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The Effect of Lamong River Flow Diversion To Bed Surface Degradation

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Abstract the Lamong River flood occurs every year due to the flow rate that enters the river is larger than its capacity. The storage capacity is reduced due to the sedimentation on the riverbed which results in a small storage capacity. Therefore, water overflows through the channel but is still held by the embankments on either side of the river. The embankment restraints flood so that the water level rises, inundates, and submerges the embankment from the bottom to the top of the embankment. The Lamong River with a trapezium-shaped channel has a bottom width of about 30 m, an upper width of 40 m and a depth of 3.5 m. In one of the river segments, the riverbed is in the form of a fixed bed and it is assumed that there is no sediment transport in this section. On the downstream side after the fixed bed section, the river segment is a mobile bed with riverbed material which has an average grain diameter of 1.5 mm, relative mass density of 2.6, and porosity of 0.3. The method of analyzing riverbed degradation was parabolic. In addition, the method of analyzing flood discharge was designed using HEC-RAS version 5.0 software. The analysis starts from normal water discharge to critical flood water discharge at the top of the embankment. The results showed that the flow rate with Q50 is 1000.00 m^3/s with a maximum flow rate of 8,0 m/s and the degradation of the river bed occurred at the beginning at the upstream point in the fixed and mobile bed. The depth of riverbed degradation is 0.8 m/yr.

Keywords: degradation, parabolic model, river flow diversion

INTRODUCTION

The Lamong River has a watershed area of 720 km^2 with a river length reaching ± 103 km which has river mouth into the Madura Strait. The Lamong River is included in the category of intermittent rivers with a relatively flat cross section of the river and there are 34 tributaries. Bankfull capacity of ± 250 m^3/sec (annual Q), while the discharge during the rainy season can reach> 700 m^3/sec.

The Kali Lamong River Basin in the upstream area includes Lamongan and Mojokerto Regencies as well as Surabaya City and Gresik Regency located in the downstream area. Of these areas, 310.12 km2 or 44% of the Kali Lamong watershed is in Gresik Districts. The downstream part of the Kali Lamong watershed is a relatively flat area with urban areas, villages, rainfed rice fields and ponds, thus affecting the shape of the river to become meanders. At the downstream side, Kali Lamong gets additional inflow from the city drainage outlets and the surrounding ponds. The location of this final project research is in Kali Lamong, Gresik Regency, East Java. The KM 0 - KM 40 which are the main focus for flood runoff embankments and riverbed degradation is shown in Figure 1

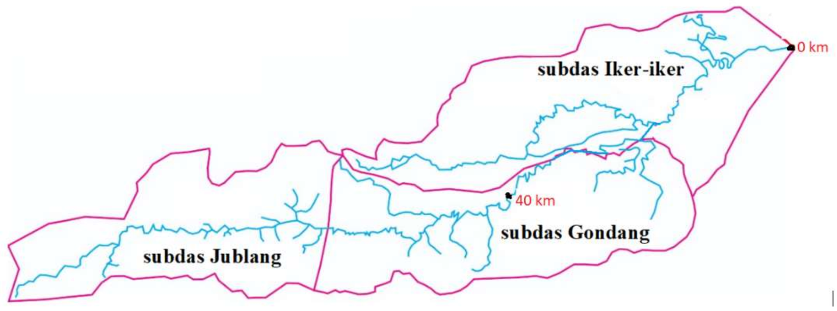

FIGURE 1. Location of the reservoir on the sub-watersheds of Lamong River

Based on the reservoir location, the Lamong watershed is divided into three sub-watersheds: the Jublang sub-watershed and the Gondang sub-watershed, with a flood control reservoir in each sub-watershed, and the Iker-iker sub-watershed, without a flood control reservoir. The sub-watershed location is shown in Figure 1. Based on the sub-watershed location, flood tracing was conducted from the upstream of Lamong River to the downstream of the Lamong River. Flood tracing is a procedure for estimating a hydrograph at a certain point in a river based on hydrograph observations at another point. According to the flood tracing, a flow hydrograph that enters and leaves each reservoir can be obtained, and flow hydrograph from each sub- watershed, so that in the end, a flow hydrograph is obtained which becomes the upstream boundary condition in the hydraulic analysis with the HEC-RAS auxiliary program.

