International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

# Sediment Flushing Simulation and Sediment Distribution in Wlingi Reservoir

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***Abstract*— *Wlingi Dam is one of the dams in Indonesia which is part of the Brantas River Basin, that has an area of 2,890 km$^2$ of catchment area and serves as a collection point and water provider for irrigation in Lodoyo and Tulungagung Timur areas by irrigating 15,132 Ha rice fields. One of the problems in the Wlingi Dam is sedimentation in its reservoir. Data shows that from the Wlingi Dam was built in 1977 the total volume of storage capacity declined from 24.00 million m$^3$ in 1977 to 2.20 million m$^3$ in 2015. This is the basis of this research this is done to find out alternative solutions that can be done to restore the total volume of the reservoir by using the efficiency of flushing sediment in the reservoir. This research was carried out by using 2 flushing scenarios, namely scenario A by using an inflow discharge for 49 hours and scenario B using an inflow discharge for 56 hours with each scenario having 7 alternative scenarios by increasing and reducing the inflow discharge based on the percentage of 10% to 30%. The results obtained in the simulation using HEC-RAS are the highest efficiency of sediment flushing obtained by increasing the inflow discharge to 110%. So in this study it was concluded that by reducing the inflow discharge in percentages for flushing the sediment it is not always directly proportional to the volume value of the sediment being flushed or to the efficiency of the sediment flushing value. The results of the sediment distribution that occurred after sediment flushing simulations on Brantas River from cross section CRB 19 to CRB 140 were the largest river scouring occurred on CRB 117 up to CRB 130 or around 700 to 1,300 m from Wlingi Dam.*

***Keywords*— *Flushing efficiency, HEC-RAS, sediment flushing, Wlingi Reservoir.*

## I. Preliminary

According to a report from the International Commission for the ICOLD Sedimentation Committee, there are different forms in each country which cause a decrease in the capacity of reservoirs. Some Asian countries have found reservoir reservoir capacity to be higher than the world average of 0.80%, this is due to geological conditions and land cover. The state reservoir capacity level of China is 2.9%, India 0.72%, Japan 0.42%, Thailand 0.56% and the Philippines 0.84% per year. Whereas in the United States the percentage reduction in reservoir capacity is 0.36% per year (Basson, 2008). How much the percentage reduction in reservoir reservoir capacity in Indonesia is not fully well-organized.

One of the reservoirs that has a sedimentation problem in its reservoir is the Wlingi Reservoir. The Wlingi Reservoir has a catchment area of 2,890 km$^2$, located in the southern slope of Mount Kelud, about 25 km downstream of the Sutami Dam. The Wlingi Dam was completed in 1977 with the function of generating electricity during peak loads, irrigation water supply and expected temporary storage of Mount Kelud eruption material which erupted on average once in 15 years.

At present the reservoir sedimentation is one of the main problems in the Brantas River Basin. In some small reservoirs such as the Wlingi Reservoir, the effective storage capacity is only 19.4% of the first capacity (Anonim PJT I, 2015). Sediment flushing in the Wlingi Reservoir has been used as an effective effort in removing sediments that have been overcome in the reservoir.

In this study will discuss about:
1. Map of sediment distribution that occurs in the Wlingi Reservoir before flushing.
2. Map of sediment distribution that occurs in the Wlingi Reservoir after flushing.
3. Alternatives to effective reservoir flushing in terms of the sediment flushing.
4. Map of sediment distribution that occurs in the Wlingi Reservoir after obtaining the most effective sediment flushing efficiency.

## II. Research Methodology

*Research Sites*

The location of the study area was carried out in Wlingi Dam, Talun District, Blitar Regency, East Java Province.

Fig. 1. Wlingi Dam location

*Analysis Method*

The following are the stages of simulation on HEC-RAS:
1. Input geometric data
2. Input sediment boundary condition
3. Input quasi-unsteady flow
4. Sediment transport simulation
5. Model calibration

Calibration uses 2 methods, namely comparing the sediment results in the HEC-RAS model with the results of



Rizhandi Nugroho Nusantoro, Dian Sisinggih, and Very Dermawan, “Sediment Flushing Simulation and Sediment Distribution in Wlingi Reservoir,” *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 1, pp. 1-9, 2018.

measurements, and calibration using the Root Mean Square Error (RMSE) method with the formula (Chai, 2014):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{obs} - X_{mod})^2} \quad (1)$$

where:
$X_{obs}$ = riverbed from observation (m)
$X_{mod}$ = riverbed the result of model (m)
n = total data

Calculating flushing efficiency using Mahmood (1) method (Anders, 2000):

$$E = \frac{V_2 - V_1}{V_0} \quad (2)$$

where:
E = flushing efficiency
$V_2$ = reservoir capacity after flushing ($m^3$)
$V_1$ = reservoir capacity before flushing ($m^3$)
$V_o$ = outflow water volume ($m^3$)

In this study, the inflow discharge was assumed to be the same as the outflow discharge because the sediment flushing system used a full opening door, so the equation that could be used in this study was simplified into:

$$E = \frac{V_s}{V_i} \quad (3)$$

where:
$V_s$ = sediment flushed volume ($m^3$)
$V_i$ = inflow water volume ($m^3$)

*Analysis of Sediment Flushing Scenarios*

The scenario in this study was carried out in the following manner as shown in Table 1 below.

