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CIRATA RESERVOIR LIFETIME PREDICTION USING NEW HYDROMETRICS AND SEDIMENT APPROACHES

*Indratmo Soekarno[1], Mohammad Farid[1] and Regina Dio Oriandra[3]

[1]Water Resources Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia; [2]Bachelor Program of Water Resources Engineering and Management, Institut Teknologi Bandung, Indonesia

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ABSTRACT: By the year 2017 Cirata reservoir has already operated for more than 30 years with a lifetime plan of 100. The annual sedimentation rate plan of Cirata Reservoir was 5.7 x 10^6 m^3, but as calculated in 2017 the annual sedimentation rate increased to 8.4 x 10^6 m^3, which has increased 77.78%. To predict the remaining lifetime of Cirata Reservoir, empiric method of reservoir lifetime was used alongside a new approach to predict the storage volume of a river in years coming by using a hydrometric and sediment approach. The result of Cirata Reservoir remaining lifetime using empirical method is 65 years, this number then used as reference to predict the remaining volume of Cirata Reservoir dead storage using sediment approach. Reservoir lifetime prediction by hydrometric and sediment approach uses the same principle by understanding that a reservoir lifetime is over by the time the dead storage full. What makes this approach differ from the empirical method is that this approach does not only focus on the when dead storage will be full, but also calculating or predicting the changes of storage volume in each elevation. Using this approach, the result shows that the volume of dead storage will already be full and exceeds its capacity by 41.9 x 10^6 m^3 in the next 65 years. Then by using the same approach and by trials and errors, the time needed to fully fill the dead storage is 60 years, or the reservoir will be defunct in 2077.

Keywords: Sediment, Reservoir, Lifetime, Dead storage, Storage volume

1. INTRODUCTION

Cirata Reservoir is one of three reservoirs along the Citarum River, the longest river in West Java, Indonesia. The main purpose of Cirata Reservoir is for hydroelectric power plants, but the other purposes of Cirata Reservoir are for aquaculture, agriculture, and river flow control. Cirata Resevoir was built in 1984 and finished in 1987, in the same year the reservoir was being operated. Located among three regions, Bandung Region, Purwakarta Region, and Cianjur Region, Cirata Reservoir has the area of 6,200 Ha, with 4 major rivers as the sources; Cimeta River, Cisokan River, Cibalagung River, and Cikundul River [1][2][3]. Other than those 4 rivers, this reservoir also got its inflow from the outflow of Saguling Reservoir which is one of Reservoir in Citarum River. Cirata Reservoir was planned to have a lifetime of 100 years, which means the dead storage of Cirata Reservoir was predicted to be full in 2087.

But as time pass by, the lifetime of a reservoir can subside, one of the common causes of the reservoir's lifetime reduction is because of sedimentation in the reservoir exceed the calculated reservoir sedimentation plan. The exceed of sedimentation can happen because of several causes, for example the change of land use in the reservoir's catchment area or sand mining along the source's river. Reservoir sedimentation is a process which suspended load brought by river flow settled on the bed of a reservoir [4].

Reservoir sedimentation is the benchmark of how long a reservoir's lifetime can last. By knowing the sediment concentration of the source's river, it can be estimated how big reservoir's dead storage volume for sediment settlement should be planned, as when a reservoir's dead storage is full that's when a reservoir considered dead or cannot be fully operated. But gradually after the reservoir operates, the source's river sediment concentration changes, causing the increase of sediment settlement in a reservoir which also might affect reservoir's lifetime [5][6]. Therefore, it is very important to find appropriate approach to predict reservoir's lifetime for the purpose of making necessary action for keeping its design lifetime.

In this paper it will be discussed how Cirata Reservoir lifetime has changed and it will be predicted with a hydrometric and sediment approach. This approach is needed in order to get more accurate predictions. If the error of the prediction error is too big, miscalculation of reservoir's lifetime will occur.

