

Article

# Sediment Characteristics and Impacts at Tugu Dam, Trenggalek, East Java

Fajar Fadillah<sup>1,a</sup>, Minarni Nur Trilita<sup>2,b</sup>, Novie Handajani<sup>3,c</sup>

Civil Engineering Study Program, Faculty of Engineering and Science, Universitas Pembangunan Nasional “Veteran” Jawa Timur

E-mail: <sup>a</sup>21035010142@student.upnjatim.ac.id, <sup>b</sup>minarni.ts@upnjatim.ac.id, <sup>c</sup>novie.ts@upnjatim.ac.id

\*Corresponding author: (21035010142@student.upnjatim.ac.id) | Phone number: +6289529358065

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## Abstract

Dam infrastructure plays a crucial role in the development and management of water resources. The Tugu Dam was constructed in 2014 and completed in 2021. High erosion rates in the Tugu Dam watershed area are a primary factor contributing to sedimentation within the reservoir. It is inevitable that river inflows carry sediment loads into the dam, which subsequently settle and cause reservoir siltation. This sedimentation-induced reduction in storage capacity can significantly impact the operational performance of the Tugu Dam. The objective of this final project is to determine the amount of sedimentation deposited, analyze the sedimentation patterns, and learn how to perform sediment modeling using the HEC-RAS application. This study employs HEC-RAS version 6.0, a software developed by the US Army Corps of Engineers, widely used for hydrologic analyses including river flow, flood modeling, dam breach simulations, and sediment transport analysis. The data utilized are secondary data obtained from the Brantas River Basin Organization (BBWS Brantas). Based on the calculations and analyses conducted in this study, sediment transport modeling requires three primary data inputs: geometric data, hydrologic data, and sediment data. The modeling results indicate a decrease in dead storage capacity from an initial 1,040,000 m<sup>3</sup> to 832,516.85 m<sup>3</sup> over a 33-year period, representing a reduction of 19.95%. Additionally, the effective storage capacity slightly decreased from 8,667,000 m<sup>3</sup> to 8,666,000.01 m<sup>3</sup>, corresponding to a minimal reduction of approximately 0.0115%. The sediment deposition pattern identified in the Tugu Dam reservoir through HEC-RAS modeling is uniform, with a total sediment accumulation volume of 207,483.14 m<sup>3</sup>.

**Keywords:** Sediment, Sedimentation transport, Dam, HEC-RAS modeling

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## 1. Introduction

The dam play a crucial role in the development and management of water resources, serving as water storage, raw water supply (for drinking water, irrigation, and household use), flood control, recreational areas, and hydroelectric energy sources [1]. Tugu Dam, located on the Keser River in Trenggalek, East Java, was constructed in response to the region's vulnerability to floods during the rainy season and droughts during the dry season. The dam supports irrigation, flood control, and raw water provision. However, sedimentation poses a significant threat to reservoir management. Sedimentation, defined

as the deposition of solid materials carried by river flow into the reservoir [2], is mainly caused by high erosion rates in the catchment area. This process reduces the reservoir's storage capacity, threatening irrigation water availability and flood control effectiveness [3]. Therefore, analyzing sedimentation rates and their impact on storage capacity is essential.

This final project has three main objectives. The first objective is to determine the sediment deposition pattern in Tugu Dam and quantify the total sediment volume deposited in the reservoir. The second objective is to analyze the magnitude of storage capacity reduction in Tugu Dam due to sediment accumulation. The third objective is to

modeling the sediment transport process in Tugu Dam using the HEC-RAS software.

The research was conducted at Tugu Dam, located on the Keser River in Nglinggis Village, Tugu District, Trenggalek Regency, East Java Province. Geographically, the dam is situated between 111°34' to 111°37' East Longitude and 8°1' to 8°3' South Latitude. The watershed area at the dam site covers approximately 43.06 km<sup>2</sup>, with a river length of 9.295 km.

human activities within a watershed, such as deforestation, intensive agriculture, and infrastructure development, can increase the rate of soil erosion and the amount of sediment entering rivers. Therefore, sedimentation rate analysis in rivers must take into account both the characteristics of the watershed and the human activities occurring within it [4].

