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Research Article

Analysis of the Sediment Dredging Activities of the PB Soedirman Banjarnegara Hydroelectric Reservoir Based on a Technical and Economic Points of View

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Abstract: The PB Sudirman hydroelectric power plant, built in 1988, has fewer than 50 years of operational life. In contrast, the planned operating life for this dam is 50 years. This dam is experiencing intensive sedimentation, which results in siltation. Dredging efforts and catchment area management are conducted to extend the operational life of the dam. Therefore, technical and economic analysis of dredging activities and the potential benefits of dredged sediment is needed to determine the solution's effectiveness. We use the site survey method to conduct an environmental impact analysis and interviews with dam managers. The identification of the extent and distribution of erosion-sedimentation was carried out as part of the technical assessment. In the economic study, we calculate the dredging costs and profits from selling dredged sediments, mainly sand. The analysis results show that the dredging of deposits in the foreset slope area is not profitable. There are 17 areas of bank spoil that have economic benefits. This study concludes that the need for dredging costs on foreset slopes is higher than the profit from selling dredging sediments.

Keywords: dredging; sedimentation; PB Soedirman Hydroelectric reservoir; Banjarnegara; Indonesia

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1. Introduction

The Soedirman Dam, often referred to as the Mrica Dam, was built in 1988 for a Hydroelectric Power Plant by damming the Serayu River [1–3]. The flow of the Serayu River before entering the Mrica Dam is fed by two other major rivers, namely the Merawu River and the Begaluh River [4,5]. In addition, the Mrica Dam functions as irrigation and a place for fish farming [6]. This dam is located in Bawang District, Banjarnegara Regency, exactly 8 km west of Banjarnegara City, Indonesia with an altitude of about 200 meters above sea level. The dam, which has a length of 6.5 km and an area of 1,250 hm^2, is the longest artificial lake or the largest dam in Southeast Asia, with an electricity production capacity of 184.5 MW [7–9]. This power plant serves to supply the electricity needs of Java-Bali. The practical operational life of the Mrica reservoir is predicted to reach 50 years since it was built. However, in only about 26 years since the inauguration, the symptoms of siltation have become more evident due to the high level of sedimentation-erosion in the Serayu River Basin, and it is estimated that the operational age is only 4-7 years away [5,6].

The volume of sediment deposited in the reservoir until 2014 had reached 88.55 million m^3, or 59.72% of the total volume. It affects a reduction in the reservoir water

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volume from the beginning of the operation, which was 148.28 million m^3 or 59.73% [10]. The sediment that settles in the reservoir is classified as very large, namely 4.2 million m^3 per year or an average of about 11,722 m^3 per day. Sedimentation rate from the Merawu, Serayu, and outside the Merawu and Serayu is 4.7 mm^3/year, 3.1 mm^3/year, and 2.7 mm^3/year, respectively. Therefore, it is necessary to immediately carry out accurate and comprehensive activities in handling sediment that settles in the Mrica Reservoir [1].

Sediment management to reduce the volume of sediment deposition that settles in the reservoir, mainly those close to the intake (foreset slope), is also performed with DDC (Draw Down Culvert). DDC operations increased from 3 times in 2007 to 14 times per year in 2013, and it is indicated that it will continue to grow if sediment management only relies on DDC operations. Hence, other sediment management is required to optimally reduce the volume of sediment deposits. The dredging method is an alternative for implementing sediment management in addition to managing the catchment area [11–13]. The dredged sediment material is temporarily accommodated in one disposal area before being moved or used economically [14–16]. This study aims to analyze the technical and economic aspects of sediment dredging activities near the intake (foreset slope) of the Mrica Banjarnegara Reservoir and the benefits of the dredged sediment. The results of the dredging study based on technical and economic points of view will be the subject of determining policies. These can be adopted by officials/formulators and policyholders of PT. Indonesia Power in sediment management in the Soedirman Mrica Reservoir. The study of the effectiveness of sediment dredging in the Mrica Dam based on technical and economic considerations is a pioneer for future research. The same method can be applied in the future to evaluate whether the solution to overcome reservoir siltation is economically viable or not. [17,18] assessed dredging sediment on the reservoir and catchment area based on an economic and technical perspective, namely the case study of Liscione Dam, Italy and the Nam Kong catchment area, Laos. Meanwhile, this study will focus on assessing sediment dredging based on technical and economic aspects in Mrica Dam, Indonesia. Basically, we will conduct similar steps but with a different case study.

