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STUDY ON THE CAUSES OF FLOODING IN BATANG MAHAT, LIMA PULUH KOTA REGENCY, WEST SUMATERA

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***Abstract**. This research is located in Batang Mahat Lima Puluh Kota Regency, about 9.26 km^2 from the narrowing location at Batu Kisok to the upstream, prone to flood. Due to several flooding events in Batang Mahat, various assumptions and hypotheses have emerged regarding the causes of Batang Mahat flooding. This research analyses the causes of flooding in Batang Mahat using Steady Flow simulation in HEC-RAS 6.2 software. The result implies that two factors caused the flood: (1) The channel capacity is insufficient to accommodate flood water discharge, where the simulation results shown at the Q_{50} discharge (2003.07 m^3/s) flood inundated several areas in cross-sections upstream and tributary. (2) The impact of the narrowing location at the river channel in Batu Kisok, which is shown by the simulation of a decrease in water elevation at eight cross-sections at the upstream and two cross-sections at the tributary after the cross-sections in Batu Kisok are widened from ±30 m to ±45 m (50%), ±60 m (100%), and ±75 m (150%).*
Keywords: Batang Mahat; flood; HEC-RAS

1. Introduction

In the last few decades, Buchenrieder *et al*. (2021) stated that the number and volatility of extreme natural hazards worldwide have increased tremendously. Floods are one of the most dangerous and increasingly frequent natural hazards causing many human and economic losses (Tanir *et al*., 2021; FAO, 2015). However, not only caused by the natural aspect, such as the high intensity of rainfall (Manhique *et al*., 2015), some human activities, such as increasing human settlements, unplanned urbanization, economic assets in floodplains (Abass, 2020; Amoako & Boamah, 2015) reducing natural water retention by land use and climate change also contribute to an increase in the risk of the flood disaster.

A flood is the costliest hazard which can cause fatalities, displacement of people, environmental damage, and severely end economic development (Remo *et al*., 2016; Tella & Balogun, 2020; Ullah *et al*., 2020). According to Khan *et al*. (2018), Flood-related damage is more likely in developing countries, where there is typically less disaster protection and inadequate planned infrastructure. In terms of the agriculture sector, floods can cause severe damage to agricultural production and threaten food security on both local and national scales (Balica *et al*., 2013; FAO, 2017; Rahman & Di, 2020). Agriculture remains a significant source of income, particularly for rural households in developing countries, where approximately 2.5 billion people, 60% of whom live in developing countries, rely almost entirely on agriculture for a living,

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producing more than half of global food production on small farms (Balgah *et al*., 2023). Ahmad and Afzal (2022) stated that flood-prone farming community is more vulnerable to climatic risks. Also, small farmers consider heavy rains and severe floods risks to agricultural production and are more risk-averse than large farmers.

This research is located in Batang Mahat, Pangkalan Koto Baru district, Lima Puluh Kota Regency, West Sumatera, which is situated in 00°13′ – 00°25′ South Latitude and 100°37′ – 100°56′ East Longitude. Based on its geographical position, Pangkalan Koto Baru District is bordered to the north by Kampar Regency, Riau Province, to the south by Harau District, to the west by Bukit Barisan District and Kapur IX District, and to the east by Kampar Regency, Riau Province (see Figure 1).

This research analyses an area of about 9.26 km^2 from the narrowing location at Batu Kisok to the upstream part of Batang Mahat, shown in Figure 2. At this location, there is a branch of Batang Mahat, which is Batang Manggilang/Malagiri. According to community information, this area flooded in 1961, 1968, 1972, 1978, 1984, 1991, 1998, 2005, and 2017 (PSDA, 2017), and the latest flood also occurred in 2019, 2020, and 2021.

The most significant flood occurred in March 2017, inundating the land and settlements in Pangkalan Koto Baru. This flood phenomenon was recorded to cause severe material losses and paralyze community activities as several essential facilities at the Pangakalan Koto Baru were inundated. Due to several flooding events in Batang Mahat, various assumptions and hypotheses have emerged regarding the causes of Batang Mahat flooding. First, by looking at Batang Mahat, hydraulic characteristics, specifically found around the Pangkalan Koto Baru bridge, are characterized by a lack of smooth flow due to the shape of the floodplain terrain and the relatively gentle slope of the riverbed and the meandering system. Such conditions are related to hydro topographic (rainfall) and geological (river bedrock) characteristics, cliff erosion activity (widening), sedimentation (silting), and narrowing of the river channel (bottleneck) hampered by hard rock blocks (PSDA, 2017). The research by Dalrino *et al.* (2018) applied to the HEC-RAS Program to analyze the Batang Mahat to the amount of flood discharge using a mathematical model approach. The model was done by Dalrino *et al.* (2018) using one-dimensional steady flow analysis. The research results obtained a general solution that suggested normalizing the river cross-section to enlarge the wet cross-section of the flow. Syahputra *et al.* (2019) also said that flooding on March 3rd, 2017, with a flood discharge of 2,745 m^3/s, was a rainfall phenomenon that caused the water discharge to exceed the carrying capacity of the Batang Mahat River.

