Integrated Sediment Management as a Sustainable Effort of Reservoir Function: A Case Study on the Sengguruh and Sutami Reservoirs

by Unmer JURNAL KEU

Integrated Sediment Management as a Sustainable Effort of Reservoir Function: A Case Study on the Sengguruh and Sutami Reservoirs

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Abstract - Sengguruh and Sutami Reservoir are facing severe sedimentation problems, that causes a significant decrease in storage capacity. Sengguruh Reservoir leaves ± 5.85% of the initial capacity, while the Sutami Reservoir only leaves ± 51.94% of the initial capacity which affects the capacity of energy generation, fulfillment of irrigation water, raw water and flood control.

Erosion and sedimentation analysis was carried out using the USLE method to determine sedimentation potential based on 2019 land use, reservoir storage capacity analysis using bathymetry results to determine sedimentation rates and prediction of reservoir life, and sediment balance analysis to determine appropriate sediment management efforts.

Integrated sediment management from upstream to downstream (reservoir) is a solution. Watershed conservation is the most important effort in sediment management, because watershed conservation can reduce sedimentation potential by 3,16%. Management and construction of sediment control structures on the Brantas River and Lesti River as well as construction of retaining structures and waste processing at the settlement pond location upstream of the Sengguruh Reservoir can reduce reservoir sedimentation by 6.95%. Sediment dredging of 250,000 m^3/yr for Sengguruh Reservoir and flushing every 3 (three) years can increase the storage capacity by 9.45%. Meanwhile, in Sutami Reservoir, through dredging efforts of at least 400,000 m^3/yr, can maintain the function of the reservoir for the next 135 years.

Keywords:- *sediment management, storage capacity,reservoirs useful life, sustainable use.*

I. INTRODUCTION

Reservoir sedimentation is one of the main problems in the Brantas Watershed which causes the reservoirs located in the upstream part of the Brantas watershed system to, namely Sengguruh Reservoir and Sutami Reservoir, experienced a significant decrease in capacity.Reduced storage capacity of these reservoirs affect the allocation of water for energy generation, fulfillment of irrigation and raw water (industry and domestic) in the dry season and the ability to control floods in the rainy season.

Sutami Dam (Karangkates) is located in Karangkates Village, Sumberpucung District, Malang Regency.The sedimentation rate in the Sutami Reservoir is very highwhich causes the storage capacity to decrease.Based on the results of echosounding measurements in 2019, it is known that the dead storage capacity of the Sutami Reservoir is 23.46 million m^3 or 26.07% of the initial dead storage capacity (90 million m^3), the effective storage capacity is 154.70 million m^3 or 61.15% of the initial effective storage capacity (253 million m^3) and the total storage capacity is 178.16 million m^3 or 51.94% of the initial total storage capacity (343 million m^3). On the other hand, as the number of settlements around the Brantas watershed increases, the demand for raw water is greater.

In 1982-1988, in the upper part of the Sutami Dam, the Sengguruh Dam was built with a reservoir of ± 21.5 million m^3 as an effort to contain and reduce sediment that enters the Sutami Reservoir.In addition, various efforts have also been made and are being carried out to reduce sediment rates, including conservation / reforestation in the upstream area of the reservoir, outreach to the community to participate in preserving the environment, and routinely dredging sediment in the reservoir.

Several efforts have been made related to sedimentation management in maintaining the function of these reservoirs. One of them is in the form of sediment dredging activities, both dredging and dry excavation, which have a direct impact on the reservoir's storage capacity. In addition, monitoring and evaluation activities on reservoir sedimentation are also carried out to determine the development of reservoir storage volumes which are carried out through topographical measurements (bathymetry) every year. [5]

Efforts to manage sedimentation in reservoirs are considered very important to conduct an in-depth study of sediment management, the results of which can be used as a reference for handling sedimentation in the reservoir. The results of this study and research can support the efforts of the Government of the Republic of Indonesia in providing sustainable water, food and energy needs.

II. LITERATURE REVIEW

The main function of a dam is to provide storage, so its most important physical feature is its effective holding capacity. What is important in this case is the relationship between the elevation and the reservoir volume and the surface area of the inundation which can all be seen in the curve of the reservoir capacity of the dam.

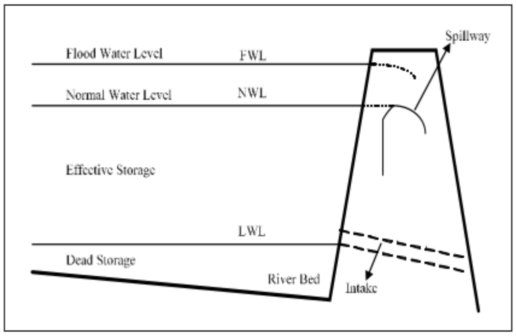

Fig. 1: Dam Storage Zones [9]

A. Estimation of Land Erosion

The Universal Soil Loss Equation (USLE) method developed by Wischmeier and Smith in 1978 is the most commonly used method for estimating the magnitude of erosion. USLE allows prediction of the average erosion rate of a particular land on a slope with a certain rainfall pattern for each type of soil and land management applications. USLE is designed to predict long-term erosion from sheet erosion and channel erosion under certain conditions. This equation can also predict erosion on non-agricultural lands but cannot predict deposition and does not take into account sediment yields from erosion of ditches, riverbanks, and riverbeds. [14]

B. Evaluation of Reservoir Storage Capacity

Evaluation of reservoir storage capacity is carried out based on bathymetry measurement data. The data used is from 2015-2019, because for 2020 the manager does not take bathymatry measurements due to the covid-19 pandemic.

C. Reservoir Useful Life

The age limit of the reservoir is determined by the expiry of the usefulness of the reservoir so that its use can be regulated for irrigation or electricity generation, where water is discharged through the intake. If the sedimentation rate has filled all parts of the dead storage, then at that time the sediment or sedimentation will reach the level of disruption of the intake function in regulating the reservoir water output.

