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The Analysis of Song Putri Reservoir Storage Area on Sedimentation Rate Using Mathematical Model Approach

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Abstrak

Waduk Song Putri adalah sebuah waduk buatan dengan tujuan untuk saluran irigasi persawahan dan pengendalian banjir, waduk ini terletak di Kecamatan Eromoko Kab. Wonogiri. Pemodelan sedimentasi pada tampungan Waduk Song Putri diperlukan untuk menganalisa besarnya endapan sedimen terhadap tampungan Waduk Song Putri. Untuk menganalisa pola aliran dan distribusi sedimen yang terjadi pada tampungan waduk digunakan Software SMS (Surface-water Modelling System) 8.0. Penelitian ini bertujuan untuk mengetahui pola aliran dan pengaruh distribusi sedimen terhadap perubahan tampungan waduk. Data-data yang digunakan antara lain : data teknis Waduk Song Putri, data curah hujan harian selama 10 tahun (2009-2018), data sedimen, data inflow waduk, dan peta batimetri. Untuk menganalisa besarnya inflow dan outflow Waduk Song Putri digunakan analisis hidrologi dengan metode empiris, sedangkan simulasi pemodelan sedimentasi menggunakan Software SMS 8.0. Berdasarkan hasil simulasi kecepatan aliran tertinggi pada periode ulang 50 tahun sebesar 0,097 m/s dan terkecil sebesar 0,00 m/s. Berdasarkan hasil simulasi perubahan dasar tampungan waduk selama 720 jam (1 bulan) didapatkan nilai pada periode ulang 50 tahun, 100 tahun serta 1000 tahun tertinggi sebesar 5,795 m dan terkecil sebesar 0,001 m, berdasarkan perhitungan prediksi tingkat pertumbuhan sedimen didapatkan hasil tingkat pertumbuhan sedimen dengan persentase untuk periode ulang 50 tahun sebesar 35,68% dengan range persentase antara 19% - 21% dan persentase sebesar 29,103% untuk periode ulang 100 tahun dengan range persentase antara 22% - 24%, sedangkan persentase tingkat pertumbuhan sedimen periode ulang 1000 tahun sebesar 98,20% dengan range persentase antara 55% - 57%.

Kata Kunci : simulasi, Waduk Song Putri, sedimentasi

Abstract

Song Putri Reservoir is an artificial reservoir with the aim of irrigation channels for rice fields and flood control. This reservoir is located in Eromoko District, Wonogiri Regency Sedimentation modeling in the Song Putri reservoir is needed to analyze the amount of sediment deposition against the Song Putri Reservoir. To analyze the flow patterns and sediment distribution that occurs in reservoirs, SMS (Surface-water Modeling System) 8.0 Softwarse is used. This study aims to determine the flow patterns and effects of sediment distribution on reservoir changes. The data used include Song Putri Reservoir technical data, daily rainfall data for 10 years (2009-2018), sediment data, reservoir inflow data, and bathymetry maps. To analyze the magnitude of inflow and outflow of Song Putri Reservoir, hydrological analysis using empirical methods is used, while sedimentation modeling simulation uses SMS 8.0. Software based on the simulation, result the highest flow velocity in the 50 year return period is 0.097 m / s and the smallest is 0.00 m / s. Based on the simulation results of changes in the reservoirs base for 720 hours (1 month), the values that in the return period of 50 years, 100 years and the highest 1000 years the highest was 5.795 m and the smallest of 0.001 m. Based on the calculation of prediction of sediment growth rates, it obtained the results of sediment growth rates with a percentage for a 50 year return period of 35.68% with a range of percentages between 19% - 21% and a percentage of 29.103% for a 100 year return period with a range of percentages between 22% - 24%, while the percentage growth rate of 1000 year return period sediments is 98 , 20% with a percentage range between 55% - 57%.

***Keywords**: Simulation, Song Putri Reservoir, sedimentation*

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Background

Reservoir is a place on the surface of the ground that is intended to store / hold water when there is excess water / rainy season, then the abundant water is used for irrigation, flood control, drinking water needs and as embankments to collect runoff water from rivers to reservoirs. Song Putri Reservoir is an artificial reservoir with the aim of irrigation channels for rice fields and flood control, this reservoir is located in Eromoko District, Wonogiri Regancy Song Putri Reservoir has a topographic shape with non-uniform elevation. The non-uniform shape of the Song Putri Reservoir creates a flow pattern that results in the uneven distribution of flow velocity and sediment distribution in reservoirs. This is very influential to changes in reservoir base configuration. Sedimentation that occurs in the Song Putri Reservoir can cause a reduction in the reservoir life span efficiency.