2. LITERATURE REVIEW

Reservoir lifetime can be interpreted as the number of years a reservoir can be used to fulfill its purpose whether for hydropower plants or irrigation or other purposes. Often, reservoir's lifetimes usually shortened quicker than the initial plan. This could be caused by several physical factors such as the decrease of land conservation and land use of a catchment area, this could lead to the increase of erosion which affects the number of sediment flow into the reservoir. Considering a reservoir's lifetime is closely related to the sedimentation of the upstream river that would settled in the bed of reservoir, it is important to calculate the possible sediment settlement and prepare a storage for this sediment to settle or dead storage, then calculate how long it would take to fully fill the dead storage, that number is considered the lifetime of a reservoir.

The sediment rate of a reservoir usually depends on its sediment settlement volume within reservoir's operation period, the increase of sediment settled in reservoir can be sought by doing field measurement. The number of sediments settled then used to calculate reservoir's sediment rate by dividing total settled sediment in dead storage by reservoir's operation period.

Trap efficiency is the ability of a reservoir to catch or trap suspended load brought by river flow to the reservoir body, but of course not all 100% of sediment could settle in the reservoir, so the percentage of sediment that could be trapped by reservoir should be measured, as the amount of sediment settled in the dead storage of a reservoir influence the lifetime of a reservoir [7].

Specific gravity is a ratio between particle weight to water density in the temperature of 40° and an atmospheric pressure of 1 atm. In general sediment particles specific gravity variates between 2.60 – 2.70, specific gravity is needed to determine the estimated lifetime of a reservoir. Specific gravity or bulk dry density of reservoir is generally between 650 – 1800 kg/m^3 [8], [9].

3. DESCRIPTION OF STUDY LOCATION

Cirata Reservoir is located at position 6°44' South Latitude and 107°18' East Longitude. It is in 3 (three) regency areas, namely Bandung Regency, Cianjur Regency, and Purwakarta Regency, with a reservoir surface area of around 6,320 Ha. It is also at a maximum elevation of +223.00 m above sea level.

Cirata Reservoir is one part (in the middle) of three large Citarum cascade reservoirs, namely Saguling Reservoir in the upstream part and Juanda Reservoir in the downstream part. It has started operating since 1988 for electricity energy production, with an installed power capacity of 1,008 MW and an average annual production capability of 1,426 GWh. Cirata Reservoir with its hydropower plant as a generating unit plays a role in providing electricity through the Java-Bali-Madura interconnection system.

In its operation for electricity generation, Cirata Reservoir which has an area of 6,320 ha, receives water from output water (outflow) of Saguling Reservoir and is required to provide water supply to the Juanda Reservoir for irrigation, raw water, electrical energy, fisheries and others, in order of priority based on applicable laws formulated in the operational system of the Citarum Cascade Reservoir (Equal Sharing) where each management unit can operate the reservoir based on a balance of the effective capacity of the water reservoir.

During the past few decades, it has been considered that Citarum River Basin has problem due to the decreasing of its environmental condition [10]. Urbanization leads to land cover changes as conversion of other land surface types to urban areas interferes the hydrologic characteristic [11]. Furthermore, it causes sedimentation in reservoir area of the dam in the downstream due to erosion in the upstream area [12].

4. METHODOLOGY

4.1 Sediment Distribution

Sediment distribution can be measured by the increase of sedimentation in the reservoir, changes of reservoir volume that are constantly monitored are easier to predict the distribution at every elevation. The decrease of volume at each elevation indicates the increase of sedimentation in that elevation in another word, it's the sediment distribution of every elevation in a reservoir.

4.2 Sediment Rate

The sediment rate is expressed in Eq. (1) below.

$$\boldsymbol{S_r = \frac{V_s}{t_2 - t_1}} \tag{1}$$

Where: Vs is Settled sediment in the reservoir (x10^6 m^3) and t_1 is the year reservoir's being operated meanwhile t_2 is the time of sediment measurement.

4.3 Trap Efficiency

Equation (2) is the formula used to calculate trap efficiency.

$$\boldsymbol{Y = 100\left(1 - \frac{1}{1+aX}\right)^n} \tag{2}$$

Where: X is the ratio between reservoir's present storage (C) and annual inflow into the reservoir (I), a and n are Constanta. By trap efficiency curve, a and n is 100 and 1,5 respectively.