D. Reservoir Sedimentation Management Efforts

Efforts to manage reservoir sedimentation can be carried out through 2 (two) approaches, namely the approach carried out in the catchment area of the reservoir, and the approach to the reservoir itself.

Reservoir sedimentation management has various alternative efforts, including: a) efforts to minimize the rate of sediment entering the reservoir through watershed management, b) minimizing sediment deposition in reservoirs through sluicing of sediment that enters the reservoir, and release methods (venting) turbidity density current, and c) removing sediment from the reservoir through flushing and dredging. [12]

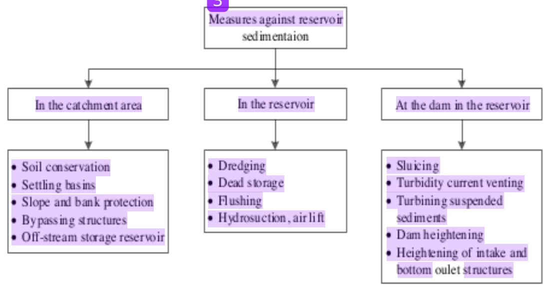

Fig. 2: Reservoir Sedimentation Management Efforts [12]

E. Sustainable Development and Management in Efforts to Sustain the Reservoir Function

Sustainable development is also very much needed in the field of water resources, both in watersheds (DAS), rivers and in reservoirs, so that the sustainability of its functions and benefits is realized. [11]

a) Sustainable Watershed Management

Watershed management is the rational use of land and water resources for maximum production with minimum risk of damage to natural resources. In a watershed system, there is a dependency between upstream and downstream. Changes in the watershed component in the upstream area will greatly affect the watershed component in the downstream area, therefore planning for the upstream area is very important.

Management of water resources must be carried out in an integrated, comprehensive, sustainable and environmentally friendly manner. Water resources management must be implemented in an integrated manner or involve all related sectors. Whole means water quality and quantity, upstream-downstream unity, and instream-offstream. Sustainable (intergenerational), and environmentally sound (ecosystem conservation) as a management unit. [13]

b) Sustainable River Management

Sustainable river management includes efforts to maintain the quality of water flow from upstream to downstream, both structurally and non-structurally. This effort can provide sustainable benefits if supported by community participation both in planning and in terms of maintenance.

One method of sustainable river management is the application of the eco-hydraulic concept. This concept is a part of integrated water resources management. The ecohydraulic concept integrates hydraulic engineering with ecology. This concept describes the influence of hydraulic engineering on river ecological systems, health requirements and the sustainability of aquatic ecosystems.

The application of the eco-hydraulic concept in river management means that the components of the watershed are seen as an integral ecological and hydraulic system. The eco-hydraulic concept aims to hold or retain water in the upstream, middle and downstream watersheds evenly. This method also maintains the riverbank area as a water storage area and can cope with drought in the dry season.

c) Sustainable Reservoir Management

The construction of reservoirs and dams requires a very large investment and does not rule out the possibility that their construction will drown residential areas, agricultural areas and historical relics, so that the reservoirs and dams that have been built must be managed efficiently and sustainably.

The existence of these reservoirs and dams will result in sediment deposition in the reservoir, which can cause an imbalance between sediment entering and leaving the reservoir. If this is not anticipated with management efforts, the sediment balance in the reservoir will not be re-established, until the reservoir capacity is completely filled with sediment deposits. Over time, the reservoir will fill with sediment. The more sediment deposits increase, the reservoir becomes less effective so that it can no longer operate as planned, where the remaining useful life of a reservoir depends on many factors, including the amount of sediment deposited into the reservoir. [7]

A planning and operation of a reservoir, if viewed from a sustainable development of water resources if as a result of the construction of the reservoir, the quantity and quality of water resources in the long term does not change significantly and the diversity of natural habitats and ecosystems is still maintained. In terms of quantity, the provision of reservoirs makes it possible to regulate irregular flow information, so that it can be utilized and adjusted as needed. Most of the existing reservoirs are designed and operated on an operating basis for a certain period of time. The concept of sustainability requires that the operation of the reservoir within a certain period of time must be changed with the view that utilization must be carried out sustainably for a long period of time. Meanwhile, in terms of quality, the concept of sustainability regulates reservoir management activities and reservoir water catchment areas in such a way that the quality of reservoir water and river water downstream of the dam can be controlled. In terms of diversity, the existence of reservoirs formed by dam structures can result in changes in habitat and food chains of ecosystems, and hinder the migration of certain species in a river system. The concept of diversity also includes cultural diversity. Where the construction of dams and dams can have an impact on population relocation and the disintegration of a developed culture, anticipation efforts must be considered. [10]

III. RESEARCH METHODS

The research design used in this study are:

- Formulate research problems and determine research objectives.
- Visiting the research location with the aim of knowing the condition of the research location and identifying existing problems.
- Define the concept and gather information about the management of the Sengguruh and Sutami reservoirs.
- Collecting data and information related to Sengguruh Reservoir and Sutami Reservoir.
- Collecting data and information related to land use in the Sengguruh Reservoir and Sutami Reservoir Catchment Areas.
- Data processing.
- Determination of alternatives in efforts to manage the sedimentation of the Sengguruh and Sutami reservoirs, both in the catchment area and in the reservoir.
- Make conclusions and suggestions on the results of the research.

