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INVESTIGATING THE EFFECTIVENESS OF BANGER RIVER FLOODWAY ON REDUCING WATER LEVEL OF LOJI RIVER IN PEKALONGAN CITY USING HEC-RAS 1D MODEL

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ABSTRACT

Pekalongan City is a lowland area and located in the northern part of Java Island. Tidal flooding often occurred at high tide when the wave run-up entered the mainland and inundated several areas in the city of Pekalongan. The inundation area in Pekalongan City reached 618 Ha in 2020. Tidal flooding became a problem because it inundated vital areas such as residential areas, public spaces, and economic centers. The area that often experiences inundation is in the area of the Loji River and the Banger River estuarine, which is a unified system on the Pekalongan River. The inundation due to tidal flooding will be more severe if it coincided with the occurrence of high discharge in the river flow. To control floods and tidal floods in the city of Pekalongan, flood control engineering was needed so a floodway known as the Banger River was built. This approach aims to reduce the area of inundation and protect existing vital areas. This study aims to assess the impact of the Banger River on reducing water level in the Loji River. The methodology used in this study is flood modeling with HEC-RAS 6.1 one dimensional model. The simulation results show that after the Banger river floodway was made, the water level in the Loji river 1.7 meters or 28% of the water level in the Loji River can be reduced.

Keywords: Banger River, Floodway, HEC-RAS

1. INTRODUCTION

Pekalongan is one of the important cities in Central Java Province. Pekalongan is an industrial city (batik and convection), a fishery production and aquaculture city. Located on the northern coast of the island of Java, Pekalongan often experiences flooding. The floods inundated residential areas near the coastal zone and the extent of the affected area increases from year to year. Coastal area of Pekalongan becomes subject to flooding as a combined result of high rainfall, land use changes, changes in river cross-section, and unusually high tides (Rahmawati and Ardhiani, 2008). In the northern part, the surface is lower than sea level, so it is difficult for water to flow into the sea. Most of those areas are inundated during high tide (Wahyudi, S, Imam, 2010). Floods in Pekalongan inundated 25 percent of the city area including nine villages in three sub-districts: North Pekalongan, West Pekalongan and East Pekalongan.

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Based on the cause, inundation can be grouped into 3 conditions. First, inundation in the pond/swamp area even though there is no rain or high tide, because the land elevation in the area is lower than the sea level or the surrounding river water level. This area covers 1,037 Ha. The second inundation is caused by high tides, as the land elevation is lower than the tides. The sea water enter the land through the river that has its downstream end at the sea. Areas prone to the inundation usually last for a rather long time between 2-14 hours. At low tide, the area will dry again. The total area of the inundation reached 1,920 hectares. The third inundation occurs because the rainwater channel and storage areas are not sufficient, so that the water discharge overflowed to the lower area. Rainwater will be more difficult to remove by gravity if there is a high tide. Thus, the inundation will be wider, deeper and it will take longer to recede (S. Imam Wahyudi et.al., 2012).

Loji River is one major river flowed through Pekalongan which has a significant contribution on flooding in the city. This river is the main river of Kupang Watershed, a part of Pemali Comal Watershed Management. With the upstream located at the foot of Mount Rogojembangan in Pekalongan City, the river passes through Pekalongan City to the Java Sea and influences the development of urban areas along the river.

Based on previous studies, the capacity of the Loji river cannot accommodate flood discharge from upstream and is exacerbated by high tides, so that a floodway was built from Loji River to the Banger River. The floodway becomes one of the largest artificial rivers in Pekalongan City and is expected to be sufficient to drain the flow discharge. Flood discharge flowing from upstream part known as Kupang River. Banger River can reduce the water level in the Loji River so the flooding in Pekalongan city will be decreased.

Figure 1. River in Pekalongan City

HEC-RAS is an open channel flow model that simulates the hydraulics of water flow through natural rivers and other channels. Prior to the 2016 update to Version 5.0, the program was one-dimensional, meaning that it has one direction of flow along the main channel. The release of Version 5.0 introduced two-dimensional modeling of flow. One-dimensional modeling is a numerical model that will analyze the hydraulic calculation such as the depth and velocity of the flow along the channel. This model is often used as a flood simulation for river capacity planning. This research used one-dimensional model to simulate flow profiles and to predict changes in the water level of Loji River.