Sedimentation is the process of transporting solid particles that are deposited by water or wind, carried by fluid flow. sediment is a collection of particles in a channel originating from various locations (erosion) that then settle or remain suspended within a watershed area [5]. based on the transport mechanism, sediment can be classified into three types: wash load, suspended load, and bed load [6]. The following are explanations of these three types of sediment based on their transportation [7].

it is inevitable that the river flow entering a dam carries sediment loads that settle and cause sedimentation, which in turn leads to the gradual shallowing of the dam reservoir [8].

The total storage capacity of a reservoir can be determined using the reservoir's bathymetric map [9]. The measurement results can be used to determine the volume and thickness of reservoir sediment, which affect the reservoir's service life and the reduction of its storage capacity [10].

There are four main sediment deposition patterns commonly found in reservoirs: delta, tapering, wedge, and uniform [5,11]. The delta pattern results from coarse sediment settling near the river inflow, tapering shows sediment thickness gradually decreasing toward the dam, wedge forms by fine sediments accumulating near the dam and thinning upstream, while uniform deposition occurs evenly throughout small reservoirs with frequent water level fluctuations and consistent fine sediment loads [11-13]. these patterns are influenced by hydrological factors,

sediment characteristics, reservoir morphology, and reservoir operation [14-15].

References HEC-RAS is software developed by the US Army Corps of Engineers designed for hydrologic analyses, including river flow, flood modeling, dam breach simulations, and sediment transport [15]. HEC-RAS is capable of performing both one-dimensional and two-dimensional analyses, as well as their combinations, making it flexible for various applications. The software can simulate one- and two-dimensional hydraulics and hydrology, encompassing five key components that can be executed within the HEC-RAS program [15].

## 2. Material and Method

This research uses data collected from the Tugu Dam Management Unit, including topographical, geometric, hydraulic, hydrological, and sedimentation data. The data were processed and analyzed using HEC-RAS software to simulate sediment transport and deposition in the reservoir. The modeling process included inputting geometric data, hydrologic data, and sediment data, followed by simulation and analysis of the results.

### 2.1. Geometric data

Entry the geometric data into HEC RAS, cross-sectional data, dam data, Manning coefficients, and downstream reach lengths data from the year 2019, which was obtained from data from the Tugu Dam Management Unit . Once all data has been input, the geometric data will appear as shown in Figure 1.

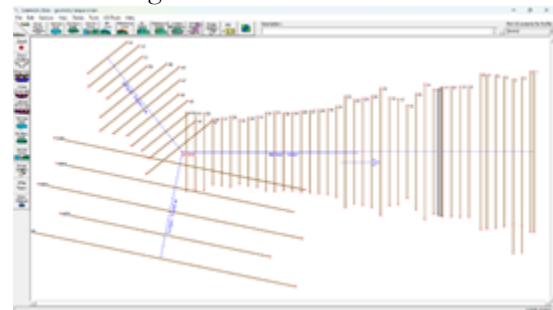


Fig. 1. Geometric data

### 2.2. Quasi-unsteady flow data

The discharge data used in this simulation are derived from rainfall-generated runoff data

spanning the period from 1987 to 2019, covering a total of 33 years. To input quasi-unsteady flow data, secondary data from the Tugu Dam Management Unit is required. Specifically, the discharge data consists of 10-day interval measurements from January 1, 1987, to December 31, 2019. For temperature, an assumed constant value of 25°C is applied, and a normal depth boundary condition is used for the downstream discharge. Figure 2 presents the hydrograph data after the discharge data has been inputted.

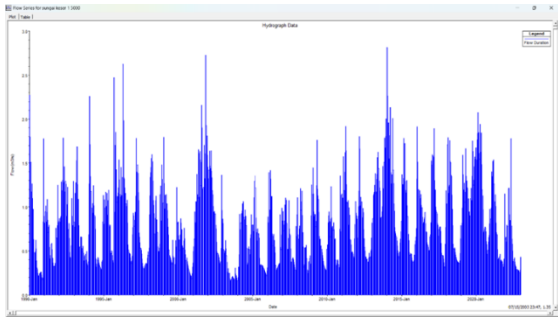


Fig. 2. Hydrograph flow data

### 2.3. Sediment Data

The sediment data utilized in this simulation dates back to 2017 and was obtained from the consulting firm involved in the Tugu Dam construction. This dataset comprises information on sediment grain size and other sediment properties, which are critical for conducting the HEC-RAS simulation. Besides specifying sediment characteristics, selecting the appropriate transport function formula is also required for the HEC-RAS modeling process. Figures 3 and 4 display the sediment data inputs necessary for the simulation.