Another research conducted by Herdianto *et al.* (2018) stated that the relatively large sedimentation rate in the upper reaches of the Batang Mahat due to the effects of land-use changes is also indicated to have the potential to lead to the silting of the river, which in turn can have an impact on flooding. Therefore, this research analyzed the causes of flooding in Batang Mahat using GIS and HEC-RAS 6.2 software.

Figure 1. Location of Batang Mahat in Pangkalan District, Lima Puluh Kota Regency

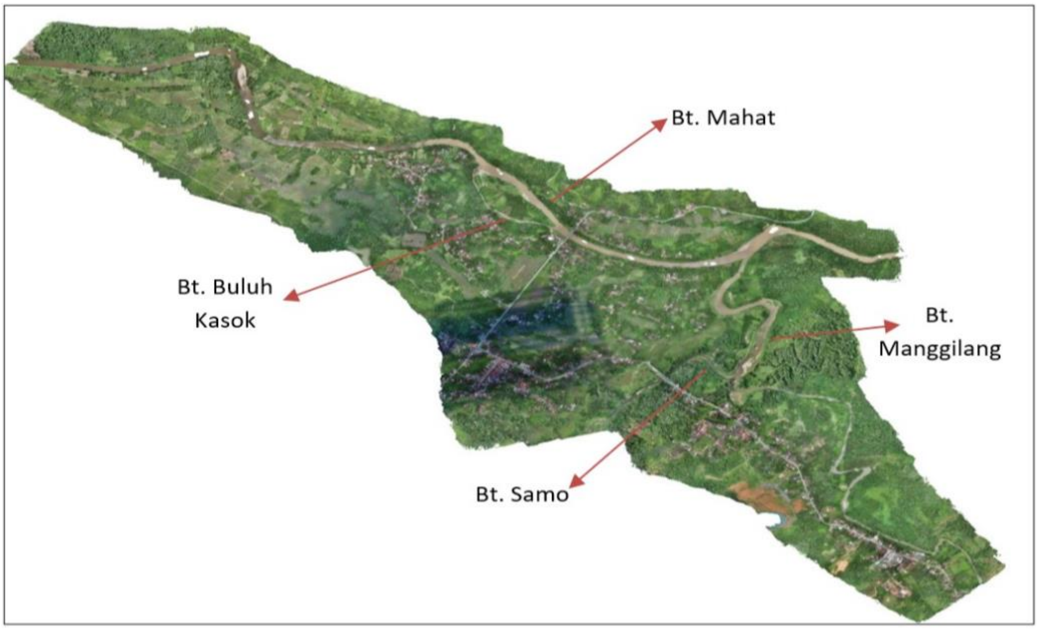


Figure 2. Batang Mahat and its tributaries

2. Methods

This research uses GIS and HEC-RAS 6.2 software. GIS is used to create the study area's river geometry, which can provide the elevation of ground and riverbeds. This research used DEM data from DEMNAS with an 8-meter resolution to create the river geometry. This DEM data was used because, according to Junaidi and Syandriaji (2023), who conducted a comparative analysis of DEMNAS, Terrestrial Measurement data, and Photogrammetry by UAV, the results indicated that the DEM derived from DEMNAS with an 8 m resolution is sufficiently accurate for flood simulation purposes. At the same time, HEC-RAS is used to compute and simulate this research by using Steady Flow analysis on the Batang Mahat River and its tributaries, Batang Manggilang/Malagiri. The utilization of steady flow analysis is commonly employed in flood analysis utilizing HEC-RAS. Oktaga *et al.* (2015) flood is a non-uniform unsteady flow that can be simulated using HEC-RAS. In HEC-RAS, unsteady flow modeling results can sometimes refer to errors and warnings caused by an unstable analysis program. Among other things, the stability program influenced the bend in the river flow, the steep slope of the river bottom, and changes in cross-section shape. Because flood handling necessitates maximum discharge and flood water level, a steady flow is frequently used to simulate flood flow. Oktaga *et al.* (2015) also stated that based on their research, steady non-uniform flow modeling tends to have higher water level elevation than inconsistent non-uniform flow modeling results.