Sedimentation that occurs must be noticed. Particular methods are needed to determine the distribution of flow velocity and sediment distribution in the Song Putri Reservoir, so that the reservoir life control age is efficient. To find out the flow pattern and distribution of flow velocity, as well as the distribution of sediment that enters the Song Putri Reservoir, we need a way to estimate this is needed with the help of computer software. One software that can help in this research is SMS (Surface water Modeling System). This program can be used for the process of simulation of flow patterns and flow velocity distribution using RMA-2 and simulation of sediment distribution using SED2D (Anonymous, 2003).

Rainfall is the amount of water that falls on a flat surface during a certain period measured in millimeters (mm) height above the horizontal surface. Rain can also be interpreted as the height of rainwater collected in a flat, non-evaporating, non-absorbing, and non-flowing place (Suroso 2006). To determine the type of method to be used in rainfall calculations, statistical parameter analysis is performed. There are several methods for calculating the amount of rainfall design. In this study analysis of rainfall design will be carried out using the following methods:

1) Gumbel Type I distribution method,
2) Normal distribution method,
3) Normal distribution method,
4) Pearson Log Type III distribution method.

Table 1 Statistical Parameters for Determining Distribution Types (Triatmodjo, 2008)

No	Distribution	Requirements
1	Normal	Cs ≅ 0,0 Ck ≅ 3,0
2	Normal Log	$Cs = Cv^3 + 3\ Cv$ $Ck = Cv^8 + 6\ Cv^6 + 15\ Cv^4 + 16\ Cv^2 + 3$
3	Gumbel Type I	Cs ≅ 1,14 Ck ≅ 5,4
4	Log Person III	If it does not indicate the nature of the three distributions above

This rainfall intensity calculation uses the Dr. method. Mononobe which is a variation of short-term rainfall equations, the equation is as follows (Soemarto, 1999):

$$I = \frac{R_{24}}{24}\left[\frac{24}{t}\right]^{\frac{2}{3}} \quad (1)$$

I : rainfall intensity (mm / hour)

R24 : maximum rainfall in 24 hours (mm)

T : duration of rainfall (minutes) or (hours)

Flow discharge is the rate of flow of water (in the form of volume of water) that passes through a cross section of the river per unit time (Asdak, 2002). The discharge unit used cubic meters per second (m3 / s). The most frequently used method for estimating discharges in a watershed where there are no observational data for discharge is the Rational Method. In this case the magnitude of the discharge is a function of the area of the watershed, the intensity of rainfall, the state of land clearing which is expressed in the runoff and slope coefficients (Loebis, 1992). The flood discharge is generic as follows:

$$Q = C.\ I\ .\ A \quad (2)$$

For the sake of practicality in determining the unit, then:

$$Qp = 0.278\ .\ C\ .\ I\ .\ A \quad (3)$$

Where :

Qp : Peak Discharge (m^3 / sec)

C : Flow coefficient

I : Rain intensity with duration equal to flood concentration time (mm / hour)

A : Watershed area (km^2)

The other debit formulas are:

Der Weduwen method used to calculate the maximum discharge in the Jakarta drainage area is formulated as follows: (Kamiana, 2011) :

$$Qmax = \alpha \times \beta \times I \times A \quad (4)$$

Where :

Qmax = maximum discharge (m^3 /sec)

α = flow coefficient

β = reduction coefficient

I = rain intensity (m^3 /sec/km^2)

A = area of watershed (km^2)

The Haspers method used to calculate the maximum discharge is formulated as follows:

$$Qmax = \alpha \times \beta \times I \times A \quad (5)$$

Where :

Qmax = maximum discharge (m^3 /sec)

α = flow coefficient

β = reduction coefficient

I = rain intensity (m^3 /sec/km^2)

A = area of watershed (km^2)

HSS Nakayasu Nakayasu method used to calculate flood peak discharge is formulated as follows :

$$\mathrm{Qp} = \frac{\mathrm{A \times R0}}{3{,}6\ x\ (0{,}3Tp + T0{,}3)} \quad (6)$$

Where :

Qp = flood peak discharge (m^3 /sec)

A = wide catchment area (km^2)

R0 = unit rain (mm)

Tp = grace period from the beginning of the flood to the peak of the flood (hours)

T0,3 = time required by a decrease in discharge, from peak discharge to 30% of peak discharge (hours).

Research Methodology

The data of the study include Song Putri reservoir technical data, daily rainfall data for 10 years (2009-2018), sediment data, reservoir inflow data, and bathymetry map obtained from BBWS Bengawan Solo. To get good and direct results, a flowchart is made of the plan and the work steps carried out, as shown in the Figure 1.