4.4 Specific Gravity

Specific gravity is measured by sediment sampling and tested in Laboratory. Miller and Lane (1953) develop an equation to predict specific gravity in the following years (T years) after the sampling [13] as can be seen in Eq. (3).

$$W_T = W_0 + 0,4343K\left(\frac{T}{T-1}(\ln T) - 1\right) \quad (3)$$

Where: W_T is specific gravity after T-years (kg/cm^3); W_0 is measured specific gravity (kg/cm^3); K is coefficient according to reservoir's type and the particles of sediment; and ln T = log e^T.

Measured specific gravity can be calculated with following Eq. (4).

$$W_0 = W_c P_c + W_m P_m + W_s P_s \quad (4)$$

Where: W_0 is measured specific gravity (kg/cm^3); W_c, W_m, W_s = coefficient of clay, silt, sand (kg/cm^3); and P_c, P_m, P_s = percentage of clay, silt, sand (kg/cm^3).

4.5 Reservoir Lifetime Using Empiric Method

Reservoir's lifetime can be calculated with empiric method, with the following Eq. [5].

$$T = V / (L \times S \times E) \quad (5)$$

Where: T is reservoir's lifetime (year); V is dead storage volume (m^3); L is catchment area (km^2); S is erosion intensity [S= V_s/L]; V_s is average sediment inflow to reservoir (m^3/year) [$V_s = W_s/\gamma_d$]; W_s is average sediment inflow mass (ton/year); γ_d is sediment dry density = 0,65 ton/m^3; E is trap efficiency (%).

Types of reservoir according to Pemberton (1989) is shown in Table 1. The first type is when reservoir always inundated, the second type is when reservoir's water fluctuation is between high and medium, the third type is when reservoir is always dry, and the fourth type is for river bed load [14].

Table 1 Types of reservoir according

Type	Coefficient (kg/m^3)			K Factor		
	Sand	Silt	Clay	Sand	Silt	Clay
1	1,550	1,120	416	0	91	256
2	1,550	1,140	561	0	29	135
3	1,550	1,150	641	0	0	0
4	1,550	1,170	961	0	0	0

Source: Pemberton (1989)

5. ANALYSIS

5.1 Sediment Distribution

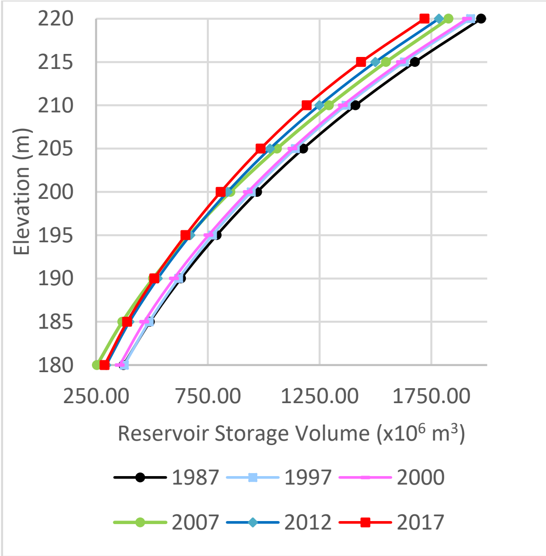

Fig. 1 Changes of reservoir's volume from dead storage to normal elevation

Table 2 Sediment volume and distribution

Elevation	Reservoir's Volume		Sediment Volume	Sediment Dist.
	1987	2017		
(m)	(x10^6 m^3)			
220	1,973	1,720	253	12
215	1,677	1,436	241	23
210	1,411	1,193	218	28
205	1,177	987	190	27
200	971	808	163	23
195	790	650	140	20
190	630	511	119	17
185	491	389	102	17
180	373	288	85	18
175	277	211	66	17
170	200	150	50	15
165	140	105	35	7
160	100	72	28	7
150	50	29	21	9
140	20	8	12	8
130	4	1	3	3
120	0	0	0	0

Sources: PT Pembangkit Jawa Bali BPWC with Center for Research and Development of Water Resources Ministry of Public Work and Housing (2017) and Analysis Result

Cirata Reservoir, as shown in the Fig. (1) above was operated for the first time in 1987 with total volume of 1,973 x 10^6 m^3 at normal elevation of 220 m above sea level, but as time goes by the storage volume was decreasing. After being operated for 30 years, in 2017 the total volume decreases to 1,719.66 x 10^6 m^3. Following to that, Table 2 shows the changes of volume at each elevation and at the same time also shows how much sediment had settled at each elevation.