TABLE 1. Alternatives scenarios for sediment flushing

| No. | **Alternative A using existing inflow for 49 hours operation** | No. | **Alternative B using inflow for 56 hours** |
|---|---|---|---|
| 1. | Existing inflow for 49 hours | 8. | Inflow for 56 hours |
| 2. | Discharge go up to 130% from existing | 9. | Discharge go up to 130% from existing |
| 3. | Discharge go up to 120% from existing | 10. | Discharge go up to 120% from existing |
| 4. | Discharge go up to 110% from existing | 11. | Discharge go up to 110% from existing |
| 5. | Discharge go down to 90% from existing | 12. | Discharge go down to 90% from existing |
| 6. | Discharge go down to 80% from existing | 13. | Discharge go down to 80% from existing |
| 7. | Discharge go down to 70% from existing | 14. | Discharge go down to 70% from existing |

## III. RESULT AND DISSCUSSION

*Map Situation Before and After Sediment Flushing*

Before analysis of sediment, the data needed to support the need for comparison of the results before and after the sediment flushing that will be carried out using the application. Mapping the sediment distribution situation before flushing is done by reducing the results from contour data before flushing in 2016 with contour data after the 2015 flushing. While mapping the sediment distribution situation after flushing is done by reducing the results from contour data after flushing in 2016 with contour data before flushing in 2016.

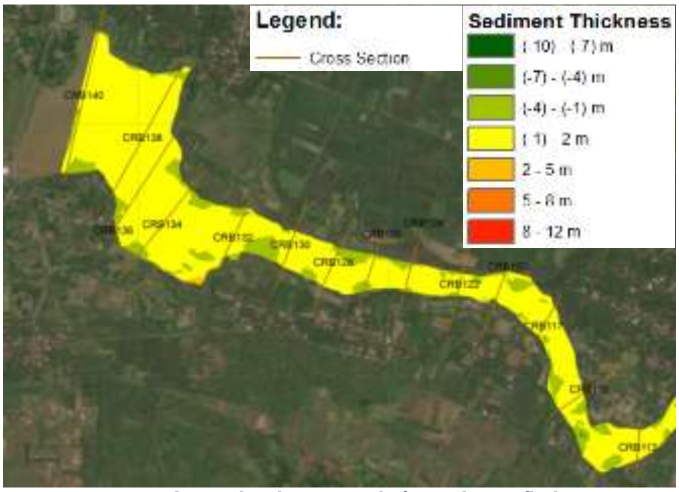


Fig. 2. Sediment distribution map before sediment flushing

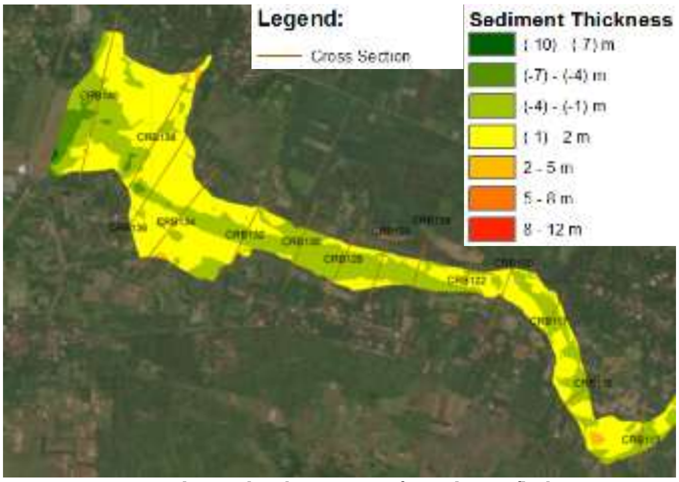


Fig. 3. Sediment distribution map after sediment flushing

*Analysis of Sediment Flushing*

In this study only 4 flushing methods were used, namely Ackers-White, Laursen (Copeland), Meyer Peter Muller, and Wilcock because in the sediment simulation process the variable HEC-RAS can be calibrated to obtain sediment flushing conditions that are close to the conditions at the time of measurement sediments only exist in all four methods. Variables that can be adjusted in the Ackers-White method are A (critical mobility), C and m (empirical coefficient), in the Laursen (Copeland) method namely $\tau_c^*$ (critical shield's stress), in the Meyer Peter Muller method $\tau_c^*$ (critical shield's stress), coefficient, and power, and Wilcock is $\tau_{rm}^*$ (reference shear stress). While for the falling speed method used is according to Ruby (HEC-RAS Reference Manual, 2010).

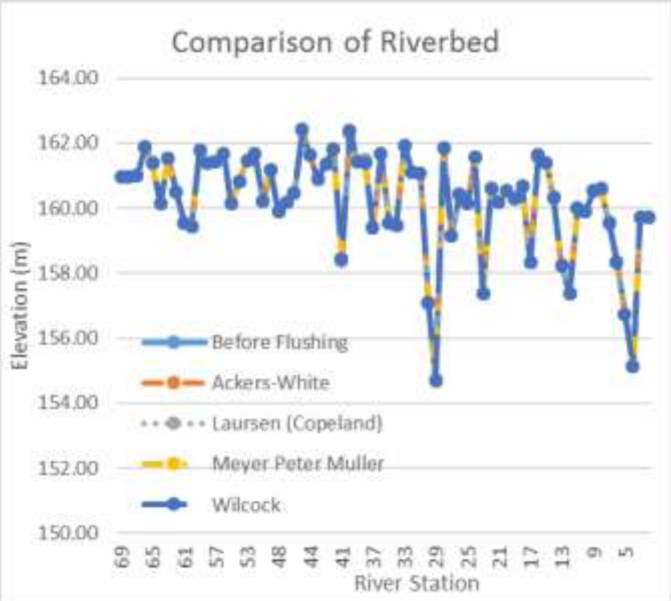


Fig. 4. Long section recapitulation of each method

*Model Calibration*

The purpose of calibrating the sediment flushing model is to find out the parameters in the calculation of the sediment simulation analysis that can be used to do the sediment analysis scenario in the next step. The value that becomes the calibration reference is the amount of sediment measured by PERUM Jasa Tirta I (HEC-RAS Users Manual, 2010).