In the geometric data editor in HEC-RAS (see Figure 3), all the required modifications and editing were done, such as determining the manning value and cross-section filtering points. This research refers to Dalrino *et al.* (2018), which provides Manning values of 0.025 for Batang Mahat's main channel and 0.033 for the river bank.

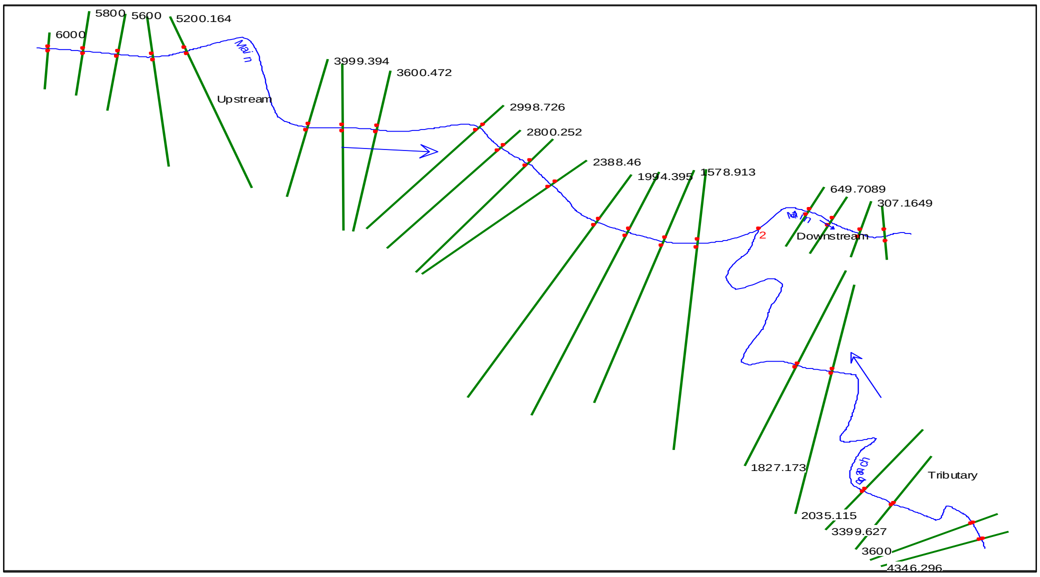


Figure 3. The result of RAS imported geometric data in HEC-RAS

The hydrological analysis was done to perform the Steady Flow analysis in HEC-RAS. Hydrology analysis is carried out to obtain design flood discharge data. The methods used to calculate the design flood using these data are Frequency Distribution Analysis (Normal, Lognormal, Gumbel, and Log-Pearson type III) and Nakayasu Synthetic Unit Hydrograph. This research uses frequency analysis Log-Person Type 3 and Nakayasu Synthetic Unit Hydrograph for 2-, 5-, 10-, 25-, 50-, and 100-year returns periods. In this study, the hydrology analysis will use Rainfall Data from rainfall stations Sontang and Suliki for 16 consecutive years, as shown in Table

1. These rainfall stations were chosen because at the study site, the rain gauge location is relatively far from the delineation of the catchment area, and these two stations are the nearest. The location can be seen in Figure 4.

