The effect of channel geometry and check dam location on sediment transport discharge in the Kuranji River

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Abstract. Rivers as infrastructure carry water from upstream to downstream to meet the water needs of communities along the river and as drainage. Therefore, it is necessary to maintain the stability of the river from erosion and sedimentation. Changes in river geometry are mostly caused by the high intensity of rainfall in the upstream section. This causes the geometry to change easily, many bends are found, river embankments collapse, and the slope and flow of the river change suddenly. As a result, water will wash away sediment from upstream to downstream with high sediment discharge. However, the sediment rate/discharge can be reduced by building a check dam, but it needs the right location so that the construction of the check dam is effective and the river flow is stable. Research using HEC-RAS has been carried out at the location of the middle section of the Kuranji River, where simulating three check dam locations shows that the reduction in sediment discharge is very effective, but other places are still the same as without the check dam. Therefore, it is recommended to build check dam series and groundsills at narrowing locations and strengthen river banks at Sta. 16 to Sta. 32.

1 Introduction

1.1 Background

Rivers and the shape of their channels are determined by the amount of rainfall, topography, and type of soil through which they flow. As a result, in areas with a steep slope, the river channel will be relatively straight, and conversely, in slightly sloping to flat areas, the river channel will be winding[1]. This results in the geometry of the river, in this case, the width and depth of the river, changing. In areas with steep slopes, the total potential energy will be large. The total potential energy will give rise to large kinetic energy in the downstream area. This energy is caused by the high flow velocity. Large kinetic energy will cause scouring to occur. Scour in the upstream area is more dominant due to subsidence of the channel bed and collapse of river banks. Sediment transport from upstream to downstream can be expressed in terms of sediment movement (volume) per unit time, called sediment rate or discharge [2, 3]. The report from BWSSV in 2011 resulted in measurements of sediment discharge in the Kuranji trunk which was quite large, namely around 566.8 tonnes/day. Also, the results of the field survey showed that several locations in the upstream area experienced collapse, such as river banks and degraded river beds.

Based on this, a study was carried out on the effectiveness of the weir construction location to control sediment discharge in the middle stream.

1.2 Location of study

The study location is in the middle stream of the Kuranji River at longitude 100° 25'17.17" E and latitude 0° 55'37.33" S. The river cliffs are still pristine rocky soil. The longitudinal slope varies, some are steep and gentle. The following are the study locations, Fig. 1. The study location is in the middle stream of the Kuranji River.

Fig. 1. The study location is in the middle stream of the Kuranji River.

The length of the Kuranji River investigated was approximately 2,000 m with a river width of between 80 m to 160 m. The river has bends and steep riverbanks from

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the ground covered with grass or wild plants. Geometrically, rivers have bends with external angles above 120°, widening, and narrowing, and the longitudinal slope of the river changes suddenly. This causes water to jump which has a local scouring effect and changes in flow speed. The narrowing also has the potential to collapse the river embankments on the left and right of the river body. Visually, this condition often begins with erosion at the base of the cliff. Next, the land above will collapse and the area of the collapsed area depends on the width of the erosion at the bottom, the type of soil, and the magnitude of the flow discharge. The collapsed cliffs on the Kuranji River cover the entire length of the river from the upstream to the middle areas [4-6].

2 Literature study

Sediment transport in rivers occurs continuously without any breaks. Sediment transport increases when the current speed exceeds the critical speed. As a result, the maximum shear stress is exceeded. The critical speed is influenced by variable flow depth, channel slope and channel roughness [7, 8]. This speed will make the material move at the bottom of the channel. The shift can roll and shift. The critical speed can be reduced by reducing the resistance or slope of the channel. Obstacles can be in the form of closed concrete partitions or perforated dams to drain flood water[9].

2.1 Construction of control sediment

Construction of control sediment is water structures in rivers that function as sediment retainers, gravity type, or other types Check dams can control the speed, discharge, and direction of sediment flow, accommodate sediment both permanently and temporarily.

