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EVALUATION OF FACTORS CAUSING ORDO 3 RIVER FLOOD IN URBAN

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ABSTRACT

The Langsur is a tributary of the Bengawan Solo River (order 3). Every year, the river experiences great flooding. It has an area of 14.88 km^2 and a length of 12.20 km. It has an average slope of 0.0008 and a small meandering in the middle. Urbanization along the upstream watershed gradually proceeds. The river empties into the Samin River with wathershed of 303.46 km^2. It continues to flow into the Bengawan Solo River. The Upstream and middle stream of Langsur flows on the edge of Sukoharjo city. Therefore if a flood occurs, the social effect is always tremendous. The city district government consciously put great efforts into the control the flooding. Before detailed designing and physical implementations, it is necessary to evaluate the major causes of the flooding. This evaluation highlights some of the causes and it includes: analysis of bankfull capacity, river storage capacity, meandering as well as downstream water level effects. The result shows that the major causes of the flooding are the downstream water level and the narrowing of the crossing. Hopefully, with knowledge of the major factors that cause the flooding, it will be a lot easier for the policy maker to appropriately and effectively control the flooding.

Keywords: Appropriate and effectively, Bankfull capacity, Causes of flooding, Down stream water level, Urbanization.

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1. INTRODUCTION

1.1. Background

Lately, flooding occurs in almost all the regions in Indonesia. The cause of this is likely due to climate changes which resulted in a higher tendency for increased rainfall intensity, changes in the rainy season, the condition of the average watershed which is increasingly damaged, and the high average sedimentation rate.

The Langsur River Channel (order 3) and the entire watershed are located in the Sukoharjo Regency. The Langsur watershed has an area of 14.88 km^2 and a length of 12.20 km. The river enters the regency level, because the entire watershed and the outflow empty directly into the Samin River located in the Sukoharjo region as shown in Fig.1. The Samin water level fluctuation greatly influences the outflow of the Langsur.

Langsur was once swampy, however, due to the urbanization process it transformed into a potential rice field and settlement ground. In the past, floods were rare, this was because the river had an average width is of 10-20 m and a depth of 3-5m (P.T. Inakko, 2017.b). Today, the river has an average width area of 5-7 m and in a certain place there is a width of 10, but the depth is shallow.

When flooding occurs, the inundation height reaches up 0.20 to 1.00 m. The duration of this flood is up to 2 days. The flooding exposes the communities around the riverside areas to, financial losses, discomfort, destruction of valuables and declining agricultural yields. The river flows along the city, so of the impact of flooding are greatly felt. The government and community should take serious measures to overcome the floods.

Before determining how to deal with the flooding, it is a vital to conduct a study to determine the main causes of the flooding in the region. The study makes the handling easy, appropriate and more effective.

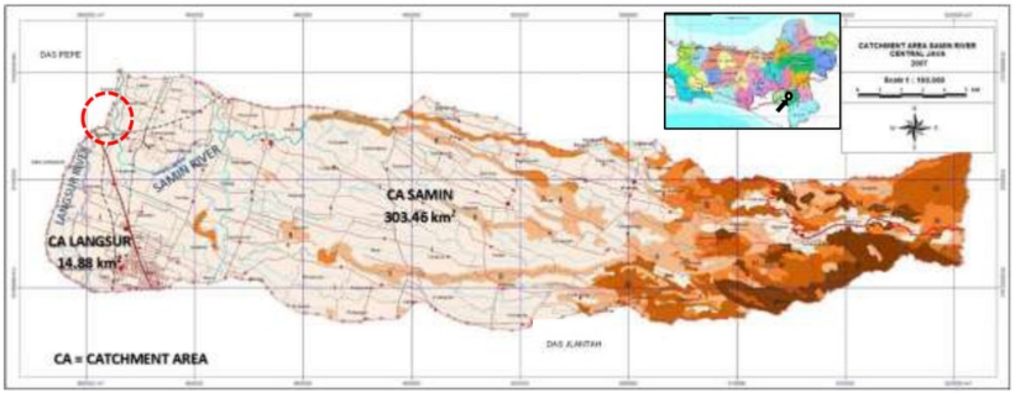

Figure 1 Langsur catchment area – Langsur and Samin River Meeting.

