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Direct Benefit Analysis of Sutami Reservoir Dredging for Electricity Generation

Setiyantono[1], Pitojo Tri Juwono[2], Suhardjono[2]
[1]Graduate School of Water Resources Engineering Department, Brawijaya University, Malang, Indonesia, 65145
[2]Water Resources Engineering Department, Brawijaya University, Malang, Indonesia, 65145

Abstract— *Sutami Dam is the largest dam in the Brantas River Basin. It is located in Malang, East Java, Indonesia which is equipped with Hydroelectric Power Plant (PLTA) with an installed power capacity of 3x35 MW. To enhance the economic life of reservoir, especially the continuity of the operation of the power plant by preventing the occurrence of disturbances due to sediment buildup at the PLTA intake, the operator has carried out routine sediment dredging activities with a dredging volume about 450,000 m3 / year. The increase of the capacity of dredging work from the current volume capacity is expected to have an impact on the length of operation of the hydropower plant so that the potential benefits in terms of increasing or additional electrical energy in the future are obtained. The analysis carried out in this study included the analysis of existing historical inflow data analysis, generated discharge analysis for the next 27 years (2018-2044), analysis of dredging volume equipment capacity (with Cutter Suction Dredger type), analysis of sediments distribution in reservoir to estimate reservoir capacity for the next 27 years and the analysis of electricity generation. The analysis was carried out in 4 scenarios, namely Scenario 1 (Scenario with no dredging activity), Scenario 2 (Dredging scenario carried out as current dredging conditions), Scenario 3 (Scenario maximizes the dredging work period with 2 units existing dredge equipment) and Scenario 4 (Scenario carried out the dredging by adding 1 unit of dredger equipment). To facilitate calculation of the Cost-Benefit Analysis of reservoir dredging, particularly in Sutami Reservoir, a simple Visual Basic Analysis Aplication has been also developed in this study. Thus, this study aims to determine which one alternative of the dredging scenarios that provides the highest value of the benefit for electricity generation.*

Keywords— *Cost-benefit analysis, dredging work scenario, electricity generation.*

I. Introduction

Sutami Dam is constructed in Brantas River, more or less 14 km downstream of the Sengguruh Dam or 40 km south of Malang City. The construction of the Sutami Dam began in 1961 and was completed in 1972. Sutami Dam and Reservoir is one of the works of the national development program carried out by the Government of the Republic of Indonesia specifically in the development of Water Resources infrastructure in the Brantas River Region in East Java Province.

This dam has a considerable role for national economic development, especially in supporting food and energy security, ensuring the availability of clean water for drinking water and fulfillment of raw water for industry. To support the national electricity supply program, Sutami Dam has been equipped with Sutami Hydroelectric Power Plant with an installed power capacity of 3x35 MW [1]. It is more or less able to generate annual energy of 488 million kWh.

Hydroelectric power generation is mainly a function of overall efficiencies of the plant, rate of turbine release, and the difference between headrace and tailrace levels [2]. The main factor affecting the size of annual electricity is the condition of water availability and the pattern of reservoir operations for a year of operation. The availability of water will affect the size of the discharge through the turbine, while the reservoir operation pattern will affect the high fall of the water towards the plant. During the operational activities, the parameters recorded during the observation activity are water elevation in the upstream of the intake and also the data of outflow. The recording of upstream turbine water elevation is based on peilschaal. Discharge is channeled to penstock towards the PLTA turbine is highly dependent on the availability of volume of water in the reservoir. The regulation of reservoir water level and outflow is determined by the pattern of operation and allocation of reservoir water in the Annual Water Allocation Plan. The greater the reservoir capacity that can be accommodated for a year, the greater the potential of energy that can be generated.

In line with the increase in population which has resulted in increasing residential areas, clearing agricultural land and implementing infrastructure development, there has been a gradual change in the area of land cover and reduction of forest area in the upper reaches of the Sutami Reservoir. Reduction of forest area as an area that functions as a catcher of water causes an increase in the rate of land erosion. In the phenomenon of land erosion, there is a transfer of soil grains to another place through the flow of water by gravity through a process called sediment transport. The soil grains carried by the flow will eventually settle in the waters area called sedimentation. Slowly the sedimentation affected the reduction of reservoir volume. In accordance with the results of the 2016 Sutami Reservoir sediment measurement, the storage volume is only 179.13 million m3 or around 52.22% of the initial storage capacity [3].

In relation to sedimentation control of the Sutami Reservoir, the dam operator in this case the Public Company Jasa Tirta I routinely carries out sediment dredging activities. The activity of dredging sediments in a reservoir clearly provides benefits in preventing blocking of hydropower intakes. The effectiveness of the sediment dredging activities on hydroelectric power generation needs to be evaluated in more detail. For this reason, a more detailed analysis is needed to draw conclusions about the benefits of dredging work in relation to the benefits of increasing the electrical energy that can be generated.

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The availability of data from the management of the Sutami Dam and the results of research related to the operation or handling of Sutami Reservoir sediments or other reservoirs that have been carried out by previous researchers is an important matter to note. The previous studies related to the value of the benefits of dredging on electricity generation has carried out on three dam series on the Brantas River [4]. Some things that have not been discussed in previous studies and the different perspectives in evaluating and estimating the value of the benefits of dredging the Sutami Reservoir sediment are opportunities to develop research on this topic.

The reservoir water level and the availability of water volume in the reservoir are the most influential factors in the amount of electricity that can be generated by the hydropower plant. Although the current sediment dredging capacity is still far below the sedimentation rate that occurred in the Sutami Reservoir, it is believed that this activity has a positive impact to slow the occurrence of sediment buildup in front of the PLTA intake. With the possibility of increasing the dredging volume of existing capacity, there is a potential profit that will be obtained in terms of increasing or additional electrical energy in the future due to the increasing duration of the hydroelectric operation. At present there is no known alternative volume of dredging the most optimal Sutami Reservoir that provides the greatest value for electricity generation.

The purpose of this study was to obtain estimates of total electrical energy and operating life of the Sutami Hydroelectric Power Plant in 2018-2044 in conditions where sediment dredging is not carried out, conditions for dredging of sediments are carried out with several scenarios of volume dredging work and finally knowing the alternative volume of annual dredging work provide the highest benefit value for electricity generation. This study can be used as a reference to estimate when there will be a disruption of the electricity generation of the Sutami Hydroelectric Power Plant due to the sediment piles in the intake.

II. Research Methodology

Study Area

The study location is in the Sutami Dam located in Karangkates Village, Sumberpucung District, Malang Regency, East Java Province. The dam is located downstream of the Sengguruh Dam and upstream of the Wlingi Dam or at 112 ° 26´ 24 "BT and 8 ° 9´ 36" LS. The Sutami Dam and Reservoir is located in the Upper Brantas Watershed, downstream of the meeting between the Brantas River and the Lesti River.

