Study on flow regime change due to weir construction plan in Batang Asai River, Sarolangun, Province of Jambi

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Abstract. The weir design process not only considers the location, dimensions, strength, and durability of the weir structure, but must also consider the effect on the flow characteristics in the river after the weir, especially related to the flow velocity characteristic around the weir. The water level will rise and affect the flow velocity downstream of the weir. Because of the fall of water, the velocity will greatly increase and the river can erode. The weir construction on the Batang Asai River, specifically located in Sarolangun, Province of Jambi, has unique conditions that cause the velocity of water after the weir to increase. Several alternatives will be analysed as solutions to deal with changes in flow velocity. The alternatives are groundstill, riverbed normalization, and river crossing widening. It was found that the alternative of river widening showed a significant reduction in flow velocity.

Keywords: Flow, Velocity, Weir, River, Erosion.

1. Introduction

Water has many benefits for human life; not only for food and drink, water is also used for various other purposes such as irrigation, electricity, and various other needs. In an effort to deliver water from rivers to the locations of its demand, water resource infrastructures are created, for example weirs. A weir is a barrier that is constructed across the river to lift the water level. In the weir design process, there are many aspects of concern, including the design process, construction, and even operation and management. The same is true for the flow conditions that occur before and after the construction of the weir. The weir construction will strongly influence the flow regime [1]. The velocity downstream of the weir will increase as much as the weir height. The high flow will have a significant effect on the river, such as scouring [2]. The velocity of water should be reduced before the water enters the natural river.

In open channel flows, it is strongly advised to define the Froude number as \( Fr = 1 \) at critical flow conditions [3-5]. Thus, \( Fr < 1 \) represents subcritical flow and \( Fr > 1 \) represents supercritical flow. If a flow is at a high flow velocity or in a supercritical condition (\( Fr > 1 \)), the flow needs to be stabilized so that it will not erode the channel. The groundsill is an alternative infrastructure that can be used to reduce the velocity [6]. Other alternatives could be to enlarge the river capacity or to put blocks or
cylindrical piers to dissipate the energy to decrease the velocity [7]. To find out the effectiveness of all the alternatives of velocity dampers, physical or artificial modelling using numerical models may be performed. A physical model will require a very large amount of time and cost; moreover, if an error occurs in making the model, additional time and costs are required to improve the physical model. In contrast to the physical model, the numerical model offers convenience of manufacture; even though the given results may not be perfectly correct, in terms of cost, a numerical model provides better benefits. This is because currently there are many kinds of software for performing hydraulic simulations that can be obtained free of charge, although with some disadvantages.

At present, hydraulic modelling can provide reliable and accurate results, especially when the model has detailed information. Thus, a properly calibrated hydraulic model can be utilized in various activities, such as assessment of flow characteristics. There are many types and choices of software for hydraulic modelling, in 1D, 2D, and even 3D. 2D modelling is considered to have a better level of accuracy than 1D modelling, especially when deeper analysis and good visualization is needed. Two-dimensional models provide a better level of effectiveness and efficiency [8-10]. Some considerations must be made to decide what kind of model will be used in a study, such as the complexity of the river scheme, the things to be observed, flow characteristics, availability of observational data, and the hardware capacity that will be used in flood modelling.

This study was carried out on the planned construction of the Batang Asai Weir in Sarolangun Regency, Province of Jambi. The condition that makes the weir interesting to be studied is that the water velocity increases downstream of the weir due to the difference in elevation between the downstream of stilling basin and the natural river; as well, when the flow enters the natural river, the velocity increases due to the contraction of the river channel. This study was conducted to evaluate the velocity problem downstream of the weir, then to find the alternatives to solve the problem by performing hydraulic modelling using a one-dimensional model.

![Specific Location of Bt. Asai Weir](image)

**Figure 1. Sketch of the Study Location**

The following are the alternative treatments to reduce the high velocity downstream of the weir: (i) construction of a groundsill downstream of the weir; (ii) widening the river width downstream of the weir to 60 m; (iii) widening the river width downstream of the weir to 100 m; (iv) widening the river width downstream of the weir to 60 m and normalizing the slope of the river bed; and (v) widening the river width downstream of the weir to 100 m and normalizing the slope of the river bed.
2. Material and Methods
This study is focused on the one-dimensional hydraulic modelling of the weir and river scheme, and the input model is secondary data obtained from previous studies. A one-dimensional model only considers flow in one dimension (single-axis flow); this is different from two- and three-dimensional modelling, which allow numerical simulations to expand the flow from the river into multiple axes [11, 12].

