Evaluation of the sand trap performance of the Pengasih weir during the operational period

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Abstract. Sedimentation is the main trigger in reducing the capacity of the irrigation channel. The weir is equipped with a sand trap, to withstand the volume of sediments originating from the upstream area, some of which enter the irrigation intake. The sand trap is designed with sufficient width and sloping energy slope, allowing sediment to settle. The Pengasih Weir, located in Kulonprogo Regency, is one of the weirs that is equipped with a sand trap building. The Pengasih Weir and the sand trap were built in 1972. With the development of current conditions, it is necessary to evaluate the performance of the sand trap of The Pengasih Weir. In this study, the evaluation of sand trap performance is reviewed during the operational (settling) period. The result showed that the Meyer–Peter Muller formula can be used as an approach in the calculation of the amount of sediment transport and also to estimate the settled volume. It is recommended to flush the sand trap in between 184.922 days. The average value of trap efficiency was 0.89\%. It can be concluded that the Pegasih Weir sand trap design still has good performance in settling the sediment inflow.

1. Introduction

Sedimentation is a great problem in the management of water resources development projects in many countries around the world, as it reduces the original capacity of the reservoirs, significantly affecting irrigation, drinking water supply, flood control, and recreational activities [1]. In irrigation systems, sedimentation can cause delays in the supply of irrigation water for paddy fields. One of the efforts to prevent sedimentation in the irrigation network is by placing a sand trap building at the location after the intake gate in the weir. The sand trap functions as an initial sediment barrier before entering the primary channel.

The sand trap is designed with sufficient width and sloping energy slope, allowing sediment to settle. The sand trap is accompanied by a flushing gate at the downstream. When the flushing gate is closed, the flow velocity in the sand trap becomes very low. That causes the sediment will easily settle in the sand trap. Periodically the sediment held in the sand trap is removed, either manually or by flushing [2]. The period between two flushing periods is called the operational (settling) period. An important factor in determining the performance of the sand trap is trap efficiency [3]. Trap efficiency is a ratio of deposited sediment to the total inflow for a given period within the reservoirs [4]. To find out the trap efficiency, it is necessary to analyze the sediment transport occurs in the sand trap. In this study, a comparison of the sediment transport is carried out with the empirical and the measurement method.
The Pengasih Weir, located in Kulonprogo Regency, is one of the weirs that is equipped with a sand trap building. The Pengasih Weir and the sand trap were built in 1972. With the development of current conditions, it is necessary to evaluate the performance of the sand trap of The Pengasih Weir.

2. Methodology

This research was conducted in the Pengasih Weir sand trap located in Kulon Progo Regency, Special Region of Yogyakarta, Indonesia. This weir gets the water supply from the Serang River.

2.1. Material

The sample used in this study is bed load. Besides, the temperature, the velocity, the cross-section, and the water level differences in operational periods were also measured. Cross-section measurements of the sand trap using the Nikon DTM total station. Measurements were conducted when the sand trap was filled with the sediment (just before it was flushed), and when the sand trap was empty (after being flushed) as shown in figure 1. That is done to determine the volume of sediment deposited between the flushing periods. Measurement of the sand trap in the empty condition is used to determine the capacity of the sand trap storage.

2.2. Sediment transport

Many formulas about sediment transport have appeared in the literature since DuBoys (1897) presented his tractive force relation[5]. In this study, the sediment transport was analyzed using two methods; there are the Meyer–Peter Muller (1948) and Einstein (1950) formula. Those two formulas are for discharge of bed sediment under conditions of uniform steady flow and do not include the wash load [5]. The sediment transport formula is given by Meyer–Peter and Mullershown in equation (1)[6].

\[
R_S = 0.047 (\gamma_s - \gamma_w) d_{50} + 0.25 \left( \frac{\gamma_w}{\gamma_s} \right)^{1/3} \left( \frac{q_s}{q_w} \right)^{2/3}
\]

(1)

Where,

\[
\begin{align*}
\gamma_w & = \text{specific weight of water (N/m}^3) \\
R_h & = \text{hydraulic radius of the channel (m)} \\
\left( \frac{k_s}{k_w} \right)^{3/2} & = \text{ripple factor} \\
S & = \text{slope of flow energy} \\
\gamma_s & = \text{specific weight of bedload (N/m}^3)
\end{align*}
\]
where, 
\[ d_{50} \] = representative diameter (mm)  
\[ g \] = acceleration of gravity (m/s\(^2\))  
\[ q_B' \] = sediment transport (Ton/m.s)

