The Impact of Sedimentation in Reservoirs on Performance Operation of Hydropower: A Case Study Sutami Hydropower Indonesia

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Abstract: ***This paper describes the sedimentation rate and the productivity of hydropower. Sedimentation of reservoirs has become a serious threat to the operation of the reservoir and hydroelectric power in Indonesia. Sedimentation rate in Indonesia resulted in a reduction in storage capacity of reservoirs; hydropower operations are disrupted, and abrade the hydropower turbines. Reservoir sedimentation in Indonesia has reduced catchment reservoirs reached 1.28% per year. Reservoirs with small capacities (less than 200 million m3) suffered a loss of storage capacity which is about 2.05%. Reservoir with a capacity of over 300 million experience loss of storage capacity which is 0.62%. Expected loss due to sedimentation in 284 large dams in Indonesia shrink water volume reached about 12.4 billion cubic meters. Economically it is converted to 84 million dollars per year. Based on the observation and analysis of historical data to reservoirs and Sutami hydropower it was found that the rate of sedimentation in the Sutami reservoir is 4.76 million m^3 / year so that the reservoir capacity remain 54% in 2011. Nevertheless, the production capacity of Sutami hydropower is still very good, indicated by the capacity factor 34% -76% range, and the average 50.5%. High rate of sedimentation in the Sutami reservoir is not provide significant impact on the productivity of hydropower, this is caused by sediment distribution pattern of horizontal and evenly on all elevations.***

Keywords: sedimentation, hydropower, renewable, energy

1. Introduction

Sedimentation rate of reservoir in entire worlds is quite high and become a common enemy for worldwide reservoir managers. Sedimentation has reduced the storage capacity of reservoirs in the entire world reaches 20% of storage capacity or between 0.5% and 1% per annum. [1][2]. It is become one of the obstacles in the development and operation of hydroelectric power plant [3][4][5].The rate of sedimentation in the reservoir which occurs in excess of the estimated planning. Age of the reservoir operations is reduced drastically compared to the estimation. Sedimentation effect is decreased by the capacity of the reservoir so that it interferes the operation of hydropower, because the operation of hydropower depends on the availability of sufficient water for hydroelectric power to operate.

The results of a study of several hydropower dams in Indonesia particularly on the island of Java, Sulawesi and Kalimantan showed no significant impact on the rate of sedimentation in the reservoir to the operating performance of hydropower, which is associated with the pattern of operation and equipment damage due to sedimentation has particles of which can make the erosion of the turbine. That kind of damage makes hydropower ceased operations and cause significant financial losses. Necessary efforts to ensure the sustainability of sediment handling the operation of hydropower. Operation of hydropower in Indonesia needs to be guaranteed continuously, because hydropower is a renewable energy, efficient and environmentally friendly.

Reservoir sedimentation in Indonesia, represented by several reservoirs showed quite high that ranges between 1-13 million m^3/year with sediment catchment efficiency ranged between 23.02%-99.22%.[6].Reservoir sedimentation in Indonesia has reduced catchment reservoirs reached 1.28% per year. Reservoir with a capacity of experiencing losing pitcher approximately 2.05%. Reservoir with a large capacity loss per year is lower, which is about 0.62%.[7]. Reservoir sedimentation affects operating performance of hydropower, especially for the dam that operates as a reservoir daily. Expected loss due to sedimentation in 284 large dams in Indonesia shrink water volume reached about 12.4 billion cubic meters. Economically when converted to 84 million dollars per year.[8]

Hydropower installed capacity in Indonesia reaches 10:29% of total generation in Indonesia, but in producing energy it only contributes 6.02% or 13009.55 Gwh. This situation shows that hydropower is only capable of producing 60% of the available capacity, meaning there are 4 % Hydroelectric power is not plugged into energy or hydropower production capacity which only reaches 60%.[9]

Handling of sediment in the reservoir operation aims to ensure the sustainability of hydropower, because the existence of hydropower should be developed to increase the number of hydropower, as well as maintaining existing ones in order to continue to operate optimally. For this purpose, it is necessary to map and analysis the potential and existing hydropower conditions. The analysis is based on field observations and historical data.

