IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 19, Issue 4 Ser. III (Jul. – Aug. 2022), PP 57-64
www.iosrjournals.org

Study of Sediment Capture Dimensions in Sand Trap at Kertosari Weir, Jember Regency

Nanang Saiful Rizal[1*], Amang Susanto[2]and Arief Alihudien[3]
[1,2,3]*Department of Civil Engineering, University Of Muhammadiyah Jember, Indonesia*
**Corresponding Author*

Abstract:
Kertosari dam was built to irrigate an irrigation area of 2,056 Ha with a length of 14,659 Km of Kertosari irrigation canal. As a result of the non-optimal function of the sand trap to capture sediment, sedimentation occurs in the irrigation canal so that the carrying capacity of irrigation water discharge is reduced, eventually decreasing agricultural production in the long term which will hamper the self-sufficiency program launched by the government. Based on the results of the calculation of the amount of sediment transport that occurs the Kertosari Dam is 8,312 tons/day or 3,160 m3/day. Furthermore, the results of the sand trap planning (V) = 284.43 m3 280 m3. For LB = 1195,462 m2, because Fr < 1 then: 0,583 < 1 with 0 = 9.039 N/m2. When the sand trap is full and empty = 47.54>1.667, the sediment that has settled in the full or empty sand trap can no longer be eroded into floating cargo.

Key words: *Sand trap; Kertosari weir; Flying sediment; Sediment settling*

Date of Submission: 18-08-2022 Date of Acceptance: 31-08-2022

I. Introduction

Water and its sources, including the natural resources contained therein, have a social function and are used for the greatest prosperity of the people. Therefore, its utilization must be planned in such a way, so that the water can be utilized as much as possible, efficiently, fairly and evenly. The rapid development of population and industry, especially in Java, has disrupted the balance between supply and use of irrigation water. On the one hand the availability of water and its sources has decreased as a result of changes in catchment areas (deforestation etc.) and on the other hand the demand for water is increasing with various uses (agriculture, industry, housing, city flushing, etc.). Another problem also arises, namely increasing soil erosion so that the silt content in river water increases, which causes silting of irrigation canals to occur more quickly. It also affects drinking water supply, flood control and recreational activities [1] [10]. The Kertosari Irrigation Network is an irrigation channel where the water flows from the Mayang River Basin. The length of the Kertosari Irrigation Channel is 14,659 Km, with an irrigation area of 2,056 Ha. Kertosari Irrigation Network is one of the irrigation canals with high sedimentation. On average, this sedimentation occurs in every tapping building starting from the upstream tapping building, namely BKS-1 in Kertosari Village, Pakusari District, to the most downstream tapping building, BKS-11 in Wirowongso Village, Ajung District, Jember Regency.

The impact of this sedimentation has a very large influence on the flow of water flowing in the Kertosari Irrigation Network. With the shallowness due to sedimentation, the channel cross section will decrease in volume which automatically makes the water flow decrease or decrease. In the dry season, water users, especially farmers, will experience a decrease in agricultural production due to insufficient water discharge for the entire area of the Kertosari Irrigation Network. The biggest impact with the decline in agricultural production will also have an impact on food stocks even though the government is proclaiming food self-sufficiency. The relevant government has so far handled this problem by carrying out normalization activities manually by involving all PPA and Pekarya staff, both from Jember Regency and East Java Province workers whose work plots are in the UPT Sumbersari area, Jember Regency, including the Kertosari Irrigation Network and the Kottok Irrigation Network. . This manual normalization activity is less effective because the results obtained are less than optimal and also require no small amount of cost. To overcome this problem, it is very necessary to build a sand trap in the Kertosari Dam Primary Canal. The problems that occur due to sedimentation in the Kertosari Irrigation Network have been going on for years. Where the relevant agencies have tried to overcome this sedimentation problem by manually normalizing the channel, but the expected results are less than optimal and cost a lot of money. The construction of the sand trap building in the Kertosari

Dam primary channel is urgently needed. The construction of this sand trap must first be carried out in-depth analysis, where later this sand trap will function to avoid and reduce sediment transport in the Kertosari Irrigation Network. It is necessary to take into account the effectiveness of rinsing as well, it causes the sediment to easily settle in the sand trap. Periodically the sediment retained in the sand trap is removed, either manually or by rinsing [2]. The period between the two flushing periods is called the operational (settling) period. There is an important factor in determining the performance of the Kertosari weir, namely the efficiency of sediment trapping [3]. The trap efficiency is the ratio of deposited sediment to the total inflow for a certain period in a water structure [4] [8].