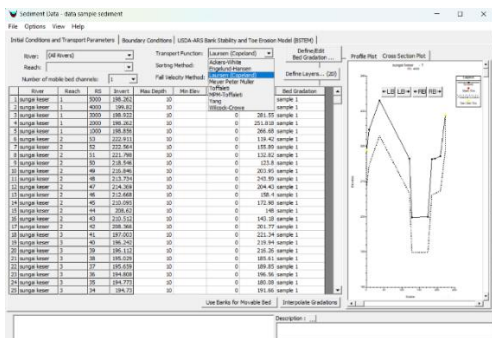


Fig. 3. Sediment transport function

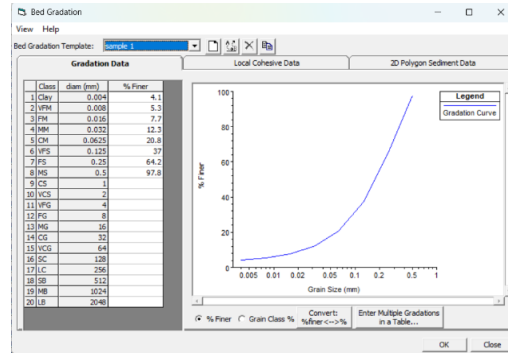


Fig. 4. Sediment gradation data

### 3. Results and Discussion

The results of the Running Sediment Analysis are in the form of graphs, tables and images of changes in the base of the river channel or reservoir. In this simulation, as shown in Figures 5 sedimentation occurs in all three river channels, namely Reach 1, Reach 2, and Reach 3. The simulation uses data spanning 33 years, from January 1, 1987, to December 21, 2019. It can be observed that in 1987, the riverbed elevation remained unchanged and stable Figures 5.

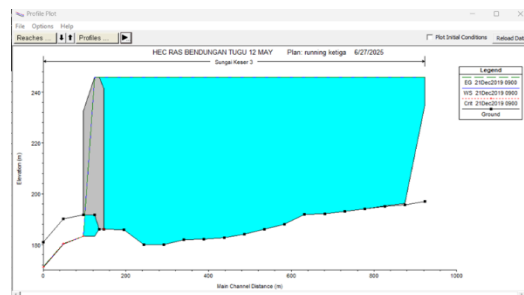


Fig. 5. Long section Reach 3 in 1987

In 2019 sedimentation and changes in riverbed elevation occurred (Figures 6). In Reach 3, the sedimentation process is very small.

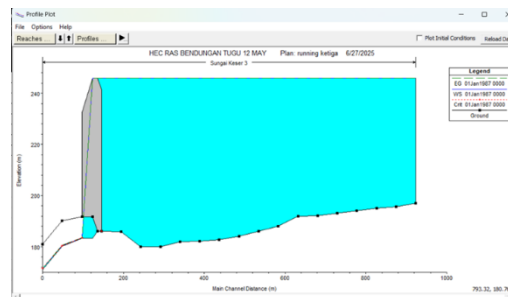


Fig. 6. Long Section Reach 3 in 2019

Table 1. Annual Total Sediment Inflow into Tugu Dam (Downstream)

No	Year	HEC-RAS Modeling Results (TON)
1	1987	27.25
2	1988	41.96
3	1989	78.80
4	1990	100.16
5	1991	127.08
6	1992	166.90
7	1993	208.52
8	1994	230.87
9	1995	271.78
10	1996	293.63
11	1997	299.56
12	1998	374.35
13	1999	413.14
14	2000	415.01
15	2001	432.33
16	2002	444.36
17	2003	463.42
18	2004	479.18
19	2005	479.18
20	2006	495.53
21	2007	519.24
22	2008	537.47
23	2009	574.93
24	2010	596.45
25	2011	1025.67
26	2012	664.66
27	2013	724.66
28	2014	757.60
29	2015	792.67
30	2016	827.90
31	2017	862.64
32	2018	927.03
33	2019	985.20

The reservoir volume parameters for Tugu Dam were obtained from the official data provided by the Tugu Dam Management Unit (UPB Bendungan Tugu). The key storage capacities are summarized as follows:

1. Maximum storage volume = 12,500,000 m<sup>3</sup>
2. Total storage volume = 9,706,000 m<sup>3</sup>
3. Dead Storage volume = 1,040,000 m<sup>3</sup>
4. Effective Storage volume = 8,667,000 m<sup>3</sup>

The HEC-RAS model also produced results showing the amount of sediment deposited at each cross-section, which are summarized in the table below.