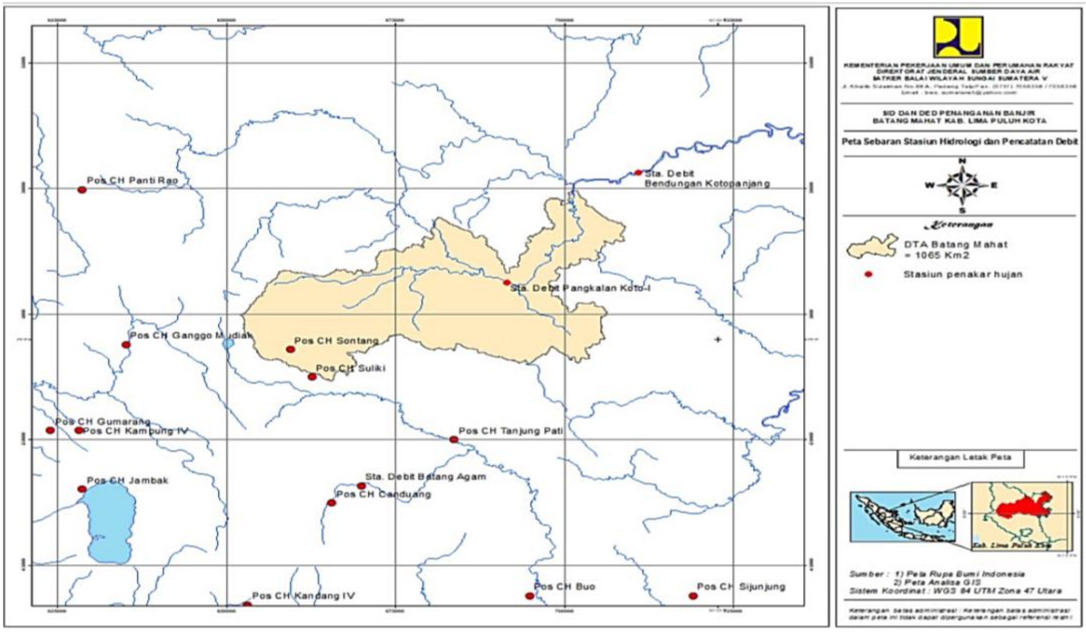


Figure 4. Location of rain and discharge station around Batang Mahat watershed

Table 1. Maximum rainfall data from sta. Sontang and sta. Suliki

No	Year	Max Rainfall		Average maximum rainfall (mm)
		Sta. Suliki	Sta. Sontang	
1	2020	68	39	54
2	2019	79	80	80
3	2018	94	160	127
4	2017	80	108	94
5	2016	82	125	104
6	2015	79	93	86
7	2014	73	90	82
8	2013	67	71	69
9	2012	68	32	50
10	2011	140	94	117
11	2010	65	60	63
12	2009	72	89	81
13	2008	107	100	104
14	2007	67	100	84
15	2006	74	250	162
16	2005	62	82	72

The calculation of the design flood is done by making a flood pattern using the Nakayasu method, and the amount of Q_{max} is calculated by the equation (1).

$$Q_{\mathrm{maks}} = \frac{1}{3.6} . A . \frac{Ro}{T_P + T_{0.3}} \qquad (1)$$

The form of the hydrograph is as equation (1-5).

○ Rising limb curve $0<t<T_P$

$$Q = \left(\frac{t}{T_P}\right)^{\frac{2}{4}} . Q_{maks} \quad (2)$$

○ Decreasing limb curve, condition -> $T_P<t< (T_P+T_{0.3})$

$$Q = 0.3^{\left(\frac{t-T_P}{T_{0.3}}\right)} . Q_{maks} \quad (3)$$

○ Decreasing limb curve, condition -> $T_P + T_{0.3}<T_P+T_{0.3}+1.5T_{0.3}$

$$Q = 0.3^{\left(\frac{t-T_P+0.5T_{0.3}}{1.5T_{0.3}}\right)} Q_{maks} \quad (4)$$

○ Decreasing limb curve, condition -> $TP+T_{0.3}+1.5.\ T_{0.3}<t$

$$Q = 0.3^{\left(\frac{t-T_P+0.5T_{0.3}}{2T_{0.3}}\right)} Q_{maks} \quad (5)$$

Where:

Q_{max} = Peak discharge (m^3/s)
Ro = Rain unit (mm)
A = Catchment area (km^2)
T_P = time log from the start of the rain to the peak of the flood (hr)
$T_{0.3}$ = time required by the discharge to decrease from peak discharge to 30% of peak discharge (hours).

The condition as below:

$T_P = T_g + 0.8\ T_r$

$T_{0.3} = \alpha T_g$ (α = Coefficient around 1.5 – 3.5)

For: L >15 Km ⟶ $T_g = 0.4 + 0.058\ L$

L <15 Km ⟶ $T_g = 0.21.L^{0.7}$

Where:

T_g = Lag time in the river stream (hour)
Tr = The time unit of rainfall (hours)
L =river Length

The results of the design flood discharge are obtained by the equation (1-5), shown in Table 2.

Table 2. Design flood discharge of Batang Mahat (upstream), Batang Malagiri (tributary), and Batu Kisok (downstream).

Return Period	**Q Batang Mahat (Upstream)**	**Q Batang Malagiri (Tributary)**	**Q Batu Kisok (Downstream)**
	1	**2**	**1+2**
2-year	610.73 (m^3/s)	410.89 (m^3/s)	1021.62 (m^3/s)
5-year	795.32 (m^3/s)	534.13 (m^3/s)	1329.44 (m^3/s)
10-year	919.50 (m^3/s)	617.03 (m^3/s)	1536.54 (m^3/s)
25-year	1084.73 (m^3/s)	727.34 (m^3/s)	1812.07 (m^3/s)
50-year	1199.27 (m^3/s)	803.80 (m^3/s)	2003.07 (m^3/s)
100-year	1322.34 (m^3/s)	885.97 (m^3/s)	2208.31 (m^3/s)