2. Materials and Methods

This study begins with studying the previous environmental impact analysis documents, followed by a survey of the study site and interviews with the management and mining communities at the sediment dredging area. We are collecting data by conducting surveys at location points, as shown in the map below (Figure 1). The scope of this study area focuses on dredging activities in the area near the intake (foreset slope), as shown in Figure 1. Dredging and other sediment management activities are adjusted to the environmental impact analysis report of sediment dredging activities in the context of maintaining the Mrica Banjarnegara Dam with an area of 266. 82 hm^2 (Figures 2 and 3). Technical analysis was carried out by analyzing secondary data from the Mrica dam on the erosion-sedimentation rate of the reservoir and the distribution of sedimentation and comparing the advantages and disadvantages of different dredgers. Then we calculate the dredging costs by referring to the environmental impact analysis report data as the basis for calculating the economics of the dredger operation.

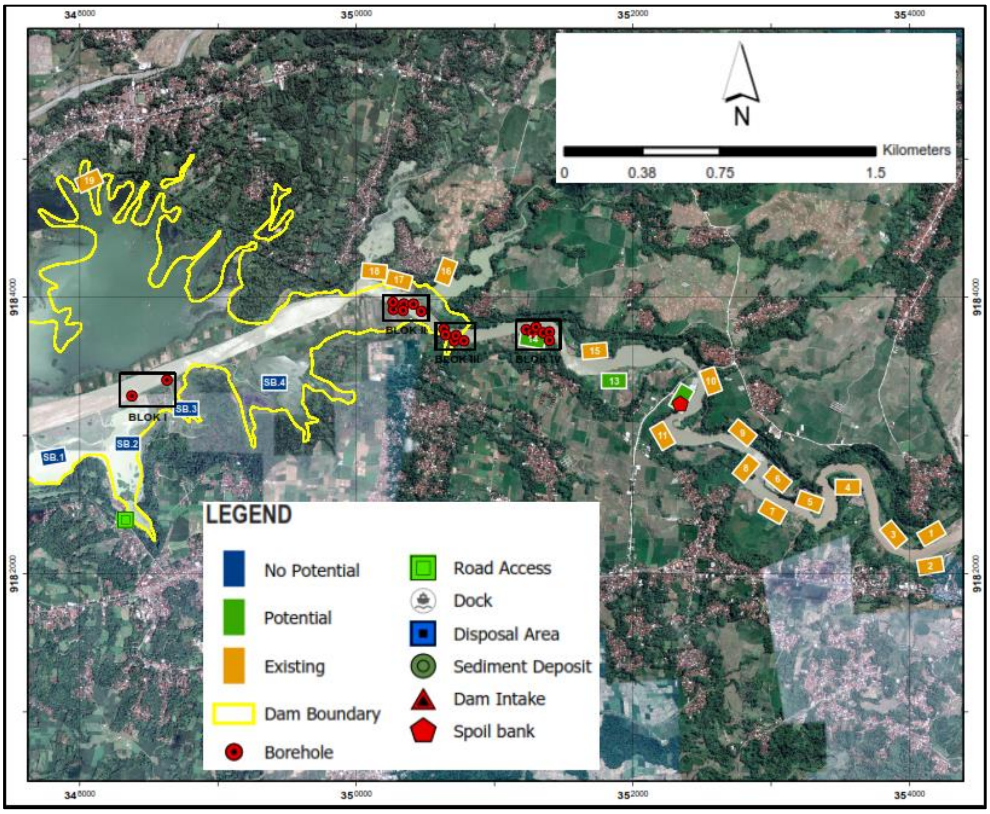

Figure 1. Spoil bank map and bore hole points. The orange rectangle symbol is a spoil bank that the public dredged with 14 points. The green spoil bank with three dots has never been dredged. The blue color spoil bank, totalling four points, will be dredged.