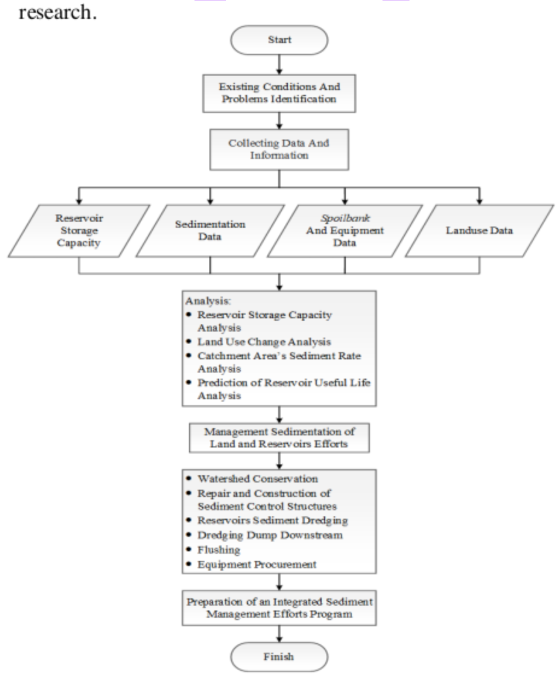

Fig. 3: Research Flowchart

IV. RESEARCH RESULTS AND DISCUSSION

A. Research Results

Sengguruh Dam and Sutami Dam are located in the upstream Brantas watershed, where the upstream Brantas watershed is hydrologically divided into 10 (ten) Sub-watersheds, with details as follows:

No.	Sub Watershed	Area (km^2)	Percentage (%)
1	Sumber Brantas	186,35	9,22
2	Bango	249,70	12,35
3	Amprong	347,47	17,19
4	Metro	299,40	14,81
5	Brantas Hulu	213,70	10,57
6	Lesti Hulu	256,21	12,68
7	Genteng	130,09	6,44
8	Lesti	233,96	11,58
9	Senggreng	34,53	1,71
10	Sumber Kombang	69,76	3,45
	Jumlah	**2.021,17**	**100,00**

Table 1: Sub-Watershed Distribution In The Upper Brantas Watershed

Source: Analysis Result, 2020

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The Upper Brantas watershed has an area of ± 2,021.17 km^2. The sub-watershed distribution map can be seen in the following figure:

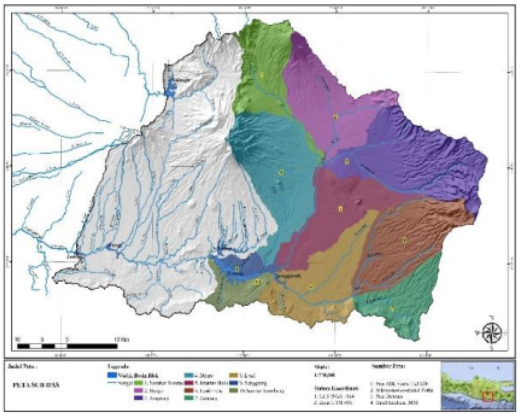

Fig. 4: Map of Sub-Watersheds in The Upper Brantas Watershed

a) Land Use Change

The area of each land use and its changes in the Brantas River system based on the results of the analysis can be seen in the following table:

Land Use	Area (km^2)		Change (%)
	2011	2019	
Hutan Lahan Kering Primer	211,23	0,00	-100,00
Hutan Lahan Kering Sekunder	42,06	243,55	82,73
Hutan Tanaman Industri (HTI)	242,26	249,33	2,84
Permukiman	233,17	258,20	9,70
Perkebunan	32,50	38,02	14,51
Pertanian Lahan Kering	114,63	127,15	9,84
Pertanian Lahan Kering Campur	106,74	345,66	69,12
Savana	2,67	2,63	-1,24
Sawah	902,63	713,16	-20,99
Semak/Belukar	118,68	33,62	-71,65
Tanah Terbuka	4,98	2,00	-59,78
Tubuh Air	9,61	7,84	-18,40
Total	**2.021,17**	**2.021,17**	

Table 2: Land Use Changein the Upper Brantas Watershed

Source: Analysis Result, 2020

b) Erosion Analysis

The results of the erosion analysis using the USLE method can be seen as follows:

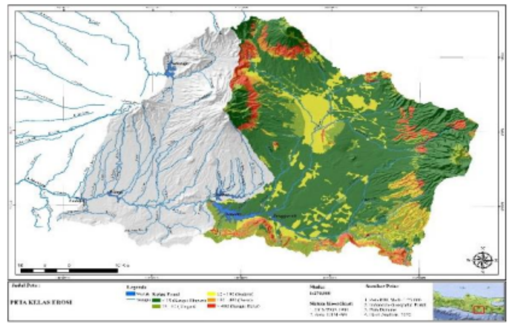

Fig. 5: Erosion Map of the Upper Brantas Watershed

- Erosion in Reservoir Watershed

The summary of the results of the analysis of erosion estimation in the Upper Brantas watershed above, can be seen as follows:

- Erosion in Sengguruh Reservoir Watershed

The sub-watersheds that affect the level of erosion in the Sengguruh Reservoir catchment are Sumber Brantas, Bango, Amprong, Upper Brantas, Lesti Hulu, Genteng and Lesti sub-watersheds with an area of ± 161,748.62 Ha and annual average erosion of 136.31 tons/ ha/year.

No.	Erosion Class	Area (ha)		Erosion Rate (ton/ha/yr)	
		2011	2019	2011	2019
1	<15 ton/ha/yr (very light)	97.999,50	92.967,54	**128,61**	**136,31**
2	15-60 ton/ha/yr (light)	19.059,48	20.305,75		
3	60-180 ton/ha/yr (medium)	24.104,50	27.060,67		
4	180-480 ton/ha/yr (heavy)	10.371,46	10.427,87		
5	>480 ton/ha/yr (very heavy)	10.213,67	10.986,79		
	Total	**161.748,62**	**161.748,62**		

Table 3: Erosion Rate of Sengguruh Reservoir Watershed

Source: Analysis Result, 2020

- Erosion in the Sutami Reservoir Watershed

The sub-watersheds that affect the level of erosion in the Sutami Reservoir catchment are the Metro, Senggreng and Sumber Kombang sub-watersheds with an area of ± 40,367.88 Ha and an annual average erosion of 111.57 tons/ha/year.