2. Energy Status in Indonesia

Management of electric energy in Indonesia is now considering the balance between supply, needs and equity between regions in Indonesia. Production capacity and demand for electricity as the annual report of PT PLN (State Electrical Company) [9] at the end of 2013 show the total installed capacity and the number of units PLN (Holding and Subsidiary) reached 34 206 MW and 4,925 units, with 26 768 MW (78.26 %) are in Java. The total installed capacity increased by 3.96% compared to the end of December 2012. The percentage of installed capacity per plant types as follows: 15 554 MW power plant (45.47%), 8814 MW Combined Cycle Power Plant (25.77%), 2,848 MW diesel power plant (8.33 %), 3,520 MW hydropower (10:29%), 2,894 MW power plant (8.46%), 568 MW geothermal power plant (1.67%), solar and wind 8.37 MW (0.02%). From the aspect of electricity production technology, it is still dominated by fossil-based generation which amounted to 78.33% and futile is 10:29% of water and geothermal at 1.67%.[10]

The use of renewable energy, especially water energy increased as illustrated in the graph (Figure 1).[8] The picture shows that there is a significant increase in the use of water energy. In 1973 only amounted to 278.8 MW increased to 3519.5 MW in 2013. The increase which almost thirteen times. This condition is possible because of the need for a reservoir for irrigation for agricultural purposes as well be used for hydropower. However, as the percentage of unstable growth rate (figure 1), the growth tends to stagnate that in 2013 only 1.2%, the highest growth in 1988, reaching 29.71%. This trend indicates that the growth of hydropower is very slow. It happens due to the possibility of large investment costs for hydroelectric power and a long time to build, it reaches about 8 years, so it takes a long time to see the benefit.

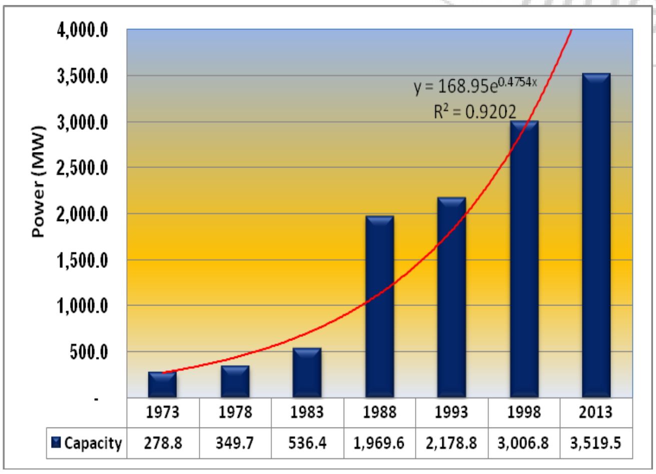

Figure 1: Hydroelectric Growth in Indonesia

3. Evaluation of Sutami Hydropower

This section will present the results of an evaluation of the operating performance of Sutami hydropower. These evaluations, in terms of several aspects namely; electrical energy production capability, suitability between reservoir operation pattern with the actual conditions, and the performance of equipment and plant operating performance. Evaluation of the production is done by taking the data monthly and yearly. Monthly data were taken in June 2011, while annual data for 10 years taken from 2003 to 2012.

Figure 2: Sutami hydropower plant

Sutami reservoirs located in Malang, East Java, Indonesia, (Figure 2) is a multipurpose reservoir. The main function of the reservoir is as a flood control with the equivalent 50-year return period of 1,650 m^3/sec, power plant 3 x 35,000 kWh (488 million kWh/year), the provision of irrigation water 24 m^3/sec in the dry season (of 34,000 ha), tourism and aquaculture.

