At sta. +30, which is the point where the check dam is located, has smaller sediment rate when the flood discharge is reduced, whether in condition with check dam or without check dam. The same thing happened at sta. +31 which is the location point before location of check dam and sta. +29 which is the location point after check dam located. However, there are 2 simulation result where when the flow discharge is reduced is cause the sediment rate to be slightly higher, it's the result of sediment rate without check dam at sta. +31 using Q3 discharge increasing compared to the Q2 discharge however, is decreasing if compared with Q1 discharge. The second simulation is the result of sediment rate with check dam at sta. +29 using Q2 is slightly higher than Q1. This is cause by other factor beside flow discharge, it's the slope and elevation of the river bed, due to change in river bed elevation after the chek dam was built.

Overall, the simulation result show that the sediment rate in condition with check dam has decreased compared to condition without check dam, this show that presence of the check dam can reduce the sediment rate tha occurred the check dam was built.

## REFERENCE

[1] A. John Chadwick and J. C. Morfett, *Hydraulics in Civil Engineering: Allen & Unwin (Publisher) Ltd*. 1986.

[2] Z. Liu, "Sediment Transport," *Sediment Transp. Lab. Hydraul. og Havnebygning Instituttet Vand, Jord og Miljøteknik Aalborg Univ.*, 1998.

[3] S. Wila Zarinda, "Analisa Perilaku Laju Sedimentasi terhadap Check dam Series Batang Kuranji Segmen Tengah menggunakan Software HEC-RAS 6.0.0," *Thesis Master Degree. Dep. Tek. Sipil – Fak. Tek. Univ. Andalas*.

[4] R. Hambali and Y. Apriyanti, "Studi Karakteristik Sedimen dan Laju Sedimentasi Sungai Daeng – Kabupaten Bangka Barat," vol. 4, pp. 165–174, 2016.

[5] R. Rosyadewi and Z. Hidayah, "Perbandingan Laju Sedimentasi Dan Karakteristik

Sedimen Di Muara Socah Bangkalan Dan Porong Sidoarjo," *Juv. Ilm. Kelaut. dan Perikan.*, vol. 1, no. 1, pp. 75–86, 2020, doi: 10.21107/juvenil.v1i1.6832.

[6] D. Daoed, *Hidrolika dan Terapan untuk Saluran Terbuka*. Padang : CV Ferila, 2010.

[7] F. D. Nurwahyuni, "Analisis Sedimentasi pada DAS Kali Tanggul Kabupaten Jember menggunakan Program HEC-RAS 4.1," pp. 68–74, 2018.

[8] D. Daoed, S. Wila Zarinda, and B. Budi Irawan, "The effect of channel geometry and check dam location on sediment transport discharge in the Kuranji River," *E3S Web Conf.*, vol. 464, p. 01003, 2023, doi: 10.1051/e3sconf/202346401003.

[9] N. Achmad, "Persamaan Angkutan Sedimen Sungai," *Univ. Janabadra, Yogyakarta*, no. February, pp. 0–57, 2011.

[10] JICA, "Check Dam Construction," *Perenc. Check Dam*, 1998.

[11] S. Pusat Penelitian dan Pengembangan Sumber Daya Air, "Pusat Penelitian dan Pengembangan Sumber Daya Air," no. 022, 2014.

[12] C. Hassan, "Sabo Plan (Perencanaan Sabodam)," no. April, pp. 22–23, 2019.

[13] 2016 HEC-RAS Reference Manual, "HEC-RAS River Analysis System Hydraulic Reference Manual," *Hydrol. Eng. Cent.*, no. February, p. 547, 2016.

[14] 2021 Laboratorium Mekanika Tanah FT Universitas Andalas, "Laboratorium Mekanika Tanah," 2021.

[15] B. Triatmodjo, *Hidrologi Terapan*. 2008.