3. Results and Discussion

The simulation was done at six discharge profiles of $Q_{2\text{-year}}$, $Q_{5\text{-year}}$, $Q_{10\text{-year}}$, $Q_{25\text{-year}}$, $Q_{50\text{-year}}$, and $Q_{100\text{-year}}$ return periods. According to the simulation, the massive flood in Batang Mahat in 2017 was with the $Q_{50\text{-year}}$ return period discharge. The results revealed that the catastrophic flood that struck Batang Mahat in 2017 was associated with a discharge corresponding to the Q50-year return period. It also strongly correlates with the flood height in the seven reference locations collected through field interviews with the community. The seven locations are Rice field, Mesjid Raya Pangkalan, TPQ Nurul Falah, Police station (Polsek) Pangkalan, gas station (SPBU) Pangkalan, RM Ombak, and SRC Iswandi Mart. At the discharge of Q50 (2003.07 m3/s), the flood occurred in an area of about 2.47 km^2, and the seven reference locations were flooded. The result of the field interview and simulation of flood height during the 2017 phenomena can be seen in Figure 5.

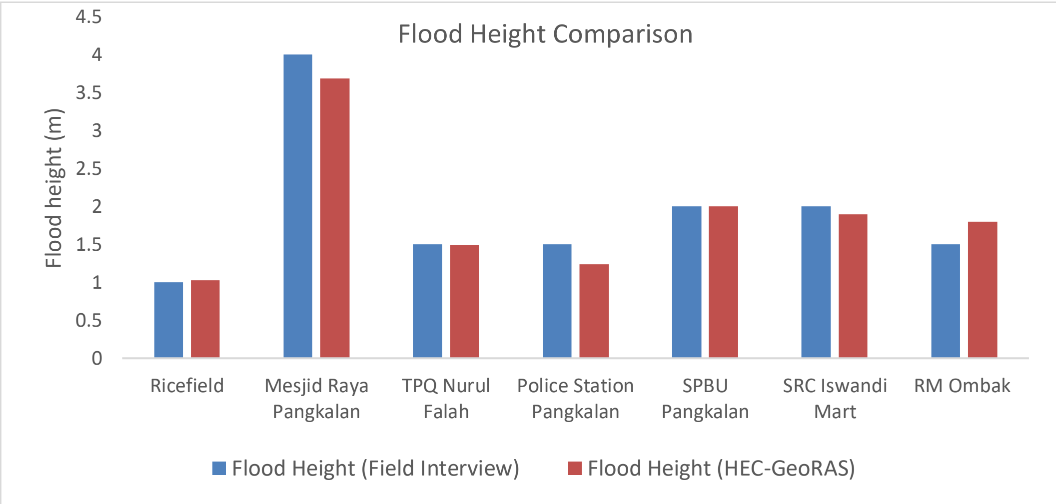


Figure 5. Flood height comparison between field interview and flood simulation

Also, the water elevation table in Table 3 shows the highest water elevation at the starting point of Bt. Malagiri (sta. 4346.29), the area around this location is ±93.52. The average settlement elevation in this location is about ±91 m, meaning that the highest flood height can reach about ±2 m. In the upstream part of Batang Mahat (sta. 5800), the highest water elevation is ±93.39 m, and the average settlement elevation is about ±89 m, meaning that the highest flood height in this location can reach about ±4 m. Lastly, in the area around Batu Kisok (sta. 649.709), the highest water elevation is +87.75; however, in these locations, there is a cliff around the river which caused this area not to be affected by the flood. This condition implies that the channel capacity of Batang Mahat is insufficient to carry the flood water discharge.

Looking at the simulation result and the river geometry of Batang Mahat, there is a narrowing location in the downstream part of the river where the flood did not affect the area around this location. Based on the geographic condition of Batang Mahat, this part of the river is a narrow location surrounded by cliffs, and there is also a big rock called Batu Kisok, as shown in Figure 6.

Table 3. Water elevations of Q_{50} year discharge for each cross-section.