1.2. Location condition

The Langsur watershed is about 14.88 km^2. The river has a length of 12.20 km and is influenced by two rain stations: Grogol and Sukoharjo. The Samin watershed however has an area of 303.46 km^2 and this is influenced by 9 rain stations. The data of Daily rainfall used was for a period of 10 years, from 2007 to 2016.

The Langsur flooded villages around the flow as shown in Fig.2. This is a photo of a flood event 04/25/2017 (photos and information, from the Langsur River Care Community) during a PKM meeting (PKM: Community Consultation Meeting).

Meandering of Langsur is located in the midstream and it narrows in several places which hampers the flow velocity. Therefore it reduces the capacity of the river. Fig.3 shows river meandering and narrowing.

The midstream and downstream area of the Langsur was swampy once. This swampy land has the following characteristics: water infiltration levels are low, very small percolation, high groundwater level and a flat ground. The aforementioned factors are potential causes of flooding because of the low infiltration capacity and small capacity storage of infiltration volumes.

Figure 2 Flooding conditions of the villages passed by the river (PT. Inakko, 2017.a)

Figure 3 Meandering and narrowing (PT. Inakko, 2017.a)

The Langsur outlet meets with the Samin and it is shown in Fig.4. It has gates which are shown in Fig.5. The downstream water level conditions greatly affect the velocity of the river. Therefore, it affects the storage capacity of the river. A potential flooding might occur if the water level downstream (Samin River) equals or exceeds the water level of the Langsur.

2. METHOD

2.1. Research flow

To analyze the causes of flooding, the identification of the field is carried out first such as collection of river morphology data, river systems, hydrology and measurement of the river situations. The next stage is hydrological analysis, which includes the river capacity discharge (bankfull), design discharge, hydraulic analysis, analysis of river flow conditions (including meanders and outlets), condition of existing structures, space around the river body, and the bankfull volume.

An analysis uses the HEC-RAS softwater (U.S. Army CEIWR - HEC, 2001). It is also includes the GIS Map to measure the teristis and reassuring the field survey. From the results of the field survey and analysis above which is supported by existing data, the causes of flooding can be deciphered.

The principle of analysis of this research is: Existing bankfull discharge analysis (Q_{bf}), the bankfull volume analysis, Q_d water level and flood mark.

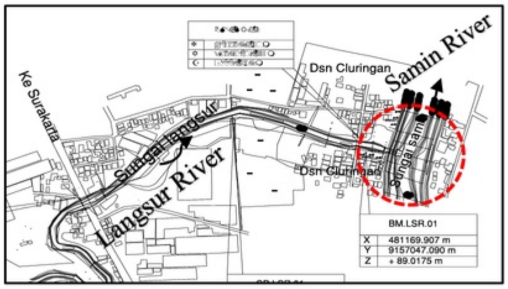

Figure 4 The meeting point of Langsung and Samin

Figure 5 The gate of Langsur river

If $Q_{bf}<Q_2$, this means the existing section is narrow and this is a potential factor that causes flooding.

Analysis of water level conditions in outlets is conducted. If the Samin water level is higher, it blocks the discharge of the Langsur. Furthermore, if the water level of the Langsur is higher, it makes its river flow with little discharge. The volume of the Langsur River discharged during the overflow will be accommodated by the Langsur River body. If the volume is not accommodated, flooding will be occurred.

River shortcut (straightening) simulations are carried out in several meandering locations. The water level at the upstream short cut is compared before and after the shortcut simulation. From the studies above, the dominant elements that cause flooding will be highlighted. These elements were noted as an important flood control measure to ensure an effective control of the flooding. The Research flow chart is shown in Fig.6

2.2. Causes of Floods

Flooding is a condition where water flowing cannot be accommodated by its channels capacity. This leads to an overflow in the surrounding areas (Suripin, 2004). According to Keller, 2000: Flooding occurs when the water discharge exceeds the capacity of the river and the excess water overflows into surrounding plains.

Factors that cause flooding can be broadly classified into two: Natural and Human factors. According to Robert J. Kodoatie and Sugiyanto, 2002, natural factors include: Rainfall, area and shape of watershed, topographic conditions and river morphology, erosion and sedimentation, decreased river capacity, influence of downstream / tidal water levels, and poor drainage systems. Whereas human factors include: improper watershed processing, development that reduces river capacity, waste disposal, low legal awareness, inadequate maintenance of rivers.