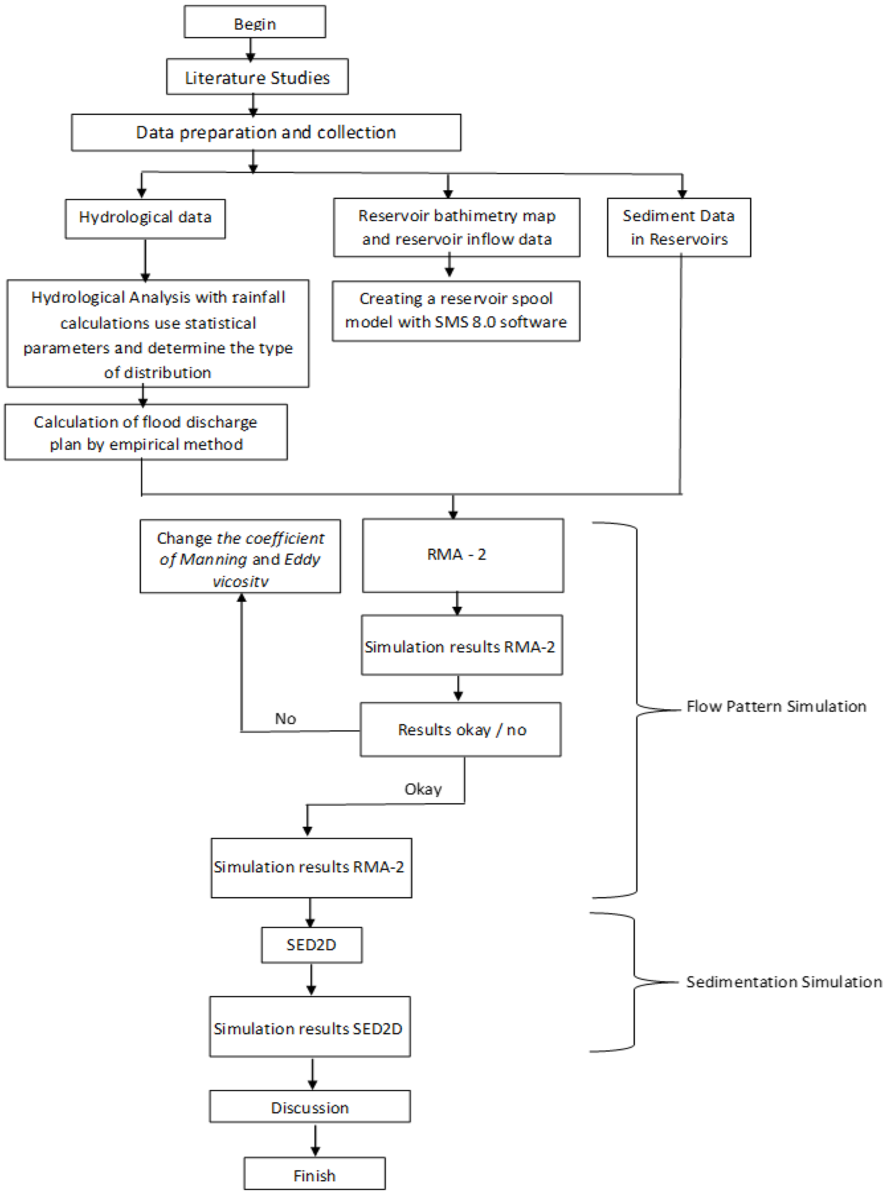

Figure 1 Flow Chart

The steps for data processing in general are as follows:

1) Hydrological analysis using empirical methods. The following processing flow:
   a. Hydrological analysis uses maximum daily rainfall data for 10 years (2009-2018).
   b. Analysis of rainfall data using the Normal Distribution Method, Normal Log Distribution, Gumbel Distribution, and Pearson Log type III Distribution
   c. Test the suitability of frequency distribution with Chi-squared and Kolmogorov Smirnov Test.
   d. The empirical method of calculating the flood discharge plan used is the Rational, Der Weduwen, Haspers and Nakayasu Synthetic Hydrographs. Reschedule flood plans in 5, 10, 25, 50, 100, and 1000 years

e. Modeling of the Song Putri reservoir uses a planned flood discharge in the return period of 50 years, 100 years, and 1000 years.

2) Surface-water modeling system 8.0 is done using 3 steps, among others as follows: Geometric modeling, The process of simulating flow patterns and flow velocity distribution with RMA-2 and simulation of sediment distribution with SED2D.

Research Result

Rainfall analysis using Arithmetic/Algebra Method. In this study there are three rain gauge stations which are considered relevant to represent rain observations in the study area (Song Putri Rain Station, Nawangan Rain Station and Parangjoho Rain Station).

Table 2 Calculation of Maximum Daily Average Rainfall by Arithmetic Method

No	Year	HIGHEST RAINFALL			
		Sta. Song Putri (mm)	Sta. Nawangan (mm)	Sta. Parangjoho (mm)	Rh Plan
1	2009	104,00	83,00	73,00	85,67
2	2010	171,00	121,00	84,00	125,33
3	2011	103,00	97,00	75,00	91,67
4	2012	91,00	112,00	79,00	94,00
5	2013	33,00	97,00	51,00	60,33
6	2014	48,00	98,00	43,00	63,00
7	2015	47,00	105,00	49,00	67,00
8	2016	67,00	114,50	63,00	81,50
9	2017	80,00	351,90	166,00	199,30
10	2018	87,50	94,00	62,00	81,17

<u>Distribution Method</u>

Frequency distribution analysis is intended to obtain the amount of rainfall that is determined based on certain design benchmarks. For the purposes of the analysis set with return periods of 5, 10, 25, 50, 100, and 1000 years, as shown in the Table 3.