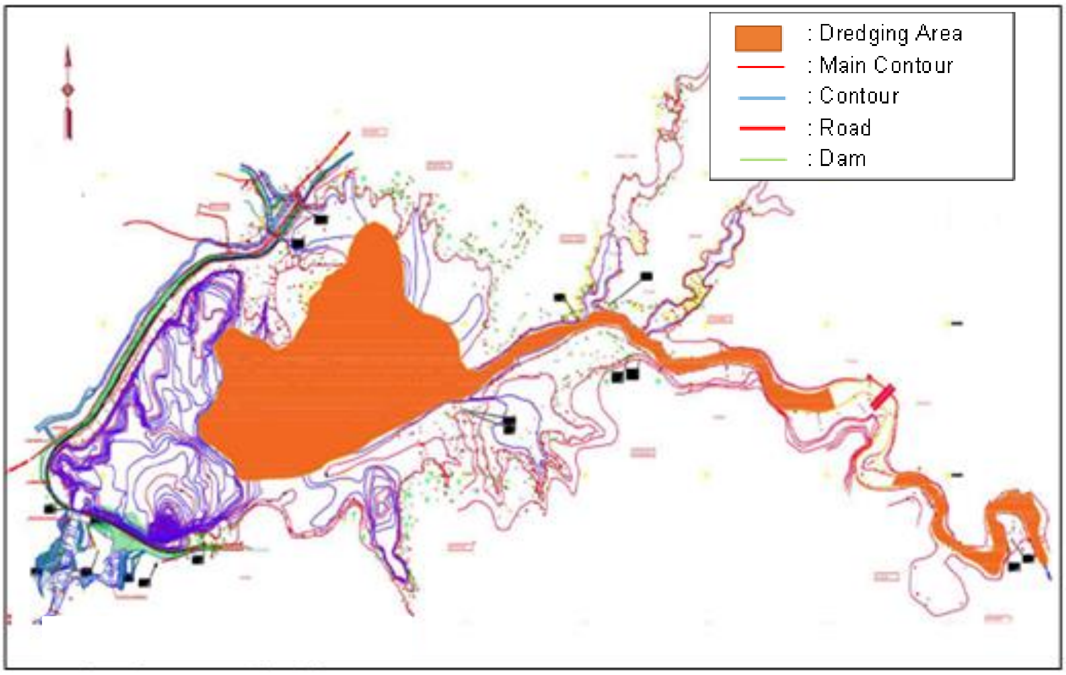

Figure 2. The dredging area is shown in the area with orange color.

3. Results

The observations of the sand mining sites exhibit that the sand produced includes medium-coarse sand (Figure 3), the quality of the sand is quite good, and one truck of medium-sized sand is sold for 41.5 USD. The amount of sand produced per day is between 20-24 trucks, but we do not acquire data on the amount of money deposited to Indonesia Power Mrica, the mining group, and the owner of the mining site.

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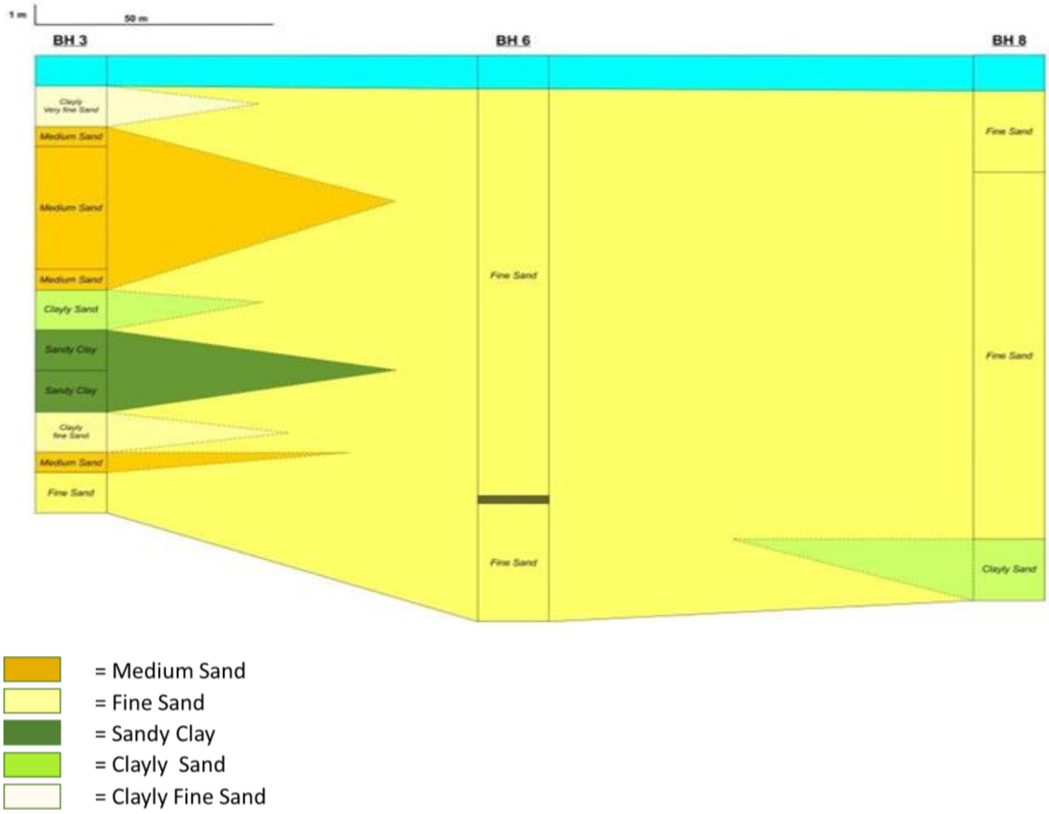