Check dams consist of two types, namely, closed and perforated types. The water-covered type will pass through the top of the bend. Meanwhile, the perforated type with small discharge will pass through the drainage hole and can also pass through the top of the weir at maximum flow. Drainage holes are not only used to drain water but also to hold back drifts in the form of wood and other drift waste [9, 10].

2.2 Discharge of sediment estimation formula

Several formulas that have been issued by previous researchers estimate sedimentation discharge based on material diameter and flow velocity. The flow is in unsteady flow conditions. The following two formulas are used based on the parameters above:

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

$$\Phi = 40\,(1/\Psi)^3 \tag{1}$$

$$\Psi = \frac{(\rho_s-\rho)D}{\rho R\prime S_o} \tag{2}$$

$$\Phi = q_s\sqrt{\frac{\rho}{(\rho_s-\rho)}\frac{1}{gD^3}} \tag{3}$$

Mayer Peter Muller's method gives the following equation:

$$\left(\frac{K_s}{K_r}\right)^{3/2}\gamma\text{RS} = 0{,}0407(\gamma_s-\gamma)d_m + 0{,}25\left(\frac{\gamma}{g}\right)^{1/3}\left(\frac{\gamma_s-\gamma}{\gamma_s}\right)^{2/3} {q_b}^{2/3} \tag{4}$$

Where, $q_s = q_b$ sediment discharge per unit width, D = sediment diameter, ρ_s mass density. K_s = roughness coefficient, K_r = grain roughness coefficient, d_{90} = grain diameter 90, γ_s = sediment specific gravity, γ = specific gravity of water, g = gravity,

3 Methodology

In the simulation, Hec-RAS software was used with input data obtained from river geometry measurements and the final report from BWSS V 2011 sedimentation discharge from field tests. Sediment was taken directly from the river and subjected to sieve analysis based on the Indonesian National Standard (SNI 03-1968-1990).

Flood discharge over a 25-year period using a rational formula at outlets in the river basin. The area of the rain catchment area, type of land cover, and river density were used as base maps from the Geographic Information Agency (BIG), and rainfall intensity from BMKG Indonesia. Then the approach for predicting sedimentation discharge uses unsteady flow conditions with bed load transportation discharge calculations using the Einstein-Brown and Meyer Pieter Muller formulas.
The simulation was carried out at three different locations and what was observed was the amount of sedimentation discharge along the river before and after the check dam, along a length of approximately 2,000 m.

4 Result and discussion

4.1 Measurement of river cross section

The simulation was carried out to determine the amount of sediment discharge that is retained and that passes through the check dam in the middle segment of the Kuranji River. The input data is river geometry approximately 2000 m long and processed using HEC-RAS 6.0.0 software. The position or location of the check dam varied throughout the research area. There are 3 simulations in this research, namely: simulation 1, the check dam is on River Sta. 1550 m, simulation 2, check dam is on River Sta. 1200 m and simulation 3, the check dam is on River Sta. 860 m downstream. Each simulation uses the Meyer Peter Muller method.

The results of measuring channel cross sections and longitudinal slopes are as shown in. Table 1. Cross-sectional dimensions and river slopeThere are several locations that have large slopes that are close to steep. Although the other locations are a bit flat. At stations 35, 36 and 39, for example, the slopes are quite steep and steep with $S_{o.} > 7\%$ and others less than 7.0%.

Table 1. Cross-sectional dimensions and river slope.