2.3. Flood Discharge Analysis using HEC-HMS Software

HEC-HMS is software developed by U.S Army Corp of Engineering in 2006.

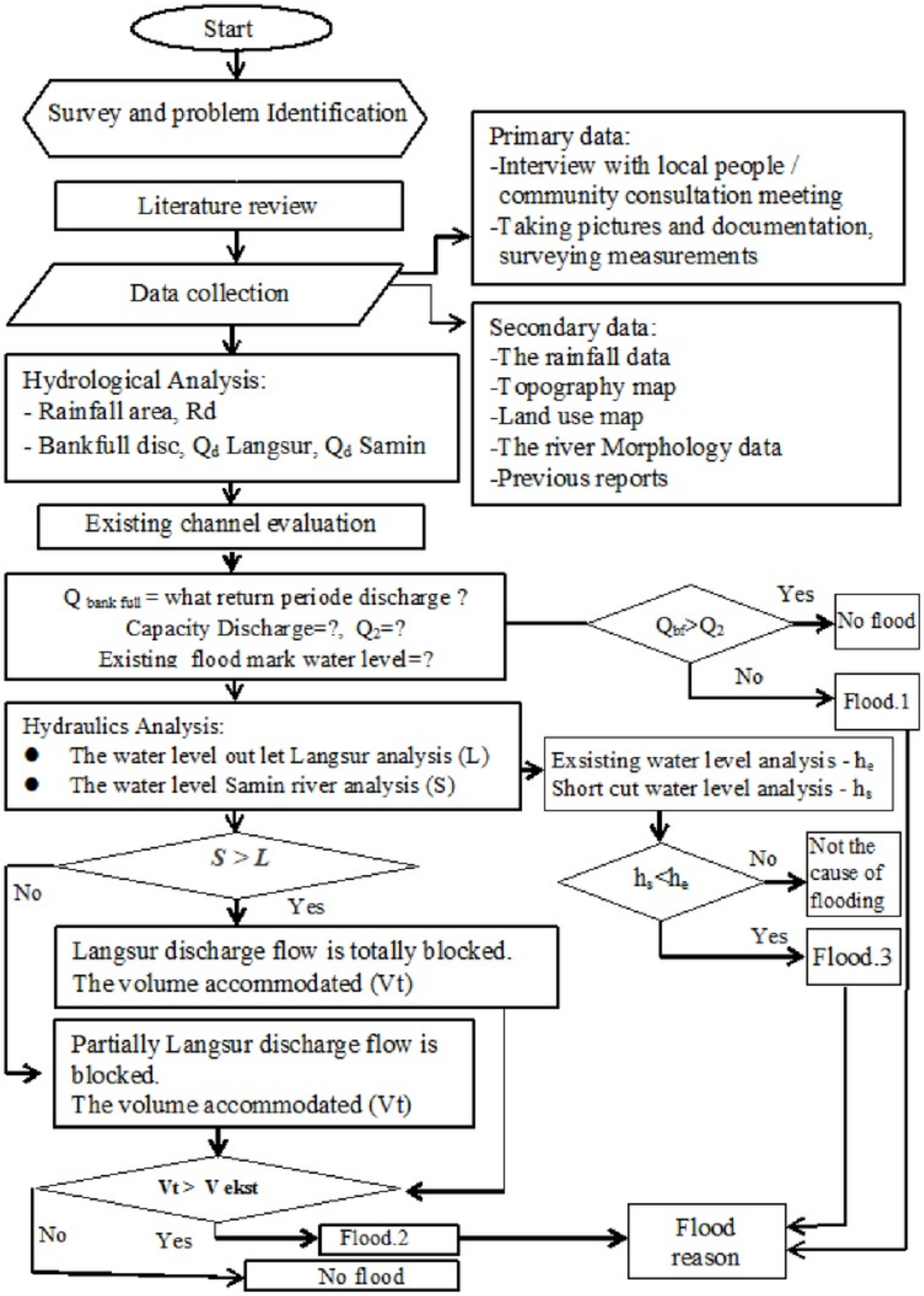

Figure 6 Research Flow Chart

This software is used for hydrological analysis by simulating the process of rainfall and run off from a riverside area. HEC-HMS is designed to be applied to a very large geographic area to solve the problems. This includes water supply for river drainage areas, hydrology of floods and water runoff in small town areas or natural water catchment areas. The resulting unit hydrograph can be used directly or combined with other software for analysis of water availability, urban drainage, forecast impacts of urbanization, overflow design, reduction of flood damage, regulation of flood handling, and hydrological operating systems.