A river basin (DAS) is an area bounded by mountainous ridges where rainwater that falls in the area will flow towards the main river at a point under review [1]. The watershed area is one of the parameters in the flood discharge analysis in a cross section. Meanwhile, flooding was caused by uncontrolled overflow of water from the embankment.

Rainfall Analysis

The rainfall data can be analysed using the Thiessen polygon method. The Thiessen polygon method is one method that can be used to determine regional rainfall. The Thiessen polygon uses the proportion of the area of influence of the rain station to overcome the variability in distances. The area of influence is determined via a polygon drawing connecting several adjacent rain stations in Fig. 2

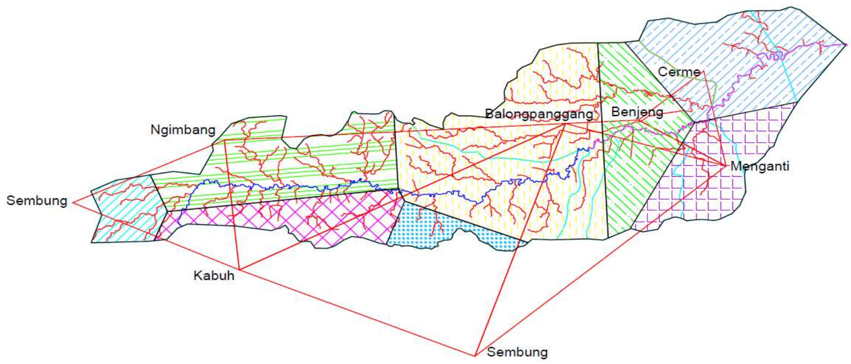

FIGURE 2. Location of Sungai Lamong sub-basin Rain Station

It can be assumed that the variation of rainfall between rain stations is linear and a particular rain station can represent the surrounding rain area. This method is suitable for flat areas with an area of 500 - 5000 km^2 and the number of rain stations that are not proportional to their area, then the rainfall data is sorted by selecting the maximum rainfall that occurs each year. Furthermore, the data is plotted against the location of the rain station. Then the regional rainfall can be calculated by the Thiessen polygon method. The processed rainfall data are analysed using several statistical parameters. The analysis process is carried out based on:

1. Standard Deviation Calculation
2. Slope Calculation
3. Kurtosis Calculation
4. Coefficient Variation Calculation

5. Pearson Log Distribution Calculation Type III
6. Distribution Fit Test

The planned rainfall is determined based on the results of statistical analysis of the available rainfall data. In the planned rainfall analysis, several stages started from determining the return period to calculating the intensity of rainfall.

Based on the calculation of rainfall intensity with a certain period, the planned flood discharge can be calculated. The planned flood discharge is calculated using the Nakayasu synthetic unit hydrograph

METHODOLOGY

River flow with meander pattern, changes in river channel due to uncontrolled sediment transport is faster than straight river flow due to horizontal and centrifugal pressure from the flow which triggers the erosion of river banks on the outside of meander bends and sedimentation on the inside of meander bends [2].

Changes in river roughness result in changes in depth, hydraulic radius and flow velocity. Theoretical calculation of speed is done by the manning equation on the river before and after there is diversion. The magnitude of change is obtained by comparing the depth, hydraulic radius, and flow velocity [3].

The method utilized in this research was quantitative descriptive method. Flood analysis was performed using the Nakayasu Synthetic Unit Hydrograph method was then calculated using HEC-RAS [4].

Research Location

The research is located in the downstream of Lamong River Figure 3.

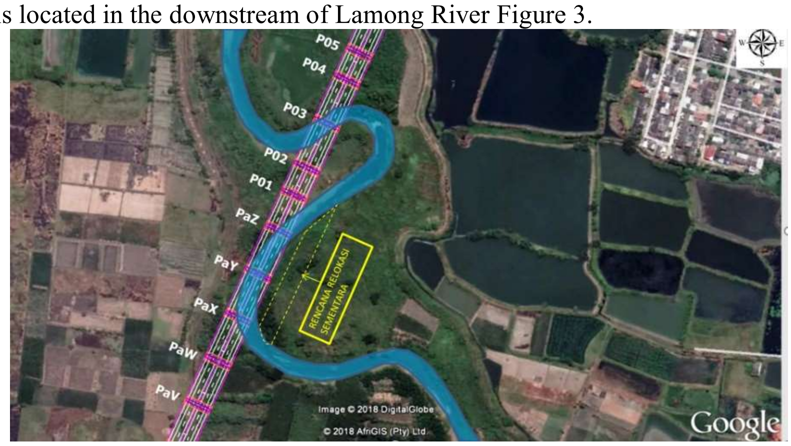

FIGURE 3. Location of river diversion at Kali Lamong River

Calculation of Return Perion Flood Discharge

Calculation of flood discharge with a return period was performed on these following steps:

a. Prepare annual maximum daily area rainfall data.
b. Perform rain distribution calculations using the Pearson Log Type III method.
c. Test the suitability of rain data distribution by the Smirnov-Kolmogorov method.
d. Perform rain return period calculations for periods 2, 5, 10, 20, 25 and 50 years using Microsoft Excel.
e. Calculates the effective rain return period 2, 5, 10, 20, 25 and 50 by correcting the rain return period based on runoff coefficient.
f. Calculate the rainfall concentration time with the Kirpich formula to estimate the duration of rain that occurs in the Kali Lamong watershed.
g. Perform flood calculation for the planned return period of Q2, Q5, Q10, Q20, Q25 and Q50 using the Nakayasu HS method.

Frequency Analysis

Designed rainfall with a certain return period is usually analyzed by frequency analysis. Frequency analysis is an analysis to determine the relationship of an extreme quantity with the likelihood (probability) of its occurrence, or often it is also presented as a relationship between a quantity and its time-span Frequency analysis is based on the statistical characteristics of the sample (data) available to obtain the probability of a population size (rainfall / discharge). The data used is the maximum annual rainfall data, which is the largest data that occurs for a year, which is measured for several years.

Analysis of the frequency of designed rainfall data can be carried out using several probability distributions, such as: Normal Distribution, 2 Parameters Normal Log Distribution, 3 Parameters Normal Log Distribution, Gumbel Distribution, Pearson III Distribution and Pearson III Log Distribution. The determination of the probability distribution used in hydrological analysis is carried out by using the frequency distribution suitability test [1].

In order to determine the fit (the goodness of fit) of the empirical frequency distribution of the data sample against the theoretical frequency distribution function which is estimated to describe / represent the empirical distribution, statistical testing is required. There are two methods of testing, namely: The Chi-Square Test and the Kolmogorov-Smirnov Test.

Calculation of Riverbed Degradation

Riverbed stability is an important part to maintain the flow in a river. The riverbed is stable if the sediment grains are static. Riverbed stability is disrupted if bottom sediment is transported so that the riverbed structure is damaged, causing degradation and agradation along the river channel. [7]. Surface erosion and moving bedload accumulate continuously causing bottom degradation. The transported sediment capacity is affected by flowrate, average flow velocity, base slope and shear stress with a value of Froude < 0,6 [5]. Degradation occurs when the incoming flow rate is greater so that basic sediment is transported [6].

A river with a trapezoidal shape, based on a fixed bed and is considered to have no sediment transport in this section. On the downstream side after the fixed bed section, the river segment is a mobile bed. Riverbed degradation will occur, upstream at fixed and mobile beds.

Depth of riverbed degradation can be calculated by the Parabolic Model [7] based on the completion of the equation:

$$\frac{\partial z}{\partial t} - K\frac{\partial^2 z}{\partial x^2} = 0 \qquad \text{a)}$$

where for degradation problems such as the problems above, the x-axis follows the initial riverbed and is positive downstream, while the z-axis shows variations in the riverbed and is positive downward.

Initial conditions and boundary conditions in Eq. (a) above is:

$$z(x,0) = 0\ ;\ \lim_{x\to\infty} z(x.t) = 0\ ;\ \ z(0,t) = \Delta h(t) \qquad \text{b)}$$

Resolving the equation (1) with initial terms and boundary conditions according to Eq. (b) is

$$z(x,t) = \Delta h\ erfc\left(\frac{x}{2\sqrt{Kt}}\right) \qquad \text{c)}$$

The variation of riverbed elevation with respect to time at point x = L = 6Rh/Se is calculated by the following equation:

$$\Delta h(t) = \frac{q_s \Delta_t}{1.13(1-p)\sqrt{K\Delta t}} \qquad \text{d)}$$

RESULT AND DISCUSSION

Hydrological Analysis

The representative rainfall stations are combined rainfall stations consisting of Bunder, Cerme, Duduk Sampeyan and Benjeng stations, and the Sembung rain recording station located in the downstream area of Kali Lamong. The combined rainfall station rain data are shown in TABLE 1.