No.	Erosion Class	Area (ha)		Erosion Rate (ton/ha/yr)	
		2011	2019	2011	2019
1	<15 ton/ha/yr (very light)	25.662,94	24.375,33	**111,89**	**111,57**
2	15-60 ton/ha/yr (light)	6.123,96	7.173,01		
3	60-180 ton/ha/yr (medium)	4.694,63	4.963,62		
4	180-480 ton/ha/yr (heavy)	1.233,90	1.242,29		
5	>480 ton/ha/yr (very heavy)	2.652,45	2.613,63		
	Total	**40.367,88**	**40.367,88**		

Table 4: Erosion Rate of Sutami Reservoir Watershed

Source: Analysis Result, 2020

The effect of watershed conservation efforts on land erosion that occurred was analyzed using the same method

(USLE), but by including changes in land use after conservation efforts were carried out. Land that has a slope of > 15% and is used as dry land and mixed agriculture, will be conserved into industrial forest plantations, which will then be analyzed to determine changes in the level of land erosion that occur after conservation efforts are carried out. The results of the analysis can be seen as follows:

No.	Erosion Class	Area (ha)		Erosion Rate (ton/ha/yr)	
		Before Conservation	After Conservation	Before Conservation	After Conservation
1	<15 ton/ha/yr (very light)	92.967,54	96.222,67	**136,31**	**133,57**
2	15-60 ton/ha/yr (light)	20.305,75	19.346,14		
3	60-180 ton/ha/yr (medium)	27.060,67	25.779,20		
4	180-480 ton/ha/yr (heavy)	10.427,87	9.844,41		
5	>480 ton/ha/yr (very heavy)	10.986,79	10.556,20		
	Total	**161.748,62**	**161.748,62**		

Table 5: Erosion Rate of Sengguruh Reservoir Watershed (After Conservation)

Source: Analysis Result, 2020

No.	Erosion Class	Area (ha)		Erosion Rate (ton/ha/yr)	
		Before Conservation	After Conservation	Before Conservation	After Conservation
1	<15 ton/ha/yr (very light)	24.375,33	24.355,35	**111,57**	**110,29**
2	15-60 ton/ha/yr (light)	7.173,01	7.604,05		
3	60-180 ton/ha/yr (medium)	4.963,62	4.527,36		
4	180-480 ton/ha/yr (heavy)	1.242,29	1.234,03		
5	>480 ton/ha/yr (very heavy)	2.613,63	2.647,08		
	Total	**40.367,88**	**40.367,88**		

Table 6: Erosion Rate of Sutami Reservoir Watershed (After Conservation)

Source: Analysis Result, 2020

- Reservoir Sedimentation Analysis

Sedimentation analysis was carried out based on the results of the erosion analysis above, with the following results:

No.	Sub Watershed	Area (ha)	SDR	Erosion rate (ton/ha/yr)	Sediment (ton/yr)	Specific Gravity (ton/m^3)	Sediment (m^3/yr)
	Sengguruh Reservoir						
1	Sumber Brantas	18.635,32	0,113	353,98	743.621,56	1,55	480.065,57
2	Bango	24.970,36	0,106	115,70	305.823,60	1,55	197.432,93
3	Amprong	34.746,58	0,098	111,60	378.891,04	1,29	294.856,84
4	Brantas Hulu	21.370,37	0,109	17,95	41.746,87	1,48	28.169,28
5	Lesti Hulu	25.620,60	0,105	50,41	136.027,14	1,51	90.383,48
6	Genteng	13.009,05	0,124	198,93	320.852,13	1,38	232.670,14
7	Lesti	23.396,33	0,107	110,98	278.280,63	1,49	187.142,32
	Total	**161.748,62**			**2.205.242,97**		**1.510.720,55**
	Sutami Reservoir						
1	Metro	29.939,54	0,102	92,24	280.916,31	1,49	188.914,80
2	Senggreng	3.452,84	0,185	25,17	16.063,84	1,49	10.802,85
3	Sumber Kombang	6.975,51	0,142	219,82	217.885,21	1,49	146.526,70
	Total	**40.367,88**			**514.865,36**		**346.244,36**

Table 7: Reservoir Sedimentation Potential

Source: Analysis Result, 2020

The total potential for sedimentation that enters the Sengguruh Reservoir is ± 1,510,720.55 m^3/year. Meanwhile, the potential for sediment entering the Sutami Reservoir is around 346,244.36 m^3/year.

- Reservoir Storage Capacity Analysis

a. Sengguruh Reservoir

The reservoir volume of Sengguruh Reservoir currently reaches 1.26 million m^3 at normal water level (El. 292.5 m).

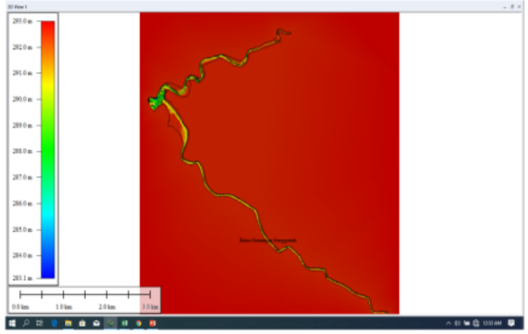

Fig.6: Sengguruh Reservoir Bathymetry Results

In addition, an evaluation was also carried out on the calculation of the storage volume of the Sengguruh Reservoir in 2017, 2018 and 2019. The results of the evaluation of the storage volume are as follows:

Elevation	Volume (million m^3)			
	2016	2017	2018	2019
285	0,00	0,00	0,00	0,00
286	0,00	0,01	0,01	0,00
287	0,01	0,01	0,01	0,00
288	0,01	0,03	0,02	0,02
289	0,02	0,07	0,04	0,08
290	0,05	0,16	0,11	0,20
291	0,14	0,41	0,30	0,44
292	0,45	0,87	0,74	0,92
292,5	0,72	1,18	1,05	1,26

Table 8: H-V Sengguruh Reservoir (2016-2019)

Source: Analysis Result, 2020

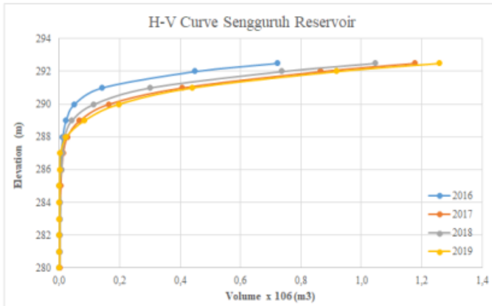

Fig.7. H-V Curve Sengguruh Reservoir

The rate of sediment deposited in the Sengguruh reservoir from 2016 to 2019 is ± 0.15 million m^3/yr.

b. Sutami Reservoir

The current storage capacity of the Sutami Reservoir is 178.16 million m^3 at a normal reservoir water level (El. 272.5 m).