Figure 3. The cross-section of block II (B 3-6-8) is dominated by medium sand

The observation of the drilling data of BH 3, BH 6 and BH 8 (Figure 4) reveal that the material produced from drilling BH 3 in a row from shallow to deep is clayly fine sand, medium sand, clayly sand, sandy clay, clayly fine sand, medium sand, and fine sand. In BH 6 drilling, only fine sand is obtained, while BH 8 drilling produces fine sand and clayly sand. Based on the correlation of three drilling data points in block II, it is found that the potential for medium sand is only in BH 3, so the economic potential in block II is small.

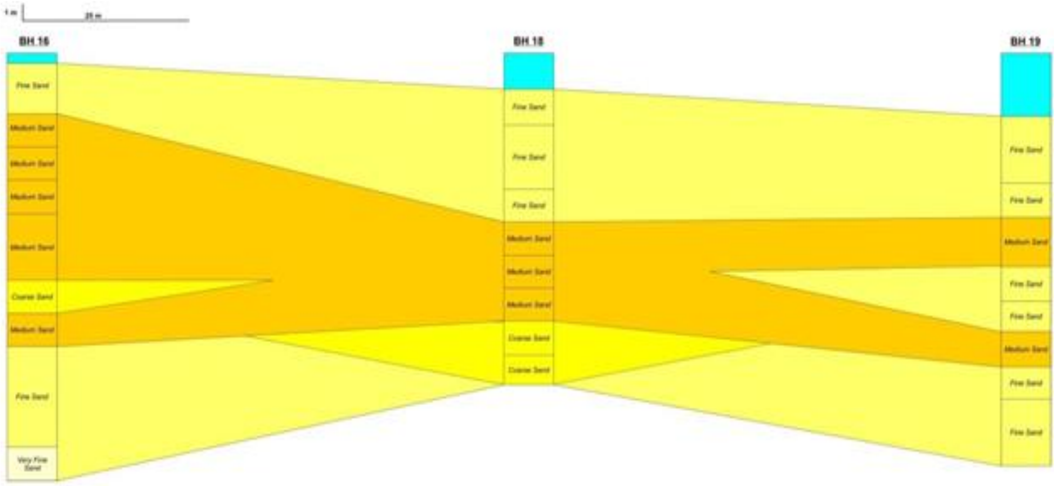

Figure 4. Medium sand dominates the cross-section of block IV (BH 16-18-19)

Observations at 3 spoil bank points (points 12, 13, and 14) based on the drilling data of BH 16, BH 18 and BH 19 (Figure 5) consist of sedimentary material, which from top to bottom is fine sand, medium sand, coarse sand, medium sand, fine sand, and very fine sand. Correlation of 3 points of drilling data in block IV obtained the dominance of medium sand sediment size at spoil bank points 12, 13, and 14. The economic potential of medium sand-sized sediment material is relatively high, where the dredged results can

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be directly sold and utilized. Block I is the block closest to the dam intake, and the drilling results represent four blue spoil banks (SB1-SB4). Sedimentary material deposited in block 1 (Figure 5) is dominated by claly sand and fine sand, claly fine sand, and clay. Clay sand material has a brown color with plastic properties. Sedimentary materials the size of loamy sand require additional treatment to be of economic value, such as materials for making roof tiles, fertilizers, or planting media.