II. Material And Methods

Description of Study

The research location is located in the Kertosari Dam Irrigation area. Geographically, it is located at the coordinates of the weir 8°10'33.40”S, 113°47'21.70”E, administratively located in Kertosari Village, Pakusari District, Jember Regency. The Kertosari weir serves service areas for 5 villages namely Kertosari Village, Wirolegi Village, Kranjingan Village, Rowo Indah Village, Wirowongso Village and 3 sub-districts namely Kec. Pakusari, District. Sumbersari, Kec. Ajung. Technically, the channel length is 14,659 km with a standard rice field area of 2,056 hectares.

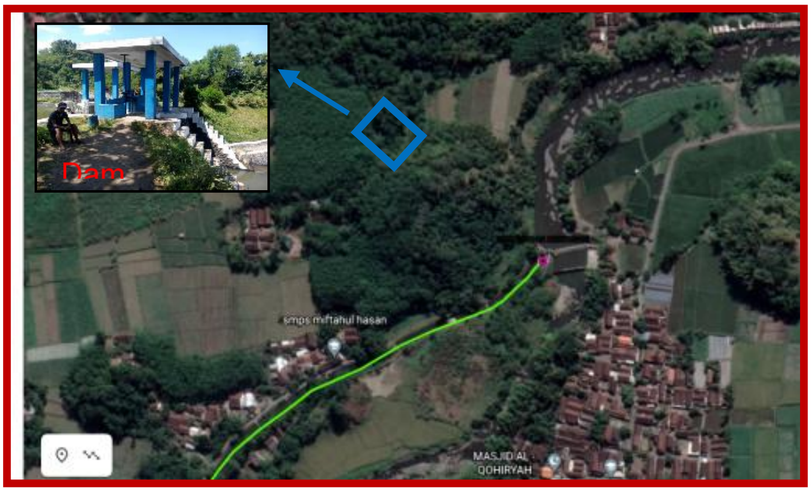


Figure 1: Research locations
*Source: Google Maps

Research Procedure

The stages in planning are as follows:
a. Kertosari Dam location survey
b. Sediment sampling at 3 location points
c. Measurement of water discharge by direct and indirect methods.
d. Measurement of weirs and irrigation canals.
e. Sediment sample laboratory test
f. Calculation of transport rate of sediment
g. Design and plan the sand trap building
h. Design and plan transitional buildings and flush doors
i. Sludge Bag Operation and Maintenance Standards

The sand trap is an enlargement of the channel cross section to a certain length to reduce flow velocity and provide an opportunity for sediment to settle. To accommodate these sediment deposits, the bottom of the channel section is deepened or widened. This reservoir is cleaned every certain period of time (approximately once a week and a half month) by rinsing the sediment back into the river with a high-speed concentrated flow. The factors to determine the dimensions of the sand trap building are as follows:

a. The speed of water flow through the sand trap building must be low, so that sediment can settle and not scatter again.
b. There should be no turbulence in the sand trap structure and the velocity of the water flow should be uniform throughout the sand trap structure.

c. The velocity of the water flow should not be less than 0.30 m/s, so that there is no growth of vegetation in the sand trap building and the water conditions of the transitional section of the building must be smooth and turbulence is not allowed.

d. The sand trap building has a flushing structure located just downstream of the sand trap building. To prevent the ingress of deposited sediment back into the main canal, the main channel threshold should be higher than the maximum height of the sediment contained in the sand trap construction.