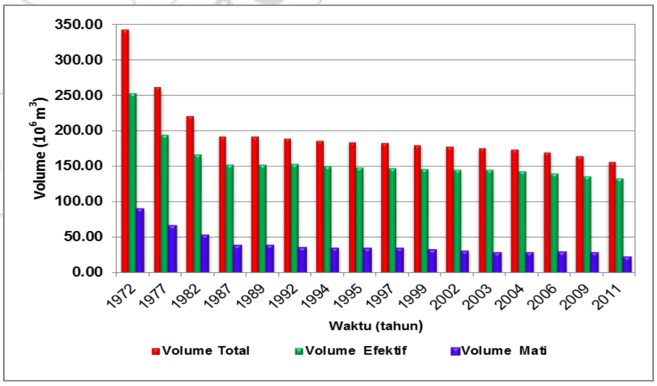

Figure 3: Sutami reservoir capacity reduction due to sedimentation

The rate of sedimentation in reservoirs Sutami increased significantly. It is based on the historical data observed since the operation in 1972-2011. Increased sedimentation occurred in all catchment area. From the data collected measurement results since 1972-2011 as shown in Figure3. The graph shows that there is a tendency volume loss and volume increased of sediment as an impact on water volume shrinkage as shown in Figure 3. In 1973, the volume of the reservoir was at a maximum elevation of 272.5m 343 million m^3. Reservoir water volume decreased by 4.76 million m^3/year. Greatest reduction period occurred in the first year out from 1972 to 1982 as much as 121.71 million m^3 or an average of 12.17 million m^3/year. In the period 1982-1992 showed smaller reduction of 3.13 million m^3/year. Lowest reduction occurred in the period 1992 - 2002, amounted to 1.18 million m^3/ year, a reduction happened to increase again in the period 2002 -2011, amounted 2.34 million m^3 / year.

Table 1: Technical specification of generator

Characteristic	*Dimenion*
1. Capacity	39.000 KVA
2. Voltage	11 KV
3. Frequency	50 Hz
4. Rotation	250 rpm
5. Quantity	3 units
6. Phase	3 phasa
7. Power factor	0,9
8. Augient Tempt	40^0 C
9. Armatur Tempt rise	75^0 C
10. Filo Ampere	72 A
11. Filo Tempt Rise	75^0 C
12. Excitation voltage	220 V
13. Cooler	recirculating air cooler
14. Rating	continue

Sutami hydroelectric first operates on September 4, 1973 or 41 years old in 2014. The first operation capacity was 70 MW, consisted of two generating units with an installed capacity of 35 MW/unit and the current total capacity is 105 MW. The technical specification generator of Sutami Hydropower as shown in Table 2. Volume of water storage capacity in Sutami reservoirs has been reduced to 46%, but Sutami hydropower still operates optimally, according to the capacity designed and even exceeded the targets.

Based on the historical data, it shows that the ratio between the input water discharge (Qin) and water discharge output (Qout) has strived to be different not too big, even as far as possible be made the same, so the availability of water in the reservoir becoming fixed as shown in figure 2. Figure 2 shows that time reservoir operation starts from June 2011-May 2012. The distribution of the operating time is a period of 10 days or one month which is divided into 3 sections. At the time interval 0-3 shows a week in June and 33-36 show in May 2012. In June - December represent the dry season and in January - May represent the rainy season. In the dry season period which ranges from a low water discharge of 40 m^3 / sec - 80 m^3 / sec.

Regulating the use of water to drive turbines is to control the water flow out. The use of certain water as needed, in accordance with the provisions required by the turbine discharge and the availability of water in the reservoir. A water discharge arrangement to come out is based on a predetermined pattern.