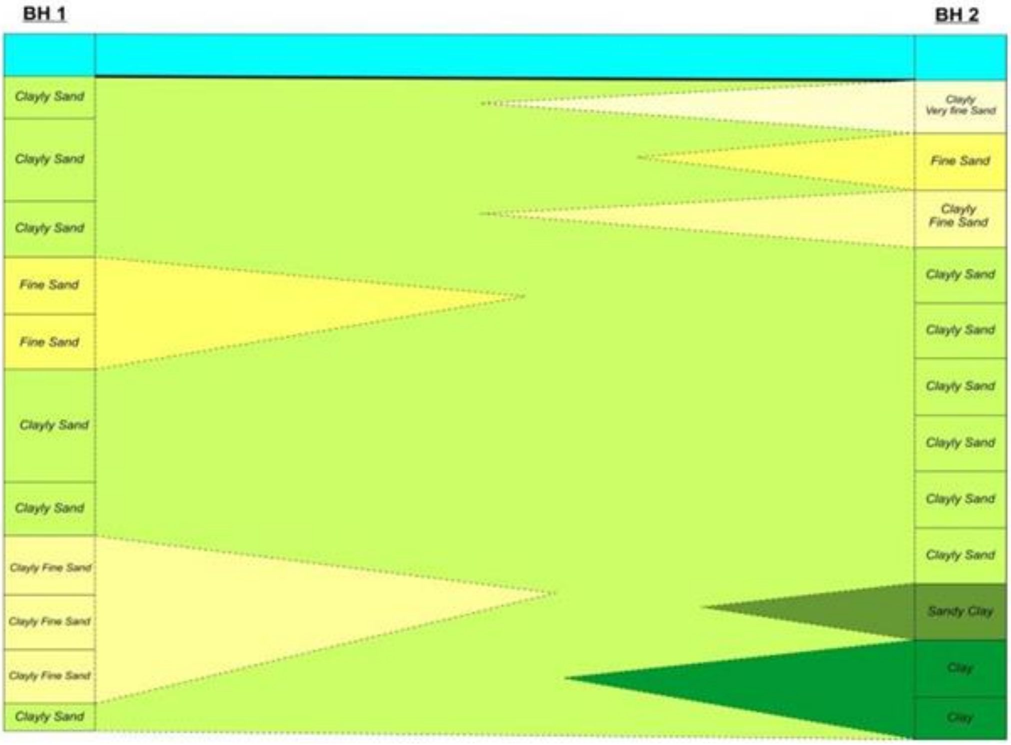

Figure 5. The cross-section of block I (BH 1-2) exhibits the dominance of claly sand.

4. Discussion

4.1. Dredging Scheme and Disposal Area

Sediment dredging on the reservoir slope requires operating expenditure (OPEX) and capital expenditure (CAPEX) financing by the asset owner because there is no economic value in sediment. Sediment dredging in bank spoil areas 3 to 19 carried out by existing dredging actors can be profitable if the sediment price meets the regulatory requirements set by the Government. Based on aerial photo analysis, the dredged sediment area reached 2,691,082.55 m^2, while the silting area, according to secondary data from an analysis report on environmental impacts, was 2,668,216.24 m^2 (Power, PT. Indonesia, 2020). The dredging area starts from the foreset slope near the intake to the headwaters of the Mrica reservoir. The disposal area is located in the south of the dredging area, so the mobilization of dredged products is easier (Figure 6).

The disposal area is a temporary shelter for dredging sediment from foreset slopes in reservoirs by filtering ponds or reservoir pools near the pier covering an area of 923,777,623 m^2 based on aerial photography analysis. In contrast, according to the previous report, the disposal area is 945,000 ha. The location can temporarily accommodate dredged sediment from the foreset area of 5.54 million m^3 (Power, PT. Indonesia, 2020). As shown in Figure 7, the area near the jetty is the most suitable place as a temporary shelter for the dredged sediment. The area already has water depths ranging from 1-3 m, and the difference in water and green belt elevations is ± 3 m. The average sediment pile is 1 m above the green belt elevation. The morphology of the landscape naturally develops in the form of pools separated by land formed by sediment deposition. This area is a temporary shelter for dredged sediments on the slopes of the foreset.