Scope of Study

In order for the discussion in this study not to widen, then the scope of the study is limited to several things as follows:

- This study does not discuss changes in sedimentation rates due to changes in the condition of Watersheds in the upper Sutami Reservoir.
- The benefits of dredging reservoirs for electricity generation are limited to the Benefit-Cost Ratio and Net Benefit parameters.
- Analysis of equipment capacity to carry out sediment dredging work is limited to the specifications of 2 (two) dredgers.
- Calculation analysis is limited to the years 2018 to 2044 (27 years). The short
- The parameters for the analysis of electricity generation activities are limited to the most dominant reservoir operating parameters, which are outflow and reservoir water level.

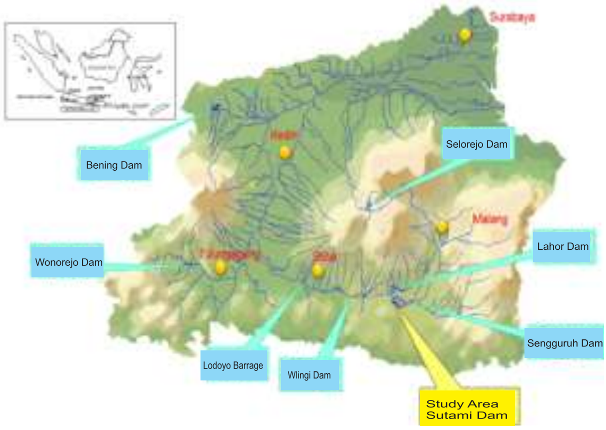

Fig. 1. Location of Study.

Basically, stage of this study can be divided into seven (7) stages of analysis, which are (1) statistical data analysis, (2) sediment distribution analysis, (3) generated discharge analysis, (4) reservoir operation simulation, (5) electricity generation analysis, (6) dredging work capacity analysis, and (7) Cost Benefit Analysis. As a final approach, test analysis will be conducted in order to exam or determine the most feasible project. In order to simplify the analysis, several assumptions were made to fulfill the requirements in the analysis processes. In this study the calculation of the analysis was carried out in a range of 10 days in which each time span was called a decade. Every month is divided into 3 decades. Simulation of reservoir operations in this study uses a parallel model that is more suitable for presenting the Sutami Reservoir operating system [5].

A. Statistical Data Analysis

Analysis of the sequence of hydrological data sequentially with statistical methods carried out includes Tests for Trend Absence, Correlation Test and Persistence Test. These tests are conducted to test that the existing inflow data series is a data series that can be used to analyze future water availability estimates. The absence trend test itself includes the Spearman method rank correlation test, Mann & Whitney test and sign test from Cox & Stuart [6].

Trends or trends can be viewed as correlations between time and variants of a hydrological variable. With this understanding, the correlation coefficient can be used to determine the absence of trends from a periodic series. One way is to use the Spearman method ranking correlation coefficient which is formulated as follows:

$$t = KP\left(\frac{n-2}{1-KP^2}\right)^{\frac{1}{2}} \quad (1)$$

$$KP = 1 - \frac{6\sum_{i=1}^{n}(dt)^2}{n^3 - n} \quad (2)$$

where:

KP : Spearman's ranking correlation coefficient
n : Number of data
dt : Rt – Tt
Tt : Ranking by time
Rt : Ranking of data in a periodic sequence
t : distribution of t value, on degrees of freedom (n-2) for certain degrees of trust (generally 5%)

The t-test is used to determine whether the time variable and the hydrological variable are dependent or independent. In this case the tests were Tt and Rt. With hypothesis H0: There is no trend, the sequence of data Rt and rank Tt are not interdependent, so if the results of the t-test show t_{result} <tc then H0 is rejected so that the data series can be concluded to have a trend.

To test whether the two groups of data in pairs are from the same population or not, the Mann and Whitney Test is used. From the two sample groups measured, namely population group A and population B, a hypothesis can be made that group A has the same distribution as B. For testing the two groups were combined and then made a series of data from the smallest to the largest, work this is called ranking. The testing stages are as follows :

1). Combine both groups A and B
2). Rank data series from the smallest to the largest
3). Calculate the number of ranks in the data set for each group
4). Calculate statistical parameters:

$$U_1 = N_1 N_2 + \frac{N_1}{2}(N_1 + 1) - Rm \quad (3)$$

$$U_1 = N_1 N_2 - U_1 \quad (4)$$

where:

U_1, U_2 : Statistical parameters
U_1 : Amount of group A data
U_2 : Amount of group B data
Rm : Value of ranking from data group A

5). Select the value U1 or U2 whose value is smaller as the value U
6). Calculate the Mann-Whitney test, as a Z value:

$$Z = \frac{\frac{U - (U_1 - U_2)}{2}}{\left[\frac{1}{2}\{N_1 N_2 (N_1 + N_2 + 1)\}\right]^{\frac{1}{2}}} \quad (5)$$

Decision :

Assuming that both samples in groups A and B have a normal distribution, then from the table the value of tc for testing the normal distribution can be determined the value of Zc (for testing two sides in a table written tc). If the value of Z <Zc then the null hypothesis can be accepted, whereas if the value of Z ≥ Zc then the null hypothesis is rejected.

Trend changes can also be indicated by a sign test from Cox and Stuart. The value of the time series data is divided into 3 (three) equal parts. Each number is n '= n / 3. If a random sample cannot be divided into 3 equal parts, then the second part is reduced by 2 or 1 piece. Then compare the values of parts to 1 and 3 by giving a sign (+) for positive and (-) values for negative values. The total number of values (+) is given an S, then the Z value can be calculated as follows:

For large samples (n ≥ 30)

$$Z = \frac{S - \frac{n}{6}}{\left(\frac{n}{12}\right)^{\frac{1}{2}}} \quad (6)$$

For small samples (n < 30)

$$Z = \frac{S - \frac{n}{6} - 0.5}{\left(\frac{n}{12}\right)^{\frac{1}{2}}} \quad (7)$$

Where :

S : Number of Sign (+)
N : Number of Data

After testing the trend data, then testing the stability of variance values and the stability of the average data series. To do the stability test the variance is done by testing the F distribution or the F-Test developed by Fisher, using the following equation:

$$F = \frac{N_1 S_1^2 (N_2 - 1)}{N_1 S_2^2 (N_2 - 1)} \quad (8)$$

Where :

F : Comparison of F
N_1 : Number of sample group samples 1
N_2 : Number of sample group samples 2
S_1 : Standard deviation of sample group 1
S_2 : Standard deviation of sample group 2

Testing the stability of the average value using the t-test with the following equation:

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sigma\left|\frac{1}{N_1} + \frac{1}{N_2}\right|^{\frac{1}{2}}} \quad (9)$$

with :

$$\sigma = \left|\frac{N_1 S_1 + N_2 S_2}{N_1 + N_2 - 2}\right|^{\frac{1}{2}} \quad (10)$$

where :

t : Calculated variable t
$\overline{X}_1$: Average of sampels 1
$\overline{X}_2$: Average of sampels 1
N_1 : Amount of sample group samples 1
N_2 : Amount of sample group samples 2
S_1 : Variant of sample group 1
S_2 : Variant of sample group 2
dk : $N_1 + N_2$ -2 = degree of freedom.