Sta.	Width	Total distance	Elv. Min	Slope	Width difference
	(m)	(m)	(m)		(m)
39	104.4	1939.0	96.0	12%	25.6
38	130.0	1905.0	91.9	1%	0.4
37	130.4	1861.0	91.4	1%	-25.8
36	104.6	1815.8	90.9	1%	4.6
35	109.2	1757.8	90.4	16%	14.1
34	123.3	1705.8	82.2	7%	6.3
33	129.6	1669.8	79.7	3%	-10.3
32	119.3	1637.8	78.8	7%	25.3
31	144.6	1574.8	74.1	0%	-10.8
30	133.8	1518.8	74.1	0%	5.4
29	139.2	1468.8	74.1	0%	-0.5
28	138.7	1418.8	74.0	1%	-15.4
27	123.4	1374.4	73.7	3%	-18.1
26	105.3	1324.4	72.3	1%	64.3
25	169.6	1265.4	72.0	0%	-16.1
24	153.5	1207.4	71.8	1%	-82.2
23	71.3	1161.2	71.3	2%	89.1
22	160.4	1111.2	70.1	-1%	-13.5
21	146.9	1063.0	70.8	1%	9.8
20	156.7	1017.0	70.6	2%	-31.0
19	125.7	967.0	69.7	1%	9.9
18	135.6	917.0	69.4	2%	33.2
17	168.8	867.0	68.5	2%	-6.6
16	162.2	815.0	67.4	-2%	-59.7
15	102.5	759.0	68.3	4%	58.6
14	161.1	707.0	66.1	3%	-19.6
13	141.5	654.0	64.7	3%	-6.6
12	134.9	602.0	63.0	3%	-18.0
11	116.9	552.0	61.7	-1%	31.3
10	148.2	502.0	62.0	1%	31.9
9	180.1	454.6	61.6	2%	-24.8
8	155.4	398.6	60.4	1%	-9.5
7	145.8	349.4	60.0	1%	30.1
6	175.9	294.4	59.3	4%	6.6
5	182.5	245.0	57.5	2%	-5.4
4	177.1	193.0	56.3	0%	-45.5
3	131.6	143.0	56.2	3%	22.4
2	154.0	93.0	54.6	2%	-15.0
1	139.0	48.0	53.6	0%	3.5
0	142.5	0.0	53.6	-	0.0

Meanwhile, from the cross-section of the river, we can see quite significant changes in the width of the cross-section (B). The difference in river bed width is negative, which means narrowing and positive, which means widening. The surface width (T) is slightly larger than the difference in river bed width.

The calculation assumes that the cross section of the river is rectangular, where the bottom width is the same as the surface width of the cross section. The change in channel base width is relatively "sudden", because the change distance is so close. So it seems as if the flow passes through an obstacle. Overall pressure height due to speed and total energy will also change. This change is called energy loss along the flow. Changing locations causes a slowdown or acceleration of flow. This change causes the flow properties from normal to supercritical or subcritical. If widening occurs, the flow speed will certainly decrease and the water depth will increase so that the F - number becomes greater than one, whereas narrowing will result in a F - number smaller than one.

As for

Fig. 2. Distance to elevation and river width is an illustration of the measurement results from Table 1. Cross-sectional dimensions and river slope, where there is a fairly steep river slope upstream and steeper downstream, as below. However, if you look at it in general, the slope of the river is relatively gentle. On the other hand, the width of the river at distances, 93 m, 193 m, 502 m, 750 m, 980 m, 1150 m, and 1350 is narrow, while the others are wide.

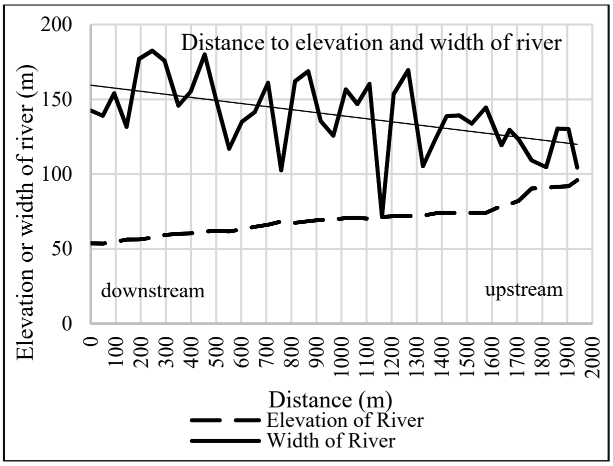

Fig. 2. Distance to elevation and river width.

4.2 Simulation of sediment discharge due to changes in check dam location

The simulation uses Hec-RAS software with input data from cross-sectional measurements, check dam locations and planned flood discharge with a return period of 25 years. Check dams are simulated at three different locations. Dam location with consideration of stationing where extreme changes in geometry (narrowing and steep slopes), as in
Fig. 2. Distance to elevation and river width.Simulation - 1 check dam is placed at stationing (STA) 1567 m, simulation - 2 at STA 1207 m and simulation - 3 at STA 867 m from downstream.