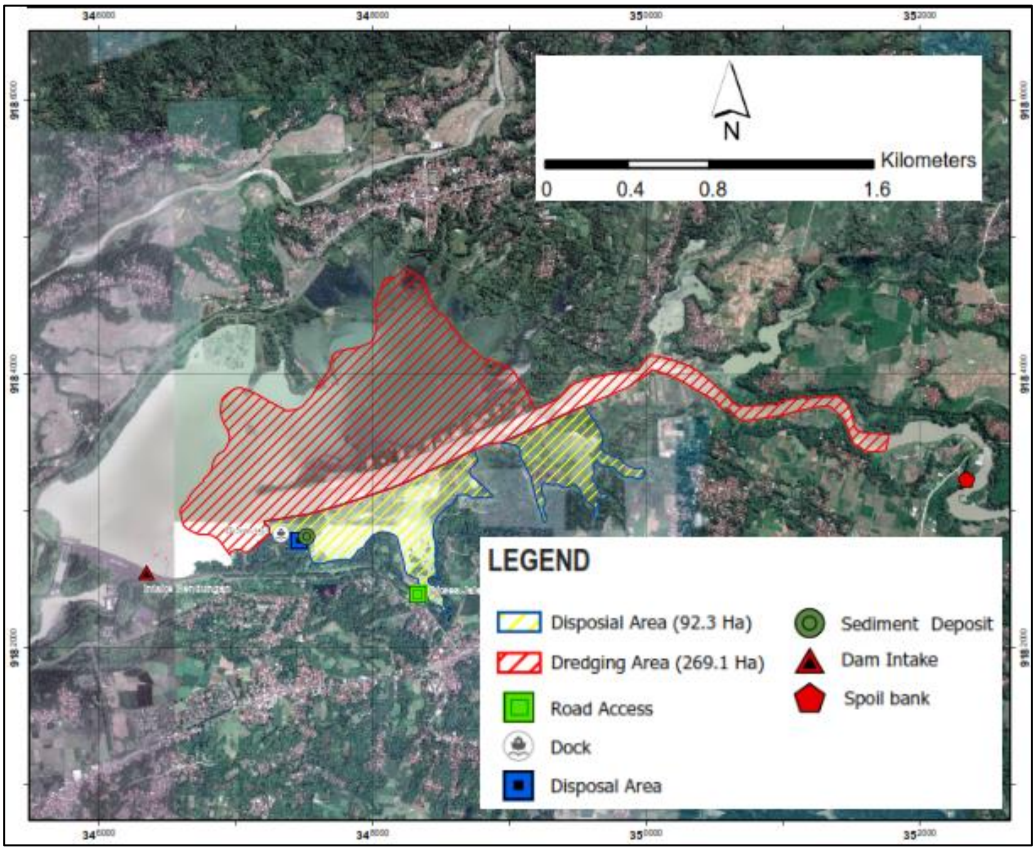

Figure 6. Map of dredging and disposal areas. The disposal area is 92.3 hm² while the dredging area is 269.1 hm².

The dredged sediment material is 4.44 million m3 per year in the dredging area, and the dredging results on the foreset slope (near the intake) are 1.1 million m³ per year. The sediment is then temporarily stored in the disposal area, which third parties can then utilize into various processed products with economic value. The party appointed to manage this dredged sediment must meet the licensing requirements in accordance with the agreement with Indonesia Power as the asset owner.

4.2. Calculation of Sediment Dredging Cost near the intake (Foreset Slope)

Dredging volume refers to the rate of sedimentation entering the reservoir per year is 4.44 million m³ which will be accommodated at 23 spoil bank points. A total of 1.11 million m³ out of 4.44 million m³ are foreset slope areas and the remaining 3.33 million m³ are existing areas where the sand quality and economic value are not high. The economic value of the existing miners is not comparable to the calculation of the planned dredging costs. The sediment dredging activity plan is carried out to save the dam's service function so that the dam's lifetime becomes longer. The total dredged area according to the normal inundation area is 266.82 hm². Sediment dredging activity plan with a sediment release target of 4.44 million m³/year using a dredging system and accommodated in a temporary stockpile or spoil bank, which will then be utilized by third parties who meet the licensing requirements. Daily dredging is 15,051 m³/day with 295 working days and 70 days of holidays in a year.