The HEC-HMS model can provide hydrological simulations from the peak of the daily flow to calculate the design flood discharge from a watershed. The HEC-HMS model includes various methods used in hydrological analysis. In the HEC-HMS model, the classical unit hydrograph theory is used, including Synder, Clark, SCS (Soil Conservation Service) synthetic hydrograph, and there is also an option to develop another unit hydrograph using the user define hydrograph (US Army Corps of Engineering, 2001) facility. Meanwhile, to complete this hydrological analysis, a synthetic unit hydrograph from SCS (Soil Conservation Service) is used by analyzing several parameters, then this hydrograph can be adjusted to the conditions in Java.

The basic concept of calculation from the HEC-HMS model is the rainfall data as water input for one or several sub-catchment sub-areas being analyzed. The data type is in form of intensity, volume, or cumulative volume of rain. Each sub-basin is considered a non-linear reservoir where the inflow is rainfall data. Furthermore, the surface flow, infiltration, and evaporation are components that emerge from the sub-basin.

2.4. Hydraulic Analysis uses HEC-RAS Software

HEC-RAS is a program package from ASCE (American Society of Civil Engineering). This program makes use of standard steps as a basis for calculation.

The main components included in the HEC-RAS analysis are: steady flow water surface profile computations; unsteady flow simulation; and calculation of water level profile. This program package is used to calculate water level profiles along river sections. Input data for this program are cross section data along the river, river elongation profiles, river hydraulic parameters (basic roughness and riverbanks), river structures parameters, design discharge, and water level downstream / in the estuary.

The output of this program can be in form of graphs or tables. Amongs them are plots from river flow schemes, cross sections, profiles, rating curves, hydrographs (stage and flow hydrograph), and also other hydraulic variables. In addition, the results of this program can also display a cross section that forms a complete three-dimensional river channel with flow.

After the cross section has been determined, HEC-RAS calculates the water level profile. The basic concept of calculating water level is based on open channel energy equation with the following formula, with illustration of Fig.7:

$$Y_2 + Z_2 + \frac{a_2\ V_2^2}{2\,\mathrm{g}} = Y_1 + Z_1 + \frac{a_1\ V_1^2}{2\,\mathrm{g}} + h_e$$

The next step in the calculation of HEC-RAS is to assume the water surface value of the initial cross-section of the channel (the downstream part). Then by using the energy equation, the water profile for all cross sections can be known.

2.5. Channel Geometry

Most of the rain events resulted in an increase in the river discharge. Besides the discharge, erosion and sedimentation also increased. Flood and sedimentation are not entirely stored in the bankfull, but some overflow into floodplain. Part of the discharge that overflows into floodplains does not affect the formation of troughs / river formations. The bankfull discharge represents the formation of a bankfull.

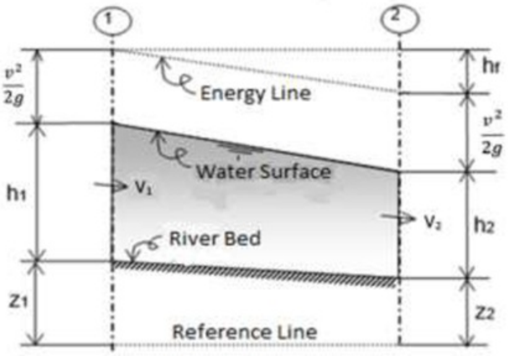

Figure 7 Energy at Open Channels (Suripin, 2004)

This bankfull discharge is very vital in the formation of troughs and survives on the long term (a stable trough). A bankfull crossing can be equalized with the magnitude of the discharge when it starts overflowing into flood plains, see Fig.8.