1. Ackers-White method

Variables that can be adjusted so that the results of the sediment volume approaching the same as the measurement results in the Ackers-White flushing method are A, C, and m.

The following are tables of "*A*" variable calibration in the Ackers-White method.

TABLE 2. Calibrating "*A*" variable for Ackers-White method

| Variable | | | Sediment Volume ($m^3$) | |
|---|---|---|---|---|
| **A** | **C** | **m** | **HEC-RAS Model** | **Observation** |
| 0.1900 | 0.25 | 1.78 | 792.53 | |
| 0.0005 | 0.25 | 1.78 | 0.00 | |
| 0.0500 | 0.25 | 1.78 | 51,094.06 | |
| 0.0100 | 0.25 | 1.78 | 537,679.71 | |
| 0.0080 | 0.25 | 1.78 | 670,274.60 | 1,026,500.00 |
| **0.0050** | **0.25** | **1.78** | **815,935.34** | |
| 0.0048 | 0.25 | 1.78 | 760,562.66 | |
| 0.0030 | 0.25 | 1.78 | 314,233.72 | |
| 0.0025 | 0.25 | 1.78 | 254,757.19 | |

Obtained from the calibration above the value of "*A*" variable which is considered close to the volume value of the sediment the measurement results are A = 0.0050.

The following is a table of the "*C*" variable calibration in the Ackers-White method.

TABLE 3. Calibrating "*C*" variable for Ackers-White method

| Variable | | | Sediment Volume ($m^3$) | |
|---|---|---|---|---|
| **A** | **C** | **m** | **HEC-RAS Model** | **Observation** |
| **0.0050** | **0.25** | **1.78** | **815,935.34** | |
| 0.0050 | 0.50 | 1.78 | 428,002.62 | |
| 0.0050 | 0.80 | 1.78 | 263,317.85 | |
| 0.0050 | 0.10 | 1.78 | 644,518.94 | |
| 0.0050 | 0.20 | 1.78 | 794,148.08 | |
| 0.0050 | 0.24 | 1.78 | 771,055.25 | 1,026,500.00 |
| 0.0050 | 0.26 | 1.78 | 708,908.58 | |
| 0.0050 | 0.21 | 1.78 | 801,766.62 | |
| 0.0050 | 0.22 | 1.78 | 759,743.79 | |
| 0.0050 | 0.23 | 1.78 | 783,069.49 | |
| 0.0050 | 0.25 | 1.78 | 815,935.34 | |

Obtained from the calibration above the value of "*C*" variable is considered close to the volume value of the sediment the measurement results are C = 0.25

The following is a "*m*" variable calibration table in the Ackers-White method.

TABLE 4. Calibrating "*m*" variable for Ackers-White method

| Variable | | | Sediment Volume ($m^3$) | |
|---|---|---|---|---|
| **A** | **C** | **m** | **HEC-RAS Model** | **Observation** |
| **0.0050** | **0.25** | **1.78** | **815,935.34** | |
| 0.0050 | 0.25 | 1.90 | 519,423.29 | |
| 0.0050 | 0.25 | 2.10 | 230,044.17 | |
| 0.0050 | 0.25 | 1.50 | 535,499.15 | |
| 0.0050 | 0.25 | 1.60 | 680,263.91 | |
| 0.0050 | 0.25 | 1.70 | 760,015.90 | |
| 0.0050 | 0.25 | 1.71 | 788,301.47 | |
| 0.0050 | 0.25 | 1.72 | 793,894.08 | |
| 0.0050 | 0.25 | 1.73 | 796,680.89 | 1,026,500.00 |
| 0.0050 | 0.25 | 1.74 | 803,955.77 | |
| 0.0050 | 0.25 | 1.75 | 752,873.11 | |
| 0.0050 | 0.25 | 1.76 | 776,234.83 | |
| 0.0050 | 0.25 | 1.77 | 767,670.40 | |
| 0.0050 | 0.25 | 1.78 | 815,935.34 | |
| 0.0050 | 0.25 | 1.79 | 717,097.47 | |
| 0.0050 | 0.25 | 1.80 | 689,038.72 | |

Obtained from the calibration above the value of the variable m which is considered close to the value of the sediment volume the measurement result is *m* = 1.78

So the variable values that can be used for further flushing analysis in the Ackers-White method are:

A = 0.005
C = 0.25
m = 1.78

2. Laursen (Copeland) method

In the sediment flushing simulation the Laursen-Copeland method is done by changing the value of $\tau_c^*$. Replacement values are done several times with the first value as the default value. The following are the results of the sediment values generated by changing the value of $\tau_c^*$.



Rizhandi Nugroho Nusantoro, Dian Sisinggih, and Very Dermawan, "Sediment Flushing Simulation and Sediment Distribution in Wlingi Reservoir," *International Research Journal of Advanced Engineering and Science*, Volume 4, Issue 1, pp. 1-9, 2018.

TABLE 5. Calibrating "$\tau_c^*$" variable for Laursen (Copeland) method

| Variable | Sediment Volume ($m^3$) | |
|---|---|---|
| $\tau_c^*$ | HEC-RAS model | Observation |
| 0.03900 | 5,693.38 | |
| 0.50000 | 550.90 | |
| 5.00000 | 166.85 | |
| 0.01000 | 17,317.60 | |
| 0.00100 | 110,233.20 | 1,026,500.00 |
| 0.00010 | 615,181.25 | |
| 0.00001 | 1,569,210.11 | |
| 0.00002 | 1,405,996.81 | |
| 0.00003 | 1,234,996.61 | |
| 0.00004 | 1,061,107.24 | |

In the sediment flushing simulation the Laursen-Copeland method is done by changing the value of $\tau_c^*$. Replacement values are done several times with the first value as the default value. The following is the result of the resulting sediment value. Obtained after changing the value of $\tau_c^*$ by using several different values the results of the sediment can approach the measurement results using the variable $\tau_c^*$ of 0,0004. So that for further flushing simulations this value can be used as an alternative to the selection of sedimentary flushing methods by changing the value of $\tau_c^*$.