Table 3. Recapitulation of XT Value in Each Distribution Method

Types Of Distribution	Return Period	Value XT
NORMAL	5	129.589
	10	147.710
	25	170.771
	50	179.420
	100	190.951
	1000	222.249
NORMAL LOG	5	123.495
	10	148.298
	25	186.462
	50	204.602
	100	226.783
	1000	264.996

GUMBEL TYPE I	5	134.827
	10	165.102
	25	203.366
	50	231.749
	100	259.922
	1000	353.491
LOG PEARSON TYPE III	5	119.920
	10	141.040
	25	168.078
	50	188.478
	100	209.185
	1000	281.539

Rainfall Intensity Graph

This rainfall intensity calculation uses the dr. method. Mononobe which is a variation of short-term rainfall equations, the equation is as follows (Soemarto, 1999):

$$I = \frac{R_{24}}{24}\left[\frac{24}{t}\right]^{\frac{2}{3}} \quad (4)$$

Below is a graph of the intensity of rainfall in the Alang watershed.

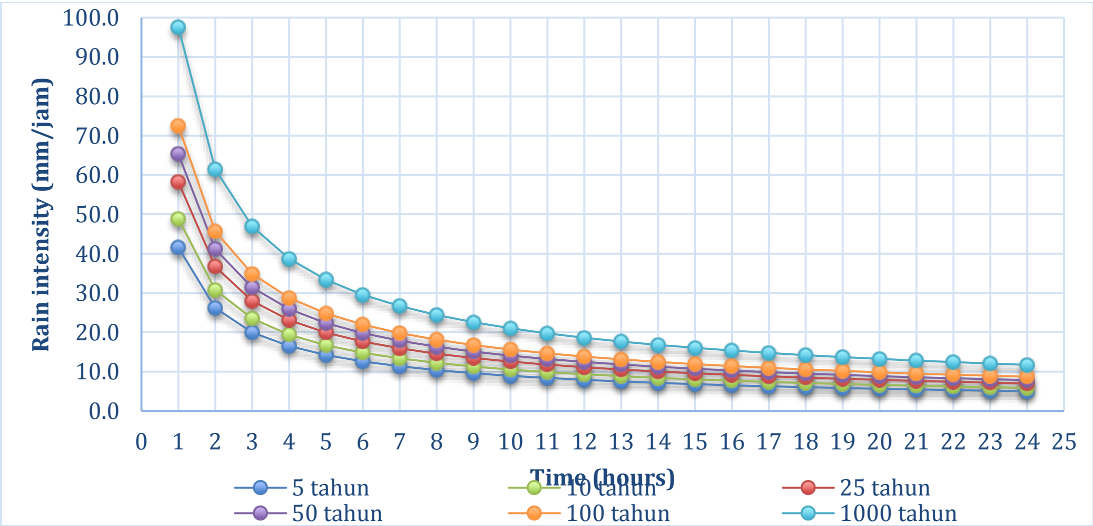

Figure 2 Rainfall Intensity Graph

Flow Search

In the flow tracking method which is carried out using the reservoir tracking method, a volume of runoff will be obtained from the reduction in the value of the inflow and the outflow of water as the result of data processing by the Nakayasu HSS. The overflow of water Is water volume units which can later be used as design plan for storage wolume of polder ponds (storage) to be used.

Recapitulation of Flood Discharge Calculation Results, as show in Table 4.

Table 4 Recapitulation of Flood Discharge Calculation Results

No	Period	Method			
		Rasional	Weduwen	Haspers	Nakayusu
1	Q5	34.053	62.159	58.108	63.44
2	Q10	40.051	73.106	68.342	74.62
3	Q25	47.729	87.121	81.444	88.92
4	Q50	53.521	97.695	91.328	99.72
5	Q100	59.401	108.428	101.362	110.67
6	Q1000	79.948	145.932	136.422	148.95

Table 5 Flow Tracking Using 50 year Inflow Outflow Discharge

t (hour)	***Inflow* (m3/dt)**	***Outflow* (m3/dt)**
0	0.000	0.000
1	5.500	1.100
2	29.029	10.206
3	27.011	28.625
4	17.536	25.116
5	11.385	16.306
6	8.515	10.811
7	6.385	8.089
8	4.787	6.065
9	3.589	4.547
10	2.691	3.409
11	2.018	2.556
12	1.513	1.917
13	1.134	1.437
14	0.850	1.077
15	0.638	0.808
16	0.478	0.606
17	0.358	0.454
18	0.269	0.340
19	0.201	0.255
20	0.151	0.191
21	0.113	0.143
22	0.085	0.108
23	0.064	0.081
24	0.048	0.060