2. RESEARCH DESIGN AND METHODOLOGY

Flood modeling is a method for predicting flooding in a watershed. The method used depends on the availability of data and the suitability of a method with the characteristics of the study area. The analysis in this study included hydrological analysis and hydraulic analysis (before and after Banger River was built).

In hydrological analysis, the methodology for analyzing flood hydrographs consists of two parts: rainfall analysis and calibration or verification analysis to obtain a synthetic unit hydrograph that is compatible with the Kupang watershed. The rainfall analysis was done using 4 rainfall stations located in the Kupang watershed: Pekalongan, Wonotunggal, Kletak and Kurtosari Duro. The maximum daily rainfall in the area was obtained by using the Polygon Thiessen and Area Reduction Factor (ARF) method. The polygon thiessen method is used to obtain accurate estimation of the spatial distribution of rainfall. ARF are factors with fixed value for changing rainfall data from point rainfall into area rainfall.

The response of a watershed (DAS) to rain is runoff. Rain is the main factor that causes flooding. The characteristics of rain that cause flooding are high rainfall intensity and long duration of rain. When a watershed responds to rain into direct runoff, the discharge characteristics are highly dependent on watershed constants and variables. One of the constants that affect it is the land use coefficient. The following picture is a flood hydrograph concept.

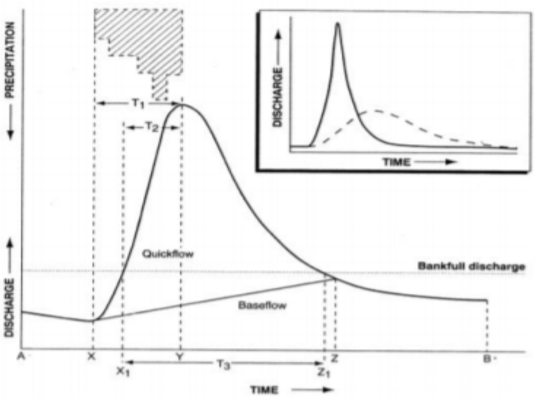

Figure 2. Flood Hydrograph Concept in a Watershed
(Source: Applied Hydrology, Ven Te Chow)

As there is no hourly rainfall data in the gauge station, the available data is converted to hourly rainfall using PSA 007 method. According to PSA 007, the rainfall distribution is arranged in the form of a clapper, where the highest value is placed on the middle, second highest on the left, third highest on the right and so on. The PSA 007 hourly rainfall distribution model is shown in Table 1. below:

Table 1. Hourly rainfall distribution of PSA 007

Hours	R/Rt		
	6 hours	12 hours	24 hours
0	0	0	0
1	0.05	0.02	0.0075
2	0.15	0.04	0.015
3	0.75	0.07	0.0275
4	0.91	0.12	0.04
5	0.97	0.21	0.055
6	1	0.66	0.07
7		0.81	0.095
8		0.88	0.12
9		0.93	0.155
10		0.96	0.205
11		0.99	0.295
12		1	0.625
13			0.745
14			0.805
15			0.845
16			0.88
17			0.905
18			0.93
19			0.945
20			0.96
21			0.9725
22			0.985
23			0.9925
24			1

Infiltration calculation is computed using Curve Number (CN) method by dividing Kupang Watershed into sub-basins. The method uses the variables from watershed characteristics such as soil type, land cover, humidity soil, and the way of land conservation. Hourly rainfall distribution and composite CN values are used as inputs to obtain SCS Synthetic Unit Hydrographs (SUH) using HEC-HMS 4.6.1. To calibrate the flood hydrograph, the flow discharge from sub-basins of Kupang Watershed with its outlet located in diversion point of Loji River and Banger River is compared with the discharge observation data that obtained from the Kupang Kuripan AWLR. Flow hydrograph used in this simulation is the discharge with a return period of 25 years as a upstream boundary condition on steady flow using HEC-RAS 6.1.