Table 2. Sediment deposition per cross section (downstream)

No	Cross Section	Sediment Deposition (ton)
1	1	0
2	2	0
3	3	0
4	4	137,99
5	5	157,82
6	6	167,12
7	7	176,04
8	8	191,17
9	9	244,07
10	10	286,71
11	11	314,34
12	12	332,61
13	13	360,89
14	14	428,57
15	15	556,45
16	16	756,06
17	17	1.039,63
18	18	1.605,56
19	19	5.927,74
20	20	206.211,92
Total sediment deposition		218.894,71

Figure 7 shows the changes in the riverbed cross-section over time, which are caused by sediment accumulation. It can be observed that the volume of sediment entering the control volume increases each year. However, the amount of sediment entering the river channel decreases as it approaches the dam, while the sediment volume at the last cross-section increases. This occurs due to energy loss in the flow caused by the dam obstructing the water flow

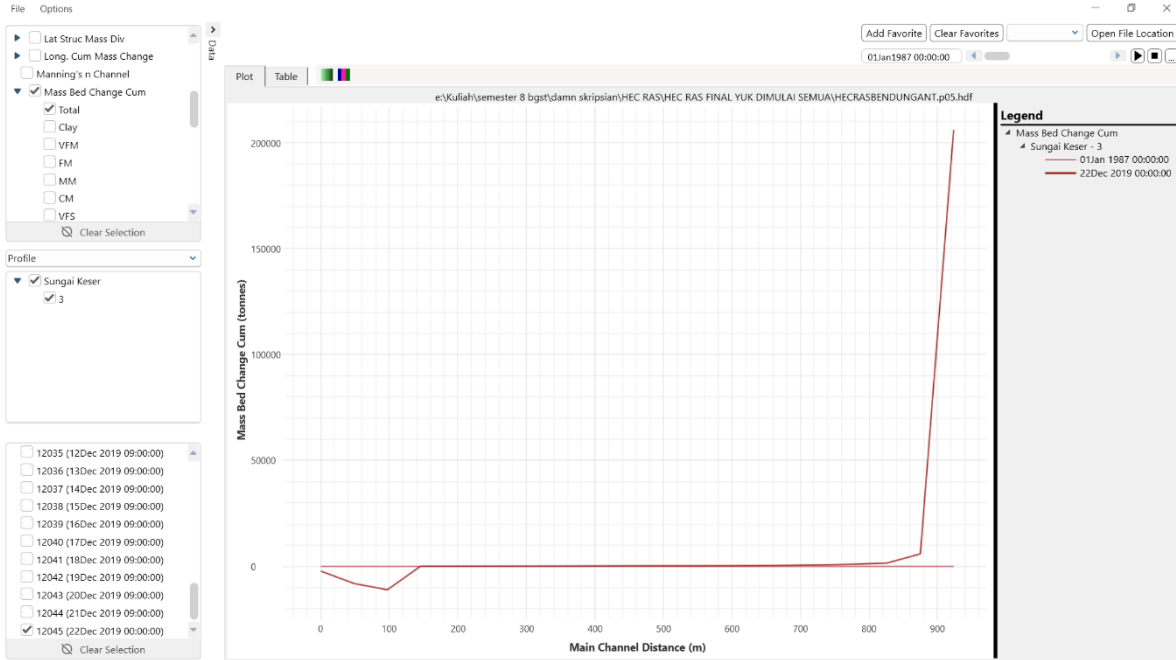


Fig. 7. Graph of Downstream Reservoir Bed Elevation Changes

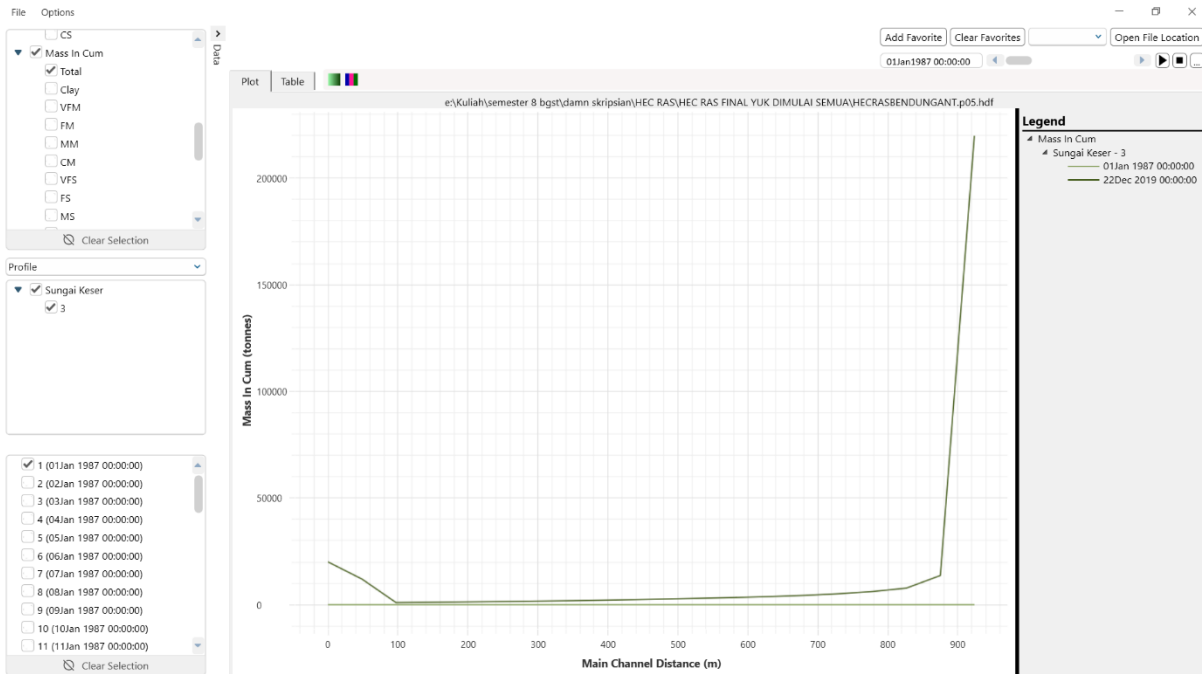


Fig. 8. Graph of cumulative sedimen transport (downstream)

In this study, the sediment bulk density is assumed to be 1.055 ton/m<sup>3</sup>. Since the sedimentation results obtained from the HEC-RAS model are expressed in tons, a unit conversion is necessary to calculate the sediment volume. After processing the data, the total sediment accumulation volume in Tugu Dam is determined to be 207,483.14 m<sup>3</sup>. Based on this,

the reduction in dead storage capacity can be calculated as follows:

1. Dead Storage volume = 1,040,000 m<sup>3</sup>
2. Total Sediment deposition = 207,483.14 m<sup>3</sup>