To find out whether the data series are interdependent or persistent, a persistence test is performed with the t-test by first calculating the serial correlation coefficient. The serial correlation coefficient is calculated by:

$$KS = 1 - \frac{6\sum_{i=1}^{m}(di)^2}{m^3 - m} \qquad (11)$$

$$t = KS\left|\frac{m-2^2}{1-KS^2}\right|^{\frac{1}{2}} \qquad (12)$$

where :

KS : serial correlation coefficient
m : N - 1
N : Number of data
di : The difference in value between data rank X_i and X_{i+1}
t : distribution value t on m-2 freedom degrees and certain degrees of trust (generally 5% rejected or 95% accepted).

B. *Sediment Distribution Analysis*

The distribution of sediment types in the Brune curve can be grouped into fine, medium (medium) and coarse [7]. To estimate the distribution of sediment in a reservoir, it can be done with 2 methods, namely (1) area-reduction method and (2) minimum power stream units and minimum stream power methods. In this study, the estimation of the distribution of sediment will use the first method, namely area-reduction method. The results of the area reduction method were relatively close to dam hydrography values [8].

As a reference to determine the distribution of sedimentation in reservoirs, a graph can be used in Fig.2 as stated by Strand and Pemberton (1982) in Yang (1996) which states that the U.S Bureau of Reclamation also uses the graph to estimate the estimated percentage of sediment distribution [9].

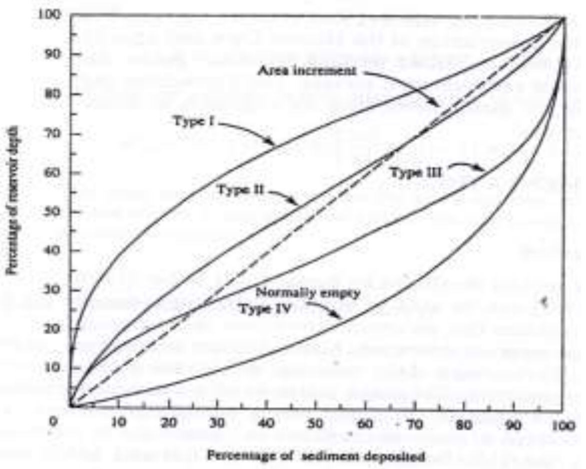

Fig. 2. Sediment Distribution Design Curves (U.S Bureau of Reclamation 1987 at Yang, 1996)

TABLE 1. Klasifikasi Waduk Berdasar Faktor Bentuk

Reservoir Type	*Classification*	*m*	*Predominant Size*
I	*Lake*	*3,5-4,5*	*Sand or coarser*
II	*Flood plain-foothill*	*2,5-3,5*	*Silt*
III	*Hill*	*1,5-2,5*	*Clay*
IV	*Normally empty*		

Source : *Sediment Transport : Theory and Practice* (Yang, 1996)

To determine distribution of reservoir sedimentation, the following procedurs should be followed:

Step 1 : plot measured sediment survey results on Fig. 2 to determine which one or two types of curves may be applied.

TABLE 2. Pilihan Tipe Kurva Sebaran Sedimen

Reservoir Operation		*Shape*		*Weighted type*
Classification	*Type*	*Classification*	*Type*	
Sediment submerged	*I*	*Lake*	*I*	*I*
		Flood plain-foothill	*II*	*I or II*
		Hill and gorge	*III*	*II*
Moderate drawdown	*II*	*Lake*	*I*	*I or II*
		Flood plain-foothill	*II*	*II*
		Hill and gorge	*III*	*II or III*
Considerable drawdown	*III*	*Lake*	*I*	*II*
		Flood plain-foothill	*II*	*II or III*
		Hill and gorge	*III*	*III*
Normally empty	*IV*	*All shape*		*IV*

Source : *Sediment Transport : Theory and Practice* (Yang, 1996)

Step 2 : determine the rate of reservoir sedimentation accumulation and total volume of sedimentation after different periods of operation.

Step 3 : plot the reservoir depth versus capacity relationship on log-log paper to determine the reservoir shape factor m.

Step 4 : from steps 1 and 3, select the reservoir type to be used.

Step 5 : compute the F values for different values of the relative depth p :

$$F = \left(\frac{Sd - Vh}{H.Ah}\right) \qquad (13)$$

where :

F : dimensionless function of total sediment deposition, capacity, depth, and area.
Sd : total sediment deposition
Vh : reservoir capacity at given elevation h
H : original depth of reservoir , and
Ah : reservoir area at given elevation *h*

Step 6 : plot *F* versus relatif depth p of reservoir under study and the typical *F-p* relationship of the reservoir type determined from step 4. The intersection of these two curves gives the new current zero elevation at the dam. Similar intersection can be obtained for the next periods of operation.

Step 7 : calculate relative sediment area for each reservoir type with the equation as bellows :

$$\text{Type I} \quad a = 5.074\,p^{1.85}(1-p)^{0.25} \qquad (14)$$

$$\text{Type II} \quad a = 2.487\,p^{0.57}(1-p)^{0.41} \qquad (15)$$

$$\text{Type III} \quad a = 16.967p^{1.15}(1-p)^{2.32} \qquad (16)$$

$$\text{Type IV} \quad a = 1.486p^{-0.25}(1-p)^{1.34} \qquad (17)$$

where :

a : relative sediment area and
p : relative depth of reservoir measured from the bottom.

Step 8 : Hitung luas dan kapasitas tampungan baru.

To calculate the volume of sediment deposited using the primoidal formula as follows:

$$Volume = \frac{Area_1 + Area_2 + (Area \ + Area_2)^{0.5}}{3} \quad (18)$$

To obtain the results of the calculation of the storage volume, an appeal was carried out in such a way that the total volume of storage was in accordance with the volume of the initial storage minus the volume of sediment deposited. The calculation can be used is the K correction factor using the formula formulation as follows:

$$K_2 = K_1 \frac{S_2}{S_1} \quad (19)$$

where :

K : correction factor

$S_{1,2}$: Capacity of reservoir (before) and (after)

