Evaluation of the Sediment Trap Structure Performance in the Saddang Irrigation

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Abstract. Irrigation canals require desilting basin to reduce sediment deposits in the main irrigation canals. The capacity of the Saddang River Irrigation Canal will be increased by 30% to accommodate long-term irrigation discharge needs. To optimize the ability of the desilting basin to trap suspended sediments, an evaluation was carried out using the 2-D finite-volume numerical method for hydrodynamic and sediment transport models. It solves the 2-D dynamic wave equations (the standard depth-averaged St.Venant equations) that are mainly used for river simulation. In addition, the diffusive wave solver is used for watershed runoff simulation and river simulation. The Community Edition SRH-2D model uses a flexible mesh that may contain arbitrarily quadrilateral and triangular cells. A hybrid mesh may achieve the best compromise between solution accuracy and computing demand. The SRH-2D Model solved variables include water surface elevation, water depth, depth averaged velocity, Froude number, and bed shear stress. Sediment Transport Model solved variables include sediment concentration, erosion and deposition, bed elevation, sediment transport rates, bed material D50 size, and bed material gradations. The optimization of the model is useful for improving the lining channel, flushing time period and the performance of the sediment trap.

1. Introduction

Irrigation modernization is seen as necessity for further efforts to overcome threats to the sustainability of irrigation country. The threat comes from various aspect such as the critical water demands for an efficient agricultural production (FAO). A considerable effort is required to be done to improve irrigation operations. The capacity of the Saddang River Irrigation Canal is projected to increased by 30% to accommodate long-term discharge needs.

Desilting basin is a temporary sediment control structure to intercept sediment-laden runoff and to retain the sediment. It has a purpose to detain sediment-laden runoff from disturbed area for sufficient time and allowing a majority of the sediment to settle within the sediment trap [1]. Dredging, dry excavation, and hydraulic flushing of sediments from reservoirs used alone or in combination are some methods that can be use for life conservation of a dam structure. [2]. The technique of flushing is not new, it has been applied since long ago. Especially for this study, this method is one of the reliable methods to maintain the sediment trap performance.

Flushing is a method by which the flow velocity in reservoir is increased to an extent so the deposited sediments within the sediment trap can be carried out of the reservoir [3]. Not every reservoir of the world can be flushed successfully due to the non-availability of sufficient water for flushing and geometric parameters like flatter bed slope and wider section, etc. Flushing also causes sediments to be released from the reservoir at a much higher concentration than occurs in the natural fluvial system.
which may create unacceptable environmental impacts downstream, however, these impacts are less severe as compared to no flushing at all [4].

An estimation on the sediment inflow and its removal from a reservoir are required, hence, numerical modelling becomes a vital aspect for the modernization of irrigation system. The selection of numerical model for flushing is also of great importance [5]. In this research, 1-D numerical model is chosen to estimate the hydraulic performance with the new proposed design discharge. The input data was provided to 1-D numerical model HEC-RAS to see whether the initial sediment trap can provide the required performance with the new proposed design discharge.

1.1. Study Area
Saddang basin is one of the major river basins in the South Sulawesi in providing water for the vast irrigation system. The Saddang river flows within two provinces, South and West Sulawesi which holds more than 5000 km² with 8 districts. Saddang watershed is a watershed that has a very wide catchment area covering Mamuju Regency (West Sulawesi), Tanah Toraja Regency, and Enrekang Regency. Saddang river has a critical role on irrigation and energy since it is also used to run hydro power plants. [6]. One of the important structures within the irrigation system is the sediment trap structure.

1.2. Rappang-Sawitto Sediment Trap
The sediment trap is an essential structure for irrigation where it eliminates all debris and fine sediment before entering the irrigation system. The Sawitto and Rappang sediment trap was designed to accommodate design discharge for 62 m³/s. The sediment trap has a width of 40 meters, an average height of 5 meters and an average length of 400 m from the intake to the flushing gate. At the end of the sediment trap consist three structures; two irrigation weirs which is equipped with three gates each, and one flushing weir equipped with 7 flushing gates as shown in Figure 1 and 2.

Figure 1 Google map view of the sediment trap located at the east side of Benteng Barrage, Saddang, Indonesia
The flushing operation was reported to have a weekly schedule. It has been observed that the flushing operation has not been efficient. Thick settlements can be found unflushed. The ministry of public works is currently expecting to improve the irrigation system to accommodate in maximum 82 m$^3$/s which exceeds from the initial design. A quick assessment was done using HEC-RAS to understand the existing design.