The sediment deposited by the sand trap will be accommodated in a reservoir at the bottom of the sand trap. This reservoir section is not included in the calculation of the wet section of the sand trap that carries water. The cross-sectional shape of the sand trap can be rectangular or trapezoidal. The size must be such that it can accommodate the deposited sand or mud. The size of the free wet profile must have sufficient area and length downstream, so that at the end of the sand trap construction, the sand/mud concentration is as low as possible according to the desired concentration. In order to determine the grain size and the type of particles present in the river flow/irrigation network, a sample of the sediment taken must be tested. There are many formulas about sediment transport, in this study sediment transport can be analyzed using two methods, namely Meyer-Peter Muller (1948) and Einstein (1950). Both formulas are for bottom sediment removal under uniform steady flow conditions and exclude load washing [5]. The sediment transport formula given by Meyer-Peter and Muller is shown in equation [6]. The magnitude of the sediment transport rate using the Meyer-Petter - Muller formula is as follows:

Floating sediment transport rate (Suspended load)

$$\mathbf{Qs = 0.0864 \,.\, c.\, Q} \qquad \textbf{(1)}$$

with :

Qs = Flying Load (tons/day)

c = floating sediment concentration (mg/lt)

Q = channel discharge (m^3/s)

Base sediment transport rate (Bed load)

$$\gamma\left(\frac{K_s}{K_r}\right)^{3/2} S_r R = 0,047(\gamma_s \,.\, \gamma)d + 0,25\rho^{1/3} \,.\, q^{2/3} \qquad \textbf{(2)}$$

with :

γ_s/γ = density of water/sediment (kg/m^3)

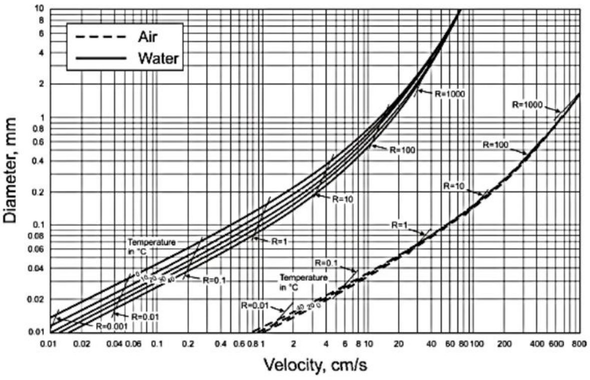
Sr = energy slope

R = hydraulic radius (m)

ρ = bedload rate in channel ((kg/s/m)

Ks/Kr = constant to find the value of Sr

In calculating the sediment transport rate, the grain diameter greatly affects the flow velocity that will occur. Figure 1 shows the relationship of falling velocity w in water to particle diameter at various different temperatures [7].



The energy slope is obtained from the Strickler equation:

$$S_r = \frac{v^2}{K_r^2 R^{4/3}} \qquad \textbf{(3)}$$

with :

V = flow rate (m/s)

The value of power loss due to friction with grains (Kr) is described by Muller as follows:

$$\boldsymbol{K_r = \frac{26}{d_{90}^{1/6}}} \quad \textbf{(4)}$$

with :

d_{90} = Percentage of diameter passing the sieve 90 %(m)

The volume that will be accommodated by the sand trap can be calculated by the formula:

$$\boldsymbol{V = 0.0005 \,.\, Q \,.\, \Delta T} \quad \textbf{(5)}$$

with :

V = Volume of sand trap required (m^3)
Q = Channel planning discharge (m^3/s)
T =Frinding Interval (s)

If :

$$\mathbf{V = Vs \,.\, T} \quad \textbf{(6)}$$

with :

V = Volume of sand trap required (m^3)
Vs = Sediment volume (m^3/day)
T = Rinsing Interval (days)

The dimensions of the sand trap should be in accordance with the rule that L/B > 8, to prevent the flow from "meandering" in the sand trap (Standard Irrigation Planning KP–02, 2013:164). If the topography does not allow this rule to be followed [9], then the sand trap must be divided along the lengthwise direction with divider walls to achieve this ratio between L and B. In determining the slope of the sand trap, the flow velocity of the sand trap at the time of flow is taken by considering the following factors:

a. The flow velocity should be low enough so that the settled particles do not scatter again.
b. Turbulence that interferes with the deposition process must be prevented.
c. Velocity should be spread evenly throughout the cross section, so that sedimentation can also be spread evenly.
d. The speed should not be less than 0.30 m/s to prevent the growth of vegetation.
e. The transfer/transition from pick-up to bag and from bag to channel must be smooth, not causing turbulence or eddies

Sludge bag planning should include checking the settling efficiency and flushing efficiency. The design sedimentation rate (W0) can be determined from:

$$\frac{H_n}{W_0} = \frac{L}{V_n} \text{ then } W_0 = \frac{H_n x V_n}{L} \quad \textbf{(7)}$$

With :