Hydraulic analysis is conducted with numerical modeling using HEC-RAS 6.1. According to Istiarto (2014) to carry out flood routing in rivers, it is necessary to simulate unsteady flows. And to estimate the flood water level along the river, a steady flow simulation can be carried out, provided that the calculated flood water level will be higher than it should be (overestimate). The hydraulic simulation in HEC-RAS is based on one-dimensional energy conservation equation. The momentum equation is used when there is a rapid change in the water surface profile. The energy conservation equation is formulated as follows:

$$Y_2 + Z_2 + \frac{\alpha_2 {V_2}^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 {V_1}^2}{2g} = h_e \tag{1}$$

Where :

Y1, Y2 = flow depth at cross sections
Z1, Z2 = elevation of the main channel inverts
V1, V2 = average velocities
α1, α2 = velocity weighting coefficients
g = gravitational acceleration

he = energy head loss

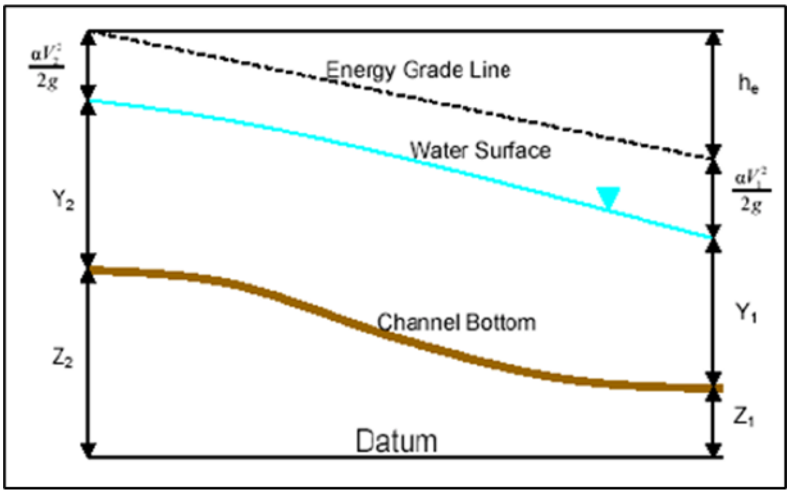

Figure 3. Energy equation diagram

The energy head loss (he) between two cross sections is consisted of friction losses and contraction/expansion losses. The equation of the energy head loss is as follows:

$$h_e = L\,\bar{S}_f + C\,.\left[\frac{\alpha_2 {V_2}^2}{2g} - \frac{\alpha_1 {V_1}^2}{2g}\right] \quad (2)$$

Where:
L = discharge-weighted reach length
Sf (bar) = representative (average) friction slope between two sections
C = expansion (or contraction) loss coefficient

The distance weighted reach length, L, is calculated as follows:

$$L = \frac{L_{lob}\,\bar{Q}_{lob} + L_{ch}\,\bar{Q}_{ch} + L_{rob}\,\bar{Q}_{rob}}{\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}} \quad (3)$$

Where:
L_{lob}, L_{ch}, L_{rob} = cross section reach lengths specified for flow in the left overbank, main channel, and right overbank, respectively
Q_{lob}, Q_{ch}, Q_{rob} = flows between sections for the left overbank, main channel, and right overbank, respectively

Cross section subdivision for conveyance calculation. The determination of total conveyance and the velocity coefficient for a cross section requires that flow be subdivided into units for which the velocity is uniformly distributed.
The approach used in HEC-RAS is to subdivide flow in the overbank areas using the input cross section n-value break points (locations where n-values change) as the basis for subdivision. Conveyance is calculated within each subdivision from the following form of Manning's equation (based on U.S. Customary units):

$$Q = KS_f^{\,1/2} \quad (4)$$

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$$K = \frac{1,486}{n} AR^{2/3} \tag{5}$$

Where:
K = conveyance for subdivision
n = Manning's roughness coefficient for subdivision
A = flow area for subdivision
R = hydraulic radius for subdivision (area / wetted perimeter)

In this modeling, four things were used as input: long and cross section data of the Loji River, initial conditions, and manning coefficients, boundary conditions (upstream and downstream). Tidal analysis used to be downstream boundary condition on this study. That was done using the Admiralty method that developed by AT Doodson in 1928. This method calculates the amplitude and lag phase of nine tidal components, there are M2, S2, N2, K1, O1, M4, MS4, K2, and P1. With these 9 components, the reference sea level can be calculated are the highest high water level (HHWL), mean water level (MSL), lowest low water level (LLWL). Tidal analysis using the Admiralty method also provides a Fromzhal number (F) which can be used to determine the classification of tidal types. The input data that used was the result of field observation of hourly sea level tides. The data was compared with BIG's prediction data from BIG website to see the accuracy of the data.