Table 6 Flow Tracking Using 100 year Inflow Outflow Discharge

t (hour)	***Inflow* (m3/dt)**	***Outflow* (m3/dt)**
0	0.000	0.000
1	6.104	1.221
2	32.218	11.327
3	29.979	31.770
4	19.463	27.876
5	12.635	18.097
6	9.451	11.998
7	7.086	8.978

8	5.313	6.731
9	3.983	5.047
10	2.987	3.784
11	2.239	2.837
12	1.679	2.127
13	1.259	1.595
14	0.944	1.196
15	0.708	0.897
16	0.531	0.672
17	0.398	0.504
18	0.298	0.378
19	0.224	0.283
20	0.168	0.212
21	0.126	0.159
22	0.094	0.119
23	0.071	0.090
24	0.053	0.067

Table 7 Flow Tracking Using Inflow Outflow Discharge 1000 Years Period

t (hour)	***Inflow*** **(m3/dt)**	***Outflow*** **(m3/dt)**
0	0.000	0.000
1	8.215	1.643
2	43.361	15.245
3	40.348	42.759
4	26.194	37.517
5	17.006	24.357
6	12.720	16.149
7	9.537	12.083
8	7.150	9.060
9	5.361	6.793
10	4.020	5.093
11	3.014	3.818
12	2.260	2.863
13	1.694	2.146
14	1.270	1.609
15	0.952	1.207
16	0.714	0.905
17	0.535	0.678
18	0.401	0.509
19	0.301	0.381
20	0.226	0.286
21	0.169	0.214
22	0.127	0.161
23	0.095	0.120
24	0.071	0.090

Based on the results of the analysis of the flow tracking that has been done, it can be shown the flow of incoming water (Inflow) and the outflow of water (outflow) that occurs so that it can be described in graphical form as this Figure 3.

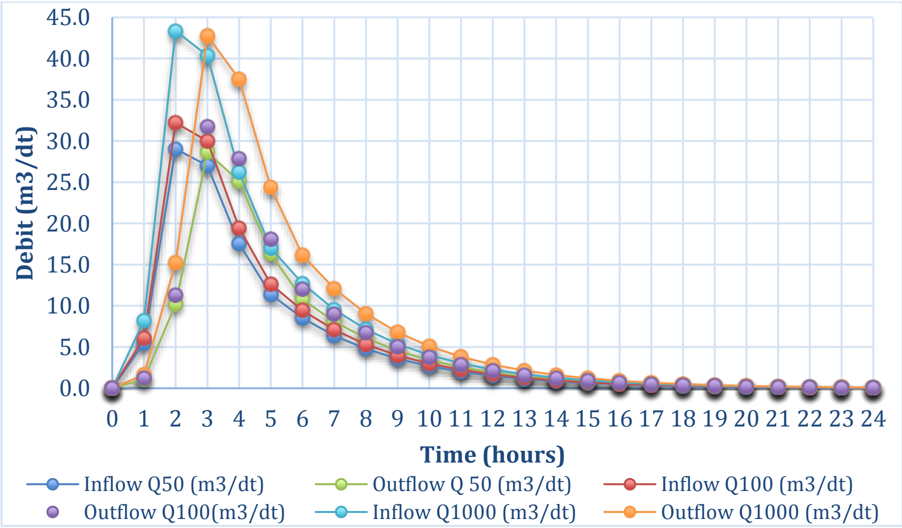

Figure 3 Q50, Q100 and Q1000 Inflow Outflow Graphs

Results of Modeling Flow and Sedimentation

Geometric modeling is the basis for modeling, before modeling with RMA2 and SED2D. Geometric modeling is based on bathymetry data that has been obtained and modified in the form of dxf files. Modeling flow patterns using the RMA2 module as the simulation. Flow pattern simulation will be modeled as many as 3 models, It is uses the results of calculations Inflow and reservoir outflow in the return period of 50 years, 100 years, and 1000 years. In the flow pattern simulation (RMA2) the results are reviewed by analyzing the flow pattern characteristics and the value of the horizontal flow velocity distribution at the point of review. Analysis of flow pattern characteristics in each review period can be displayed 3 review points. Location of Point of Review, as show in Figure 4.