Simulation results -1, as in Table 2. Simulation results – 1 with check dam position at a distance of 1567 m from downstream and Fig. 3. Discharge of sediment with check dam at a distance of 1567 m from downstream. In the table and figure, it can be seen that the sediment transport.

Table 2. Simulation results – 1 with check dam position at a distance of 1567 m from downstream.

Sta	Distance	with check dam		without check dam	
	(m)	ton/day	ton/day/m	ton/day	ton/day/m
34.0	1939.0	75.9	0.7	75.9	0.7
44.0	1905.0	6564.4	50.5	6564.4	50.5
45.2	1861.0	1253.2	9.6	1253.2	9.6
58.0	1815.8	819.3	7.8	819.3	7.8
52.0	1757.8	4981.8	45.6	4981.8	45.6
36.0	1705.8	6989.5	56.7	6989.5	56.7
32.0	1669.8	5488.3	42.3	5477.9	42.3
63.0	1637.8	7096.0	59.5	7115.9	59.6
56.0	1574.8	779.7	5.4	1002.3	6.9
50.0	1518.8	415.7	3.1	839.4	6.3
50.0	1468.8	2609.8	18.7	3967.8	28.5
44.4	1418.8	2859.6	20.6	5662.5	40.8
50.0	1374.4	545.7	4.4	3053.2	24.7
59.0	1324.4	4318.1	41.0	4109.6	39.0
58.0	1265.4	664.0	3.9	689.0	4.1
46.2	1207.4	6874.1	44.8	2260.3	14.7
50.0	1161.2	2100.5	29.4	2097.7	29.4
48.2	1111.2	1042.2	6.5	1044.6	6.5
46.0	1063.0	4529.1	30.8	4467.7	30.4
50.0	1017.0	1051.9	6.7	1179.7	7.5
50.0	967.0	5075.5	40.4	5072.6	40.4
50.0	917.0	7011.0	51.7	7008.5	51.7
52.0	867.0	1587.3	9.4	1585.3	9.4
56.0	815.0	1021.0	6.3	1020.4	6.3
52.0	759.0	4076.3	39.8	4071.1	39.7
53.0	707.0	3375.8	21.0	3375.7	21.0
52.0	654.0	4906.3	34.7	4094.4	28.9
50.0	602.0	5777.0	42.8	5772.6	42.8
50.0	552.0	6909.1	59.1	6907.5	59.1
47.4	502.0	5005.4	33.8	5001.6	33.7
56.0	454.6	5809.6	32.3	5806.5	32.2
49.2	398.6	7655.2	49.3	7654.7	49.3
55.0	349.4	4929.0	33.8	4928.9	33.8
49.4	294.4	7633.8	43.4	7631.4	43.4
52.0	245.0	4610.8	25.3	4609.2	25.3
50.0	193.0	6261.8	35.4	6261.0	35.4
50.0	143.0	889.2	6.8	1993.6	15.2
45.0	93.0	7608.3	49.4	7657.5	49.7
48.0	48.0	1555.5	11.2	1555.3	11.2
0.0	0.0	3529.4	24.8	3527.5	24.7

Debit of sediment decreased before the dam and after the check dam compared to conditions without the check dam. Meanwhile, other areas are the same as without check dams.

Simulation - 2 with the check dam position placed at a distance of 1207 m from the downstream of the river. The simulation results are shown in Table 3. Simulation results – 2 with check dam position at a distance of 1207 m from downstream and

Fig. 4. Discharge of sediment with check dam at a distance of 1207 m from downstream, there appears to be an increase due to the fact that in the downstream area of the check dam there is a narrowing and a change in the longitudinal slope which is quite steep.