RiverCode	ReachCode	Sta.	Profile	Water Elevation
Branch (Bt. Malagiri)	Tributary	4346.296	Q_{50}	+93.52
Branch (Bt. Malagiri)	Tributary	4209.762	Q_{50}	+93.37
Branch (Bt. Malagiri)	Tributary	3600	Q_{50}	+93.05
Branch (Bt. Malagiri)	Tributary	3399.627	Q_{50}	+91.92
RiverCode	**ReachCode**	**Sta.**	**Profile**	**Water Elevation**
Branch (Bt. Malagiri)	Tributary	2035.115	Q_{50}	+88.74
Branch (Bt. Malagiri)	Tributary	1827.173	Q_{50}	+88.91
Main (Bt. Mahat Up)	Upstream	6000	Q_{50}	+93.22
Main (Bt. Mahat Up)	Upstream	5800	Q_{50}	+93.39
Main (Bt. Mahat Up)	Upstream	5600	Q_{50}	+93.14
Main (Bt. Mahat Up)	Upstream	5398.76	Q_{50}	+91.91
Main (Bt. Mahat Up)	Upstream	5200.164	Q_{50}	+92.01
Main (Bt. Mahat Up)	Upstream	3999.394	Q_{50}	+90.84
Main (Bt. Mahat Up)	Upstream	3797.555	Q_{50}	+91.04
Main (Bt. Mahat Up)	Upstream	3600.472	Q_{50}	+90.69
Main (Bt. Mahat Up)	Upstream	2998.726	Q_{50}	+88.97
Main (Bt. Mahat Up)	Upstream	2800.252	Q_{50}	+89.80
Main (Bt. Mahat Up)	Upstream	2602.475	Q_{50}	+89.56
Main (Bt. Mahat Up)	Upstream	2388.46	Q_{50}	+89.49
Main (Bt. Mahat Up)	Upstream	1994.395	Q_{50}	+89.14
Main (Bt. Mahat Up)	Upstream	1799.477	Q_{50}	+89.19
Main (Bt. Mahat Up)	Upstream	1578.913	Q_{50}	+89.06
Main (Bt. Mahat Up)	Upstream	1384.871	Q_{50}	+89.12
Main (Batu Kisok)	Downstream	649.7089	Q_{50}	+87.75
Main (Batu Kisok)	Downstream	495.1637	Q_{50}	+87.69
Main (Batu Kisok)	Downstream	307.1649	Q_{50}	+87.34
Main (Batu Kisok)	Downstream	153.8967	Q_{50}	+85.15

Figure 6. The Narrowing Location in Batu Kisok Caused the Bottleneck to the River.

According to measurement data, the river elevation at Batu Kisok is the lowest compared to the other area in Batang Mahat, where the river's depth at Batu Kisok reaches 15 meters. Also, from the long section of Batang Mahat River, as shown in Figure 7 and Figure 8, the river elevation in Batu Kisok is about +75.45 m. At the upstream part of the river, the river elevation is +85.60 m. The river length is 6071.278 m, and the river slope can be obtained, which is about 0.00167.

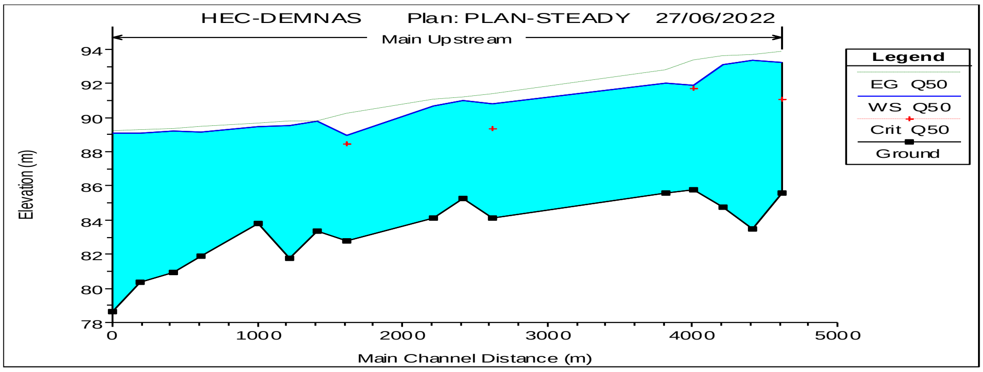


Figure 7. Long-section Bt. Mahat (upstream)

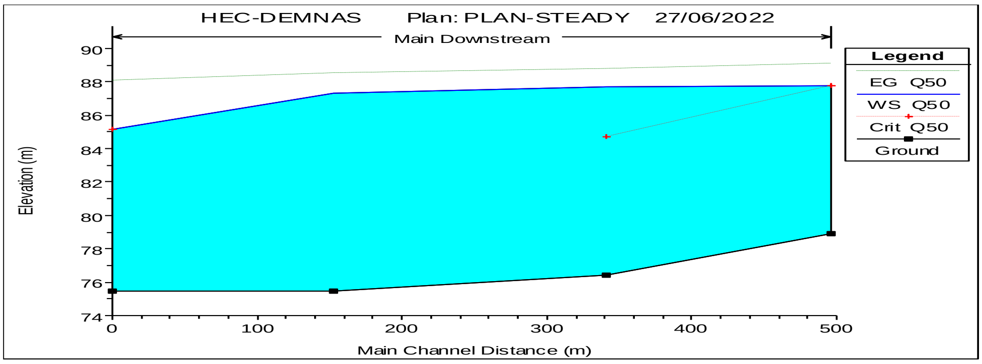


Figure 8. Long-section Batu Kisok (downstream)