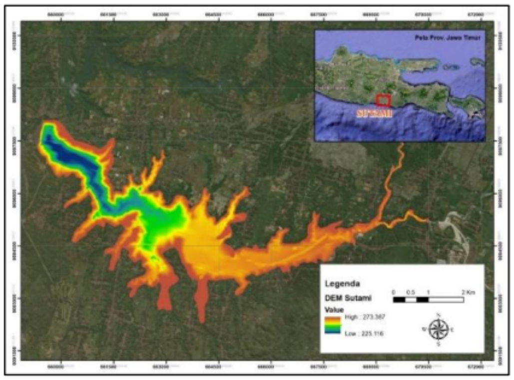

Fig. 8: Bathymetry Results of Sutami Reservoir

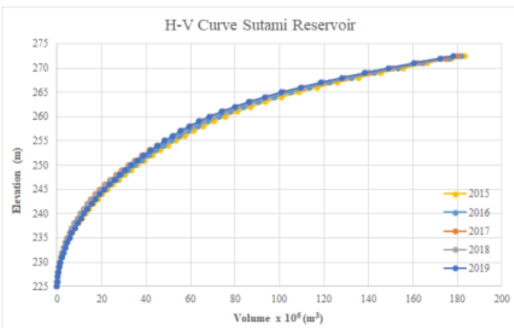

Fig. 9: Sutami Reservoir H-V Curve (2015-2019)

The average rate of sediment deposit in the Sutami Reservoir is 1.44 million m^3/year.

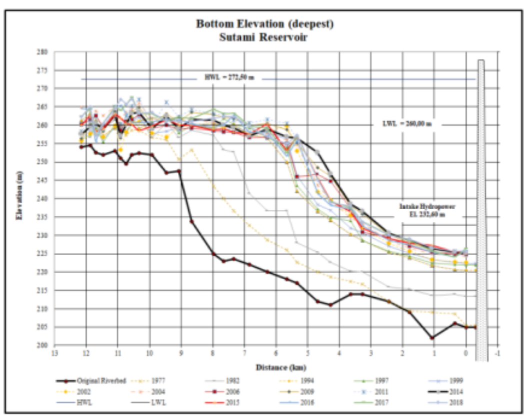

Fig. 10: Recapitulation of Sutami Reservoir Bottom Elevation (1971-2018)

Characteristics of sediment deposits in the Sutami Reservoir, generally occur in an area of more than ± 6 km upstream of the dam. While the area between the dam up to ± 6 km is quite stable and does not show a significant increase in sedimentation. This is in line with the general characteristics of dams which have large and deep reservoirs (H > 50 m).

B. Discussion of Research Results

a) Sengguruh Reservoir Sediment Management

a. Sengguruh Reservoir Upstream Area

Handling in the upstream area of the Sengguruh Reservoir aims to control the source of sediment leading to the Sengguruh Reservoir, while at the same time maintaining sedimentation in the Sutami Reservoir. Handling activities are carried out through:

- Conservation activities in the upstream reservoir area
- Maintenance of sabo dams / check dams in the upstream area of the reservoir

Watershed conservation activities that will be carried out in an effort to control the potential for sediment entering the reservoir are assumed to be carried out in areas with land use in the form of dry land and mixed agriculture on slope conditions > 15%. The results of the analysis show that by carrying out conservation activities according to the assumptions above, there is a decrease in land erosion that occurs from ± 136.31 tons/ha/year to ± 133.57 tons/ha/year (about 2.01%) in the Sengguruh Reservoir watershed, while in the Sutami Reservoir watershed, land erosion decreased by ±1.15% (from ±111.57 tons/ha/yr to ±110.29 tons/ha/year).

The thing that is considered in carrying out sabo dam and check dam maintenance activities is the accessibility of the work location for the implementation of maintenance activities.

The check dam location that allows for maintenance activities based on the identification results is BRCD 5 located in Coban Talun, in Tulungrejo Village, Bumiaji District, Batu City.

In addition to handling sediment that goes to the Sengguruh Reservoir, the flow of waste from the upstream area of the reservoir is also a problem for the Sengguruh hydropower plant. The amount of waste that goes to the hydropower plant and is filtered in the trashrack intake of the hydropower plant will reduce the generation capacity of the Sengguruh hydropower plant.

One of the recommended efforts to handle the waste that goes to the Sengguruh Reservoir is to construct a waste retaining structure in the upstream of the Sengguruh Reservoir.

Taking into account the existing location and structure, the settlement pond which is right upstream of the inundation of the Sengguruh Reservoir can be used as a location for constructing a trash rack, so that it can help reduce the flow of waste from the upstream of the Brantas River to the Sengguruh Reservoir.

b. Reservoir Sengguruh Storage Area

This study examines the possibility of controlling reservoir sediment by flushing through the Sengguruh Dam spillway.