C. Generated Discharge Analysis

Recording hydrological data such as past inflow discharge data is very useful. One of its uses is to estimate the inflow discharge that may occur in the future. There are 4 methods for reliable discharge analysis, among others: (1) Minimum Average Debit Method; (2) Flow Characteristic Method; (3) Basic Year Planning Method; and (4) Basic Moon Planning Method. Each method has its own characteristics according to needs) [10]. In this study, to estimate the availability of water discharge in the future it can be done by analyzing the autoregression model of historical debit data in previous months or years. Estimates of inflow discharge in the coming months can be estimated with the following formulas:

$$Q_{p,j+1} = \overline{Q}_{j+1} + B_j * (Q_{p,j} - \overline{Q}_j) + t_{p,j} * S_{j+1} * \sqrt{(1 - R_j^{\,2})}$$

$$Q_j = \frac{1}{N} \sum_{P=1}^{N} Q_{j,p} \quad (21)$$

$$S_j = \sqrt{\frac{\sum_{P}^{N} \left(Q_{j,p} - \overline{Q}_j\right)^2}{N-1}} \quad (22)$$

$$R_j = \frac{\sum_{P=1}^{N} \left(Q_{p,j} - \overline{Q}_j\right) \sum_{P=1}^{N} \left(Q_{p,j+1} - \overline{Q}_{j+1}\right)}{\sqrt{\sum_{P=1}^{N} \left(Q_{p,j} - \overline{Q}_j\right)^2} \sqrt{\sum_{P=1}^{N} \left(Q_{p,j+1} - \overline{Q}_{j+1}\right)^2}} \quad (23)$$

$$B_j = R_j \left(\frac{S_{j+1}}{S_j} \right) \quad (24)$$

dengan :

$Q_{p,j+1}$: Estimated discharge on month (j + 1)

$Q_{p,j}$: J month discharge known in year p

$\overline{Q}_{j+1}$: Average discharge for months to (j + 1) during N years of observation

$\overline{Q}_j$: Average discharge for months to (j) during N years of observation

$\overline{S}_{j+1}$: Standard deviation of average discharge in months (j+1) during N years of observation

$\overline{S}_j$: Standard deviation of average discharge in months (j) during N years of observation

$t_{p,j}$: random variables are standard normal distributions, with zero averages and one variance, for month J in year p.

R_j : The serial correlation coefficient between the average discharge in month j and month to (J+1) during the N year of observation

B_j : Regression coefficient in month j for the estimate of month to (J+1)

D. Reservoir Operation Simulation

In accordance with its characteristics as an annual reservoir, the operation pattern of the Sutami Reservoir during the year shows the period of filling of the reservoir (December-May period) and reservoir water allocation (June-November Period).

Low water level operating low limit is at +260.0 m elevation and the upper limit of high water level operation (High Water Level) is +272.5 m elevation. In special conditions during drought, the elevation of +246.0 m is determined as the elevation of Dry Alert. After calculating the average actual elevation data of reservoir operations 2008-2017 and plotted on the chart, it can be seen that the 1978 study pattern elevation line is between the average operating line elevation line for 2008-2017 with the elevation pattern line in the Plan Sutami Reservoir Annual Water Allocation.

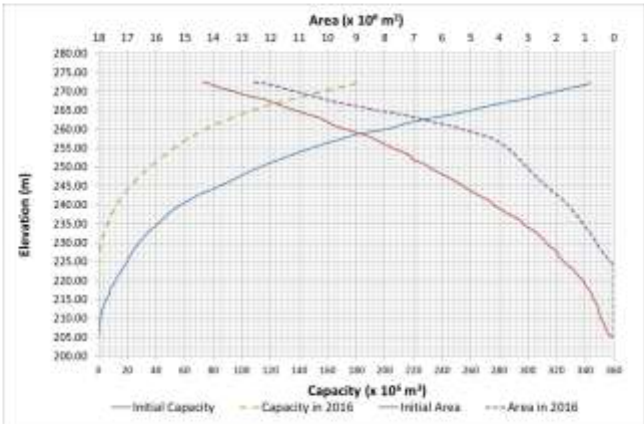

Fig. 3. Area and Capacity Curve of Sutami Reservoir (Jasa Tirta Public Corporation, 2016)

To calculate the inflow into the reservoir, the reservoir volume equilibrium formula is used as specified in the Sutami Dam Operation and Maintenance Manual (Manual) as follows:

$$Q_{in} = Q_{out} + \frac{\Delta S}{\Delta t} \quad (25)$$

where :

Q_{in} : Inflow (m3/sec)

Q_{Out} : Outflow (m3/sec)

ΔS : Storage alteration during Δt time.

Δt : time step (t = 3.600 sec).

E. Electricity Generation Analysis

Analysis at this stage was carried out with an optimization simulation model of the use of reservoir water in the reservoir by observing the operational limits of the reservoir including the limits of the hydroelectric turbine capacity. Reservoir operations are planned according to the elevation set in the pattern with the minimum operating requirements of Qoutflow equal to the average realization of Qoutflow in 2008-2017. If

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the calculated Qoutflow has not met the minimum Qoutflow, the elevation is reduced by a 5 cm step until the Qoutflow is met. If up to the limit of the decrease in elevation the magnitude of the Qoutflow has not been fulfilled, then the elevation is determined by the consequences of Qoutflow under the minimum conditions. With Qoutflow output data, then generation electricity can be calculated. On a graph of the relationship between the height (head) and the efficiency factor where the turbine efficiency factor varies at any given height [11].

For operational purposes, the determination of outflows through hydropower turbines is not carried out based on the graph of hydroelectric turbine power output because it will produce inaccurate readings. Calculation of outflow discharge is done by using the formula of the relationship between the energy generation of the Sutami Hydroelectric Power Plant and the outflow through PLTA turbines which is based on the table of generation of power ratio. The power ratio table is a table that contains a comparison of the power generated by the generator for 24 hours against the outflow discharge through the turbine (Q_{Out} Turbine) [12].

Relationship between power ratio, power generation (commonly referred to as Generating Power in MW) and turbine outflow discharge can be described using the following formula:

$$P = \frac{(Q\ x\ Power\ Ratio)}{24} \qquad (26)$$

di mana :

- P : Generated Power (MW)
- Q : Discharge inflow trough turbine (m/detik)
- Power Ratio : Ratio between electric power to be generated during 24 operation hours and outflow (Q_{Out} Turbine).

The total electrical energy that can be generated during the year of operation by the generator is related to a year of operating hours.

F. *Dredging Work Capacity Analysis*

Sediment cleaning methods in general can be divided into two methods, namely dry excavation and dredging methods. The reservoir sediment excavation can be carried out using a dry excavation method if the conditions of the land and material to be excavated are relatively dry or low in water content. The sediment cleaning method with dredging is usually carried out for sediments below the water level. When viewed from the side of equipment used, dredging of sediments is usually divided into three namely mechanical dredging, hydraulic dredging and flushing. Based on the area of disposal of sediments (disposal area), the disposal of sediments can be divided into 2 (two), namely riverine disposal (area of downstream sediment disposal) and off-stream disposal [13]. The off-stream disposal area of sediment discharge channelled outside the inundation/groove area by making embankment beds namely spoilbank.