2. Methods

2.1. HEC-RAS Hydraulic Program

HEC-RAS is an Open Channel Hydraulics Model for analyzing the canals and irrigation structures to convey discharge. This model was developed by the US Army Corps of Engineers [7]: Hydrological Engineering Centre to predict floods from rivers to settlements around watersheds. This model has a user-friendly graphical interface, data storage and management tools as well as reporting. The main input of HEC-RAS for conducting hydraulic analysis is canal geometry and flow data [8]. Basic geometric data consists of physical features of the channel, namely channel length, Left and right embankment, cross and long sections of the canals. While additional geometric data specifying bridges and culverts, embankment alignment, measurement structures such as weir and flume, inline structures and storage areas can also be modelled.

HEC-RAS could perform one-dimensional and two-dimensional hydraulic model calculations. Based on the objectives of this study, HEC-RAS provides different options for carrying out irrigation canal analysis which is a one-dimensional fixed flow for calculation of surface water profiles, one-dimensional and two-dimensional unstable flow simulations, quasi-unstable flow for sediment transport calculations and water quality analysis.

Figure 2 LIDAR LAS data of the Sawitto -Rappang desilting basin sediment trap

2.1.1. Energy Equation

The fundamental hydraulic equations that govern the 1-D and 2-D model comprise the mass conservation or continuity, momentum conservation or energy, and flow resistance equations. In this case, the continuity equation describes discharge as a constant and continuous over a specified period. This equation is given as [7]:
\[ Q = v_1 A_1 = v_2 A_2 \]  \hspace{1cm} (1)

Q refers to the discharge, \( v_1 \) is the velocity of upstream, \( v_2 \) is the velocity downstream, \( A_1 \) and \( A_2 \) is the cross-section area upstream and downstream respectively.

The energy equation is used to calculate the total head of water as the summation of the bed elevation, average flow depth, and the velocity head at a cross-section. Equation 2 illustrates the brief principle of water surface study in the HEC-RAS model.

In canal simulation, channel roughness is one of the important yet sensitive parameters. The HEC-RAS model applies the Manning equation that differs slightly from the Strickler Manning equation given in KP-03 ‘Canals’. Friction slope is estimated by the below Manning equation:

\[ Q = K \sqrt{S_f} \]  \hspace{1cm} (2)

Where \( K \) is the channel conveyance (m) and \( S_f \) is the friction slope. The conveyance can be calculated as follows:

\[ K = \frac{1}{n} A R^{\frac{2}{3}} \]  \hspace{1cm} (3)

Where \( n \) is the Manning roughness coefficient, and the \( R \) is the hydraulic radius. The value of the Manning coefficient can be selected from a table or be determined by iteration through field measurements. For this study, the coefficient will be acquired by field measurement. Table 2.2 contains roughness values that are generally used.

2.1.2. Sediment Modelling

HEC-RAS sediment routing routines solve the sediment continuity equation also known as the Exner equation:

\[ (1 - \lambda_p) B \frac{dp}{dt} = -\frac{\partial Q_s}{\partial x} \]  \hspace{1cm} (4)

The equation is solved by computing a sediment transport capacity for control volume (\( Q_s \)-out) associated with each cross section and comparing it to the sediment supply (\( Q_s \)-in) entering the control volume from the upstream control volume or local sources. If the capacity is greater than supply, HEC-RAS satisfies the deficit by eroding bed sediment. If the supply exceeds the capacity, HEC RAS deposits the sediment surplus.

HECRAS includes eight sediment transport potential functions. Since sediment transport is sensitive to so many variables, transport potential computed by the different equations can vary by different magnitudes.

2.2. Irrigation standard regulation

The standard parameter for sediment trap performance has been regulated by the Ministry of Public Works in Indonesia in SDA-KP Irrigation Manual. Sediment trap design depends on few factors in which the dimension of the sediment trap depends on the velocity of the flow that is expected to be lower than 0.3 m/s to prevent growth of vegetation, the absent of supercritical flow, a uniform flow throughout the lateral cross-section. This hydraulic parameter can be estimated using Meyer-Peter Mueller using HEC-RAS. The sedimentation is expected to settle over 0.5%.