a. Mean Sea Level (MSL)
   MSL = A (S0)
b. Lowest Low Water Level (LWL)
   LLWL = A(S0) – (A(M2) + A(S2) +A(K1) +A(O1) +A(P1) +A(K2) A(N2)
c. Highest High Water Level (HHWL)
   HHWL = A(S0) +(A(M2) + A(S2) +A(K1)+A(O1) +A(P1) +A(K2) +A(N2)
d. Formzahl (F)
   F=AK1+AO1

Where :
F : Tidal constant

Figure 4 below illustrates the flow chart of the major steps of carried out in the present study.

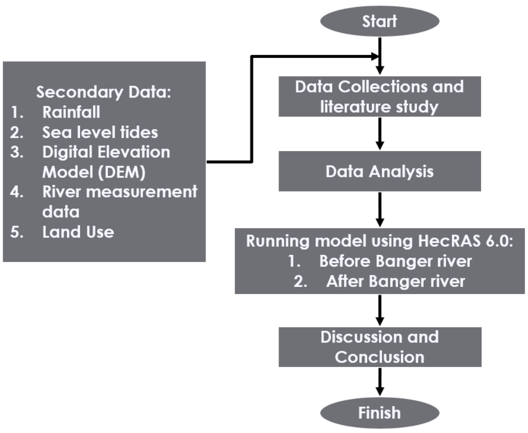

Figure 4. Flow chart of modelling

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3. RESULT AND DISCUSSION

The result of flood modeling is obtained by using 1-D Modeling (One Dimensional Modeling) using steady flow HEC-RAS 6.1 Software.

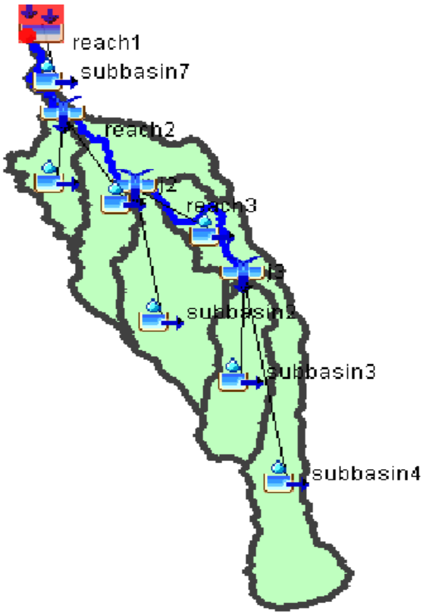
4.1 HYDROLOGY ANALYSIS

Estimated rainfall plan is done by four methods: Normal, Log Normal, Gumbel, and Log Pearson Type III. Each of these methods uses statistical parameters which include the mean, standard deviation, coefficient of variation and coefficient of skewness (Ratna Musa et al., 2014). Based on Chi-Square and Smirnov-Kolmogorov test results, the Log Pearson Type III distribution is selected. Then the discharge with a return period of 25 years is calculated using HEC-HMS 4.6.1 with SCS USH for upstream boundary before Banger River exist with a maximum discharge value of 317.68 m^3/s. And discharge with a return period of 25 years for upstream boundary after Banger River wa built with a maximum discharge value of 163.40 m^3/s.

Table 2. Kupang Watershed Annual Maximum Daily Rainfall

No.	Year	Sta. Pekalongan	Sta. Kletak	Sta. Wonotunggal	Sta. Kurtosari	Ttotal
		1.28%	6.93%	7.40%	84.39%	
1	2001	125	122	88	112	111.08
2	2002	175	166	230	209	207.14
3	2003	150	154	124	96	102.78
4	2004	159	153	127	113	117.40
5	2005	91	81	132	82	85.75
6	2006	240	127	200	199	194.61
7	2007	209	120	185	222	212.03
8	2008	187	95	102	145	138.89
9	2009	138	87	104	201	185.12
10	2010	161	75	201	128	130.15
11	2011	101	102	126	114	113.89
12	2012	76	69	98	85	84.74
13	2013	133	95	144	106	108.40
14	2014	239	216	277	285	279.04
15	2015	135	119	183	200	192.30
16	2016	112	106	137	125	124.40
17	2017	130	89	166	102	106.19
18	2018	162	130	122	121	122.22
watershed area (km^2)		1.81	9.85	10.52	119.89	142.06