The sediment volume column shown above represents the accumulative sediment volume and the column next to it shows the sediment distribution of each elevation.

5.2 Sediment Rate

From Table 2 above, it showed that from 1987 to 2017 the total sedimentation on the bed of Cirata Reservoir is 254,4 x 10^6 m^3. By using Eq. (1) Cirata Reservoir's sediment rate can be calculated:

$$S_r = \frac{V_s}{t_2 - t_1}$$
$$S_r = \frac{253{,}3\ x\ 10^6\ m^3}{2017-1987}$$
$$S_r = 8.44\ x\ 10^6\ m^3/year$$

5.3 Trap Efficiency

At present, the total storage of Cirata Reservoir is 1,720 x 10^6 m^3 and dead storage volume of 288.24 x 10^6 m^3. According to PT Pembangkit Jawa Bali BPWC and Center for Research and Development of Water Resources Ministry of Public Work and Housing, Cirata Reservoir receive its inflow from four main rivers and Saguling Reservoir. The outflow of Saguling Reservoir annually that get into Cirata Reservoir is more or less 2,670 x 10^6 m^3 and the inflow from the main rivers is more or less 2,499 x 10^6 m^3 annually, it makes the total annual inflow of Cirata Reservoir is 5,169 x 10^6 m^3. So Cirata Reservoir trap efficiency percentage can be calculated with Eq. (2) as follow:

$$Y = 100\left(1 - \frac{1}{1+aX}\right)^n$$
$$Y = 100(1 - 1/(1 + 100\ x\ (1,720\ x\ 10^6)/(5,169\ x\ 10^6\ )))^{1.5}$$
$$Y = 95,66\%$$

5.4 Specific Gravity

Measure specific Gravity obtained from sampling taken in the reservoir and then test the samples in the laboratory. Table 3 shows the result of sediment particle sample testing from Center for Research and Development of Water Resources Ministry of Public Work and Housing Laboratory. The sample taken were 27 samples, but the first sample and the 27th sample will not be used because the samples was not taken on the bed of Cirata Reservoir, instead it was taken in the source's river of Cirata Reservoir and in the tailrace area of reservoir.

Cirata Reservoir can be categorized as first type reservoir by Pemberton's table because Cirata Reservoir is always inundated, which mean the coefficient for sand, silt, and clay are 1550 kg/m^3, 1120 kg/m^3, and 416 kg/m^3 respectively. With Eq. (4) the measured specific gravity can be determined:

$$W_0 = W_c P_c + W_m P_m + W_s P_s$$
$$W_0 = 416\ x\ 27\% + 1,120\ x\ 26\% + 1,550\ x\ 47\%$$
$$W_0 = 904.55\ kg/m^3$$

Table 3 Sediment particles distribution

Sampling Location	Sand (%)	Slit (%)	Clay (%)
2	15.48	39.40	45.12
3	2.27	23.42	73.86
4	10.50	23.42	66.08
5	5.34	26.54	68.12
6	42.62	38.17	19.21
7	16.10	22.37	61.53
8	36.96	18.29	44.75
9	9.50	39.57	50.93
10	19.38	31.80	48.82
11	30.66	23.22	46.12
12	24.64	26.08	49.28
13	36.70	23.44	39.86
14	28.04	23.61	48.35
15	30.76	23.72	45.52
16	39.14	25.83	35.03
17	11.70	39.41	48.89
18	39.34	25.77	34.89
19	45.06	23.41	31.53
20	55.20	17.12	27.68
21	52.48	16.59	30.93
22	42.22	17.40	40.38
23	48.30	16.72	34.98
24	21.58	20.76	57.66
25	8.20	24.44	67.36
26	1.36	39.75	58.89
Average (%)	27	26	47

Sources: PT Pembangkit Jawa Bali BPWC with Center for Research and Development of Water Resources Ministry of Public Work and Housing in 2017

K factor of sand, silt, and clay for type one reservoirs are 0, 91, and 256 respectively. Same sa W_0 or measured specific Gravity, K factor is calculated with Eq. (4):

$$K = K_c P_c + K_m P_m + K_s P_s$$
$$K = 256\ x\ 27\% + 91\ x\ 26\% + 0\ \ x\ 47\%$$
$$K = 144.07$$