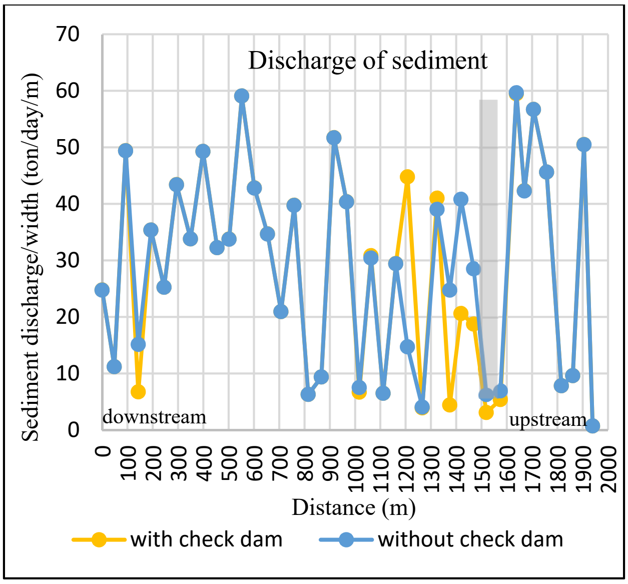

Fig. 3. Discharge of sediment with check dam at a distance of 1567 m from downstream.

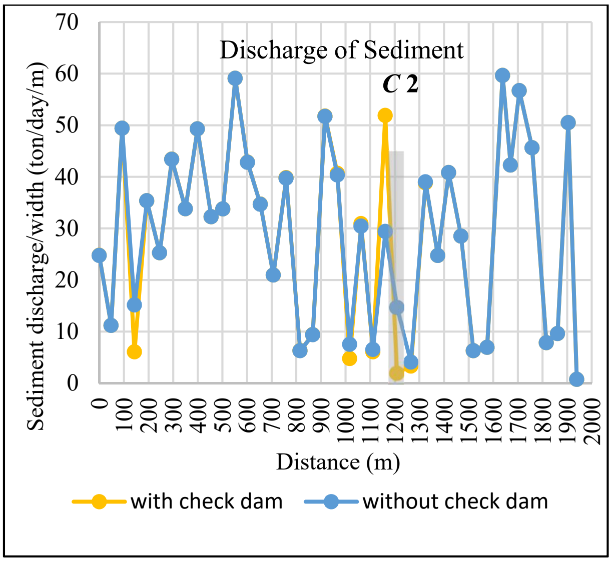

Fig. 4. Discharge of sediment with check dam at a distance of 1207 m from downstream.

The sediment discharge transported after the check dam increased compared to conditions without the check dam, but in the range of 100 - 200 m there was a decrease in sediment transport. For other locations there are no changes with and without check dams.

Table 3. Simulation results – 2 with check dam position at a distance of 1207 m from downstream.

Sta	Distance	h check dam		Without Check dam	
	(m)	ton/day	ton/day/m	ton/day	ton/day/m
34.0	1939.0	75.9	0.7	75.9	0.7
44.0	1905.0	6564.4	50.5	6564.4	50.5
45.2	1861.0	1253.2	9.6	1253.2	9.6
58.0	1815.8	819.3	7.8	819.3	7.8
52.0	1757.8	4981.8	45.6	4981.8	45.6
36.0	1705.8	6989.5	56.7	6989.5	56.7
32.0	1669.8	5477.9	42.3	5477.9	42.3
63.0	1637.8	7115.9	59.6	7115.9	59.6
56.0	1574.8	1002.1	6.9	1002.3	6.9
50.0	1518.8	839.4	6.3	839.4	6.3
50.0	1468.8	3967.7	28.5	3967.8	28.5
44.4	1418.8	5662.5	40.8	5662.5	40.8
50.0	1374.4	3053.9	24.8	3053.2	24.7
59.0	1324.4	4087.6	38.8	4109.6	39.0
58.0	1265.4	561.1	3.3	689.0	4.1
46.2	1207.4	304.6	2.0	2260.3	14.7
50.0	1161.2	3700.7	51.9	2097.7	29.4
48.2	1111.2	971.6	6.1	1044.6	6.5
46.0	1063.0	4540.3	30.9	4467.7	30.4
50.0	1017.0	747.5	4.8	1179.7	7.5
50.0	967.0	5110.4	40.7	5072.6	40.4
50.0	917.0	7017.5	51.7	7008.5	51.7
52.0	867.0	1591.0	9.4	1585.3	9.4
56.0	815.0	1021.8	6.3	1020.4	6.3
52.0	759.0	4080.7	39.8	4071.1	39.7
53.0	707.0	3376.1	21.0	3375.7	21.0
52.0	654.0	4907.4	34.7	4094.4	28.9
50.0	602.0	5778.6	42.8	5772.6	42.8
50.0	552.0	6909.7	59.1	6907.5	59.1
47.4	502.0	5005.9	33.8	5001.6	33.7
56.0	454.6	5809.8	32.3	5806.5	32.2
49.2	398.6	7655.2	49.3	7654.7	49.3
55.0	349.4	4929.0	33.8	4928.9	33.8
49.4	294.4	7633.8	43.4	7631.4	43.4
52.0	245.0	4610.8	25.3	4609.2	25.3
50.0	193.0	6261.8	35.4	6261.0	35.4
50.0	143.0	796.2	6.1	1993.6	15.2
45.0	93.0	7608.2	49.4	7657.5	49.7
48.0	48.0	1555.5	11.2	1555.3	11.2
0.0	0.0	3529.5	24.8	3527.5	24.7