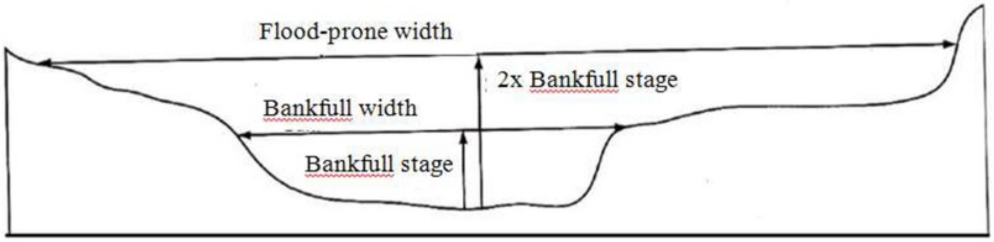

Figure 8. Illustration of the width and stage of Bankfull (Fangmeier, dkk, 2006)

Bankfull discharge can be compared to discharge return period 1-3 years (Q_1-Q_3) (Fangmeier, et al, 2006). Rosgen, 1996, obtained an amount of bankfull equivalent to $Q_{1.5}$ for rural areas and $Q_{1.2}$ for urban areas. Doll et al., 2002, got the equivalent of $Q_{1.3}$ for urban areas and $Q_{1.4}$ for rural areas.

Changes in the shape of river troughs (bankful width) are responses to changes in sediment supply and continuous flow patterns (Graf, 1975, Leopold, 1973). Paul and Meyer, 2001: urbanization on watersheds will be addressed in relation to the shape of river troughs according to the process sequence as shown in Fig.9.

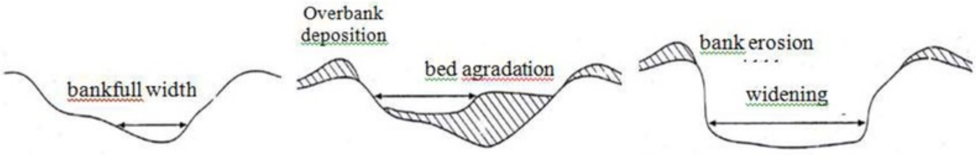

Figure 9 Changes in cross section due to watershed urbanization (Paul dan Meyer, 2001)

Existing bankfull cross section is the result of a long process of relatively stable hydraulic conditions. Changes in watershed due to continuous urbanization cause increasing sedimentation in rivers. This increment results in narrowing of the trough section. However, if the urbanization stops, so land cover increase also stops (housing, asphalt roads). This will result in a decrease in the level of sedimentation, but an increased discharge. Next, erosion occurs in the trough, and a new bankfull development appears which can even be wider (Hammer, 1972).

3. RESULT AND DISCUSSION

3.1. Result analysis

3.1.1. Bankfull capacity

The Langsur flow is divided into 4 sections, namely section one in the upstream section (from P244-P168), section two (from P168-P128), section three (from P128-P68) and section four downstream (from P68-P0). This is done to increase the efficiency of the dimensional design because of varying amounts of discharge. From the HEC RAS analysis (trial and error), the bankfull discharge is successive: $Q_{bf1} = 15.4\ m^3/s$, $Q_{bf2} = 15.8\ m^3/s$, $Q_{bf3} = 20.5\ m^3\ s$, $Q_{bf4} = 90\ m^3/dt$.

The results of return period discharge analysis its succession are: $Q_2 = 60\ m^3/s$, $Q_5 = 71.2\ m^3/s$, $Q_{25} = 86.2\ m^3/s$, $Q_{50} = 92\ m^3/s$. Samin river discharge: $Q_2 = 1053.8\ m^3/s$, $Q_5 = 1285.3\ m^3/s$, $Q_{25} = 1707.1\ m^3/s$, Q50 = 1906.8 m^3/s.

The flood discharge that had occurred in the River Langsur based on the flood mark (Flood mark) Fig.10 as high as 0.60 cm in P190 (section 1) was: 32.36 m3/sec.