Table 3. SCS USH using HEC-HMS



Tr	HSS Flood Discharge using HEC-HMS (m3/s)
2	106.09
5	181.67
10	243.70
25	317.68
50	363.15
100	524.36

Figure 5. Kupang watershed Flood discharge using HECHMS 4.6.1 (before Banger River exist)

Table 4. Discharge Distribution on Kupang Kuripan AWLR (after Banger River was built)

No	Tr	Discharge Distribution on Kupang Kuripan AWLR (mm)			
		Normal	Gumbel	Log Normal	Log Pearson III
1	2	53.9097	45.1833	42.0064	36.4221
2	5	98.6093	92.1285	71.9834	65.5971
3	10	121.9973	123.2103	95.4165	98.1242
4	25	146.9299	162.4823	128.8539	163.4005
5	50	163.0317	191.6165	156.4443	238.2158
6	100	177.5125	220.5355	186.2683	345.8738

4.2 TIDAL ANALYSIS

The input data that used was the result of field observation of hourly sea level tides. The data was compared with BIG's prediction data from BIG website to see the accuracy of the data.

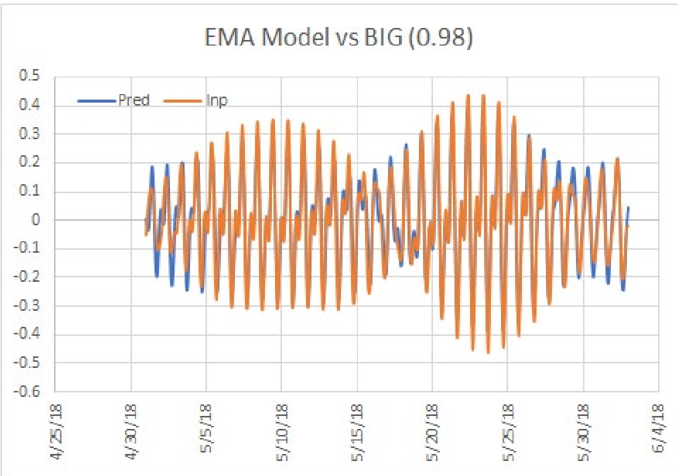


Figure 6. Comparison of Water Level Elevation from Model and BIG

The results of calculations using the Admiralty method is shown in Table 5. below:

Tabel 5. Calculation of Tidal Parameters using the Admiralty Method

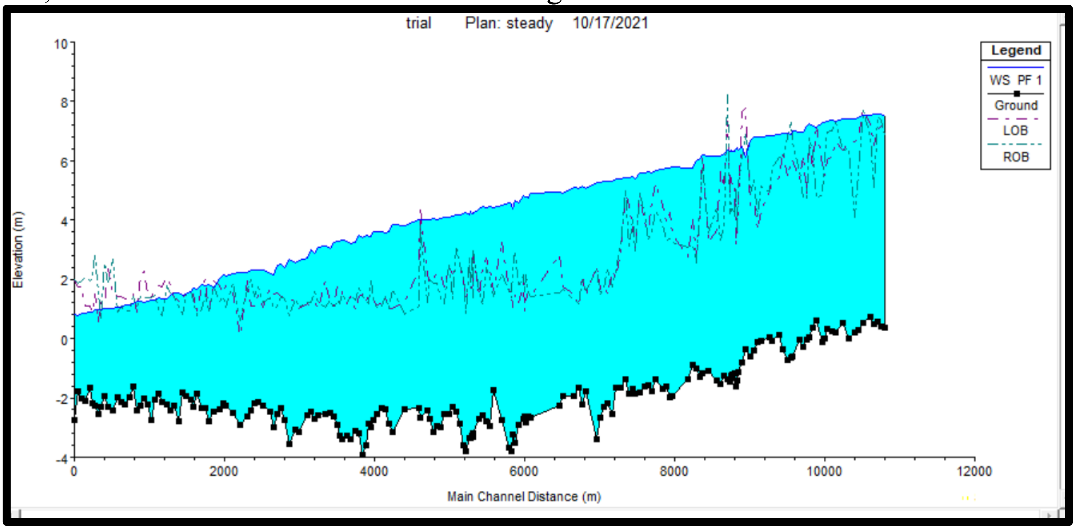
NAME	AMPLITUDE	PHASE	(G)	FREQUENCY	(OM)
K1	0.107	61.5	15.04107	182.3	0.935
O1	0.055	165.8	13.94304	219.1	0.894
P1	0.263	349.8	14.95893	260.2	1
Q1	0.01	104.2	13.39866	249.9	0.894
M2	0.088	173.3	28.9841	37.5	1.024
S2	0.17	25.5	30	90	1
N2	0.059	182.8	28.43973	68.3	1.024
K2	0.142	299.2	30.08214	185.3	0.837