3. Meyer Peter Muller method

The value calibration is done by replacing the values $\tau_c^*$, coefficient, and power. The following are the results of the calibration process using the Meyer-Peter Muller method.

TABLE 6. Calibrating $\tau_c^*$ , coefficient, dan power value for Meyer Peter Muller method

| Variable | | | Sediment Volume ($m^3$) | |
|---|---|---|---|---|
| $\tau_c^*$ | coef | power | HEC-RAS model | Observation |
| 0.0470 | 8.00 | 1.5 | 72.85 | |
| 0.0470 | 12.00 | 1.5 | 960.26 | |
| 0.0470 | 4.93 | 1.6 | 371.01 | |
| 0.0010 | 8.00 | 1.5 | 808.70 | |
| 0.0001 | 8.00 | 1.5 | 812.61 | |
| 0.0470 | 10.00 | 1.5 | 809.34 | 1,026,500.00 |
| 0.0470 | 20.00 | 1.5 | 1,556.63 | |
| 0.0470 | 100.00 | 1.5 | 7,123.06 | |
| 0.0470 | 8.00 | 1.1 | 660.01 | |
| 0.0470 | 8.00 | 1.8 | 430.38 | |
| 0.0470 | 8.00 | 2.0 | 331.32 | |

Obtained after changing the value of $\tau_c^*$ with the beginning of the value as the default value, the second value uses the correction value Wong and Parker, and the third value by changing the coefficient value to 12.00, the sediment results do not differ much by using the initial or default values so that it can be concluded for Sediment flushing simulation using the Meyer-Peter Muller method by changing the value of the coefficient variable does not have a far-reaching effect on the results of changes in sediment produced.

4. Wilcock method

For calibration using the Wilcock method the parameter that is replaced is the same as the two methods above, namely using the parameter $\tau_{rm}^*$. The following are the calibration results by replacing the value $\tau_{rm}^*$ .

TABLE 7. Calibrating $\tau_{rm}^*$ value for Wilcock method

| Variable | Sediment Volume ($m^3$) | |
|---|---|---|
| $\tau_{rm}^*$ | HEC-RAS model | Observation |
| 0.0400 | 61.51 | |
| 0.5000 | 20.24 | |
| 0.0100 | 660.01 | 1,026,500.00 |
| 0.0010 | 660.01 | |
| 0.0005 | 660.01 | |

By looking at the sediments produced using the Wilcock method it was found that the sediment values did not significantly affect the value of the variable $\tau_{rm}^*$. So it can be concluded that Wilcock method with the replacement of the value $\tau_{rm}^*$ cannot be used as further analysis.

*Calibration using Root Mean Square Error (RMSE)*

RMSE is an alternative method for evaluating forecasting techniques that are used to measure the accuracy of the results of forecasting a model. RMSE is the average value of the number of squared errors, it can also state the size of the error produced by a forecast model. A low RMSE value indicates that the variation in value produced by a forecast model is close to the variation in the value of his observations.

By using the A variable parameter in the Ackers-White method which was the previous calibration process, here is an example of calculating the RMSE Ackers-White method using parameter A 0.005.

Column [1] explain the number of cross section in River Brantas CRB 19 up to CRB 140, column [2] up to [5] is the calculation of the RMSE. The result of the RMSE calculation for Ackers-White method with A value of 0.005 is 2.3022.

TABLE 8. Calculation RMSE for Ackers-White method with "*A*" value of 0.005

| No. | Elevation of Riverbed (m) | | | $(X_{obs} - X_{mod})^2$ |
|---|---|---|---|---|
| | Before Flushing | After Flushing HEC-RAS Model | After Flushing Observation | |
| [1] | [2] | [3] | [4] | [5] |
| 1 | 160,953 | 160,953 | 159,687 | 1.603 |
| 2 | 160,953 | 160,999 | 159,687 | 1.722 |
| 3 | 160,994 | 160,990 | 160,196 | 0.630 |
| … | | | | |
| 67 | 159,721 | 158,807 | 154,075 | 22.397 |
| 68 | 159,721 | 159,722 | 154,075 | 31.885 |
| | | | **RMSE =** | **2.3022** |

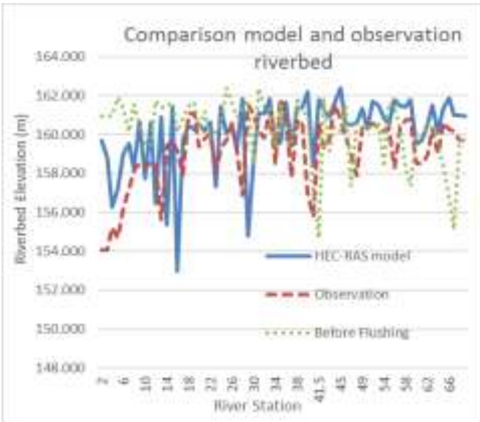


Fig. 5. Comparison between model and observation riverbed using RMSE

After several calibration processes have been carried out so that the value is closest to zero, then the following is the result of recapitulating the RMSE value with various values of "*A*" variable.