W_0 = Design sedimentation rate (m/s)
Hn = Design water depth (m)
Vn = Flow velocity (m/s)
L = Channel length (m)

Determine deposition efficiency:

$$\frac{W}{W_0} \text{ and } \frac{W}{V_0}. \quad \textbf{(8)}$$

with :

W = settling velocity of particles whose size is outside the planned particle size (m/s)
W_0 = Design deposition rate (m/s)
V_0 = Average flow velocity in the sand trap(m/s)

III. Discussion

For the purposes of designing the dimensions of the sand trap, the sediment transport rate in the mud pocket at the Kertosari Weir is calculated first. For this purpose, a calculation of the flow rate entering the Kertosari Dam intake is carried out based on the results of measuring the flow velocity that enters the intake as follows:

$$\mathbf{Q = V \,.\, A.\, k}$$
$$= 0.619 \,.\, 4{,}230 \,.\, 0.913$$
$$= 2{,}391 \text{ m}^3/\text{s}$$

With the total incoming discharge, the rate of Sediment Transport is then calculated. The calculation of the sediment transport rate includes floating sediment and bottom sediment using the Meyer – Peter Mueller method (Irrigation Planning Standard KP-02-2013;167) as follows:

Flying sediment transport rate (Qs)

Qs **= 0.0864 . c. Q**
= 0.0864 . 443.8. 2,391
= 0.09168 kg/sec
= 7,921ton/day

Bottom sediment transport rate (Qb)

Qb **= qb . B**
= 0.00067 . 6.75
= 0.00452 kg/sec
= 0.391 ton/day

The incoming sediment is the sum of floating sediment and bottom sediment, then the total sediment transport that enters the Kertosari Weir Intake is the basis for determining the volume of sediment to be accommodated with the following calculations:

Qt **= Qs + Qb**
= 7.921 + 0.391
= 8,312 tons/day.

Based on the above calculations, it can be explained that the total sediment transport is strongly influenced by the amount of discharge that enters the Kertosari weir intake. The greater the incoming discharge (Qinflow = 2,391 m^3/s) of course the potential for sediment discharge will be greater. From the calculations, it can be seen that the largest contribution of sediment in the form of floating sediment is 7.931 tons/day, meaning that if this sediment is not captured, it will enter the primary channel and then go to the secondary channel and tertiary channel and this will disrupt the performance of the irrigation system in the Kertosari irrigation area. Therefore, efforts need to be made so that the mud pocket can be planned effectively so that it can capture sediment optimally and efficiently. In planning the sand trap, it is necessary to calculate the sediment accumulation in the time duration for the operation and maintenance of the Kertosari sand trap. The volume of sediment that enters the sand trap can be calculated as follows:

Vs **= Qt / s**
= 8,312 / 2,630
= 3.160 m^3/day

In the standard operation of a sand trap, it really determines the level of operation and durability of the sand trap building, so the sediment storage calculation is carried out by taking into account the storage time of 45 days, 60 days, 75 days and 90 days, the results are presented in table -1.Based on the following table, the holding period of 90 days is selected with the detailed calculations presented as follows:

V = Vs . T
= 3.160m^3/day . 90 days
= 284.43 $m^3 \approx 280\ m^3$

Based on the above calculation, the volume of the sand trap in the 90-day rinse interval is 280 m^3. Furthermore, the calculation of the initial estimate of the average surface area of the sand trap is carried out using the following equation:

$$\boldsymbol{LB} = \frac{\boldsymbol{Q}}{\boldsymbol{W}} = \frac{2{,}391}{0{,}002} = 1195{,}462\ \boldsymbol{m^2}$$

Table 1. Calculation of sediment storage volume for 45 days, 60 days, 75 days and 90 days

No	Flushing time (day)	Qt (ton/day)	γs (ton/m^3)	Vs m^3/day)	V (m^3)
1	45	8.312	2.63	3.160	142.221
2	60	8.312	2.63	3.160	189.627
3	75	8.312	2.63	3.160	237.034
4	90	8.312	2.63	3.160	284.441

The dimensions of the sand trap should be in accordance with the L / B > 8 rule to prevent the flow from "meandering" in the bag. So :