TABLE 1. Maximum daily rainfall data

Year	Combined Ranfall Station
1998	73
1999	101
2000	69
2001	105
2002	93
2003	34
2004	62
2005	35
2006	120
2007	51
2008	58
2009	81
2010	97
2011	71
2012	54
2013	70
Average	73,34

The results of frequency analysis calculation of the maximum daily rainfall utilizing Normal Distribution, Normal Log Distribution 2 Parameters, Normal Log Distribution 3 Parameters, Gumbel Distribution, Pearson III Distribution and Pearson III Log Distribution for combined station rain data (Bunder, Mirror, Sitting Sampeyan and Benjeng) can be seen in TABLE 2.

With a difference of 5% critical value. This condition means that the maximum difference in critical value that occurs cannot be greater than the allowable critical difference of 5%, for that it is necessary to test The Goodness of Fit. From the test results, the three methods are acceptable for the calculation of the maximum rain return period.

TABLE 2. Agreement of frequency distribution

No	Critical Value Difference 5%				
	Normal	Log Normal	Gumbel II	Pearson III	Log Pearson III
1	10,53	48,33	-8,53	13,65	10,77
2	2,99	2,28	-0,77	-5,2	-9,09
3	-25,37	1,49	2,38	-4,45	-8,65
4	-11,02	0,29	4,96	-4,27	-8,76
5	-36,59	-6,06	2,34	-9,37	-14,15
6	-34,77	-10,69	1,47	-12,87	-17,92
7	-22	-13,98	2,1	-15,11	-20,42
8	-38,79	-16,73	3,62	-16,89	-22,45
9	-55,85	-33,43	-8,13	-32,69	-38,49

10	0	-33,8	-1,84	-32,21	-38,25
Maximum difference	55,85	32,08	8,53	32,69	38,49
Agreement Test	declined	accepted	accepted	accepted	declined

The designed rainfall used for the base discharge analysis plan is the result of the frequency analysis of the Gumbel method as shown in TABLE 3. The Gumbel distribution is generally used for extreme data analysis, for example for the analysis of the frequency of rainfall or floods, as well as straight line equations for the Gumbel distribution using empirical equations. The Gumbel distribution method is also be affected by many variables, those are reduced variable, reduced mean, reduced standard deviation.

TABLE 3. Designed Rainfall

Return Period	Frequency Analysis of Designed Rainfall (mm)				
	Normal	**Log Normal**	**Gumbel II**	**Pearson III**	**Log Pearson III**
2	73,34	69,5	69,76	72,7	71,59
5	94,16	91,78	96,99	84,99	94,69
10	105,06	105,88	115,01	105,49	107,57
25	113,98	122,15	137,79	113,29	121,6
50	124,14	136,46	154,69	126,29	130,61
100	131,08	149,24	171,46	130,63	138,83

To obtain flood discharge using this approach, it is necessary to know in advance the maximum rainfall that occurred in the review area obtained from the calculation of the maximum rainfall.

The calculation of the Lamong River watershed flood discharge used the Nakayasu Synthetic Unit Hydrograph (SUH) method. HSS Nakayasu is a synthetic unit hydrograph formula based on the investigation of unit hydrographs on several rivers in Japan. (Soemarto, 1999) However, the basic definition used in the HSS Nakayasu remains similar to the definition of hydrograph in general. In general, synthetic unit hydrograph is a hydrograph of direct runoff (without base flow) produced by an effective rain of 1 mm which occurs evenly in a watershed with a certain intensity and duration. (Natakusumah, Hatmoko, & Timidzi, 2012) are described in table 4.

TABLE. 4. Nakayasu Synthetic Unit Hydrograph of the Lamong Watershed

No	Parameter	Symbol	Rate	
1	Watershed Area	A	720	km2
2	Main River Length	L	103	km
3	Parameter Alpha	a		
-	for common watershed, a		2,0	
-	for the slow rising hydrograph section			
	& fast descending section, a		1,5	
-	for the fast rising hydrograph section			
	& slow descending section, a		3,0	
4	Unit Rainfall	Ro	1	mm
5	Time Concentration	tg		
	If L < 15 km, then tg = 0,21 * $L^{0,7}$		5,40	hours
	If L > 15 km, then tg = 0,4 + (0,058 * L)		6,39	hours
6	tr = 0,5 tg up to 1,0 tg	1	6,39	hours
7	Time of Decline			
	from Tp to (Tp+30% time decline)	$T_{0,3}$		