The sediment dredging work in the Sutami Reservoir is carried out with hydraulic equipment in the form of the Cutter Suction Dredger (CSD) type dredger with the off-stream disposal method (Fig.4 and Fig.5). The sediments dredged by dredgers are accommodated in an embankment in the greenbelt area (green belt area) called spoilbank.

Fig. 4. Scheme of Sutami Reservoir Dredging Work

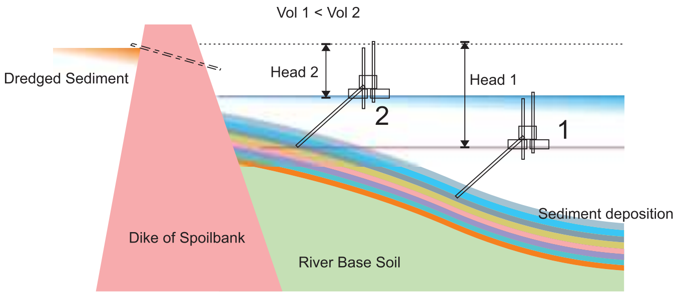

Fig. 5. Ilustration of dredging work at the resrvoir

Under the same equipment performance conditions, changes in production capacity at each decade will vary depending on the vessel pump capacity and changes in pressure height due to the spoilbank embankment elevation on reservoir water level elevation when the vessel is operating *(H)*. Besides being influenced by these factors, the dredger production capacity is actually influenced by 3 other factors which are the effectiveness of implementation time *(Em)*, the effectiveness of tool performance *(Ew)* and the effectiveness of operator performance *(Eo)*. The capacity of dredging work is expressed as:

$$CSD\ Cap = Vessel\ Cap\ (f(H, Em, Ew, Eo)\ x\ WorkHour\ x\ 10 \qquad (27)$$

TABLE 3. Summary of Project Alternatives (Project Scenarios)

NO.	PROJECT ALTERNATIVE	REMARK
1	Scenario 1	No Dredging
2	Scenario 2	Scenario carried out as current dredging conditions (Maximum duration of the project approximately within 8 months per year with the average of quantity of dredging work around 450.000 m3 sediment/tahun. Number of CSD : 2 Units
3	Scenario 3	Scenario maximizes the dredging work period with 2 units existing dredge equipment). Number of CSD : 2 Units.
4	Scenario 4	Scenario carried out maximizes the dredging work period of the dredging with adding number of dredger equipment up to 3 units of CSD.

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To carry out an analysis of the benefits of dredging sediment reservoirs, it is necessary to simulate the implementation of the Sutami Reservoir dredging scenarios for 27 (twenty seven) years (2018-2044). The simulation includes 4 (four) scenarios shown in Table 3.

G. Cost-Benefit Analysis

Zerbe Jr, 2006 stated that Cost-Benefit Analysis (CBA) is a method to analyze a proposed or previously enacted project, most of it related with public interest, whereby it is knowingly involves difficulty to determine the economic benefit of this kind of project. CBA may assign a monetary value to each input and outputs resulting from the project. The values of the inputs and outputs are then compared [14]. The purpose of a CBA, like any policy analysis, is to provide information that will materially assist decision-making [15].

This analysis is intended to obtain answers to the formulation of the problem of how many dredging alternatives and the most optimal volume estimates are measured from the value of the benefits of dredging sediment to the generation of hydroelectric power plants. The value of the benefits of dredging sediments is calculated based on the amount of additional electrical energy produced which is calculated from the difference in the total electrical energy of each scenario dredging the total electrical energy produced if no dredging is carried out. The benefit value is reflected in the calculation of the value of the Benefit-Cost Ratio (B/C ratio) and the amount of Net Benefit of the dredging work of the Sutami Reservoir in each dredging scenario.

This stage discusses the use of CBA to analyze the feasibility of three (3) dredging work alternatives (scenario 2, 3, and 4) simulated in this study, to determine the most appropriate alternative. Basically, this method will determine which one is the best alternative from the side of economic parameters (B/C Ratio and Net Benefit).

Benefit-Cost Ratio (BCR) is the present value of the estimated benefits divided by the present value of the estimated costs [16] which is expressed as:

$$BCR = \frac{\sum_{t-1}^{n} Bt/(1+r)^t}{\sum_{t-1}^{n} Ct/(1+r)^t} \quad (28)$$

Net Benefit is the present of estimated benefits minus cost which is expressed as:

$$Net\ \text{Benefit} = \sum_{t=1}^{n} \frac{(Bt - Ct)}{(1+r)^t} \quad (29)$$

A CBA involves the identification and specification of a set of alternatives. In most cases, a 'do nothing' option should be included as a base case. This option is generally required because costs and benefits are nearly always measured as incremental to what would have happened had the project not gone ahead.

To select the best scenario for an activity that has a BC Ratio value > 1 or feasible, then Incremental BC Ratio is calculated by Step as follows:

1) Sort the scenario of activities from the cheapest activities to the most expensive ones.
2) Compare the cheapest projects with the second cheapest option by reducing the total benefits for each project and dividing it by the difference in the total cost for each project.

$$Incremental\ BCR = \frac{\text{PV of Benefit 1 - PV of Benefit 2}}{\text{PV of Cost 1 - PV of Cost 2}} \quad (30)$$

3) If the incremental BCR obtained is lower than the incremental BCR target, then discard the higher cost option (project 2 in this case) and use the lower cost option (project 1) to compare with the next project on the rising cost list.
4) Repeat Step (2-3) until all project options have been analyzed.

As the basis of recommendation, analysis was performed to ensure that the conclusion will be taken confidenly. At the completion of the test analysis, the assessment of the results were based on the incremental BCR ranking, whereby the most stable project (in terms of the B/C ratio and net benefit) will be selected as the most feasible project.

H. Visual Basic for Aplication (VBA) Template Building

In this study many calculations were repeated. With facilities available in Microsoft® Office Excel®, this problem can be solved specifically by using the Visual Basic for Aplication (VBA). In details, we use the related references to build a simple deterministic and stochastic simulation syntac models [17, 18].