Flushing effectiveness analysis was carried out using the HEC RAS computer simulation model with the results as shown in the image below:

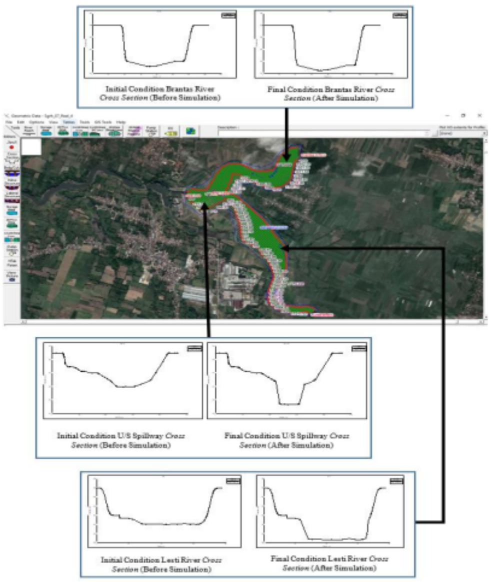

Fig. 9: Simulation Results of Flushing Effect in Sengguruh Reservoir

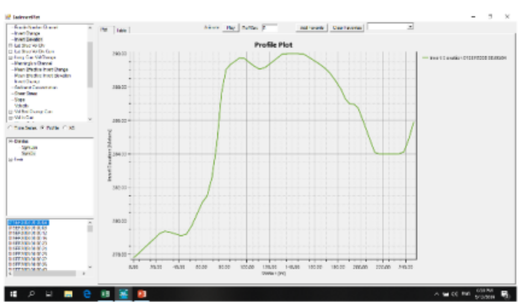

Fig. 12: Longitudinal Section of the Sengguruh Reservoir (Before Flushing Simulation)

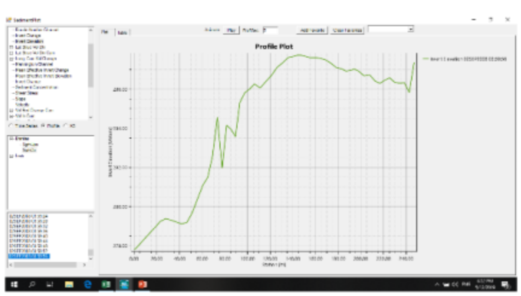

Fig.10: Upper Longitudinal Section of Sengguruh Reservoir (After Flushing Simulation)

Considering the simulation results and the bottom elevation condition of the Sengguruh Reservoir, the sediment flushing method through the spillway is an alternative for handling sediment control in the Sengguruh Reservoir in addition to dredging activities in the reservoir. Some things that need to be considered in the implementation of flushing through the spillway include:

- The elevation of the sill spillway of the Sengguruh Dam is the same as the sill elevation of the hydropower intake, so that during flushing there is a possibility of entering and accumulating sediment in the intake area of the hydropower plant.
- In addition to sediment, the accumulation of garbage in the intake area of the hydropower plant, which is generally filtered in the trashrack intake of the hydropower plant, has the risk of blocking the flow of water at the intake of the hydropower plant, thereby reducing the capacity of hydropower generation.

Based on the above, it is proposed to build a structure that can secure the intake of the hydropower plant, namely by constructing a pond structure and an additional guide wall upstream of the intake area. This structure extends the guide wall structure at the intake of the Sengguruh hydropower plant and forms a storage pond equipped with a secondary trashrack and a radial gate, so that it is hoped that the waste will be secured before entering the intake area. The illustration of the structure can be seen in the following figure:

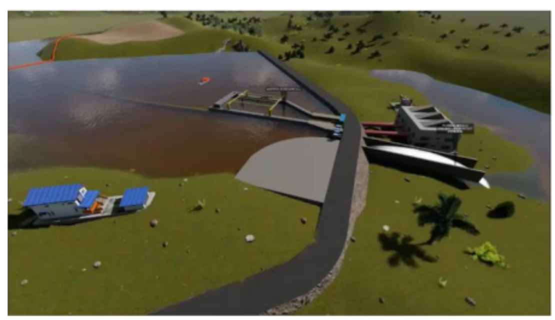

Fig. 11: Illustration of Pond Structure Plan and Additional Guide Wall at Sengguruh Hydropower Intake Area

The limited sediment storage (spoilbank) for dredging activities of the Sengguruh Reservoir must be followed up with efforts to find and identify new spoilbank locations as an effort to anticipate and prepare for dredging activities.

b) Sutami Reservoir Sediment Management

In accordance with the characteristics of the sediment deposits in the Sutami Reservoir, the dredging location is recommended to be more than 6 km from the dam shaft.

The proposed sediment handling method in the Sutami Reservoir is by dredging the reservoir.

The problem in carrying out dredging activities is the limited spoilbank area, so the volume of dredging activities will be limited by the ability to provide land for spoilbank.

An alternative in the dredging implementation method is to discharge it downstream of the Sutami Dam.

The dredging pipeline for downstream disposal in the Sutami Reservoir is on the left side of the reservoir, then it crosses the dam next to the spillway. The discharge point of the dredging pipe is at the downstream of the spillway.

The distance from the dredging location to the dumping point is about 9 km. The pipe used can be a combination of floating pipe (< 1.5 km) and land pipe (7.5 – 8 km). A booster pump with a capacity of >1000 HP is planned to be installed at every 2 km distance, so 3 units of a booster pump are needed.

c) Analysis of Reservoir Useful Life and Sediment Balance of Sengguruh Reservoir

Evaluation of the results of bathymetry measurements at the Sengguruh reservoir shows that in 2018-2019, the sediment deposit in the reservoir was 130 thousand m^3, while in dredging activities it reached 250 thousand m^3, so the estimated total volume of sediment depositin the reservoir was 380 thousand m3. Meanwhile, based on the analysis of land sedimentation in the catchment area of the Sengguruh Reservoir, the potential for sediment entering the Sengguruh Reservoir reaches 2.21 million tons/year or about 1.51 million m^3/yr. To maintain the reservoir capacity as it is today, the need for dredging activities is 250 thousand m^3/yr.