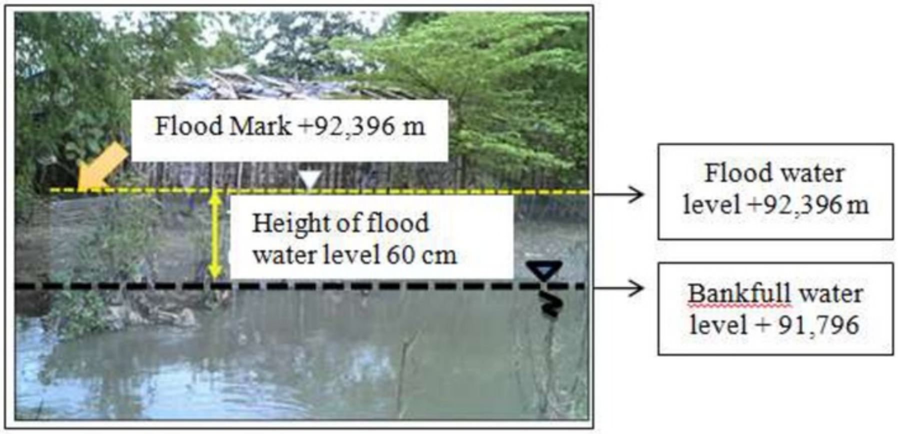

Figure 10 Flood Mark

From the HEC-RAS analysis, the water level relation in the outlet (meeting) of the Langsur River and Samin River to discharge during the same return period (analyzed separately) as Table 1 below:

Samin water level is always higher. Therefore, the flow is always stalled at the time of large discharge / flood. The water level in the Langsur out let and Samin at Q_{25} conditions are as shown in Fig.11

The volume of water during the river discharge is suspended (Q_{25}): 3,306,780 m^3. The volume of water during the discharge of the Langsur River is suspended (Q_2): 2,336,580 m^3. Bankfull volume (capacity volume) along the existing straight river: 126,345 m^3. The capacity of the river Q_{bf} and Q_2 for each section is shown in Table 2.

Tabel 1 Water level at the Langsur River outlet

Qt Return period	Langsur river		Samin river	
	Q (m3/dt)	Out let water level (m)	Q (m3/dt)	Water level at Langsur out let (m)
2	60	86.24	1053.8	89.48
5	71.2	86.51	1285.3	90.13
25	86.2	86.83	1707.1	91.17
50	92	86.94	1906.8	91.62

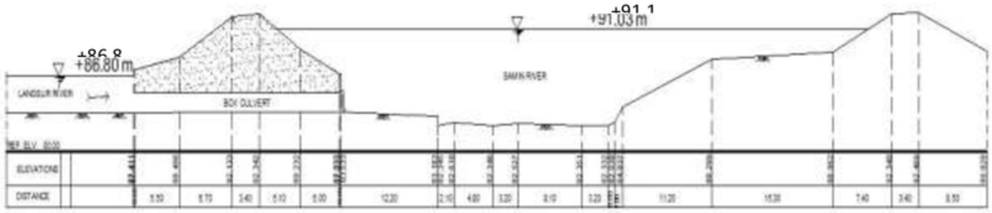

Figure 11 Water level in Langsur out let Q_{25}

Tabel 2 The comparison of Q_{bf} and Q_2 of Langsur river Per sections

section	Q_{bf} (m^3/dt)	Q_2 (m^3/dt)	Information
1	15.4	46.1	Overflowing
2	15.8	52.4	Overflowing
3	20.5	58.4	Overflowing
4	90	60	Not overflowing

Discharge return period per section, as shown in Table.3 as follows:

Tabel 3 Debit Return period per section

Section	Q2 (m3/dt)	Q5 (m3/dt)	Q10 (m3/dt)	Q25 (m3/dt)	Q50 (m3/dt)
1	46.1	53.3	59.3	65.2	69.3
2	52.4	61.1	67.3	74.2	79.1
3	58.4	69.3	76	83.9	89.5
4	60	71.2	78.1	86.2	92

Based on the extrapolation of the discharge of return period in Table 3, the amount of flood mark and bankfull discharge for each section are as follows:

Flood mark discharge is equivalent to $Q_{0.3}$, and $Q_{bf1} \approx Q_{0.03}$, $Q_{bf2} \approx Q_{0.03}$, $Q_{bf3} \approx Q_{0.03}$, than $Q_{bf4} \approx Q_{50}$

3.1.2. River Short Cut Simulation

The results of the river short cut simulation analysis, elevation and water level in the upstream short cut (6 short cut locations) and existing conditions (meandering conditions), based on Q_2 as in Table 4.