I. Analysis Framework

The flow to do all stages of the whole analysis is illustrated in the following flow-chart:

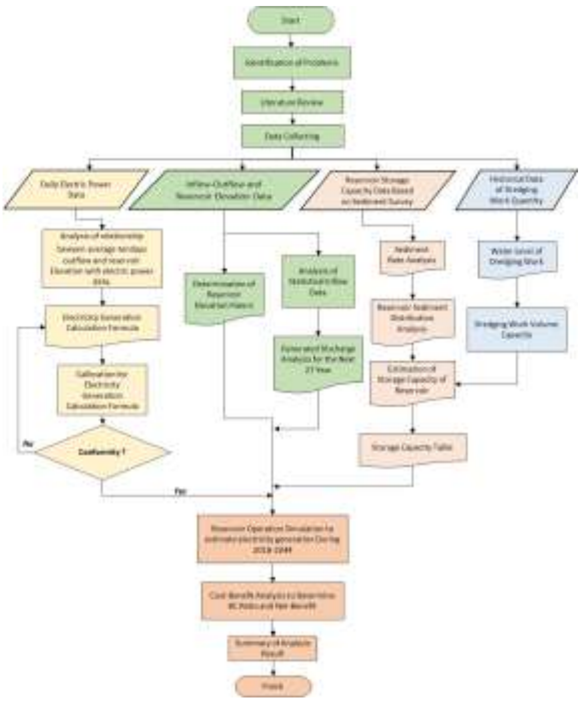

Fig. 6. Flowchart Analysis

III. Result and Discussion

To carry out the Sutami Reservoir operation simulation, it is necessary to enter data that will be used as a reservoir inflow data. With the availability of 10 daily historical inflow data for 27 years (1991-2017), the authors conducted inflow data testing to ensure that the data can be used for analysis. From testing the tail flow discharge data of the Sutami Reservoir inflow time, it was concluded that the inflow discharge data for 1991-2017 was data that had a trend, homogeneous and persistent so that the data could be used to estimate future deit inflow. The historical actual debit chart 1991-2017 is shown in Fig.7.

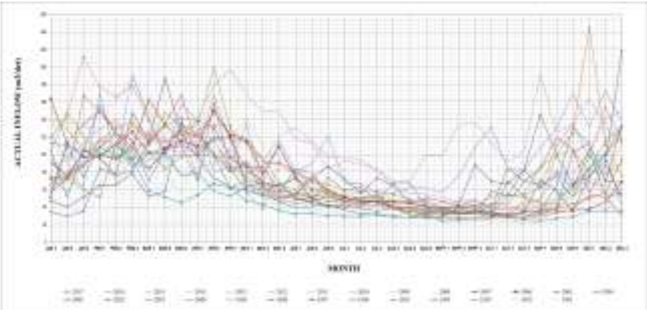

Fig. 7. Graphic of Sutami Reservoir Discharge Inflow Based on Historical Data 1991-2017 (Jasa Tirta Public Corporation, 2018)

To estimate the inflow discharge for several years to come, the authors use monthly autoregression calculations (Markov models). Estimation of the inflow discharge from 2018-2044 was calculated by using (20) to (24). The result of the calculation is shown at Fig. 8

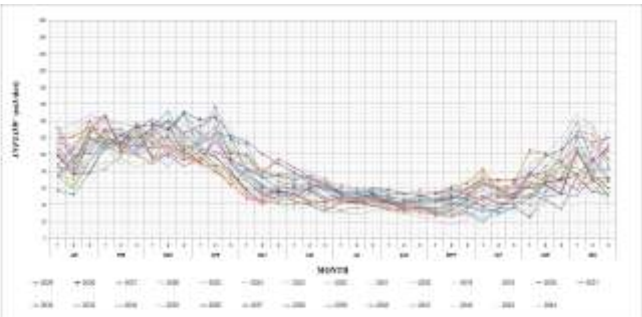

Fig. 8. Graphic of Predicted Discharge Inflow of Sutami Reservoir (2018-2044)

In relation to this study, the picture above illustrates that the sediment layer deposited in the reservoir spreads at various elevations. As an initial reference, the deepest reservoir base is at +205.00 elevation. The inlet elevation towards the hydroelectric turbine is at an elevation of +246.00 m which states that the hydropower operation can run normally if the water supply conditions are smooth or there are no obstructions to the inlet. Under water conditions below +246.00 elevation, hydropower can no longer be operated. The Sutami reservoir operating limit scheme is shown in Fig.9

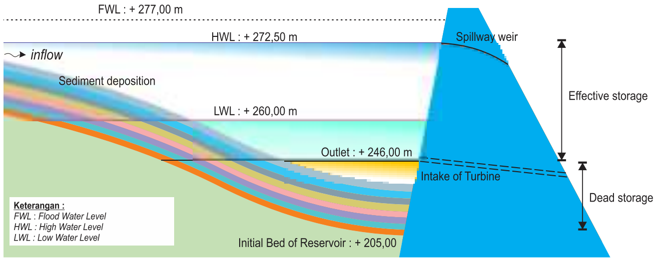

Fig. 9. The Sutami reservoir operating limit scheme

To simplify the determination of operating pattern elevation plans for the analysis of Sutami Reservoir operations in 2018-2044, an elevation plan based on a 1978 pattern study was used (Nippon Koei Co. Ltd, 1978).

Fig. 10. Patern of Water Elevation for Reservoir Operation Simulation

From the calculation data of sediment distribution, a graphic image of the relationship between the percentage of sediment deposited and the depth percentage of the Sutami Reservoir is made. The lines on the graph are then plotted on the Sediment Distribution Design Curve (Fig. 11).

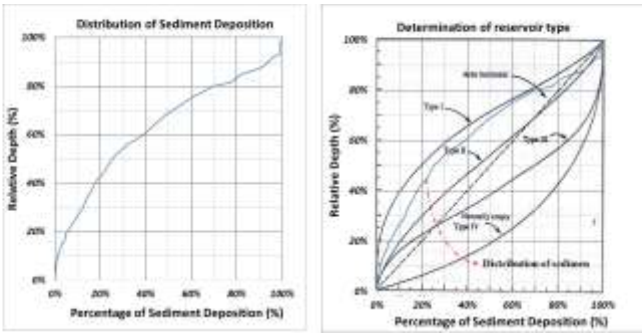

Fig. 11. Determination of Sutami reservoir type

The graph plot results of the relationship between the percentage of sediment deposited with the percentage of the Sutami Reservoir depth on the image of the sediment distribution design curve above, up to a 40% depth of storage characteristics such as medium type II reservoir between 50% to 100% depth indicating sediment distribution characteristics in the Sutami Reservoir characteristics of type I storage. In addition to the picture of the sediment distribution curve above, the determination of the type of sediment distribution is also viewed from the shape factor m. According to reference

Table 1 and Table 2, for reservoirs with type II reservoir operations and storage with type III form factor (m), the selected weighted storage type is type II or III. Taking into account the type of sediment distribution, operating factor and m depth value factor, the constituent in this case determines the type of storage of the Sutami Reservoir is the type II reservoir. To determine the basic elevation of the sediment, first calculate the dimensionless number F. The number F is a function of the total deposited sediment, initial capacity, depth and surface area obtained by using (13).