	$T_{0,3}$ = a * tg		19,181	hours
8	Time to Peak	Tp		
	Tp = tg + 0,8 tr		11,509	hours
9	Runoff Coefficient	C	0,800	
10	Flood Peak Dischage	Qp		
	Qp = (C. A. Ro) / (3,6 * ((0,3 Tp)+$T_{0,3}$))		7,069	m3/s/mm
11	Synthetic Unit Hydrograph			
-	Qt When 0 < t < Tp	Qa	Qp * ((t / Tp)^2,4)	
-	Qt When Tp < t < (Tp+$T_{0,3}$)	Qd1	Qp * (0,3^((t-Tp)/($T_{0,3}$)))	
-	Qt When (Tp+$T_{0,3}$) < t < (Tp+$T_{0,3}$+1,5$T_{0,3}$)	Qd2	Qp * (0,3^((t-Tp+0,5$T_{0,3}$)/(1,5$T_{0,3}$)))	
-	Qt When (Tp+$T_{0,3}$+1,5$T_{0,3}$)< t < T decline	Qd3	Qp * (0,3^((t-Tp+1,5$T_{0,3}$)/(2,0$T_{0,3}$)))	

The results of calculations with Nakayasu Synthetic Unit Hydrograph are shown in the flood discharge hydrograph.

While the calculation results with HS Nakayasu are shown in the flood discharge hydrograph graph in Figure 4, where the designed flood discharge due to rainfall return period (QT) in the Lamong Watershed is Q5 = 612.35 m3/s, Q10 = 727.17 m3/s. , Q25 = 872.24 m3?s and Q50 = 1000.00 m3/s.

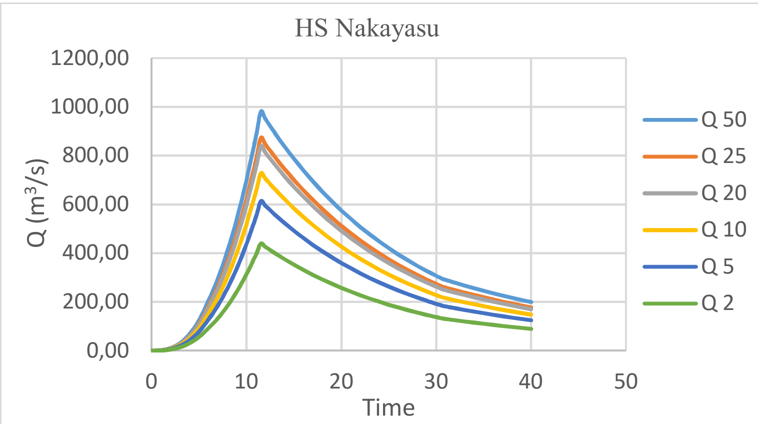

FIGURE 4. Nakayasu Synthetic Unit Hydrograph

The comprehensive designed flood on the Nakayasu synthetic unit hydrograph which is occurred in Lamong River is presented in Table 5.

TABLE 5. Nakayasu Synthetic Unit Hydrograph

Method	Q (m^3/s)					
	Tr 2	Tr 5	Tr 10	Tr 20	Tr 25	Tr 50
Nakayasu Synthetic Hydrograph	438,94	612,35	727,17	837,3	872,24	1000

Pattern dan velocity of the flow

Flood Return Period (T) calculation of Lamong River flood discharge, which is determined by Q50, is 1000.00 m^3/sec based on Nakayasu SUH analysis. It is used as a basis for hydraulic analysis with HEC-RAS [4]. The research location is on the inflow and outflow bends that are bounded by the right and left banks of the river.

The cross section of the Kali Lamong river in trapezoidal shape with a width of 30 m and a width of 40 m. At the channel location is provided cross section which then modeled waterflow simulation in a river to describe the flow pattern along the river. Simulations are carried out in real terms by flowing water into channels which are generally made on a physical scale or virtually by performing a series of hydraulic calculations in a computer application program (mathematical model). Through the physical model, a number of physical phenomena of waterflow in a real channel or river (prototype) are imitated in a smaller size channel or river (model). Geometry imitation to transfer the actual (prototype) river or channel geometry to the river or duct (model). For mathematical models, the river geometry is simulated by maintaining the size according to the real size (scale 1: 1). The data needed to simulate this geometry includes a river flow situation map, a cross-sectional and longitudinal view of the river, as well as drawings of buildings or hydraulic structures along the river flow as FIGURE 5, and then analyzed according to the desired discharge.