After W_0 and K Factor were determined, the specific Gravity of sediment particles (W_T) in Cirata Reservoir can be calculated or predicted for the years to come using Eq. (3) as follow:

$$W_T = W_0 + 0,4343K(\frac{T}{T-1}(lnT) - 1)$$

$$W_T = 904,55 + 0,4343\ x\ 144,068\ x\ \left(\frac{2017\text{-}1987}{(2017\text{-}1987)\text{-}1}(\ln(2017\text{-}1987))\text{-}1\right)$$

$$W_T = 1,062.12\ \mathrm{kg/m^3}$$

According to Soewarno (1991), reservoir sediment specific Gravity is between 650 – 1800 kg/m^3 [15], as calculated above Cirata Reservoir's sediment specific gravity is 1,062.12 kg/m^3, which is still between the range set by Soewarno.

5.5 Reservoir Lifetime Using Empiric Method

Reservoir lifetime can be predicted using empiric method with Eq. (5). To get factor S or Erosion Intensity, the data needed are volume of sedimentation in dead storage, the sediment specific gravity of reservoir, catchment area, and sediment dry density. In Table 2 it is shown that sediment volume in dead storage is 84.76 kg/m^3 as the dead storage elevation of Cirata Reservoir is at 180 meter above sea level, Cirata Reservoir's sediment specific gravity is 1062.12 kg/m^3, the catchment area of Cirata Reservoir is 4,119 km^2, while the value of sediment dry density of Cirata Reservoir is 0.65 as tested by Center for Research and Development of Water Resources Ministry of Public Work and Housing Laboratory.

$$S = \frac{Vs}{L} \qquad (6)$$

$$S = \frac{(W_T\ x\ 10^{-3}\ x\ Sediment\ Volume)}{Operating\ Time\ (Years)\ x\ \gamma_d} \Big/ L \qquad (7)$$

$$S = \left(\frac{1{,}062.12x\ 10^{-3}\ x\ 84.76x10^6}{30\ x\ 0.65} \Big/ 4,119\right)$$

$$S = 1120.84\ ton/km^2\ a\ year$$

As the erosion intensity already obtained as shown above by using Eq. (6) and Eq. (7) and as calculated before that the trap efficiency of Cirata Reservoir is 95.66%, also as shown in Table 2 that the dead storage volume at present time is 288.2 x 10^6 m^2, the lifetime of Cirata Reservoir can be predicted:

$$T = V\ /\ (L\ x\ S\ x\ E)$$

$$T = 288.3\ x\ 10^3 / (4.119\ x\ 1120.84\ x\ 95,66\%)$$

$$T = 65,257\ Years$$

$$T = 65\ Years$$

As calculated using empirical method above, the remaining lifetime of Cirata Reservoir is around 65 years, which mean the lifetime of Cirata Reservoir is shortened by 5 years, as the lifetime of Cirata Reservoir supposedly still have 70 years.

6. RESULT AND DISCUSSION

Reservoir's remaining lifetime can be predicted using various method, like empirical method as used above or by reservoir storage approach just to name a few. Reservoir lifetime prediction usually refers back to reservoir's volume and using sediment rate as reference of how long it takes with the said sediment rate to fill the remaining dead storage.

Table 2 Sedimentation increase

2017		
Elevation (m)	Sediment Volume ($x10^6$ m^3)	Increase of Sedimentation each year (Sr') ($x10^6$ m^3)
220	253.34	8.45
215	241.06	8.04
210	218.47	7.28
205	190.41	6.35
200	163.03	5.43
195	139.67	4.66
190	119.33	3.98
185	101.96	3.40
180	84.76	2.83
175	66.33	2.21
170	49.71	1.66
165	35.03	1.17
160	28.16	0.94
150	20.71	0.70
140	11.60	0.39

In Cirata Reservoir the storage volume measurements and sedimentation in the reservoir are carried out every 5 years by Center for Research and Development of Water Resources Ministry of Public Work and Housing with PT Pembangkit

Jawa Bali BPWC, the agency that manage Cirata Reservoir. The measurements in the reservoir are done with barometry method, resulting the changes of reservoir storage in each elevation. In Table 2 above, shown the cumulative of reservoir's volume and sediment volume in each elevation, with that available data the increase of sedimentation in each elevation can be calculated. The changes or increase of sedimentation in each elevation can be used as reference to calculate the sediment rate in each elevation, as it still has the same principle as calculating sediment rate of the reservoir, the amount of sediment settled in the reservoir over time divided by how long the reservoir has been operated. Table 4 shows the analysis result of the increase of sedimentation in every elevation annually or the sediment rate of every elevation annually, or for short can be written as Sr'.