TABLE 9. Recapitulation of RMSE calculation for Ackers-White method

| Variable | | | RMSE |
|---|---|---|---|
| A | C | m | |
| 0.1900 | 0.25 | 1.78 | 2.1111 |
| 0.0005 | 0.25 | 1.78 | 2.9948 |
| **0.0500** | **0.25** | **1.78** | **2.0935** |
| 0.0100 | 0.25 | 1.78 | 2.1938 |
| 0.0080 | 0.25 | 1.78 | 2.2387 |
| 0.0050 | 0.25 | 1.78 | 2.3022 |
| 0.0048 | 0.25 | 1.78 | 2.3402 |
| 0.0030 | 0.25 | 1.78 | 2.2750 |
| 0.0025 | 0.25 | 1.78 | 2.2498 |

TABLE 10. Recapitulation of RMSE for Laursen-Copeland method

| Variable $\tau_c^*$ | RMSE |
|---|---|
| 0.039 | 2.1083 |
| 0.5 | 2.112979 |
| 5 | 2.113585 |
| 0.01 | 2.101796 |
| 0.001 | 2.083686 |
| 0.0001 | 2.101919 |
| 0.00001 | 2.20905 |
| 0.00002 | 2.213488 |
| 0.00003 | 2.185398 |
| 0.00004 | 2.159426 |

TABLE 11. Recapitulation of RMSE for Meyer Peter Muller method

| No. | Variable | | | RMSE |
|---|---|---|---|---|
| | $\tau_c^*$ | coefficient | power | |
| 1 | 0.047 | 8 | 1.5 | 2.113299 |
| 2 | 0.047 | 12 | 1.5 | 2.113146 |
| 3 | 0.047 | 4.93 | 1.6 | 2.113434 |
| 4 | 0.001 | 8 | 1.5 | 2.113285 |
| 5 | 0.0001 | 8 | 1.5 | 2.113283 |
| 6 | 0.047 | 10 | 1.5 | 2.113210 |
| 7 | 0.047 | 20 | 1.5 | 2.112833 |
| 8 | 0.047 | 100 | 1.5 | 2.109984 |
| 9 | 0.047 | 8 | 1.1 | 2.113137 |
| 10 | 0.047 | 8 | 1.8 | 2.113380 |
| 11 | 0.047 | 8 | 2 | 2.113431 |

TABLE 1. Recapitulation of calculation using RMSE for Wilcock method

| Variabel $\tau_{rm}^*$ | RMSE |
|---|---|
| 0.04 | 2.113602 |
| 0.5 | 2.113588 |
| 0.01 | 2.113608 |
| 0.001 | 2.113617 |
| 0.0005 | 2.113618 |

From the four methods that were passed in the calibration process, the decision making for the method to be used in this study was using the Laursen-Copeland method with the reasons for the Meyer Peter Muler and Wilcock method the sediment volume generated from the HEC-RAS model was far from the volume of the sediment measure-ment. So there are two methods whose results are close to the measurement results, namely the Ackers-White and Laursen-Copeland methods. Comparison of the RMSE value with the calculation of the Ackers-White and Laursen-Copeland method ie 2.30 for the Ackers-White method and 2.16 for the Laursen-Copeland method and the sediment values generated from the Ackers-White method at 815,935 $m^3$ and the Laursen-Copeland method as big as 1,061,107 $m^3$. So that the Laursen-Copeland method is closer to measuring conditions in the field.

*Analysis of Flushing Scenarios*

Scenarios are carried out with 2 alternatives, namely by increasing the inflow with 6 different values for each alternative, namely the existing inflow plus 10 to 30 percent of the existing inflow and the existing Inflow minus 10 to 30 percent of the existing value.

After the flushing scenario process is carried out with scenarios A and B. The following are the results of the alternative scenario B which is the most effective in terms of the amount of sediment being flushed at 1,372,291 $m^3$.

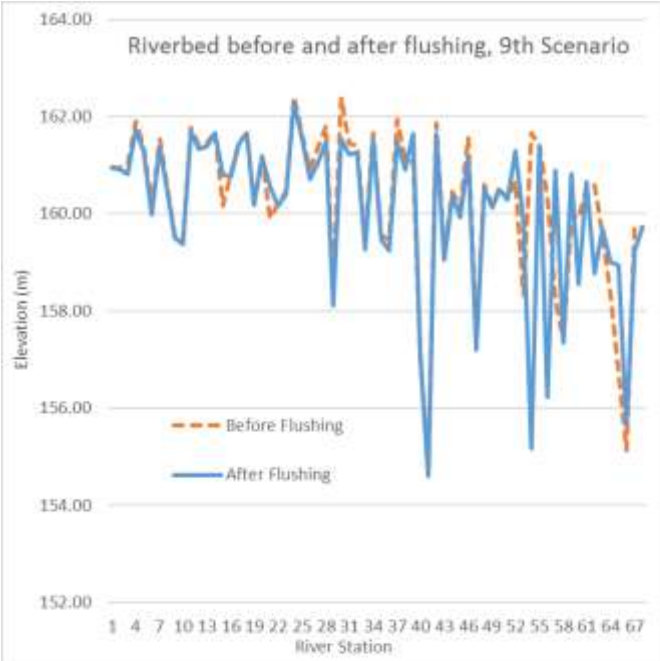


Fig. 6. Riverbed before and after sediment flushing in 9th scenario


Fig. 7. Map of scouring and accumulation in 9th scenario

The figure above is a mapping of the scour and accumulation distribution in Brantas River from CRB 19 to CRB 140 in units of volume ($m^3$).