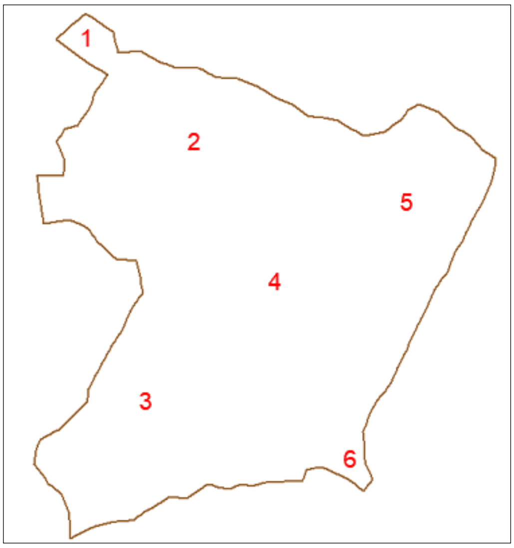

Figure 4. Location of Point of Review

From the results of the simulation of flow patterns in the form of vectors, it can be seen the characteristics of flow patterns at points A, B, and C at each return period by obtaining the same flow pattern characteristics. In condition A, the flow of water entering the reservoir is not similar because the flow velocity changes with distance due to changes in appearance from small to large. Hence the flow direction spread to fill every part of the reservoir. In condition B, the water flow is trapped on one side of the reservoir so that the direction of flow tends to spin. These conditions can be caused by differences in the viscosity of the water so that there is a change in speed that causes the water to move irregularly to form a vortex. And in condition C, the water flow is not uniform because the flow velocity changes with distance due to containment in the reservoir downstream.

There is no significant difference between the characteristics of flow patterns at each return period, but the difference can be seen based on the magnitude of the velocity distribution resulting from the simulation results. The recapitulation of the horizontal flow velocity distribution of the simulation results at each review point on the return period of 50 years, 100 years, and 1000 year for 24 hours can be seen in table 8.

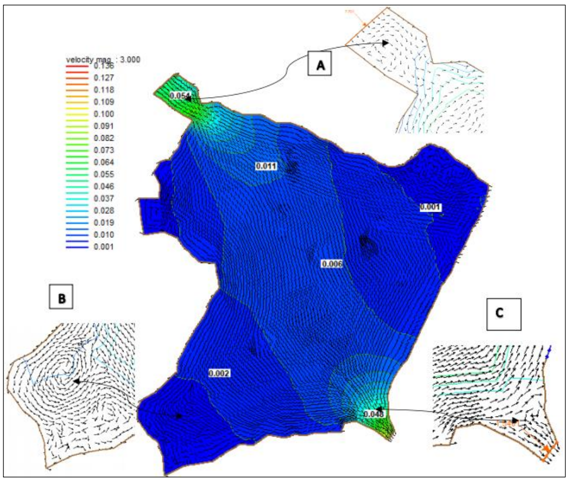

Figure 5 The results of running RMA2 on flow patterns in the 50-year return period in vector form.

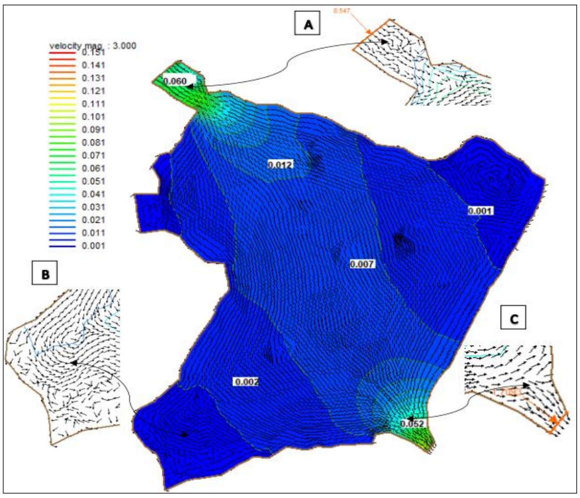

Figure 6 The results of running RMA2 on flow patterns in the 100-year return period in vector form

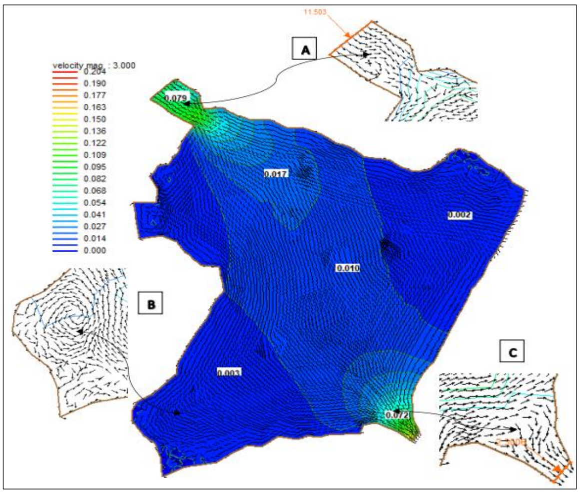

Figure 7 The results of running RMA2 on flow patterns in 1000-year return periods in vector form.