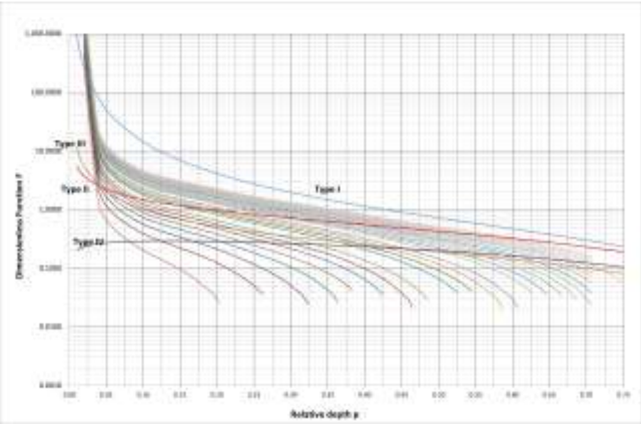

Fig. 12. Relationship between dimensionless fungtion F and relative depth p

In the study of storage capacity and sedimentation management of the Sutami, Selorejo and Wlingi Reservoir (2016), the amount of sedimentation rate per year that enters the Sutami Reservoir is set at 1.7 million m^3/year [19]. Based on the initial capacity storage and capacity storage in 1917, average sedimentation rate can be calculated. The average sedimentation rate during 1972-2017 = (343 million m^3 - 174.01 million m^3)/45 years = 3,755,160 m^3/year. Trapping efficiency was calculated by formula found by Susilo (2001) [20]. With an estimated trapping efficiency (Brune modification by Susilo) of 76.77%, the estimated sediment inflow is 3,755,160: 76.77% = 4,891,441 m^3/year. Based on the average actual inflow entering the Sutami Reservoir in 1991-2017 (2.397.478.225 m^3) so the average sediment inflow concentration can be estimated at 4,891,441: 2,397,478,225 = 0.00204. After calculating the difference in sediment volume deposited in the reservoir to the initial volume, the estimated volume of the Sutami Reservoir in 2018-2044 can be calculated.

Determination of the new base elevation that occurs every year is determined based on the intersection between the F-p curve and the Type II curve F-p (Fig.12). It is done for every scenario. To estimate the base elevation of new reservoirs, sediment area and storage volume during 2018-2044 are determined based on the actual elevation of the 2016 echo-sounding sediments.

The comparison of new baseline elevations for each scenario of Sutami Reservoir dredging can be seen in Table 4.

TABLE 4. Result of new zero elevation dam computation

Year	New Zero Elevation of Dam			
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
2018	224.74	224.69	224.68	224.64
2019	225.13	225.05	225.03	224.96
2020	225.53	225.37	225.33	225.22
2021	225.83	225.67	225.62	225.50
2022	226.29	226.01	225.95	225.78
2023	226.82	226.40	226.30	226.03
2024	227.57	226.93	226.78	226.41
2025	228.49	227.53	227.31	226.80
2026	230.40	228.45	228.16	227.36
2027	231.92	229.71	229.05	228.04
2028	233.28	231.30	230.76	228.80
2029	234.40	232.76	232.14	230.35
2030	235.72	233.65	233.22	231.40
2031	237.01	234.52	233.95	232.41
2032	238.37	235.76	235.05	233.36
2033	239.91	237.17	236.36	234.26
2034	241.13	238.29	237.55	235.23
2035	242.13	239.43	238.60	236.24
2036	242.97	240.61	239.72	237.27
2037	244.05	241.73	241.05	238.45
2038	245.14	242.54	241.91	239.44
2039	246.09	243.22	242.56	240.39
2040	247.30	244.03	243.30	241.24
2041	248.57	244.94	244.06	241.97
2042	250.04	245.87	244.97	242.62
2043	251.60	246.88	245.86	243.27
2044	253.16	248.06	246.86	244.00

With the knowledge of new reservoir elevations, the relative area of sediment at each depth can be calculated by using (15). The results of the calculation of relative depth p, new base elevation, sediment area at base elevation (Ao) and relative sediment area Ap(o) can be calculated. By this data, this new base elevation will be used to determine the assumption that if new zero level is +246.00 m or above then turbine of hydropower operation will be disrupted due to blocking or blockage of sediments (coloured cell).

In accordance with the assumptions of the suitability of the Sutami Reservoir type, the relative area of the sediment at each elevation can be calculated by using (15). From the table of sediment area at each depth, the volume of sediment deposited can be calculated. After the volume of sediment deposited at each depth elevation is known, the storage volume can be calculated from the 2016 volume difference minus the sediment volume of the year.

The volume of storage in the coming year is estimated based on the broad results of distributed sediments. To obtain a match result of the calculation of total storage for each year, we used (19) to appeal K correction factor. After calculating the difference in sediment volume deposited in the reservoir to the initial volume, the estimated volume of the Sutami Reservoir in 2018-2044 can be calculated. The comparison of estimated reservoir storage for each scenario is shown in Table 5.

TABLE 5. Estimated Storage Capacity of Sutami Reservoir at 2018-2044

Year	Storage Capacity at Level + 272,50 (m^3)			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2018	170.74	170.74	170.74	170.74
2019	166.79	167.24	167.36	167.71
2020	163.12	164.02	164.27	164.96
2021	159.47	160.81	161.18	162.21
2022	156.08	157.88	158.36	159.75
2023	152.07	154.30	154.91	156.63
2024	148.63	151.32	152.04	154.11
2025	144.88	147.99	148.83	151.23
2026	141.48	145.04	146.00	148.74
2027	137.62	141.61	142.69	145.76
2028	134.12	138.55	139.74	143.15
2029	130.56	135.42	136.73	140.47
2030	126.90	132.18	133.60	137.67
2031	123.55	129.25	130.79	135.18
2032	120.45	126.57	128.23	132.96
2033	116.89	123.43	125.20	130.25
2034	113.10	120.05	121.93	127.30
2035	109.76	117.12	119.11	124.80
2036	106.35	114.12	116.22	122.22
2037	103.10	111.27	113.48	119.80
2038	99.17	107.73	110.05	116.66
2039	95.81	104.75	107.17	114.08
2040	92.81	102.14	104.67	111.90
2041	89.52	99.23	101.86	109.39
2042	86.32	96.41	99.14	106.96
2043	83.03	93.48	96.32	104.44
2044	79.77	90.59	93.53	101.93

With the formulation of electrical energy calculations based on the actual inflow and elevation conditions in the reservoir operation simulation, an annual electrical energy estimate is generated for each scenario as follows:

TABLE 6. Estimation of Energy Production of Sutami Hydro Power Plant

Year	Energy Production per Year (GWh)			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2018	482.11	482.11	482.11	482.11
2019	442.04	441.98	441.96	441.92
2020	403.38	403.32	403.30	403.25
2021	500.81	500.75	500.73	500.68
2022	418.94	418.88	418.87	418.78
2023	464.38	464.31	464.30	464.29
2024	407.80	407.74	407.73	407.68
2025	488.65	488.59	488.57	488.53
2026	438.17	438.11	438.10	438.06
2027	445.94	445.88	445.86	445.82
2028	467.55	467.49	467.47	467.43
2029	420.23	420.16	420.14	420.10
2030	385.68	385.63	385.62	385.57
2031	460.90	460.85	460.84	460.80
2032	502.45	502.39	502.38	502.34
2033	432.76	432.71	432.70	432.66
2034	445.76	445.71	445.69	445.66
2035	424.18	424.14	424.12	424.08
2036	546.19	546.15	546.14	546.10
2037	453.69	453.65	453.64	453.60
2038	389.79	389.76	389.76	389.73
2039	-	449.60	449.60	449.58
2040	-	434.30	434.29	434.25
2041	-	456.68	456.67	456.64
2042	-	460.78	460.78	460.77
2043	-	-	475.52	475.48
2044	-	-	-	463.75
TOTAL	9,421.38	11,221.67	11,696.88	12,159.65

When the application of VBA run, it facilitated the calculation of the volume of sediment dredged by CSD. The calculation result showed in Table 7.