Table 2: Technical specification of generator

Year	$Q_{outflow}$ (m^3/sec)			Q_{inflow} (m^3/sec)		
	Max	Min	Average	Max	Min	Average
2003	145.44	92.01	125.89	205.48	100.84	151.73
2004	162.75	103.57	129.07	275.06	98.26	182.44
2005	147.47	106.13	127.04	228.64	109.82	148.09
2006	139.94	112.49	125.34	242.72	116.05	147.94
2007	152.85	96.49	122.15	236.29	95.36	137.13
2008	161.77	94.93	125.84	279.87	109.26	157.66
2009	149.69	94.42	135.6	252.2	99.44	159.94
2010	153.7	128.41	144.76	320.38	135.27	182.34
2011	145.66	121.04	134.37	256.18	113.12	147.84
2012	143.82	104.75	131.40	249.78	103.03	145.33

Application of reservoir operation pattern is appropriate for the regulation of water, although there is a slight difference, but still within the acceptable limits. As shown in Figure 4, in 2011 the use of water is generally not appropriate to the prediction. The use of water more than the expectation occurred between October and November and other months under pattern. Water use has been set to achieve a balance between the incoming water flow and water discharge out.

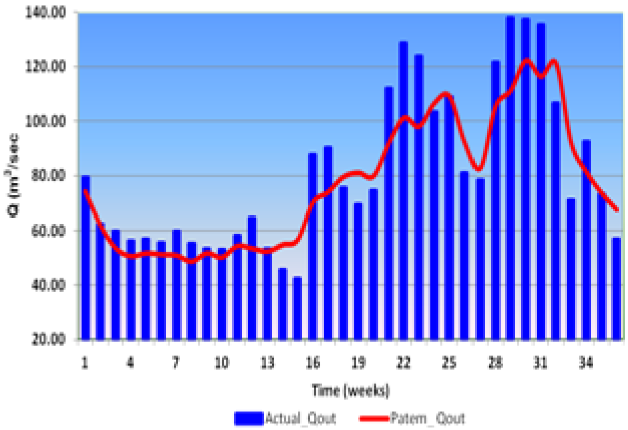

Figure 4: Actual of Qout and prediction of Qout

In addition to take into account the flow of water into and out of water discharge, Sutami reservoir operate to drive a turbine hydropower purposes, also considering the elevation of the reservoir. Elevation reservoirs for hydropower operation are at the lowest elevation of 260 m to the elevation above 272. 5m, in July - November elevation of the reservoir is maintained at an elevation of 260 m - 265 m. In November – May water level is maintained at an elevation of 260 m - 265 m and in April - June the water level is maintained at an elevation of 265 m - 270.5 m. The condition is illustrated in Figure 5.

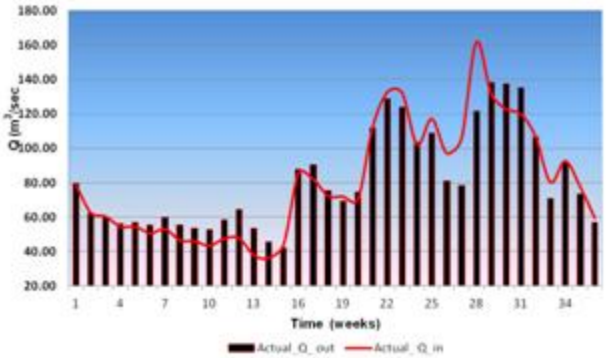

Figure 5: Actual of Qout an Qin

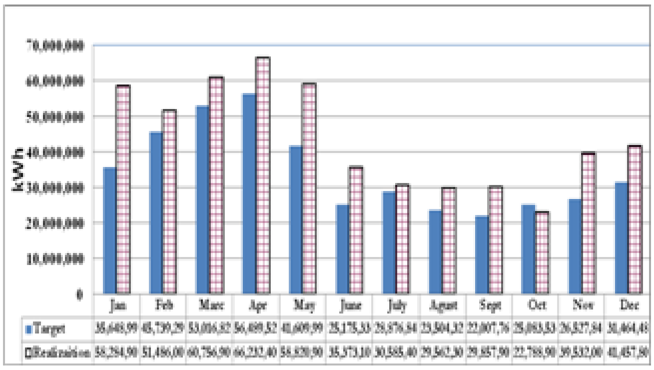

Figure 7: Target and realization of energy production 2012

The pattern of water management in 2011/2012 is shown to be effective, it can be seen from the production of electrical energy as in Figure 6 that the highest power production occurred at the height of the rainy season in March-April, production reached 60 million kWh of electrical energy and the lowest production occurred in August -September which is the peak of the dry season so the electric energy production is only about 20 million kWh – 25 million kWh

Based on data collected over 10 years, the period from 2003 to 2012 in Figure 8 and Table 2 shows that the total production of electricity annually fluctuate or unstable. Lowest production occurred in 2003 amounted to 308,938,070.00 kWh and the highest occurred in 2010 amounted to 698,046,400.00 kWh. The maximum production capacity of Sutami hydropower is 900,000,000.00 kWh per year.