F	0.627907
MSL	0.000264
HHWL	0.825264
LLWL	-0.82474
LAT	-0.89374

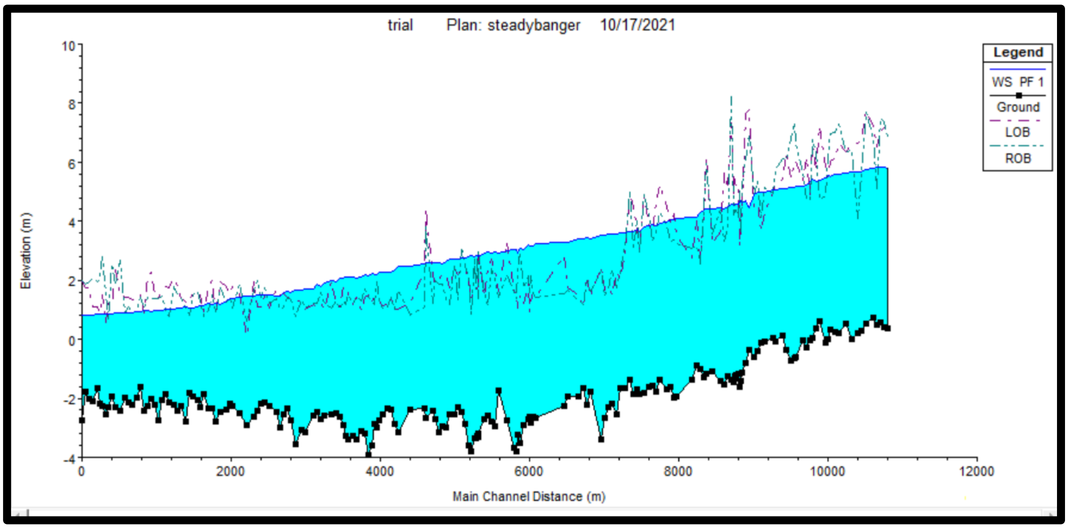
The results of tidal analysis were 0.825 m for HHWL, -0.824 m for LLWL, and 0.000264 m for MSL. The results of these calculations also provided a Formzhal number (F) of 0.0.627, where the F value was between 0.25 and 1.5, so the type of tidal at the Loji River estuary was mixed tides, prevailing semi diurnal. This mixed tide means in one day, there are 2 high tides and 2 low tides with different value between the first and the second high tides and the first and the second low tides as well.

4.3 HEC-RAS ONE DIMENSIONAL MODELING

The 1-D modeling using HEC-RAS 6.1 software for steady flow conditions using input data in the form of long section, cross section, boundary condition data upstream and downstream, and manning coefficient. The following figure is the result of modeling on the 1-D Kupang watershed before and after the Banger River Floodway was made. The result shows that the water level upstream before the existence of the Banger River was 7.5 m, whereas after the existence of the Banger River it was 5.8 m.



(a)



(b)

Figure 7. Results of 1D Modeling in the Loji river for a 25 years return period: (a) before the Banger river; (b) after the Banger river

4. CONCLUSIONS AND RECOMMENDATION

As can be seen from the simulation results above, the construction of the Banger River has reduced the water level in the Loji River. The water level upstream before the existence of the Banger River was 7.5 m, whereas after the existence of the Banger River it was 5.8 m. Further research is needed to find other infrastructure that can control the water level in the Loji river considering that the city of Pekalongan has the highest level of land subsidence in Indonesia.

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