$$\begin{aligned} \text{Reduced dead storage} &= 1,040,000 \text{ m}^3 - 207,483.14 \text{ m}^3 \\ &= 832,516.85 \text{ m}^3 \end{aligned}$$

Consequently, the effective storage capacity changes due to sediment deposition in the dead storage zone, calculated as :

$$\begin{aligned} \text{Total storage} &= 9,706,000 \text{ m}^3 - 207,483.14 \text{ m}^3 \\ &= 9,498,516 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Effective storage} &= 9,498,516 \text{ m}^3 - 832,516.85 \text{ m}^3 \\ &= 8,666,000.01 \text{ m}^3 \end{aligned}$$

The reduction in effective storage occurs because the reservoir bottom elevation increases due to sediment accumulation, which alters the total storage capacity and ultimately decreases the effective storage.

#### 4. Conclusions

Based on the calculations and analyses conducted in this study, it can be concluded that sediment transport modeling requires three main types of data. this data needs to be analyzed and entered into the HEC-RAS : geometric data, hydrologic data, and sediment data. The modeling results indicate a decrease in dead storage capacity from an initial value of 1,040,000 m<sup>3</sup> to 832,516.85 m<sup>3</sup> over a period of 33 years, representing a reduction of 19.95%. Furthermore, the effective storage capacity also changed, decreasing slightly from 8,667,000 m<sup>3</sup> to 8,666,000.01 m<sup>3</sup>, corresponding to a minimal reduction of approximately 0.0115%. The sediment deposition pattern detected in the Tugu Dam reservoir through HEC-RAS modeling is uniform, with a total sediment accumulation volume of 207,483.14 m<sup>3</sup>.

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