The disposal area is a temporary shelter for sediment material dredged from the reservoir. The stockpile or spoil bank is located adjacent to the dredging site. The filtering pool, which functions as a disposal area, has an area of 94.5 hm², water depth ranging from 1-3 m; the difference in water elevation with the green belt is about 3 m and an average elevation of sediment pile 1 m above the green belt elevation. Based on these dimensions, the disposal area can accommodate a maximum dredged yield of 5.67 million m. By increasing the disposal area to 36.71 hm² and an average height of 3 m, the disposal area can accommodate a maximum dredging result of 1.1 million m³. Currently, the disposal area reaches 131.21 hm^2 and can accommodate a maximum dredging yield of 6.77 million m^3 (Figure 1).

The dredging target in blocks 3-19 is 3.33 million m^3, while the dredging target for foreset slopes in blocks SB.1 – SB.2 is 1.11 million m^3 within a year. The selection of the type of dredger considers the impact factors of the occurrence of water turbidity, namely the suitability of the dredged material, loss of water to transport sediment, dredging productivity, and suitability with the depth of the dredged sediment. Technically, the Cutter Submersible Hydraulic Dredge Pump (CSHDP) is suitable for dredging various materials according to the sediments in the PB Reservoir. Sudirman in the form of mud, clay, sand and stone. The sediment's depth to be dredged follows the capabilities of CSD and CSHDP (Adri & Susilowati, 2022). Economically, (CSHDP) is most suitable for dredging because the water loss factor is the least, and the productivity is quite large compared to other methods.

The capacity factor of Mrica's power plant reaches 80% with an annual production of 350,400 m^3. Total revenue is around 30,000 per m^3 with a margin of 6,911 per m^3. Operating expenditure data, namely expenses made by PT. Indonesia Power UP Mrica as the manager of the hydropower plant to meet operational needs are as follows (Table 1):

Table 1. Operational expenditure data. Total operating expenses reached Rp. 8.09 million.

No	Electricity supply components (BPP)	Fixed Cost	Variable Cost	Total	Percentage (%)	BPP/m³
1	Operating cost		3,438,440,000	3,438,440,000	42.50	9,813
2	Maintenance cost		1,290,600,000	1,290,600,000	15.95	3,683
3	Employee cost	1,313,791,304		1,313,791,304	16.24	3,749
4	Administration		130,880,000	130,880,000	1.62	374
5	Depreciation	1,916,666,667		1,916,666,667	23.69	5,470
	Total	3,230,457,971	4,859,920,000	8,090,377,971	100,00	23,089

Table 2. Data of dredged sediment production. Sediment dredging volume per year is 1,110,000 m^3

No	Disposal Area	Production Data Analysis		
		Sand Pump	Cutter Submersible Hydraulic Dredge Pump (CSHDP)	Excavator
22	SB.2	18	1	0
23	SB.1			
Total		18	1	-
Production per equipment/day m³		280	3,483	0
Total Production/day m³			3,763	
Total Production/year m³			1.110.000	

Foreset slope dredging cost calculation

Foreset slope dredging fee (per year)

= ({BPP (Rp)/m^3} x total production of foreset slope/m^3)

= Rp 23.089 x 1.110.000 m^3

= Rp 25.628.790.000 per tahun

4.3. Economic Analysis

The four points of the Spoil Bank close to the intake are uneconomical areas for dredging because the dredging material, landscape, and disposal area are not economically profitable. Observations showed that the dredged sediment consisted of fine clay-fine sand, but the grain size was dominated by fine clay, which had almost no value (Widodo & Artiningsih, 2021). Block 3-19 is considered to have better potential compared to other blocks. The results of dredging in block 17 obtained backfill sand with details of the price per cycle of IDR 325,000 at seven points and IDR 270,000 at seven points. In Pucang the price of sand per rit reaches Rp. 600,000 at three points. The average price per rit of sand reaches Rp. 350,000. Here are the details of the calculation:

Table 3. Profit sharing area analysis

No.	Expenditure components	Cost	Explanation
1	Selling Price of Sand	350,000	Rp/Rit/8m³ or Rp. 43,750/m³
2	Tax (20%)	70,000	20%
3	Barge fuel cost (± 0,5-1 ltr/Rit)	3,600	Rp/Rit/barge/8m³
4	Sand extraction fee	60,000	Rp/Rit/barge/8m³
5	Unloading sand from Pontoon to land	60.000	Rp/Rit/barge/8m³
6	Loading Fees to Truck	60,000	Rp/Rit/barge/8m³
7	Fuel cost SP 3-4 ltr/barge (@8.000/ltr)	24,000	Rp/Rit/barge/8m³. 3 liter/barge
8	Barge rental fee	20.000	
9	Deposit rental fee	20,000	
10	Profit sharing	-	
	Territorial fee	8,000	1000/m³
	Total cost	271,600	
	Difference (SAND PUMP Owner) = A-B-C	24,400	

Profit sharing:

Per day = Average/day (15 rit) x Nominal profit sharing per rit

= 15 x IDR 24,400

= IDR 366,000.

Per year = Profit per day x Number of days in a year

= IDR 366,000 x 295 days

The total volume of dredged sediment in the SB area. 3 to 19 is assumed to be 15 cycles x 8 m³ x 17 points x 295 days = 601,800 m³ per year. If we assume that 17 points of Spoil Bank (SB 3 to 19) classified as profitable areas are considered to have the same sediment potential as the calculation above, then in one year for 17 blocks, it produces 17 x Rp 107,970,000 = Rp 1,835,490,000. From this nominal, we can conclude that the dredging of blocks 3-19, which are considered to have good sediment potential, did not generate sufficient profit to finance the dredging of the foreset slopes. It is because the sand produced is of medium to low quality with a low market price but is still subject to tax. Withdrawing taxes from dredgers weighs heavily on his income.

When we compare the cost of dredging on the foreset slope (near the intake) with a Cutter Submersible Hydraulic Dredge Pump (CSHDP) dredging vessel, the calculation below can be seen: The costs incurred in dredging on the foreset slopes are Rp. 25,628,790,000/year, while the income from the upstream dredging by existing miners based on the assumption from the above calculations will result in a sand profit of Rp 1,835,490,000/year, the manager of the Mrica reservoir, it is necessary to provide funds of Rp. 23,793,300,000/year as the difference between the cost of dredging foreset slope sediment (near the intake) and the income from existing miners. The loaded cost can be higher if not all blocks have the same sand sediment potential. It has the consequence that IP Mrica PGU, the owner of the assets, needs to provide these funds to finance the dredging of foreset slope sediments continuously every year in the amount of Rp.23,793,300,000/year. It is to restore the function of the Mrica reservoir so that the reservoir's lifetime returns to the initial plan design. Profits were obtained from sediments in SB. 3 to 19 (outside the foreset slope) is IDR 1,835,490,000/year, but until now, the profit-sharing agreement has not been regulated.

4.1.1. Subsubsection

5. Conclusions

Sediment dredging in the foreset slope area (SB 1 & 2) has no economic value, so it becomes a cost source for the asset owner. Spoil Bank, located relatively close to the intake or called foreset slope (SB 1 & 2), cannot be developed for a profitable business unless treatment is carried out on the dredged sediment. The 17 points of Spoil Bank (SB 3 to 19), which are now managed by the existing dredgers, can be classified as economically profitable dredging areas. The amount of profit of 17 Spoil Bank points depends on the amount of sand sediment content according to the classification and quality of the sand as the basis for determining the selling value and sales tax. The area and volume of the disposal area for temporary shelter dredging based on aerial photo analysis is 923,777,623 m^2 or 92,377 hm^2, while the disposal area according to the environmental impact analysis report is 94,5 hm^2, and the disposal volume is 5.67 million m^3. Analysis of the cost of dredging sediment on forest slopes with a volume of 1.1 million m^3 per year is Rp. 25,628,790,000/year. Existing miners' revenue from upstream dredging (SB 3 to 19), if each location has the same quality and quantity of sand, then the sale of sand is Rp 1,835,490,000/year. However, there is no profit-sharing agreement for the sale value. Indonesia Power Mrica PGU, the owner of the Mrica reservoir assets in sediment management, allocates CAPEX and OPEX budgets for dredging on foreset slopes at Rp. 23,793,300,000 continuously every year.

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