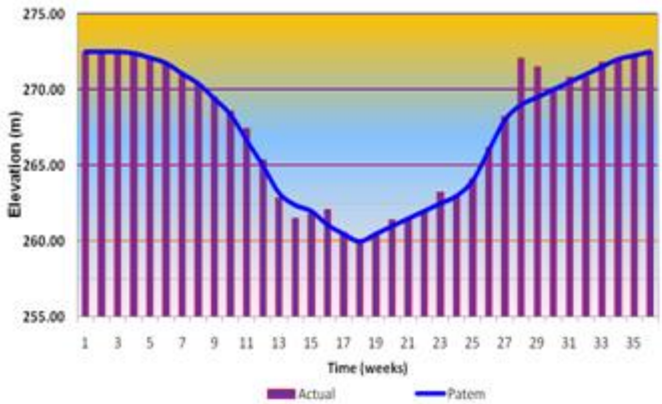

Figure 6: Actual and pattern of reservoir elevation

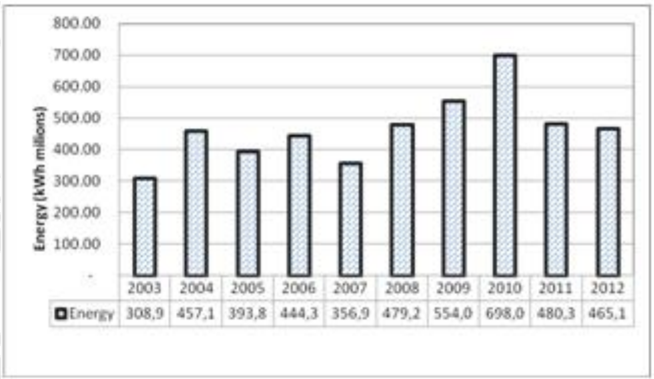

Figure 8: Energy production 2003-2012

Achievement of production like this depends on the condition of availability of water in the reservoir, where the dry season water flow input is low, then the output is set to a low discharge, as the result, the production of electrical energy is not maximal. However, it remains to meet the peak load for 5 hours/day. Based on the existing data, it can be concluded that the performance of the operation of Sutami hydropower of electrical energy production indicator is still very productive. It is because the pattern of water in the reservoir settings can be managed consistently. Performance of Sutami hydropower evaluated in the time period 2003-2012. The purpose of the evaluation is to look at the effect of the rate of sedimentation of the amount of energy produced by hydropower. In general, the production of electrical energy by a hydroelectric power, influenced by the balance between incoming water discharge (Q_in) and regulation of water flow out (Q_out), so that the volume of the reservoir in optimal conditions to operate. Reservoir sedimentation rate in effect on the reduction of the volume of water in the reservoir. The higher the rate of sedimentation caused the higher the volume of water reservoirs which experienced a reduction.

Discharge water that drives the turbine or debit lowest output in 2003 the maximum 145, 44 m^3/sec and at a minimum of 92.10 m^3/sec and average discharge of 125, 89 m^3/sec. In 2010 the flow of water that moves highest turbine namely; maximum and minimum 153.70 128.41 m^3/sec and the mean discharge 144.76 m^3/sec.