The sediment transport formula is given by Einstein shown in equation (2).

\[ \Psi = f(\Phi^*) \]  \hspace{1cm} (2)

The flow intensity parameter is shown in equation 3.

\[ \Psi^* = \frac{\rho_s - \rho}{\mu} \times \frac{d}{\mu RS} \]  \hspace{1cm} (3)

The flow intensity parameter required the parameters below.

\[ \mu = \left( \frac{C}{C_{d90}} \right)^{3/2} \]  \hspace{1cm} (4)
\[ C = 18 \log \frac{12h}{k} \]  \hspace{1cm} (5)
\[ C_{d90} = 18 \log \frac{12h}{d_{90}} \]  \hspace{1cm} (6)

The transport rate function is shown in equation 7.

\[ \Phi = \frac{q_B}{\gamma_S \sqrt{\frac{\rho}{(\rho_s - \rho)}}} \times \frac{1}{g d^3} \]  \hspace{1cm} (7)

Where,
\[ \rho \] = density of water (kg/m\(^3\))  
\[ \rho_s \] = density of sediment (kg/m\(^3\))  
\[ d \] = representative diameter, \( d_{35} \) (mm)

The flow intensity parameter \( \Psi^* \) is used to obtain the rate function \( \Phi^* \) from the Einstein graph, as shown in figure 2. After that, the sediment transport \( q_B \) can be determined with equation (7).

\[ \text{Figure 2. The relationship between the intensity parameter and the rate function given by Einstein [5, 6].} \]
2.3. Trap Efficiency

To find out the trap efficiency, it is necessary to analyze the fall velocity. Fall velocity is the most important property of a sediment particle in the field of practical sediment engineering [7]. The fall velocity over the entire range of the Reynolds number, in terms of drag coefficient, is given in equation (8) [7].

\[ w^2 = \frac{4g d}{C_D} \times \frac{(\gamma_r - \gamma)}{\gamma} \]  

(8)

Where,

- \( w \) = fall velocity of the particle (m/s)
- \( d \) = particle size (mm)
- \( C_D \) = drag coefficient

Figure 3 shows the fall velocity \( w \) in water plotted against particle diameter \( d \) for reference quartz spheres for different temperatures [5,7].

![Figure 3. Fall velocity of quartz sphere in water [5,7].](image)

After the fall velocity of each particle size is obtained, then it is used to calculate the trap efficiency of the sand trap. The trap efficiency is plotted to the Champ Graph, as shown in figure 4.
3. Results and Discussion

3.1. Analysis of sediment particle size

The bedload sample was tested by the sieve method and combined with the hydrometer test. The results showed that most of the particles of the bedload were sand. The distribution of sediment particle sizes can be seen in figure 5. Based on figure 5, it can be seen that 94.72% of the bed load sample was sand, while the remaining 5.28% was silt. Then, the particle size variation related to the percent passing can be obtained (table 1). The specific weight from the test was 2.46 N/m$^3$.

![Figure 5. Distribution of bedload particle size.](image)
3.2. Analysis of sediment transport and flushing period

The analysis of sediment transport used Meyer-Peter Muller and Einstein formula, as given in equations 1 and 2. The results showed that sediment transport from that two formula was 0.52 m³/day and 0.31 m³/day, respectively. Empirical transport sediment result were then compared to the measured sediment transport yield. The second method was approached by a comparison between the volume that settles during the flushing period. The volume was obtained from the difference between the results of the cross-section measurements under sediment-filled conditions and under empty conditions (after being flushed). It was obtained that the volume which settles was 36.51 m³. The number of days between therecond flushing periods was 80 days. Therefore, the sediment transport from the measurement results can be determined, which was equal to 0.46 m³/day. Based on the three sediment transport values, it can be used to calculate the volume that has been settled for 80 days. The results showed that the value from the measured method similar to the Meyer-Peter Muller method. It can be concluded that the Meyer-Peter Muller formula can be used as an approach in the analysis of sediment transport in Pengasih Weir sand trap. That means if the measured volume data is not available, then the Meyer-Peter Muller formula can be used to calculate the amount of sediment transport in Pengasih Weir sand trap.