Table 8 Distribution of Flow Velocity (m / s)

Review Point	Location	Flow Speed (m/s)		
		Reset period 50 year	**Reset period 100 year**	**Reset period 1000 year**
1	Inflow	0.038	0.042	0.058
2	Middle of the reservoir	0.008	0.009	0.012
3	West of the reservoir	0.001	0.002	0.002
4	Middle of the reservoir	0.004	0.005	0.006
5	East of the reservoir	0.000	0.000	0.001
6	Outflow	0.035	0.037	0.053
The smallest		0.000	0.000	0.000
The biggest		0.097	0.107	0.145

The results of sedimentation simulation in the form of changes in the base of the Song Putri Reservoir in the return period of 50 years, 100 years, and 1000 years during 720 can be seen in the following figure 8. Changes in the base of the Song Putri Reservoir (bed change) in the 50 year return period.

Recapitulation of the horizontal flow velocity distribution of simulation results at each point of view in the return period of 50 years, 100 years, and 1000 years for 24 hours can be seen in table 9.

Table 9 Changes in Reservoir Basis (m)

Review Point	Location	Bed Change (Reset Period)		
		50 year	100 year	1000 year
1	Inflow	4.382	4.512	4.782
2	Middle of the reservoir	0.511	0.526	0.570
3	West of the reservoir	0.020	0.020	0.024
4	Middle of the reservoir	0.068	0.069	0.089
5	East of the reservoir	0.031	0.032	0.040
6	Outflow	0.106	0.115	0.120
The smallest		0.001	0.001	0.001
The biggest		5.795	5.795	5.795

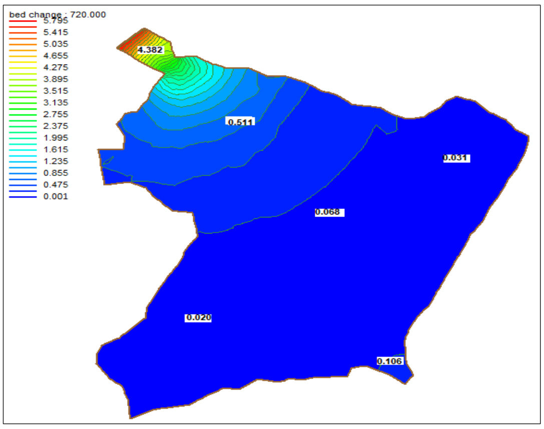

Figure 8 Changes in the reservoir base (bed change) at the 50-year return period.

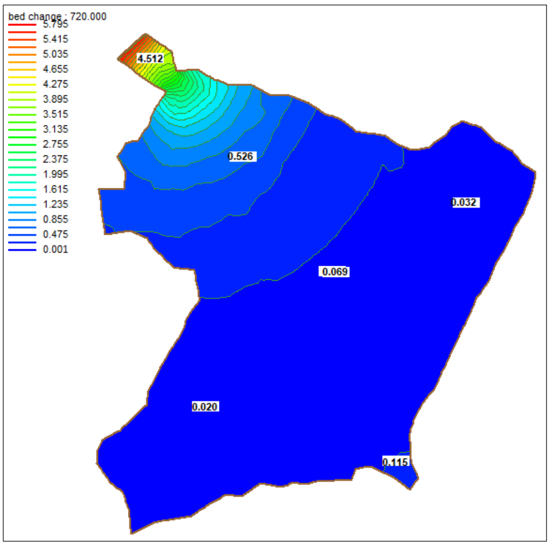

Figure 9. Changes in bed reservoirs at 100 years of return.

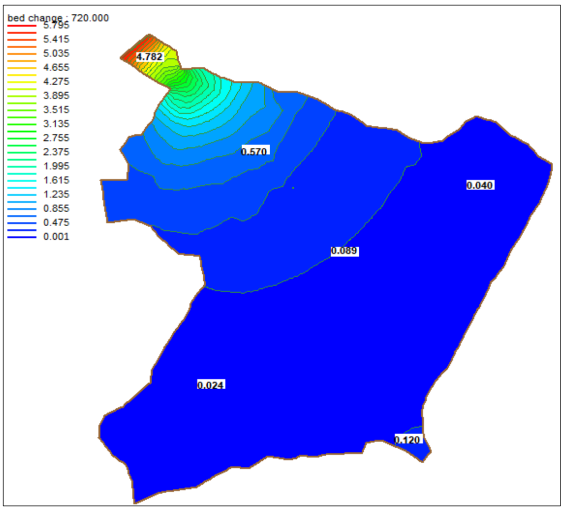

Figure 10. Changes in the reservoir base during a 1000 year return period.

Based on flood measurement data (Q) and sediment concentration (Cs), suspension discharge (Qs) can be comma and the suspension discharge curve is made (graph of the relationship between Q and Qs). Using these equations, the prediction of sediment growth rate can be calculated which is presented in Table 10.

Table 10 Results data from the calculation of the re-debit and modeling SMS 8.0.