2.3. Data Collections

There are several data required to commence this research. The geometrical data for the hydraulic modelling was acquired through terrestrial survey of the cross-section with a 50 m spacing. The elevation of both structures are also surveyed and inputted into the model.
Table 1 Sediment trap features for Rappang-Sawitto Irrigation, Indonesia

| Subject                          | Unit   | Value |
|----------------------------------|--------|-------|
| Construction Year                | Year   | 1938  |
| Discharge Capacity               | m³/s   | 60    |
| New Discharge Demand             | m³/s   | 82    |
| Length                           | m      | 400   |
| Average Slope                    | -      | 0.009 |
| Average Width                    | m      | 40    |
| Average Top Bank Elevation       | +MSL   | 23    |
| U.S. Elevation                   | +MSL   | 19.5  |
| D.S. Elevation                   | +MSL   | 16.5  |
| Sill Elevation Irrigation Gate   | +MSL   | 19    |
| Sill Elevation Flushing Gate     | +MSL   | 16    |
| Average Duration Operational     | Days   |       |
| Average Duration Maintenance     | Days   |       |

Figure 3 Boundary condition existing sandtrap

2.4. Boundary Conditions
To acquire the best representation of the day to day operational basis, the model is simulated using an unsteady model. The boundary condition was set to replicate an operational duration of 2 days and 1...
day of unoperated/flushing situation. The flushing gate are opened during flushing condition (Figure 3). The hydrograph can be seen in the figure. It shows that the discharge is maintain at 80 m$^3$/s. For the sediment data, sediment size focused on a grain diameter of 0.1 mm or $d_{50}$ equals to 0.1 mm. As written in the standard regulation for irrigation, the model uses Meyer-Peter Mueller method as the sediment equation.

3. Results

3.1. Simulation: Operation

During operational, the simulation shows a high velocity near the downstream flushing gate which is unlikely due to the closure of the gate. This is one of the limitations of HEC-RAS, where no cross-section cannot be dry and should be filled with water. But nonetheless, the result can still be accepted since the acceleration at the end of the simulation (after the location of the flushing gate). It can be indicated where there is an evident deceleration near the flushing gate with nearly zero velocity. It can be validated through the reported survey where a major sediment issues is located near the flushing gate (Figure 4).

![Simulation result for the operational boundary conditions](image1)

![Simulation result for the operational boundary conditions](image2)

![Simulation result for the operational boundary conditions](image3)

Figure 4 Simulation result for the operational boundary conditions
3.2. Simulation: Flushing

As for flushing simulation, the simulation recorded to have a high velocity. The high velocity should help the sediment to be flushed away. The Froude number shows that supercritical flow is present within the sandtrap during flushing. One of the major reasons is the slope of sediment trap. The slope has an average of 0.01 or a reduction of 3.5 meters within 400 meters. The slope causes a high velocity, and the uneven bed slope causes fluctuation of velocity and Froude number (Figure 5).

![Simulation result for the flushing boundary conditions](image)

Figure 5 Simulation result for the flushing boundary conditions

3.3. Sediment Estimation Output

The simulation was conducted using the same boundary condition as the flushing and operational simulation. The output is the accumulation of settled sediment within the sediment trap canal. The sediment output shows a reduction of settled sediment at the end of the sandtrap. The simulation shows that the sediment is not fully flushed away. This is an indication of an inefficient sandtrap structure.
4. Conclusion

The sediment trap of the Rappang-Sawitto Irrigation System is targeted to supply a higher discharge demand in the near future. The existing sediment trap is expected to deliver a limited performance on meeting the new discharge demand. Based on the simulation assessment using HEC-RAS, the sediment trap is expected to deliver the irrigation demands. Unfortunately, there are several findings:

- The bed slope of the sediment trap is inefficient. A steep slope causes a high velocity during flushing where in KP-03 irrigation standard for sediment trap demands a maximum of 1 m/s of velocity is required.
- The current sediment trap design is sufficient with an additional attention on the flushing schedule. A frequent flushing may reduce the probability for the sediment to settle and harden. In reality, the flushing occurs weekly or monthly which may cause a sediment problem near the flushing gate.
- During flushing, HEC-RAS cannot estimate a simulation with near zero discharge which would happen during the flushing. In this study, a constant 25% of maximum discharge is used.
- HEC-RAS can estimate hydraulic performance of a sediment trap by using a detailed geometry of the canal.
- If the bed of the canal does not vary in longitudinal profile, it is best to use unsteady flow simulation to connect the hydraulic estimation between cross-sections.
- Further improvement can be done by thoroughly investigating the sediment transport within the sandtrap to acquire real data for the sediment input for the model.

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