Dredging activities combined with flushing / flushing through the spillway regularly every 3 (three) years, will further increase the storage capacity of the Sengguruh Reservoir by 9.45%. The calculation of the storage capacity of the Sengguruh Reservoir with additional flushing activities every 3 (three) years can be seen in the following table:

Year	Gross Storage Capacity	Sediment Removal Dred-ging	Flushing	Total	Gross Storage Capacity after Removal	Yearly Volume Inflow	Sediment Inflow	Trap Efficiency	Sediment Volume Deposit	Sediment Volume Outflow
	(milion m^3)	(milion m^3)			(milion m^3)	(milion m^3)	(milion m^3)	(%)	(milion m^3)	(milion m^3)
2020	1,26									
		0,25	0,00	0,25	1,51	2.313,53	1,51	19,94%	0,30	1,21
2021	1,21									
		0,25	0,00	0,25	1,46	2.219,00	1,44	20,02%	0,29	1,15
2022	1,17									
		0,25	0,12	0,37	1,54	2.222,00	1,44	20,29%	0,29	1,15
2023	1,25									
		0,25	0,00	0,25	1,50	2.011,00	1,31	22,57%	0,30	1,01
2024	1,20									
		0,25	0,00	0,25	1,45	1.985,00	1,29	22,14%	0,29	1,00
2025	1,17									
			0,12	0,25	1,42	1.850,00	1,20	23,06%	0,28	0,93

Table 9: Sediment Balance of the Sengguruh Reservoir (2019-2025)

Source: Analysis Result, 2020

d) Analysis of Reservoir Useful Life and Sediment Balance of Sutami Reservoir

The results of the analysis of the sedimentation rate in the Sutami Reservoir reached 1.44 million m^3 per year, the plan for handling sedimentation in the Sutami Reservoir is expected to maintain the reservoir's useful life of more than 100 years in terms of utilization.

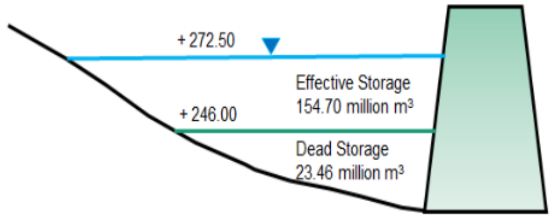

Fig. 12: Schematic of the Sutami Reservoir Storage Capacity

The useful life of the reservoir and the sediment balance of the Sutami Reservoir were simulated with and without sediment management efforts, namely without dredging efforts and with dredging efforts.

The useful life of the Sutami Reservoir without sediment dredging efforts can still be utilized for up to ± 70 years, while through dredging efforts with a volume of 400,000 m^3/year, the useful life of the Sutami Reservoir can last up to ± 135 years.

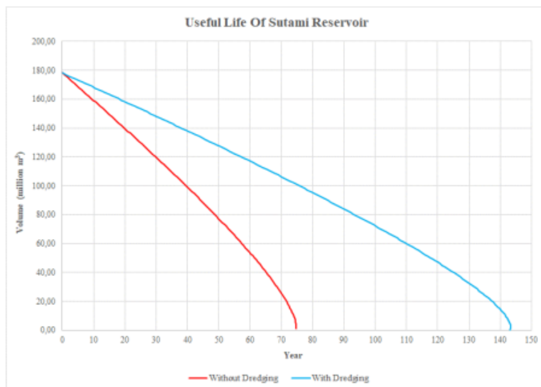

Fig. 13: Graph of Useful Life the Sutami Reservoir

A. *Sedimentation Management Plan for Sengguruh Reservoir and Sutami Reservoir*

The arrangement of sediment management is carried out by considering the following reservoir functions:

- Sengguruh Reservoir

  Sengguruh Reservoir is located at the most upstream location on the Brantas River system, besides being intended to extend the useful life of the Sutami Reservoir, there is a hydropower plant that needs to be maintained.

- Sutami Reservoir

  The Sutami Reservoir is the main controller of the Brantas River system, both as a flood control and regulating the availability of water for the dry season and a hydropower plant with a capacity of 3x35 MW.

  Sediment deposits in reservoirs are mostly affected by sediment flow from watershed erosion. It is important to consider reservoir sediment management and sediment outflow control in the watershed simultaneously as comprehensive sediment management measures. Sediment management measures are carried out by preventing sediment from going to the reservoir with watershed conservation activities and maintaining sabo dams and check dams as well as direct handling in reservoirs.

- Sediment Management in the Watershed

Watershed management is the most important part of reservoir sedimentation management efforts. The better the watershed conditions, the less sediment production that occurs. Watershed sediment management, in this case the upstream Brantas watershed, is carried out through conservation activities, in the form of forest and critical land rehabilitation, and reforestation involving several authorized agencies, namely BBWS Brantas, Ministry of Forestry, PJT I and the Malang Regency Forestry Service.

The types of watershed conservation activities are taken based on the existing activity plans of the relevant agencies, including the RPJMD Document and the Brantas Watershed Management Plan and Pattern Document. Based on these data, the conservation activities carried out are the rehabilitation of 75% of the existing critical land, the movement of planting 1 billion trees, forest rehabilitation of 63% of the damaged forest area, and the planting of 265 thousand trees for conservation using fruit trees planned by PJT I. It is hoped that these conservation efforts can be carried out as planned so that the watershed conditions are getting better and sedimentation can be reduced.

- Sediment Control in Existing Sediment Control Structures

The existence of a sediment control structures is very necessary in an effort to manage sediment. However, with the condition of the existing sediment control structures, it is necessary to carry out sediment management in the existing sediment control structuresas follows:

Routine dredging on Check Dam BRCD 5

- ➢ Dredging at Check Dam BRCD 5 (minimum) is 10,000 m^3/year. Disposal of dredged material on the right side of the check dam storage area by making an embankment (estimated total storage volume of 150,000 m^3).
- ➢ Construction of a trash racking system and its supporting facilities at the Kali Brantas Settlement Pond in Sukorejo Village, Gondanglegi District, Malang Regency.