Batu Kisok caused the bottleneck where the river's capacity is insufficient to accommodate the flood water discharge and caused flooding to the land and settlement area in the upstream part of Batang Mahat. In addition, by looking at the cross-section data from the HEC-RAS simulation, cross-section sta.153.897, where the Batu Kisok is located, has the smallest river width and the deepest riverbed compared to other cross-sections of rivers in Batang Mahat and Batang Malagiri. Cross-section sta.1994.395 (Upstream) and sta.1827.173 (Tributary) is taken as a comparison of river width and riverbed of cross-section sta.153.897 (Batu kisok), as shown in Figure 9, Figure 10, and Figure 11.

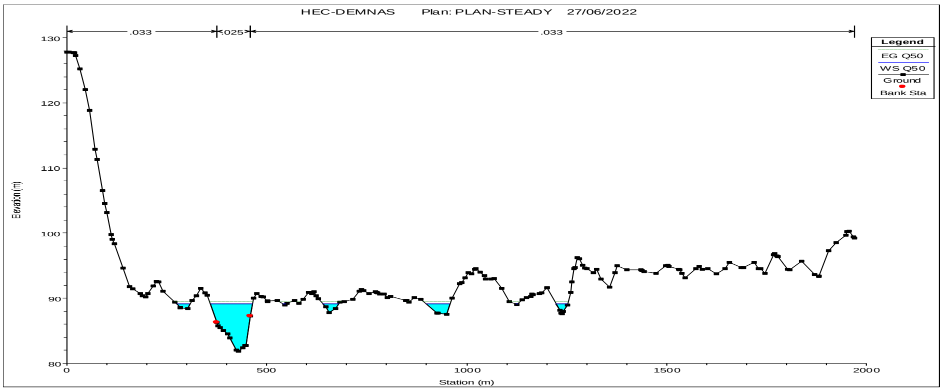


Figure 9. Cross-section sta.1994.395 at Bt.Mahat (upstream) with the discharge of Q_{50}

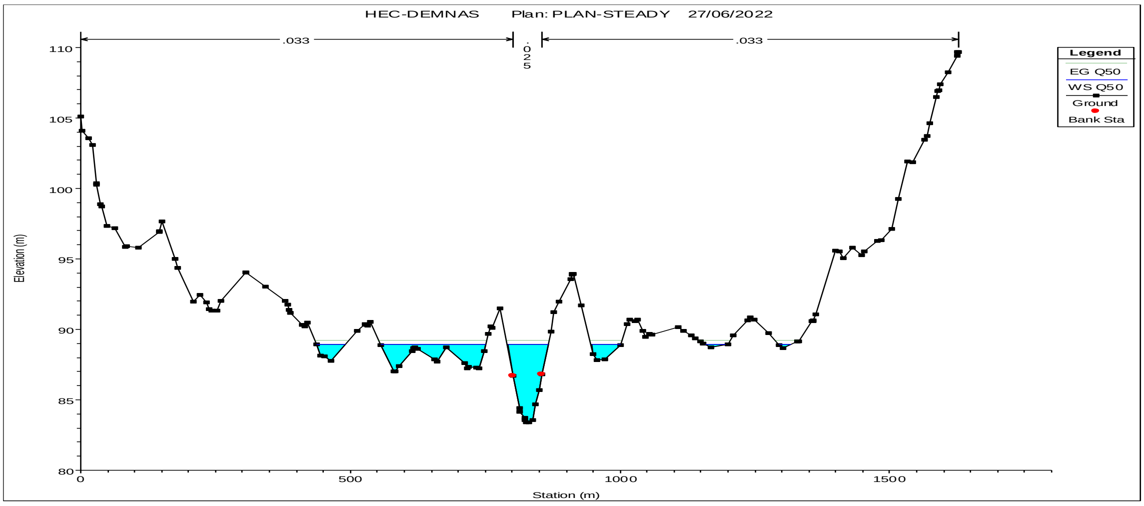


Figure 10. Cross-section sta.1872.173 at Bt. Malagiri (tributary) with the discharge of Q_{50}