Previously the present specific gravity of sediment particles in Cirata Reservoir had been calculated, by using measured specific gravity (W_0) and K Factor, with the same method sediment particles specific gravity of years to come can be predicted. By referencing the equation to calculate erosion intensity, the equation to calculate the average sediment inflow into reservoir shown above was calculated with the following Eq. (8).

$$\boldsymbol{V_s = W_s/\gamma_d} \tag{8}$$

W_s or average sediment mass in reservoir is the total mass of sediment in the reservoir, and is measured by using specific gravity of sediment particles in reservoir and the sediment rate or the settled sediment, as mention above this method calculate the change of storage volume in every elevation, making the equation to calculate V_s in each elevation (h) for years to come into Eq. (9).

$$\boldsymbol{V_{sh} = \left[\left(W_0 + 0,4343K\left(\frac{T}{T-1}(lnT) - 1\right)\right) xSr'x10^{-3}x\,T\right]/\gamma_d} \tag{9}$$

Where: T is operation time (year); and Sr' = every elevation sediment rate (x10^6 m^3/ y).

The result of the equation above is the average sediment inflow that would be settled in a certain elevation. As years pass by it will show how much the decrease of the storage volume is, by referencing the result with the present storage volume, especially dead storage volume, the year or time when the dead storage will be full can be predicted, or can be written into the following Eq. (10).

$$\boldsymbol{V_{h,n} = V_{0h} - V_{sh}} \tag{10}$$

$$\boldsymbol{V_{h,n} = V_{0h} - \left[\left(W_0 + 0,4343K\left(\frac{T}{T-1}(lnT) - 1\right)\right) xSr'x10^{-3}x\,T\right]/\gamma_d} \tag{11}$$

Where: $V_{h,n}$ is storage volume at certain elevation in year – n (x10^6 m^3); and V0h is storage volume of the referenced year (2017) at certain elevation (x10^6 m^3)

Supposedly the remaining lifetime of Cirata Reservoir is 70 years or will be defunct by the year 2087, meanwhile according to calculation using Empirical Method before, the remaining lifetime of Cirata Reservoir is around 65 years or will be defunct by the year 2082. By using Eq. (10) above it will be calculated the dead storage volume 70 years and 65 years to come, as the dead storage elevation of Cirata Elevation is at 180 meter above sea level with present storage volume of 288.23 x10^6 m^3, and sediment rate (Sr') of 2.83 x10^6 m^3.

$$\boldsymbol{V_{180,2087} = 288.23\ x\ 10^6 - \left[\left(904.55 + 0.4343\ x\ 144.07\ x\ \left(\frac{70}{69}(\ln 70) - 1\right)\right) x2.83\ x\ 10^6\ \ x\ 10^{-3}\ x\ 70\right] / 0.65}$$

$$\boldsymbol{V_{180,2087} = \ -68.68\ \ x\ 10^6\ m^3}$$

From the calculation above it can be concluded that by the year 2087 or 70 years after 2017, the dead storage of Cirata Reservoir will be already full and exceed its capacity, which means the all the sediment entering the reservoir will be settled in the effective storage.

$$\boldsymbol{V_{180,2087} = 288.23\ x\ 10^6 - \left[\left(904.55 + 0.4343\ x\ 144.07\ x\ \left(\frac{65}{64}(\ln 65) - 1\right)\right) x2.83\ x\ 10^6\ x\ 10^{-3}\ x\ 65\right] / 0.65}$$

$$\boldsymbol{V_{180,2087} = \ -41.94\ \ x\ 10^6\ m^3}$$

As shown above, the result of dead storage volume calculation 65 years in the future is no differ from the result of 70 years in the future, the dead storage will be filled full by then and exceed the planned capacity.