Tabel 4 Water level decrease in upstream due to river Short Cut based Q_2

No	STA		Length (m)		upstream water level (+m)		Decreases (Δh) (m)	Water level high
	start	end	existing	short cut	existing	short cut		existing
1	P.175	P.162	650	420	92.43	92.23	0.2	2.84
2	P.150	P.141	450	240	91.88	91.56	0.32	3.71
3	P.128	P.117	550	240	91.34	91.26	0.08	3.63
4	P.74	P.67	350	180	89.31	89.19	0.12	3.35
5	P.54	P.39	750	300	88.82	88.56	0.26	3.84
6	P.28	P.16	600	220	87.96	87.81	0.15	3.38
					Average		0.19	3.46
						In %	5.45	

3.2. Discussion

Stable river crossing is when the bankfull discharge (river capacity) Q_{bf} is equivalent to the discharge between Q_1-Q_3 (Fangmeier, et al, 2006). The current river discharge capacity exists currently per successive sections such as Table 2. The capacity of the river in all sections is smaller than in Q_2, except for section 4. Thus, it can be ascertained that in almost every year there will be flooding. Especially in section 4: $Q_{bf} > Q_2$, so there is no flood every year. The last flood that occurred was shown in the flood mark in P.190 (section 1) and it was as high as 0.60 m, from the back analysis, the magnitude of $Q = 32.36\ m^3/s$.

The amount of the discharge is equivalent to $Q_{0.3}$ return period which is far below two years. This indicates that floods always occur yearly. In addition, Paul and Meyer, 2001 reported that the process of river morphology from a stable condition (existing bankfull) narrows due to high sedimentation. This results due to an increase in upstream urbanization, and will attain a new stability if the urbanization process stops.

If the urbanization process is completed, the land is mostly covered with buildings, the roads with asphalt, leading to a decrease in sedimentation and an increase in run off. Therefore, the river erodes to attain a new balance which will be wider. The watershed is gradually experiencing urbanization characterized by an increasing population. The urbanization process changes the extent of impervious natural vegetation and agricultural land which is widespread (Dobbs at al., 2014; Robinson and Lumbholm, 2012). This is relevant to the research of Jing Li et al., 2017, which states that higher the ratio of grass land cover (plant), it will result a decrease in discharge and a later accurrance of the flood peak. Langsur in the opposite position, the ratio of land cover decreases (due to urbanization), so that the discharge increases and the time of peak Tc is short.

The Langsur outlet meets with the Samin. The Samin discharge in each return period is much greater than the Langsur discharge (Table.1). This is easy to understand because the area of the Samin basin is much larger. From the HEC-RAS analysis, the Samin water level elevation at the meeting point and during the discharge with the same return period is always higher. This caused the river to be retained in the Langsur, as a result back water occurred. The volume of Langsur discharge which was blocked by the Samin water level during the period of rain accumulated in Langsur. This volume, for $Q_2 = 2{,}336{,}580\ m^3$, and for $Q_{25} = 3, 306, 78\ m^3$. If the volume is compared with the storage ability of the Langsur, the value is $126{,}345 m^3$, then it can be ascertained that there is a flood. The extent of the flood and the duration of the inundation is dependent on the time of the river discharge to flow out.

The river short cut simulation results in certain places, with Q_2 existing water levels (meandering conditions) which is higher than the water level after short cut (Table 4). But the average decline is just 19 cm or 5.45%. Thus, the meandering effect on the causes of flooding is not significant.

From the analysis above, it can be concluded that the capacity of the river (cross section) and the condition of outlet is the main cause of floods. And because the Langsur system does not have another outlet, the storage pond and pump are needed to deal with flooding.

4. CONCLUSION AND RECOMMENDATION

4.1. Conclusion

The floods that occurred in the Langsur River were caused by the following:

- The existing section could not accommodate dominant debit (Q_2) that occurred, especially in section 1 to section 3. River capacity (bankfull discharge) Q_{bf} is smaller than Q_2 inferring the river section in the process is narrowed.
- In a downstream river mouth, the Samin water level elevation is higher than the Langsur water level during the flooding conditions (in the same return period), resulting in a discharge from the Langsur that cannot flow into the Samin (exit), so flooding occurs in the Langsur.
- Decreasing water levels due to river short cut is not significant. Therefore meandering the river is not the main cause of flooding.
- The main cause of flooding is the condition of outlet and the narrow cross section.

4.2. Recommendation

In designing, the capacity of the Langsur and the condition of the outlet needs to be considered before taking any action. The Langsur dimension must be able to skip Q_{25}, and it is necessary to design storage pond to accommodate the Langsur discharge which is blocked by Samin. It must also have a Pump to get rid of trapped water.

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