TABLE 7. Estimated Volume of Reservoir Dredging Work

Year	Dredging Volume per Year (m^3)			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2018	-	453,210	574,827	923,423
2019	-	450,400	572,444	919,655
2020	-	446,373	567,514	912,049
2021	-	454,964	577,209	927,116
2022	-	453,034	575,279	924,144
2023	-	453,999	576,244	925,630
2024	-	440,117	561,557	902,867
2025	-	454,964	577,209	927,116
2026	-	454,027	575,557	924,527
2027	-	453,034	574,774	923,349
2028	-	450,312	572,557	919,942
2029	-	452,882	574,827	923,423
2030	-	447,014	569,259	914,834
2031	-	454,181	575,852	924,976
2032	-	454,964	577,209	927,116
2033	-	452,069	574,314	922,658
2034	-	453,705	575,651	924,698
2035	-	451,962	574,207	922,493
2036	-	454,964	577,209	927,116
2037	-	454,481	576,376	925,800
2038	-	435,588	557,833	897,120
2039	-	454,692	576,737	926,372
2040	-	452,654	574,600	923,084
2041	-	453,999	576,244	925,630
2042	-	454,696	577,209	927,116
2043	-	-	577,209	927,116
2044	-	-	-	922,493
TOTAL	-	11,292,299	14,919,924	24,891,875
AVERAGE	-	451,691	573,843	921,921

Asumption that used in Cost Benefit Analysis:

1). The Discount Factor is set at 12% as is commonly used in economic analysis in the field of Water Resources in Indonesia.
2). The analysis was carried out at the time the economic price of Fuel as the main ingredient of the work of 14,100 rupiahs per liter.
3). The direct cost of dredging work is Rp. 18,700 per m3 or the average of the Work Unit Price dredging with 2 (two) units of equipment, is 27,400 rupiahs per m^3. The annual increase in costs is assumed to be 5.5% (assuming an inflation rate of 5.5%).
4). The estimated volume of spoilbank preparation work is set at 30% of the volume of sediment dredging work.
5). Equipment maintenance costs are assumed to be 3% of the operational costs of dredging.
6). The basis for fixing electricity sales tariffs from PLN refers to the circulation of PT. PLN (Persero). Assume a rate increase of 10% every 4 years.
7). The investment value of a dredger is assumed to be Rp. 20 billion rupiah with a useful life period of 10 years. Reinvestments are carried out every 10 years. The benefits of dredging for hydroelectric power generation are limited to sediment elevation reaching an elevation limit of +246 m (assuming the hydropower operated without sediment disturbance).

With these assumptions, the result of the Cost-Benefits Analysis can be seen in Table 8.

TABLE 8. Value of Benefit and Cost of The Dredging Works

Criteria	Value (Billion Rupiahs)			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Benefit	-	348.92	421.42	484.13
Cost	-	223.00	277.01	447.18

The results obtained indicate that the highest B/C Ratio is found in scenario 2 which is equal to 1,565. In terms of Net Benefit, scenario 3 provides the greatest benefit value with a amount of 144.41 billion rupiahs. In the condition of implementing dredging work with scenario 4, B/C Ratio and Net-Benefit values in a series are 1.083 and 36.95 billion rupiahs.

TABLE 9. Cost Benefit Analysis (CBA) Result.

Parameters.	Scenarios Condition		
	2 toward 1	3 toward 1	4 toward 1
Net-Benefit (Billion Rupiahs)	125.92	144.41	36.95
B/C Ratio	1.565	1.521	1.083

Tthere is a conflict between the value of the B/C Ratio and Net-Benefit parameters especially between scenario 2 and 3, then to determine the alternative scenario of dredging work that provides the highest benefit value, an incremental B/C Ratio method has been analyzed with the results as follows:

TABLE 10. Incremental B/C Ratio Result.

Parameters.	Increment Result		
	3 against 2	4 against 3	4 against 2
Increment of Benefit (Billion Rupiahs)	72.50	62.71	135.21
Increment of Cost (Billion Rupiahs)	54.01	170.18	224.18
Increment of B/C Ratio	1.34	0.37	0.60

The result shows that scenario 3 against 2 has the highest value of Incremental B/C ratio. However, to ensure the results of this study provide strong conviction, a test analysis has been carried out with input of different generation of discharge conditions. The test has been carried out twice which are shown in Table as follows:

TABLE 11. Incremental B/C Ratio Result (Test 1).

Parameters.	Increment Result		
	3 against 2	4 against 3	4 against 2
Increment of Benefit (Billion Rupiahs)	74.48	70.01	144.49
Increment of Cost (Billion Rupiahs)	53.94	170.42	224.39
Increment of B/C Ratio	1.38	0.41	0.64

TABLE 12. Incremental B/C Ratio Result (Test 2).

Parameters.	Increment Result		
	3 against 2	4 against 3	4 against 2
Increment of Benefit (Billion Rupiahs)	68.70	64.78	133.48
Increment of Cost (Billion Rupiahs)	54.00	170.10	224.09
Increment of B/C Ratio	1.27	0.38	0.60

Both of results of the test by recalculating with different generated discharge showed that scenario 3 provides the highest value of the dredging benefit.

IV. Conclusion

By the incremental BC Ratio method, scenario 3 (scenario maximizing existing equipment capacity) with an average volume of dredging per year ± 573,853 m3 is an alternative scenario that provides the highest value for long-term benefits of electricity generation. Scenario 3 will provide additional electrical energy about 2,275,499,988 kWh. The feasibility parameter value of the scenario is 1.521 for B/C Ratio and 144.41 billion rupiahs for Net-Benefit.

With accurate sedimentation rate data, the life of the reservoir operation can be estimated with results close to the actual conditions. It is recommended that the operator of the Sutami Reservoir review and re-evaluate the amount of sedimentation rate obtained from the data from reservoir bathimetry measurements (sounding activities). However, the formulation and accuracy of the results of calculations in this study are not perfect and still need further development. There is an opportunity for other prospective researchers to conduct research related to the pattern of sediment distribution in front of the hydropower plant intake in relation to early detection of possible sediment buildup that will disrupt its operations in the future.

Acknowledgment

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