Based on the results of cross-section measurements, it can also be obtained the capacity of the sand trap, which was equal to 84.40 m³. The results were then used to estimate the time taken to meet the capacity of the sand trap. Ideally, the sand trapis flushed when it has reached full condition of capacity. The full-time estimation results are shown in table 2. Based on table 2, it can be seen that the full time from the measured and Meyer-Peter Muller methods were 184.922 days and 162.162 days, respectively. Those values are close, but it is recommended to use a slightly more extended day period. The aim is to avoid excessive water disposal, which can interfere the irrigation water supply.

Table 2. The full-time estimation of the Pengasih Weir sand trap

| Methods          | Sediment transport (m³/day) | The real number of flushing days | Sediment that settles for 80 days (m³) | Difference (%) | Full-time (days) | Full-time (months) |
|------------------|-----------------------------|---------------------------------|---------------------------------------|----------------|------------------|-------------------|
| Measurement      | 0.46                        | 80                              | 36.511                                | -              | 184.922          | 6.164             |
| Meyer-Peter Muller | 0.52                      | 80                              | 41.635                                | 14.04          | 162.162          | 5.405             |
| Einstein         | 0.31                        | 80                              | 24.595                                | 32.64          | 274.518          | 9.151             |

3.3. Analysis of trap efficiency

There are several methods in estimating the trap efficiency of settling basins used for hydropower, water supply, and irrigation projects. Some of them commonly used methods are Camp method, Hazen method, Vetter method, physical model, and three-dimensional numerical analysis [7]. Trap efficiency calculates the percentage of the sediment volume inflow that remains in the sand trap [9]. In this study, trap efficiency uses the Camp method. The Camp method required the input of fall velocity, design fall velocity, and flow velocity. The fall velocity was determined with equation 8, while the flow velocity used the measured velocity in sand trap; the value was 0.187 m/s. The fall velocity was calculated using the equation 8. The design fall velocity used the representative particle size d₅₀. Then the calculation of input parameter for the Camp graph shown in table 3. The input parameter from the
Table 3 was then plotted to the Camp Graph as shown in figure 6. Each particle size showed the different trap efficiency. The larger the diameter of particle size, the higher the trap efficiency. For the particle size of $d_{80}$, $d_{90}$, and $d_{100}$, the trap efficiency was 1. It means that all the volume with that particle size can be completely settled. However, the particle size of sediment entering the sand trap was varying. The average value of trap efficiency in Pengasih Weir sand trap was 0.89%. It can be concluded that the Pegasus Weir sand trap design still has good performance in settling the sediment inflow.

| Particle variation | $d$ (mm) | $w^2$ ($m^2/s^3$) | $w$ (m/s) | $w/w_o$ | $w/v_o$ |
|-------------------|----------|-------------------|-----------|----------|----------|
| $d_{10}$          | 0.1020   | 0.0041            | 0.0644    | 0.6838   | 0.3441   |
| $d_{20}$          | 0.1326   | 0.0054            | 0.0734    | 0.7796   | 0.3924   |
| $d_{30}$          | 0.1611   | 0.0065            | 0.0809    | 0.8594   | 0.4325   |
| $d_{40}$          | 0.1896   | 0.0077            | 0.0877    | 0.9323   | 0.4692   |
| $d_{50}$          | 0.2181   | 0.0089            | 0.0941    | 1.0000   | 0.5033   |
| $d_{60}$          | 0.2467   | 0.0100            | 0.1001    | 1.0634   | 0.5352   |
| $d_{70}$          | 0.3055   | 0.0124            | 0.1114    | 1.1834   | 0.5956   |
| $d_{80}$          | 0.3683   | 0.0150            | 0.1223    | 1.2994   | 0.6540   |
| $d_{90}$          | 0.4668   | 0.0190            | 0.1377    | 1.4629   | 0.7362   |
| $d_{100}$         | 4.7500   | 0.1929            | 0.4392    | 4.6664   | 2.3485   |

**Figure 6.** Trap efficiency for the particle size variation.

4. Conclusion

The evaluation of the sand trap performance of Pengasih Weir is reviewed during the operational period. Some things evaluated in this study are sediment transport, flushing period, and trap efficiency. Based on the results and discussion, it can be concluded that the Meyer-Peter Muller formula can be used as an approach in calculation the amount of sediment transport and also to estimate the settled volume in Pengasih Weir sand trap during the operational period. It is recommended to flush the sand trap in between 184.922 days. The average value of trap efficiency was 0.89%. It can be concluded that the Pegasus Weir sand trap design still has good performance in settling the sediment inflow.
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