- Sediment Control in Sengguruh Reservoir

➢ Flushing throughspillway

Flushing through the spillway at the Sengguruh Reservoir is quite effective, as is the result of the analysis above. However, with the sill spillway elevation condition that is parallel to the hydropower plantintake sill elevation, there is a risk that some sediment will accumulate in the hydropower plantintake area. Flushing activities are proposed every 3 (three) years, according to the results of the analysis.

➢ Flushing in the hydropower intake area

Flushing in the hydropower intake area needs to be carried out in accordance with the Sengguruh Dam Operation and Maintenance Guidelines document. In terms of implementation in the field, the operating frequency is less than that recommended in the OP Guidelines document, it must be considered against the sediment conditions in the hydropower intake area.

➢ Dredging

Dredging activities in the Sengguruh Reservoir are recommended for a minimum of 250,000 m^3 (2022-2027) to maintain the function of the hydropower plant.

➢ Construction of a reservoir and additional intake guide wall in the intake area of the Sengguruh hydropower plant

The construction of a storage pond and guide wall aims to maintain the function of the Sengguruh hydropower plant. The construction of the reservoir and guide wall is a fairly large structure, so that the stages of investigation, planning and implementation need to be carefully and wellprepared. Since the structure is located in the containment area of the dam, it is necessary to obtain a recommendation from the Dam Safety Commission (KKB).

- Sediment Control in Sutami Reservoir

Dredging in the Sutami Reservoir as the results of the above analysis, the dredging volume (minimum) in 2022-2027 is 400,000 m^3. The following year's dredging can be increased according to equipment availability and spoilbank. The dredged results are channeled downstream of the dam as an anticipatory measure to overcome the limitations of the spoilbank.

- Procurement of Supporting Facilities / Equipment
  - ➢ Sengguruh Reservoir
    - Trash Skimmer Boat and Conveyor Belt
    - Dredger with water jet, capable of moving with its own motor (self propelled), and dredging depth up to 9 m.
    - HCE Longboom
  - ➢ Sutami Reservoir
    - Dredger with water jet, capable of moving with its own motor (self propelled), and dredging depth up to 18 m.
    - Booster Pump capacity > 1000 hp, 3 units.
    - Exhaust pipe 12 inch (HDPE) 9,000 m long equipped with a 1,000 m long floater.

V. CONCLUSION

Watershed management is the most important part in efforts to manage sediment in the Sengguruh and Sutami reservoirs. Watershed is the dominant contributing factor in the occurrence of sedimentation in reservoirs. With watershed management in the upstream part of the Sengguruh Reservoir and Sutami Reservoir, it will be able to reduce sediment that enters the river and is eventually carried into the reservoir. The management of the Upper Brantas watershed as an effort to control sedimentation in the Sengguruh Reservoir and Sutami Reservoir is carried out with conservation efforts and the management of sediment trapstructures along the Lesti River and the upstream Brantas River. The conservation efforts of the Upper Brantas watershed were taken based on the activity plan documents of several agencies authorized in conservation activities in the Upper Brantas watershed, namely the Malang Regency RPJMD Document, the tree planting activity plan by Perum Jasa Tirta I and the WS Brantas Water Resources

Management Plan Document where in the document the plan for conservation activities to be carried out, especially the rehabilitation of forests and critical lands, especially in the Upper Brantas watershed is mentioned. With the implementation of these efforts, the potential for erosion and sediment that occurs will be reduced by ± 3.16%. Meanwhile, efforts to manage the existing sediment trapstructuresalong the Lesti River and the upstream Brantas River are carried out through the implementation of sediment dredging activities in the sediment trapstructures, so that they can again be useful for capturing and holding sediment that enters the river. In addition, the construction of a waste catchment facility at the location of the settlement pond upstream of the Sengguruh Reservoir and its processing facilities, so that waste does not enter the Sengguruh Reservoir and interfere with the utilization of the reservoir. The existing sediment control structures along the Lesti River and the upstream Brantas River which are in a damaged condition are also planned to be rehabilitated, so that they can return to their function of capturing and holding sediment. In addition to managing the existing sediment control structures, the planning and construction of new sediment control structures is also being carried out in stages along the Lesti River and the upstream Brantas River as an effort to improve sediment management in the river. With the implementation of these efforts, the sediment in the river will be reduced by about 6.95%.

Sediment management in the Sengguruh Reservoir is carried out through flushing, dredging and construction of a storage pond and additional intake guide wall in the intake area of the Sengguruh hydropower plant. Flushing activities are carried out through the hydropower plant overflow and intake. As a daily reservoir that functions as a regulator/controller of discharge fluctuations that occur in a relatively short time span, which is only one day, the implementation of flushing at the Sengguruh Reservoir is very effective in reducing sedimentation that settles in the reservoir. Flushing activities are proposed to be carried out every 3 (three) years. In addition to flushing, dredging activities also need to be carried out as an effort to maintain the function of the reservoir for hydropower. This dredging activity is proposed with a minimum volume of 250,000 m^3/year. Another effort that needs to be done as an effort to manage sediment in the Sengguruh Reservoir is the construction of a storage pond and guide wall which aims to maintain the function of the Sengguruh hydropower pl11 where further dredging activities can be concentrated on the reservoir. The storage capacity of the Sengguruh Reservoir will increase by 9.45% with the implementation of these efforts.

Sediment dredging and flushing are the most effective alternatives in reducing sedimentation of the Sengguruh Reservoir, where the analysis results show that dredging activities combined with flushing / flushing through the 7illway regularly every 3 (three) years, will further increase the storage capacity of the Sengguruh Reservoir. Meanwhile, in the sediment management effort of the Sutami Reservoir, sediment dredging and sediment disposal downstream of the dam are the most effective alternatives in reducing sedimentation in the Sutami Reservoir, where through dredging activities with a volume of 400,000 m^3/year, the Sutami Reservoir can still be utilized for ± 135 years future.

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