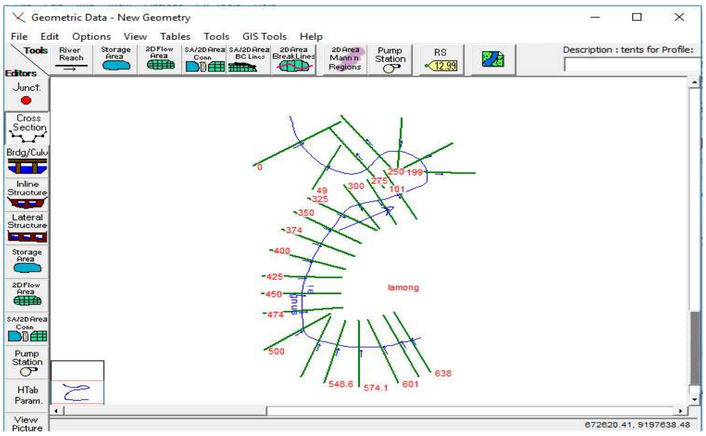

FIGURE 5. Cross Section and Geometry Model of The Lamong River

The analysis was carried out to determine the hydraulic ability of the Lamong River to drain the planned flood discharge. The river geometry data from KM 0 - KM 40 were modeled, the flood discharge from the HSS Nakayasu calculation was entered to be simulated. The simulation is carried out with several limiting conditions:

In the process of entering the Nakayasu HSS discharge data from the sub-watershed to the Lamong River, Boundary Conditions in the form of Flow Hydrograph are used for the upstream sub-watershed KM 40 and Lateral Inflow Hydrograph. Flow hydrograph was chosen for the upstream sub-watershed of KM 40 because the discharge in the sub-watershed was flowed continuously from the upstream point to the downstream section of Lamong river under review. Lateral inflow was chosen because the discharge from the A-H sub-watershed flows laterally (from the river in the sub-watershed beside the Lamong River to the Lamong River) at a certain point in the Lamong river section under review. At the downstream of Lamong river (KM 0) the Hydrograph Stage is used. The use of these conditions is because the water level data that occurs can be entered as data for analysis. Therefore, the data for the maximum tide level elevation as high as +0.67 obtained from the results of the field survey can be used to determine if there is backwater downstream of the Lamong River.

Based on the simulation results, almost all the water level elevation points of the Lamong River are above the surface elevation of the border as shown in FIGURE 6.

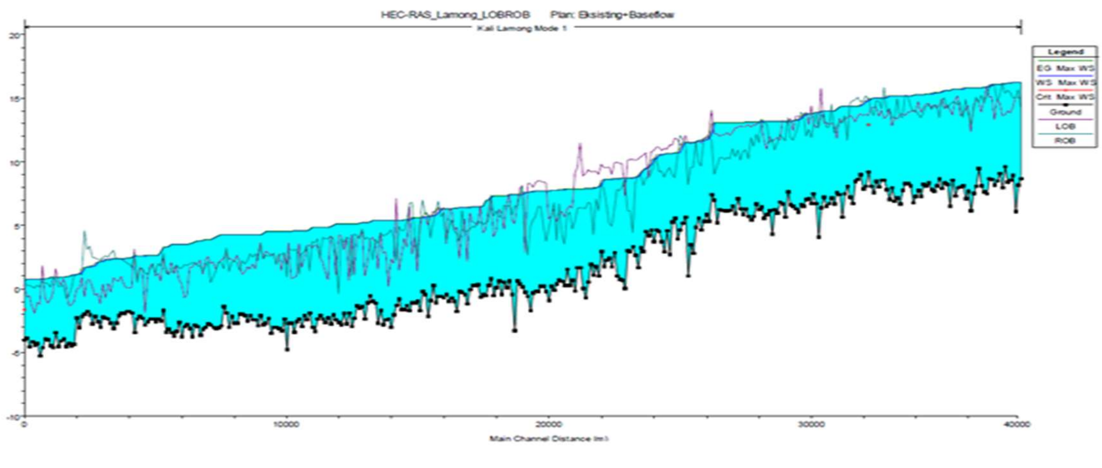

FIGURE 6. The simulation results

An example is KM 8 the flood water level is at an elevation of +4.18, while the highest elevation of the left bank is +3.80 and +3.80 on the right bank as shown in Figure 7. Therefore, it can be concluded that in the existing conditions the Lamong River is unable to drain the flood discharge from the 50-year return period plan. Therefore, flood control efforts are required to deal with the overflow from the Lamong River.