Reset Period	**Q**	**V**	**Cs**	**Qs**	**Vol**
	m^3/dt	**m/dt**	**kg/m^3**	**kg/dt**	**m^3**
Q50	99.72	0.038	0.378	37.692	8615400.101
Q100	110.67	0.042	0.382	42.276	9561901.787
Q1000	148.95	0.058	0.411	61.218	12869234.437

Based on the calculation of predicted sediment growth rates the results of sediment growth comma with a percentage for a 50 year return period of 35.68% with a range of percentages between 19% - 21% and a percentage of 29.103% for a 100 year return period with a percentage range between 22% - 24%, while the percentage of sediment growth rates for 1000 year return periods is 98.20% with a range of percentages ranging from 55% - 57% (Figure 11 and Table 11).

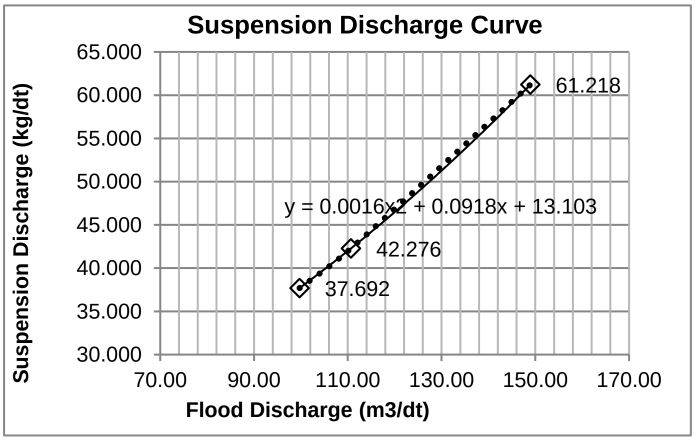

Figure 11 Suspended Debit Curve Curves

Table 11 Predictions of Sediment Growth Rates

Review Period	Accretion Year (x)	Sediment (y)	Growth Rate (i) (%)	Range (%)
Q50	50	17.103	35.68	19%-21%
Q100	100	29.103	41.23	22%-24%
Q1000	1000	1613.103	98.20	55%-57%
Amount			**175.11**	
Average Growth Rate			**58.37**	

CONCLUSIONS

Based on the analysis, the following conclusions can be drawn:

The calculation of rainfall using the Log Pearson III resulted for a 5 year return period of 119,920 mm, a 10 year return period of 141,040 mm, a 25 year return period of 168,078 mm, a 50 year period of 188, 478 mm, a 100 year return period of 209,185 mm, and the 1,000 year return period is 281,539 mm.

The flow patterns that result from the simulation for 24 hours in the return period of 50 years, 100 years, and 1000 years do not have a significant difference. In each return period, the water cycle in the reservoir is formed.

Based on the simulation results of the highest flow velocity in the 50 year return period of 0.097 m / s and the smallest of 0.00 m / s with details of each review point (Inflow of 0.038 m / s; middle of 0.008 m / s and 0.004 m / s; west and east of 0.001 m /

s and 0.00 m / s; outflow of 0.035 m / s). In the 100 year return period the highest flow velocity is 0.107 m / s and the smallest is 0.00 m / s with details of each review point (Inflow of 0.042 m / s; middle of 0.009 m / s and 0.005 m / s; west and east 0.002 m / s and 0.00 m / s; outflow of 0.037 m / s). The highest flow velocity in the 1000 year return period is 0.145 m / s and the smallest is 0.00 m / s with details of each review point (Inflow of 0.058 m / s; middle of 0.012 m / s and 0.006 m / s; west and east 0,002 m / s and 0,001 m / s; outflow of 0,053 m / s).

Based on the simulation results of changes in the reservoir base for 720 hours (1 month) the values obtained in the return period of 50 years, 100 years and 1000 years the highest of 5.795 m and the smallest of 0.001 m, with details of each review point that is the return period 50 years (Inflow of 4.382 m; middle of 0.511 m and 0.068 m; west and east of 0.020 m and 0.031 m; outflow of 0.106 m), while 100-year return periods (Inflow of 4.512 m; middle of 0.526 m and 0.069 m; west and east of 0.020 m and 0.032 m; outflow of 0.115 m), and 1000 year return period (Inflow of 4.782 m; middle of 0.570 m and 0.089 m; west and east of 0.024 m and 0.040 m; outflow of 0.120 m) .

Based on the calculation of predicted sediment growth rates the results of sediment growth comma with a percentage for a 50 year return period of 35.68% with a range of percentages between 19% - 21% and a percentage of 29.103% for a 100 year return period with a percentage range between 22% - 24%, while the percentage of sediment growth rates for 1000 year return periods is 98.20% with a range of percentages ranging from 55% - 57%. Thus it can be concluded that the greater the year increase, the greater the percentage of sediment growth rate in the Song Putri reservoir.

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