L/B >8
L. B = 1195,462 m^2
8B . B = 1195,462m^2
B^2 = 1195,462/8
= 149,433 m^2
B = $(149{,}433)^{1/2}$
=12,224 m
B < 12,224 m - → take B = 12.00 m
L >96.00m - → taken L = 100.00 m

So that :
L/B>8
Check = 100.00/12.00=8,333>8 fulfill
requirements!
So, the initial estimation of the sand trap channel is:
Width B = 12.00 m
Length L =100.00 m

To ensure that the sediment is able to flow properly when captured, it is necessary to design the ideal slope of the mud pocket on the Kertasari weir. The slope of the bottom of the sand trap under normal exploitation or the sand trap is almost full (In)

$$\boldsymbol{I_n = \left(\frac{V_n}{Ks\,.\,R_n^{2/3}}\right)^2 = 0{,}000091}$$

When it flows to the flushing point, there is a process of changing the dimensions of the sand trap from the original width B = 12 m to a smaller width. The Transitional Part can be calculated using the following equation:

Lp = 8 to 10 z where:
z = (B – b) / 2
Z = (B – b) / 2
= (12.00 – 10.70) / 2 = 0.65 m
Lp < 10 z = Lp < 10. 0.65 = 6.50 m
Lp > 8 z = Lp > 8. 0.65 = 5.20 m

So in the transition conditions can be designed and taken the transition width Lp = 6.00 m. Based on the calculation, it turns out that the required volume of the sand trap (V) is 280 m^3, so that the length of the sand trap becomes:

V = (0.5 . b. L) + 0.5 (Ib - In) . L2 . b
280 = (0.50. 10.70. L) + 0.5 (0.00307 – 0.000091) . L2 . 10.70
280 = 5.350 L + 0.01595 . L2
280 = 5,350 . 46,023 + 0.01595 . 46.0232
280 = 280 (Ok!!!!)

By trial and error (trial and error is obtained), then obtained L = 46,02 m
Then take the length of the Sand trap L = 46.00 m
Width of each Storage Base = 5.35m
Length (L) = 46.00m
Transition Section (Lp) = 6.00m
Transition Section respectively (z) = 0.33 m
Depth during normal exploitation (Hn) = 0.65m
Depth during Flushing (Hb) = 0.30m
Flushing energy slope Ib (0.00307x46.0) = 0.14 m

Furthermore, a check is made on the functioning of the sand trap, so using the normal speed of 0,30 m/s and when it is full, it is determined as follows:

Deposition efficiency:

Velocity during normal exploitation (Vn)	= 0.300m^3/s
Depth during normal exploitation (Hn)	= 0.650 m
Sand trap Length (L)	= 46.00 m
Count :	
w_0 = (Hn . Vn)/L= (0.65 . 0.30)/46.00	=0.002167 m/s
From the graph with w_0 = 0.002167 m/s, the grain diameter	= 0.010 mm < design diameter = 0.011 mm.

Thus the material that has settled will not scatter again.

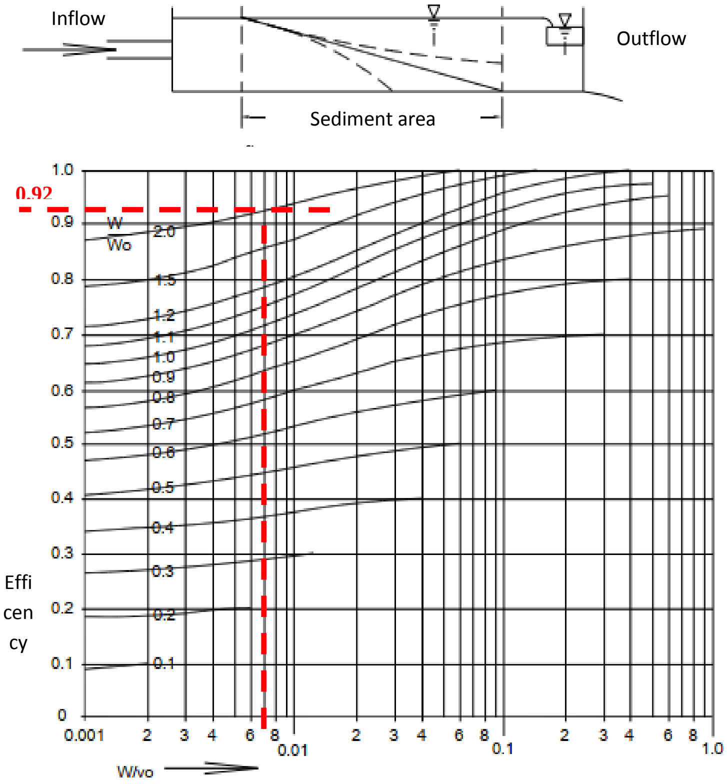


Figure 2: Camp Sediment Disposal Graph for Turbulence Flow

Flushing efficiency:

When the sand trap is full:

$$\frac{\boldsymbol{V^*}}{w} > \frac{5}{3}$$

$$V^* = \sqrt{g\,.H.I_n} = \sqrt{9{,}81\,.\,0{,}30\,.\,0{,}0000907}$$

$$= 0{,}016 \text{ m/s}$$

So :

$$\frac{\boldsymbol{V^*}}{w} = \frac{0{,}016}{0{,}002} = \boldsymbol{8{,}169} > 1{,}667(\ \boldsymbol{Ok}\ !!!\ )$$

$$\frac{\boldsymbol{V^*}}{w} > \frac{5}{3}$$

$$V^* = \sqrt{g\,.H.I_n} = \sqrt{9{,}81\,.\,0{,}30\,.\,0{,}00307}$$

$$= 0{,}095 \text{ m/s}$$

$$\frac{\boldsymbol{V^*}}{w} = \frac{0{,}095}{0{,}002} = \boldsymbol{47{,}54} > 1{,}667(\ \boldsymbol{Ok}\ !!!\ )$$

Therefore, the sediment that has settled in the sand trap in a full or empty state can no longer be eroded into floating cargo. Based on the Shield Graph in Figure 3, for the value of τ_0 = 9.039 N/m^2, the maximum grain diameter is washed off = 9.80 mm. Thus, sediment with a diameter of less than 9.80 mm will be flushed in the Kertosari Dam sand trap.

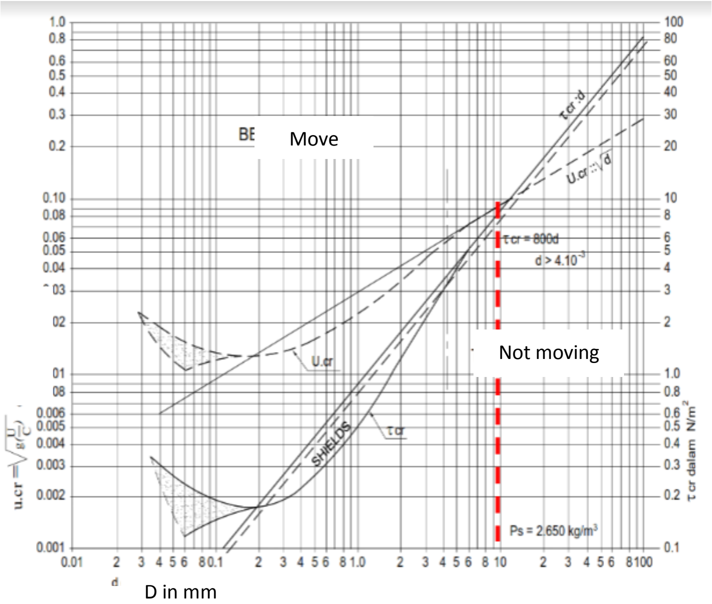


Figure 3: Critical Shear Stress and Critical Shear Velocity
as a function of grain size for s = 2.650 kg/m^3

IV. Conclusion

By using the Meyer-Petter – Muller formula based on irrigation planning standards, planning criteria, (Kp 02; Year 2013), analyzing the rate of sediment transport, the amount of sediment transport in the primary channel of the Kertosari Weir Irrigation Network is: 8,312 tons/day. The volume of the sediment is: 3.160 m^3/day, the bottom slope of the sand trap during normal exploitation is 0.000091 m, and during flushing is 0.00307 m. Controlling the functioning of the sand trap, the sedimentation efficiency is 92%, the flushing efficiency is the maximum grain diameter. 9.80 mm thus diameter < 9.80 mm will be rinsed, The effect of turbulence from water when the sand trap is full: 8.169>5/3, when the sand trap is empty 47.54>5/3, so that the sediment which has been deposited cannot be eroded again into floating charge.

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