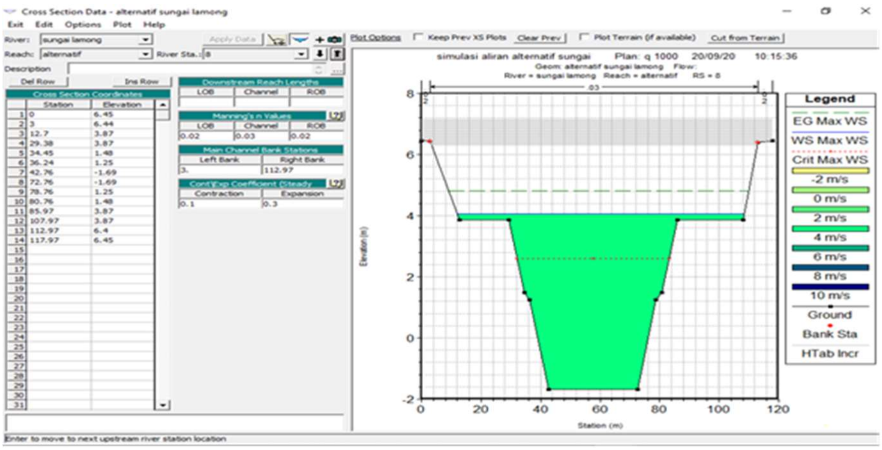

FIGURE 7. The flood water level

The running results with HEC-RAS [4], the pattern and flow velocity in the Lamong river channel.
The flow velocity at the bottom of the channel reaches 6 m/s to 8 m/s, then at that place, scours occur which causes a fairly deep degradation or decrease in the bottom.

Riverbed degradation

Lamong River has a trapezoidal shape with a bottom width of B = 30 m. In one of the river segments, the riverbed is in the form of a fixed bed and it is assumed that there is no sediment transport in this section. On the downstream side after the fixed bed section, the river section is a mobile bed with riverbed material that has an average diameter = 1.5 mm, relative mass density Ss = 2.6, and porosity p = 0.3. Flowrate is Q = 1000.00 m^3/s with a depth of h = 3.0 m, the basic roughness is 0.03. The slope of the riverbed is 0.001, from the river data, the amount of transported sediment discharge (qs) is calculated using the Meyer Peter Muler method as follows:

$$q_{sb} = \frac{1}{g(\rho_s-\rho)}\left[\frac{g\rho\ \ hb\xi_M S_e - 0{,}047\,g(\rho_s-\rho)d_{50}}{0{,}25\rho^{1/3}}\right]^{3/2} \qquad \text{e)}$$

q_{sb} = 0,000804175 m^2/s

The sediment transported in the river cross section is 0.000804175 m2 / s. Diffusion coefficient (K):

$$K_o \equiv K = \frac{1}{3} b_s q_s \frac{1}{1-p}\frac{1}{S_e^o} \qquad \text{f)}$$

= 11,48821 m^2/s

Degradation of riverbed :

$$\Delta h(t) = \frac{q_s \Delta t}{1{,}13(1-p)\sqrt{K\Delta t}} \qquad \text{g)}$$

= 0,8394 m

The depth of river bed degradation was calculated using the Parabolic Model of 0,8394 m/year with rain time of 6 hours / day and transported sediment (qs = 0.000804175 m2 / s)

CONCLUSION

According to the results of the analysis and discussion, the following conclusions are obtained as follows:

1. Design flood discharge due to raining period (QT) in the Kali Lamong River Basin is Q5 = 612.35 m^3/second, Q10 = 727.17 m^3/second, Q25 = 872.24 m^3/second and Q50 = 1000.00 m^3/second.
2. Flow velocity that occurs in the diversion channel reaches 6 to 8 m/s with a scour on the bottom and slope profile.
3. Basic degradation reaches 0.8394 m annually, which is analyzed by the parabolic method.

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