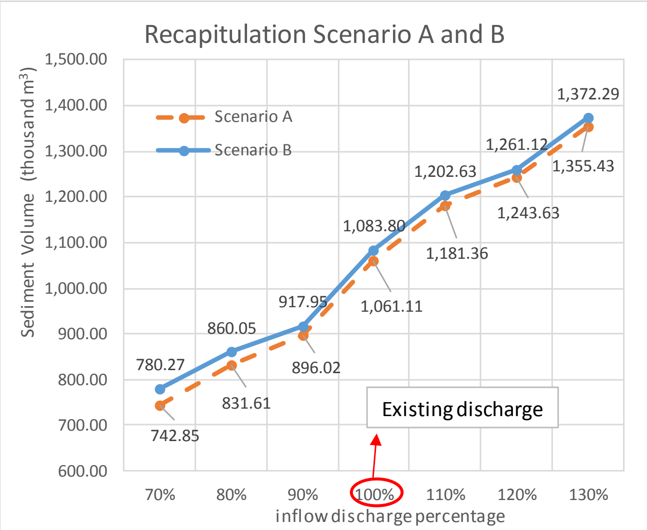


Fig. 8. Recapitulation sediment volume from scenario A and B

From the above scenario process it can be concluded that the sediment flushing simulation uses HEC-RAS by increasing and decreasing the value of the inflow discharge by using a percentage that can positively affect the change in sediment produced. This is evidenced by increasing the value of the existing inflow by adding 30% of the existing inflow value. However, to produce a larger amount of sediment from flushing conditions that have been carried out by Perum Jasa Tirta I, further studies are needed regarding the inflow that enters the Wlingi Reservoir because the inflow discharge entering the Wlingi Reservoir is closely related to the amount of outflow issued by Sutami Reservoir and Inflow discharge values that enter through the Wlingi Reservoir tributaries so that flushing in the Wlingi Reservoir cannot immediately simply add the Inflow that enters the Wlingi Reservoir to produce the amount of sediment to be flushed. Some of the factors that can affect the amount of sediment that is flushed are grains of sediment, determination of bank points on HEC-RAS, and others.

*Verification of Model Results with Measurement*

From the scenario process after the most efficient results are obtained, a comparison of the results from the model scenario is done with the results of the measurements. The following is the cross section produced from the CRB 130 section.

The graph below is the result of one cross section. Can be seen in the graph above that there are still differences found in the cross section of the results of measurements after flushing with the results of the HEC-RAS model. Therefore the results obtained from HEC-RAS cannot be said to be 100% correct.

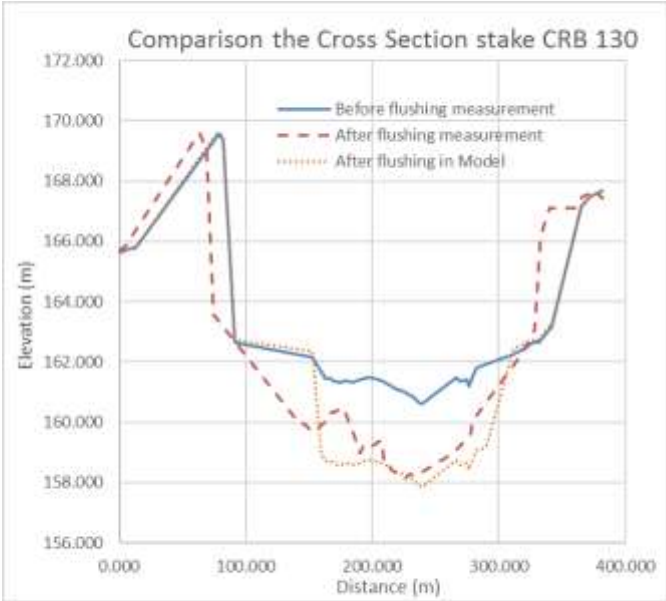


Fig. 9. Comparison the cross section stake CRB 130

*Analysis of Flushing Efficiency*

The difference between the volume of reservoir reservoir capacity after flushing with the volume of reservoir reservoir capacity before flushing can be interpreted as the volume of eroded sediment, and because the sediment flushing in the Wlingi Reservoir is carried out with full drawdown method which means the flushing door is assumed to be fully open, then the volume of water outflow can be equated as the volume of water inflow.

The following is an example for calculating the inflow value taken from 2016 Inflow flushing discharge data which has been changed to a volume unit.

TABLE 12. Calculation of water volume on existing inflow discharge

| Date | Time | Discharge ($m^3/s$) | Water Volume ($m^3$) |
|---|---|---|---|
| March 24th | 23:00 | 199.20 | 717,120.00 |
| March 25th | 00:00 | 201.00 | 723,600.00 |
| | 01:00 | 181.52 | 653,472.00 |
| … | | | |
| March 26th | 00:00 | 243.22 | 875,584.08 |
| | 01:00 | 187.37 | 674,528.04 |
| … | | | |
| March 27th | 00:00 | 184.53 | 664,315.92 |
| **Total Water Volume** | | | **31,851,695.88** |

By taking the volume value of the sediment that flushed in 4th scenario using the Laursen (Copeland) method, the volume value of the flushed sediment was 1,061,107 $m^3$. So if the value is entered into the equation (3) it will produce:

$$E = \frac{1,061,107}{31.851.696}$$

$$E = 0.0333$$

$$E = 3.3314\ \%$$

So the efficiency value obtained by using the value of the amount of sediment calibrated with the total volume of water obtained from the 2016 flushing discharge data is 3.3314%.

For the efficiency value of several alternative processes of the Inflow scenario, the following is the recapitulation of efficiency in each scenario.