Simulation results -3 with check dam position at a distance of 867 m from downstream, are obtained as Table 4. Simulation results – 3 with check dam position at a distance of 867 m from downstream and Fig. 5. Discharge of sediment with check dam at a distance of 867 m from downstream.

Table 4. Simulation results – 3 with check dam position at a distance of 867 m from downstream.

Sta	Distance	With check dam		Without Check dam	
	(m)	ton/day	ton/day/m	ton/day	ton/day/m
34.0	1939.0	75.9	0.7	75.9	0.7
44.0	1905.0	6564.4	50.5	6564.4	50.5
45.2	1861.0	1253.2	9.6	1253.2	9.6
58.0	1815.8	819.3	7.8	819.3	7.8
52.0	1757.8	4981.8	45.6	4981.8	45.6
36.0	1705.8	6989.5	56.7	6989.5	56.7
32.0	1669.8	5477.9	42.3	5477.9	42.3
63.0	1637.8	7115.9	59.6	7115.9	59.6
56.0	1574.8	1002.1	6.9	1002.3	6.9
50.0	1518.8	839.4	6.3	839.4	6.3
50.0	1468.8	3967.7	28.5	3967.8	28.5
44.4	1418.8	5662.5	40.8	5662.5	40.8
50.0	1374.4	3054.3	24.8	3053.2	24.7
59.0	1324.4	4109.6	39.0	4109.6	39.0
58.0	1265.4	689.0	4.1	689.0	4.1
46.2	1207.4	2260.3	14.7	2260.3	14.7
50.0	1161.2	2097.7	29.4	2097.7	29.4
48.2	1111.2	1044.6	6.5	1044.6	6.5
46.0	1063.0	4467.8	30.4	4467.7	30.4
50.0	1017.0	1177.1	7.5	1179.7	7.5
50.0	967.0	5064.1	40.3	5072.6	40.4
50.0	917.0	1781.1	13.1	7008.5	51.7
52.0	867.0	821.0	4.9	1585.3	9.4
56.0	815.0	1001.5	6.2	1020.4	6.3
52.0	759.0	4070.9	39.7	4071.1	39.7
53.0	707.0	3374.5	20.9	3375.7	21.0
52.0	654.0	4904.6	34.7	4094.4	28.9
50.0	602.0	5772.9	42.8	5772.6	42.8
50.0	552.0	6907.6	59.1	6907.5	59.1
47.4	502.0	5001.9	33.8	5001.6	33.7
56.0	454.6	5807.2	32.2	5806.5	32.2
49.2	398.6	7654.4	49.3	7654.7	49.3
55.0	349.4	4928.8	33.8	4928.9	33.8
49.4	294.4	7631.7	43.4	7631.4	43.4
52.0	245.0	4609.4	25.3	4609.2	25.3
50.0	193.0	6261.2	35.4	6261.0	35.4
50.0	143.0	1998.6	15.2	1993.6	15.2
45.0	93.0	7607.6	49.4	7657.5	49.7
48.0	48.0	1555.4	11.2	1555.3	11.2
0.0	0.0	3528.0	24.8	3527.5	24.7

With check dam at a distance of 867 m from downstream, it can be seen that in the area near the check dam the decline in sedimentation discharge has dropped drastically with a quite significant difference from 51 tons/day/m to below 9 tons/day/m.