Using hydrometrics and sediment approach, it's calculated how long it will take to fully fill Cirata Reservoir's dead storage by trials and errors. The Table 5 below is the result of the calculation. In the table it shown that by the year 2075 there are no room left for sediment settlement, Cirata Reservoir's dead storage is already filled full, meaning the remaining lifetime of Cirata Reservoir is 60 years from the year 2017.

Table 5 Changes of reservoir storage volume

Elev.	2017	2022	2027	2032	2037	2042	2047	2052	2057	2062	2067	2072	2077
(m)	(x 10^6 m^3)												
220	1,720	1,657	1,589	1,520	1,450	1,378	1,306	1,233	1,159	1,085	1,011	936	860
215	1,436	1,376	1,312	1,246	1,179	1,111	1,042	973	903	832	761	690	618
210	1,193	1,138	1,080	1,021	960	898	836	773	709	645	581	516	452
205	987	939	889	837	784	730	675	621	565	510	454	397	341
200	808	768	724	680	634	588	542	495	447	400	352	303	255
195	650	616	579	540	501	462	422	382	341	300	259	218	177
190	511	481	449	417	383	350	316	281	247	212	177	141	106
185	389	364	337	309	280	252	222	193	163	134	104	73	43
180	288	267	245	222	198	174	150	125	101	76	51	26	1
175	211	194	177	158	140	121	102	83	64	45	25	5	0
170	150	138	125	111	97	83	69	55	40	26	11	0	0
165	105	96	87	77	68	58	48	38	27	17	7	0	0
160	72	65	57	50	42	34	26	18	10	1	0	0	0
150	29	24	19	13	7	1	0	0	0	0	0	0	0
140	8	6	2	0	0	0	0	0	0	0	0	0	0

7. CONCLUSION

From the analysis and calculation that have been done above, it can be concluded as several points below.

1) The sedimentation rate of Cirata Reservoir is increasing, the planned sedimentation rate was 5.7 x 106 m^3 annually and now it became 8.4 x 106 m^3 only 30 years into operation from 1987 to 2017.
2) The sediment settled in the dead storage by 2017 is 84.76 x 106 m^3, with total sedimentation of 253.34 x 106 m^3 in the reservoir, making 168.58 x 106 m^3 of sedimentation settled in effective storage, or the sedimentation in effective storage to dead storage have a ratio of almost 2:1.
3) Citarum Reservoir has a trapping efficiency of 95.66%, which means 95.66% of sediment brought by river flow into reservoir will be settled and the rest will be carried out by the reservoir's outflow.
4) Sediment particles of Cirata Reservoir have a measured specific gravity of 904.55 x 106 m^3 and predicted specific gravity of 1,062.12 kg/m^3 by 2017.
5) By using empirical method to predict the remaining lifetime of Cirata Reservoir, the result is 65 years, or the dead storage of reservoir will be full by the year 2082, instead of 70 years like it supposed to be. But by analyzing it using hydrometrics and sediment approach, by the year 2082, Cirata Reservoir's dead storage is already full and exceeds the capacity available.
6) Using hydrometrics and sediment approach by trials and error, by the year 2077 or 60 years after 2017, the dead storage of Cirata Reservoir is already full. Which means that the reservoir's lifetime is shortened by 12 years, making the actual lifetime of the reservoir to became only 88 years from the life plan of 100 years.

The sediment rate used in this paper is the average reservoir's sediment inflow within the operating time of 30 years, but as known before that the sediment rate of Cirata Reservoir is increasing as time goes by, this of course could be used as consideration to calculate reservoir's lifetime. Instead the sediment rate used to calculate reservoir's lifetime is supposedly the estimation of sediment rate year by year to come if there are no means taken to reduce the sedimentation in the reservoir. Moreover, in this paper, the sediment carried from Saguling Reservoir is considered as really small that it would not affect the increase of sedimentation in Cirata Reservoir, what should be done is that there should be a test conducted on the outflow of Saguling Reservoir to consider whether the sediment flow would affect Cirata Reservoir or not. Dredging can be considered as an effort to extend the lifetime of the Cirata Reservoir. Furthermore, it is also important to control sediment rates in rivers that enter the reservoir by structural measurement such as check dam.

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