2.1. Governing Equation
The equations used in the numerical model are the Saint-Venant equations. The Saint-Venant equations consist of the continuity and the momentum equations, as given below:

Continuity
\[ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_1 \]  

Momentum
\[ \frac{\partial Q}{\partial t} + \left( \frac{\partial Q^3}{\partial x} \right) + gA \frac{\partial h}{\partial x} + \frac{n^2 gQ}{AR^{1/4}} = 0 \]

where \( Q \) is discharge (\( m^3 \ s^{-1} \)), \( A \) is cross-sectional area (\( m^2 \)), \( q_1 \) is distributed lateral inflow or outflow along the x-axis from the watercourse (\( m^2 \ s^{-1} \)), \( n \) is Manning’s roughness coefficient, \( \alpha \) is the momentum distribution coefficient, \( g \) is the acceleration of gravity (\( m \ s^{-2} \)), \( R \) is hydraulic radius (m), and \( h \) is the water level (m).

2.1.1. Topographical Data
The topographical data of the Batang Asai River following the Batang Asai weir design is based on data obtained from the planning consultant and the Sumatera VI River Authority (Balai Wilayah Sungai Sumatera VI).

2.1.2. Hydrograph Design
The input discharge used in flood inundation evaluation can be seen in Figure 3. The discharge input was taken from a previous study conducted by the Sumatera IV River Authority (Balai Wilayah Sungai Sumatera IV). It can be seen in Figure 3 that there are no significant differences among the \( Q_{25} \),
Q_{so}, \text{ and } Q_{100} \text{ peak discharges. The values for the } Q_{50} \text{ and } Q_{100} \text{ peak discharges are } 815 \text{ m}^3\text{s}^{-1} \text{ and } 837 \text{ m}^3\text{s}^{-1}.

**Figure 3.** Hydrograph Design of the Batang Asai Weir

### 3. Results and Discussion

The velocity profile analysis process was carried out due to the construction of the Batang Asai Weir in the river. The velocity profile generated from flood modelling that has been done previously along the study location after the construction of the Batang Asai Weir is shown in **Figure 4**.

**Figure 4.** Velocity profile due to Q_{so}

**Figure 4** shows that the velocity profile of water after the weir continues to increase further; after STA 2900 meters, the velocity continues to increase until it reaches almost 3 ms\(^{-1}\). The increase in flow velocity is expected to occur due to the drop in level at the downstream of the weir, from a height...
of 66 m to 63 m. In addition, there is a difference in cross-sectional width between the weir and the river thereafter. These conditions are shown in Figure 5 below.

![Figure 5](imageurl)

**Figure 5.** The Difference of Level between the Weir Location and the Bt. Asai River Condition

In order to reduce the velocity of the river downstream of the weir, several efforts have been made as discussed previously in the Introduction, including constructing structures such as a groundsill to reduce the flow velocity, widening the river, and normalizing the riverbed. From the modelling of several proposed alternatives, the following results were obtained.

From Figure 6, with the construction of the groundsill, the increase in velocity continues to occur even though the groundsill is present; this shows that the contraction on the river has a large effect on the flow velocity (green line), as the velocity increases to almost 4 m/s\(^{-1}\) due to the contraction and the height of the fall. After an increase in velocity, the velocity decreases and again increases after falling from the second groundsill, almost approaching 4 m/s\(^{-1}\). When the river width downstream of the weir becomes 60 m, the water level seems to be affected. The water level upstream of the contraction starts to decrease because there is no longer restraint due to the contractions that occur just before the widening to 60 m. This also affects the decrease in flow velocity. The flow velocity, which initially reached 3 m/s\(^{-1}\) during the contraction, decreased to 2 m/s\(^{-1}\) as the river width increased. The water level and the velocity of the third alternative decreased (Figure 6 (iii)), but the normalizing of the slope of the river actually increased the velocity (Figure 6 (iv)).

The same occurred when the downstream river width was increased to 100 m. A decrease in velocity can be seen very clearly. In Figure 6, it can be seen that the water velocity increases instantaneously at STA 3+183 but does not exceed 1.5 m/s\(^{-1}\). Then, in the next figure, when the channel is widened to 100 m and the riverbed is normalized (Figure 6 (v)), the flow velocity is actually higher than the condition where the riverbed is not normalized. This is similar to the condition of the channel as widened to 60 m. The increased river width decreases velocity fairly well, especially if the river width is greater than 100 m.
Overall, from the alternatives given, widening the channel is the most effective alternative for reducing flow velocity compared to constructing groundsill. This can be seen from the phenomenon that occurs when the water passes through the channel with a width between 100 meters and 60 meters. The contraction effect is more dominant on the flow, so the presence of the first groundsill had less effect on flow velocity reduction.

4. Conclusion
The addition of a groundsill does not majorly impact the downstream flow velocity. The main problem in the downstream flow can be said to be caused by the geometry of the cross-section of the river, which becomes narrower (a contraction). This is evidenced by the widening, which gives sufficient influence on the flow velocity downstream of the weir. Riverbed normalization downstream of the weir in fact increases the velocity. Thus, the best solution is to widen the river to 100 m in the narrow cliff segments from STA 2 + 900 to STA 3 + 200.
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