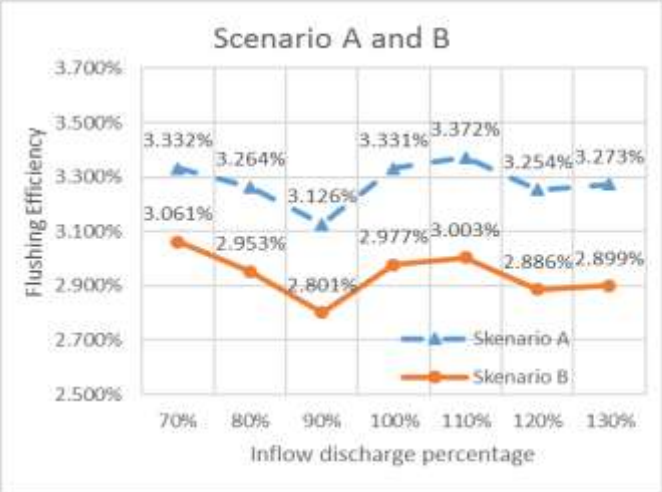


Fig. 10. Recapitulation of flushing efficiency

It can be concluded from the graph above which illustrates that by increasing the inflow based on percentage, will result in a decrease in the efficiency of reservoir flushing. This is because increasing the inflow will increases the total volume of water used for flushing sediments, while the volume of sediment produced by increasing the inflow discharge always has a positive effect on increasing the amount of sediment volume.

If the efficiency value is plotted into the efficiency value graph in the journal entitled Evaluation of Efficiency of Sediment Reservoir Flushing in Kurobe River by Prof. Tetsuya Sumi from Kyoto University, the results obtained are as follows.

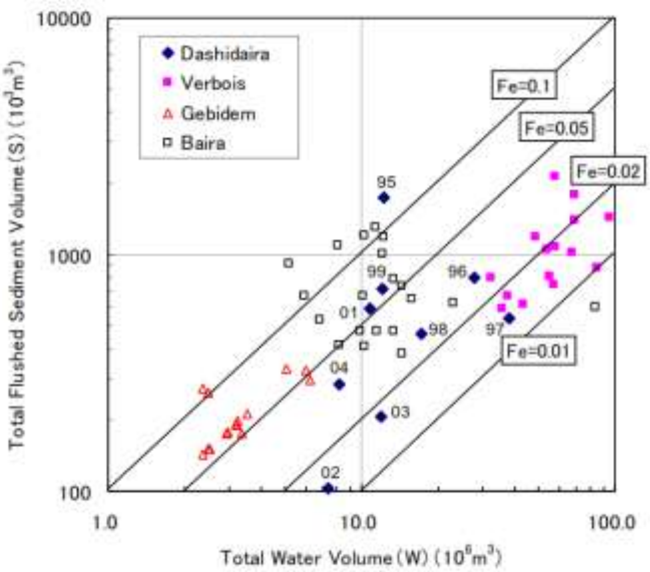


Fig. 11. The efficiency value of sediment flushing from various countries

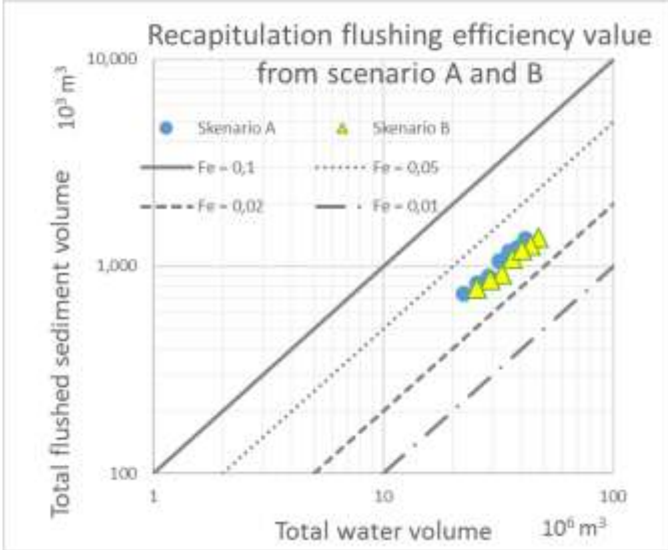


Fig. 12.Plotting flushing efficiency value from scenario A and B

From the plotting graph above, it can be concluded that the value of flushing efficiency (Fe) in several alternative scenarios results in varying values with an average efficiency value of 3% due to differences in the amount of sediment produced by each flushing scenario. If the results of the calculations in this study are compared with the results obtained from several distributions of efficiency values from several countries, the efficiency values in this study are still acceptable because the efficiency values produced are still in the range of 0.01 (1%) to 0.05 (5 %).

*Selecting of Scenarios*

It can be concluded from the two scenarios of flushing the reservoir above by increase and decreasing the reservoir inflow in scenario A and B which is the highest volume of sediment eroded in scenario A of 1.355.432 $m^3$ in alternative scenario number 2 with increase the discharge value by 30% from the existing inflow, while the highest amount of sediment eroded in scenario B is 1,372,291 $m^3$ which is found in alternative scenario number 9 by increasing the discharge value by 30% from the inflow value of 56 hours. However, if viewed from the sediment flushing efficiency parameter in scenario A has the highest efficiency value of 3.37% in alternative scenario number 4 by increasing the inflow value by 10% from the existing value, while in scenario B has the highest efficiency value of 3.06 % in alternative scenario number 14 by reducing the discharge value by 30% from the inflow value of 56 hours operation. So with these differences, the selection of the selected scenario is using scenario A, namely by using a flushing inflow value for 49 hours operation by increasing the inflow value by 10% against the existing value, arguing that the efficiency value of scenario A is greater than scenario B, and consideration of the difference in the value of the volume of sediment being flushed that is not too significant between scenarios A and B.

Whereas for sediment distribution maps, the results showed that the highest scour value was 103,272 $m^3$ which occurred on section 62 which was simulated in alternative scenario A using the inflow value which was increased by 30% from the existing inflow. While the highest deposition value of 8,558 $m^3$ that occurred on section 66 which was simulated in alternative scenario B used an inflow discharge value which was reduced by 10% from the 56 hours inflow. The location of the maximum scouring is located on CRB 117 up to CRB 130 or around 700 to 1,300 m from the Wlingi Dam.