In Fig. 5. Discharge of sediment with check dam at a distance of 867 m from downstream shows that the amount of sediment transport is almost the same, where upstream of the weir the sediment discharge decreases, and after the weir the sediment discharge appears to increase and is the same as without the check dam distance of 867 m from downstream.

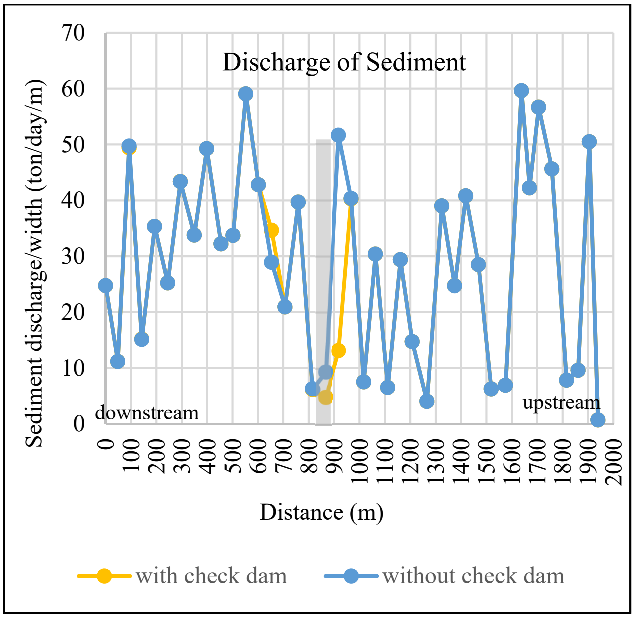

Fig. 5. Discharge of sediment with check dam at a distance of 867 m from downstream.

4.3 Discussion

The cross section of the Kuranji River shows changes in the width of the river bed, in accordance with the behaviour of the river which is short and straight[1, 11]. Changes in both narrowing and widening come and go, so this is one of the factors causing the influence of check dams to not be very useful in disaster control. Moreover, it has joined the river slope in a long direction, which in several places is in the steep category at Sta. 32, 34 and 39.

Overall, using a check dam can reduce sedimentation discharge. But in simulation -2 and simulation -3 where after the weir there was an increase. This is due to narrowing and sudden changes in slope, see Figure. 2 Distance to elevation and river width. It also has an impact on downstream locations which produce results with and without check dams that are almost the same [10-12].

Therefore, when just one check dam is used and placed anywhere, the effect is not very significant. Except for locations upstream from the check dam. This is in accordance with the opinion of several previous researchers, that dams can reduce sediment transport, but it will increase after check dams [13-15] Increased sediment discharge as a result of the jump from the water that falls after the weir. For this reason, it needs to be equipped with ground sills or energy absorbers [16-19]. The next action for the middle segment of the Kuranji River requires placing check dams in several extreme places. This type of sediment control system is usually called a series dam [20, 21]

5 Conclusion

In general, the effect of check dam placement can influence the magnitude of sediment transport downstream of the weir, but upstream of the weir it can reduce the rate or sediment discharge. Changes in the magnitude of sediment transport after the check dam can be greater, as a result of changes in the dimensions of the width of the channel bed and the slope of the channel in the longitudinal direction. All of this can be controlled by making groundsills or installing mountain rocks (rip-rap) as energy absorbers.

The Kuranji River can make sediment control more effective by arranging the location of the check dam series, namely at distances of 150 m, 550 m, 750 m, 950 m, 1200 m, 1400 m and 1850 m. Varying cross-sectional areas of rivers due to narrowing or widening will cause local scouring to occur at the foot of river cliffs. Next there will be a collapse of the river bank. For this reason, regular maintenance is needed by creating a groundsill or energy absorber.

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