The highest water level input for ten years was 320.38 m^3 /sec occurred in 2010 and the lowest discharge was 205.48 m^3 /sec, occurred in 2003. The highest input Debit minimum was 135.27 m^3/ sec, occurred in 2010 and the lowest age was 95.36 m^3/sec, there happen to know debit 2007. The highest average output was 182.44 m^3/sec occurred in 2004 or 2010 more than the 182.34 m^3/sec in 2010. Although debit the highest rates in 2004, but the production of electrical energy was only 447.2 million kWh, compared to the 2010 production reached 698.1 million kWh. Thus the average discharge high output is not similar to high energy output.

The maximum output of the highest water level was 162.75 m^3/sec in 2004, the lowest 145.44 m^3/sec in 2003. Debit highest minimum output was 128.41 m^3 / sec in 2010 and the lowest was 92.01 m^3/sec occurred in 2003. The highest average water flow output was 144.76 m^3/sec occurred in 2010 and the lowest mean water level was 122.15 m^3 / sec in

2007. These results indicate a peculiarity because water discharge lowest output, should produce a number of lowest production. The fact that the energy production in 2007 amounted to 356.9 million kWh entering the second-lowest category, because the lowest was in 2003 that 308.9 million kWh. This is possible because the operation hours in 2007were longer than 2003 or in 2003 the operation hours were shorter due to the repair and maintenance of hydropower equipment.

Performance of hydropower generating electricity may be indicated by fluctuations in reservoir elevation and the elevation of the tail race. As the table shows that the elevation of the reservoir average in ten years ranging from 266.64 m - 269.46 m. The highest elevation is in 2010 which amounted to 269.46 m, it is in line with the highest amount of electricity production in 2010 and the lowest water elevation occurred in 2009. This condition shows discrepancy between the results and the production of high water in the reservoir elevation. Indeed lowest elevation reservoirs produce low production, high effective as experienced reductions.

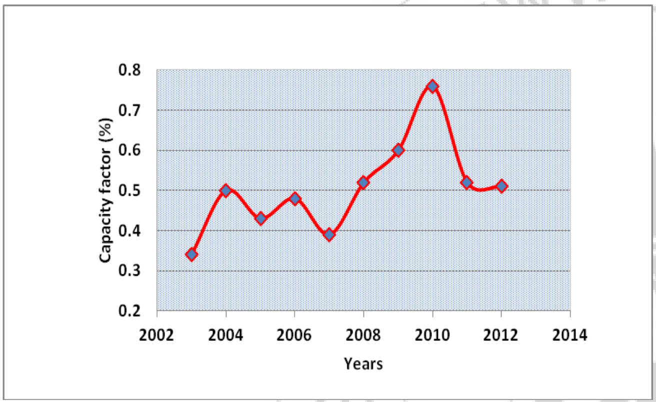

Figure 8: Capacity factor of Sutami Hydropower

One indicator to determine the importance of a hydropower plant operating performance is a factor of power generation capacity. Capacity factor is the ability of plants produce energy in one year based on the power capable owned [11]. In other words, the annual capacity factor is the total energy production in one year divided by the power capable multiplied by the number of hours (8670 hours) for one year.

Based on this formula, the Sutami hydropower capacity factor has been calculated and is listed in Figure 8. Based on the calculations, the performance of Sutami hydropower in ten years has been very well because of the capacity that ranges from 34% -76% and if the average reached 50.5%, the condition is well above the standard of the hydropower capacity factor of 30% [11]. When the average capacity factor is 50.5%, the production of Sutami hydroelectric kWh per year may reach 464.5 million each year.

4. Conclusions

1. Sedimentation in Sutami reservoirs increased from planning targets since functioned in 1972 and in 2011 has undergone a volume loss of 46% at an elevation of 272.5 m and a surface area shrinkage of 45% -46%. Depreciation area and volume evenly in all elevations.
2. The increase in the volume of sediment in the reservoir has not had a significant impact on the production of electrical energy Sutami hydropower. Sutami Hydropower Performance in ten years has been very well because of the capacity that ranges from 34% -76% and if averaged reached 50.5%. Electric energy production in 2012 exceeded the target. This achievement is because of the pattern of reservoir operation that has been established to regulate the use of water and sediment distribution pattern horizontally

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