After selecting the most effective alternative scenario, mapping the distribution of sediment thickness is done by reducing the results of mapping in HEC-RAS with contour data before the sedimentation is carried out by Perum Jasa Tirta I. Then the following are the results of sediment height mapping using data the results of the most effective alternative scenarios.

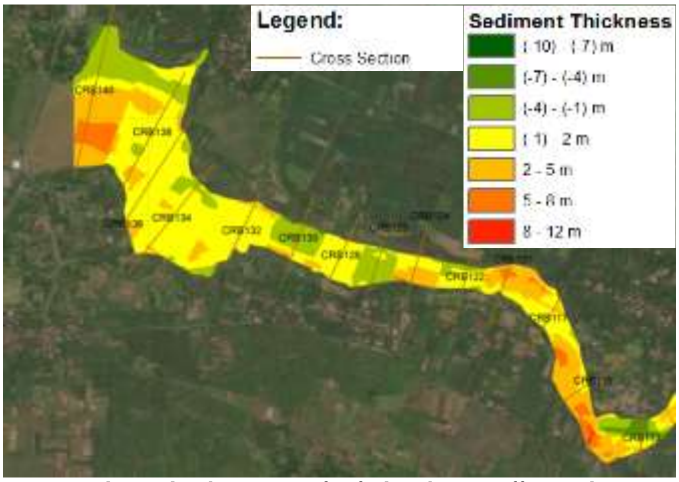


Fig. 13. Sediment distribution map after finding the most effective alternative scenario

## IV. CONCLUSION

The conclusions that can be drawn from this study are as follows:

1. The analysis of sediment distribution that occurred in the Wlingi Reservoir before sediment removal was carried out based on the contour map of the results of the measurement of Perum Jasa Tirta I in 2015 and 2016 was that the value of sediment thickness varied from 5.79 m to -6.7 m. This indicates that there is grinding and hoarding that occurs during the period of time the contour map is measured. The highest hoarding value is located between the CRB 132 and CRB 134 section on the left side of the cross section, this is because this section is a part of the river that is easily deposited because it is located in the bend of the river that juts into. While the highest value for scouring is located between the CRB 130 and CRB 132 section, this occurs because the part in this part of the river flow turns to adjust the flow of the river so that there is grinding.
2. The analysis of the distribution of sediments after sediment flushing was carried out in 2016 found that the scouring and deposition values compared to the map before sediment flushing showed higher numbers of embankments and scour, this indicates the movement of sediments moving from one point to the point others that can result in the point where the initial grinding occurs will become a backfill or vice versa due to the river inflow rate. The value of scouring and deposition occurs between the ranges of values of 11.23 m to -9.12 m. The highest value of hoarding is located on the CRB 138 section on the right side of the cross section, this occurs because of the position in the cross section that protrudes in so that the flow velocity that occurs at this point is small which results in this part being easily deposited. The highest value of grinding is in the downstream area around the flushing door, this is because the highest current velocity value occurs along the river current leading to the flushing door.
3. After analyzing the flushing scenario with 14 alternative scenarios, the results chosen which are considered to be the most efficient scenario are based on the greatest efficiency value, namely by using an alternative flushing inflow discharge for 49 hours by increasing the discharge value by 10% of the existing inflow. The results obtained were the volume of flushed sediment of 1,181,358 $m^3$ with a flushing efficiency of 3.37%. This value if associated with previous research that occurred in dams in several countries, namely Dashidaira Dam (Japan), Verbois Dam (Switzer-land), Gebidem Dam (Switzerland), and Baira Dam (India), efficiency value for this flushing alternative still in the range of efficiency values of 1% to 10% so that the efficiency value can still be said to be successful.
4. After obtaining the most efficient flushing alternative, the analysis results of the sediment distribution that occurred in the Wlingi Reservoir starting from CRB 19 to CRB 140 obtained the results that the stockpile that occurred was started from CRB 19 to CRB 107, then crushing was started from CRB 109 to CRB 138 with the maximum position of scouring is located in CRB 117 with scour value of 103,272 $m^3$. In detail, the sediment distribution map produced using measurement data compared to using the application is different, the distinguishing factor is that in the measurement data there are stakes that occur sedimentation that has gone through the dredging process using equipment when flushing was carried out. Whereas in the HEC-RAS simulation, flushing is carried out only by relying on river inflow only to move sediment grains.

## REFERENCES

[1] S. Anders Brandt, "A review of reservoir desiltation," *International Journal of Sediment Research*, vol. 15, issue 3, pp. 321-342, 2000.
[2] Anonim, "HEC-RAS River analysis system user's manual," U.S. Army Corps of Engineers, Institute for Water Resources. Hydrologic Engineering Center, California, 2010.
[3] Anonim, "HEC-RAS River analysis system hydraulic reference manual," U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, California, 2010.
[4] Anonim, "The Brantas River rehabilitation project, supporting report I, evolution of River dredging works in Wlingi and proposed further dredging plan for Wlingi and Lodoyo reservoirs," Perum Jasa Tirta I, 2015.
[5] Basson, "Sedimentation and sustainable use of reservoir and river systems," Draft ICOLD Bulletin, 2008.

[6] T. Chai and R. R. Draxler, "Root mean square error (RMSE) or mean square error (MAE) –Arguments against avoiding RMSE in the literature," *Geosci. Model Dev*., vol. 7, issue 3, pp. 1247–1250, 2014.

[7] Sumi Tetsuya, "Evaluation of efficiency of reservoir sediment flushing in Kurobe River," *Fourth International Conference on Scour and Erosion*, 2008.