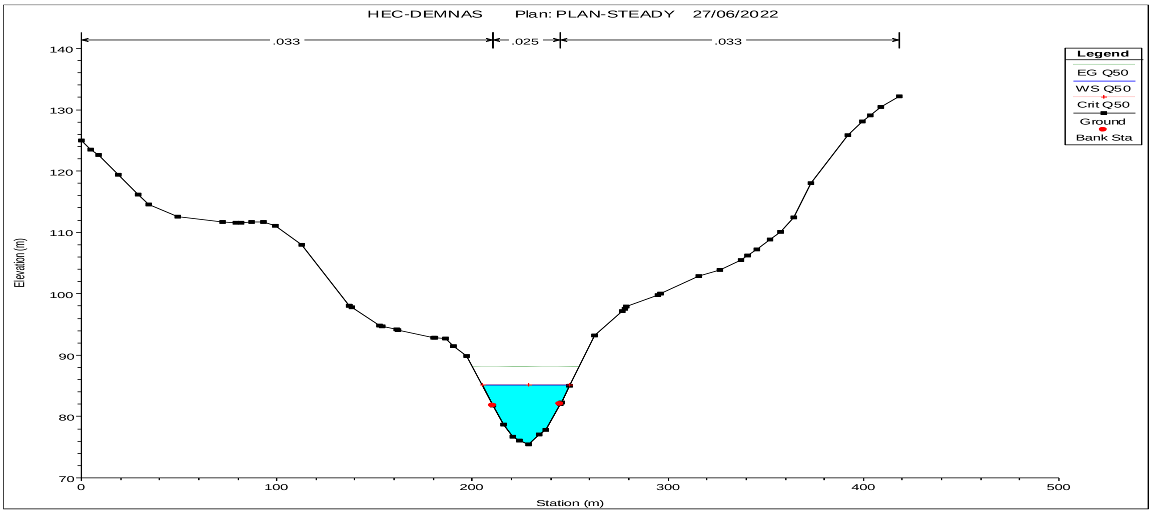


Figure 11. Cross-section of Sta. 153.897 at Batu Kisok (downstream) with the discharge of Q_{50}

Based on the Figure 9, Figure 10, and Figure 11, cross-section sta.1994.394 has a river width of about 84.06 m and riverbed of about 8 m, cross-section sta.1827.173 has a river width of 52.26 m and riverbed of about 6 m, and cross-section sta.153.897 has river width about 30 m and riverbed 17.76 m. According to this cross-section profile of Batang Mahat, the discharge of 2003.07 m3/s that flows to Batu Kisok (sta.153.897), which has a deep riverbed and narrow river, can cause flooding at the upper reaches of Batang Mahat (sta.1994.395) and Batang Malagiri tributary (sta. 1827.173).

Moreover, according to the cross-section profile, the river is only sufficient to accommodate water discharge at the maximum of about 1329.44 m3/s ($Q_{5\text{-year}}$ return period). While if more than 1329.44 m3/s, it would cause flooding to the settlement, as shown in the cross-sections in figures 9 and 10. To assess the impact of the narrowing location in Batu Kisok on the flood in Batang Mahat, this research aims to widen the cross-sectional area at this specific point. The widened cross-sections are sta. 153.897, sta. 307.165, sta. 495.164, and sta. 649.709, the river's dimension widens from ± 30 m to ± 45 m (50%), ± 60 m (100%), and ± 75 m (150%). The result of water elevation for each cross-section before and after the widening can be seen in Table 4.

Table 4. The change in water elevation before and after widening on cross-section sta. 153.897, sta. 307.165, sta. 495.164, and sta. 649.709

RiverCode	Sta.	Profile	Before Widening	Widening to ± 45 m (50%)	Widening to ± 60 m (100%)	Widening to ± 75 m (150%)
Branch (Bt. Malagiri)	4346.296	Q_{50}	93.52	93.52	93.52	93.52
Branch (Bt. Malagiri)	4209.762	Q_{50}	93.37	93.37	93.37	93.37
Branch (Bt. Malagiri)	3600	Q_{50}	93.05	93.05	93.05	93.05
Branch (Bt. Malagiri)	3399.627	Q_{50}	91.92	91.92	91.92	91.92
Branch (Bt. Malagiri)	2035.115	Q_{50}	88.74	88.26	88.26	88.26
Branch (Bt. Malagiri)	1827.173	Q_{50}	88.91	87.73	87.73	87.73
Main (Bt. Mahat Up)	6000	Q_{50}	93.22	93.22	93.22	93.22
Main (Bt. Mahat Up)	5800	Q_{50}	93.39	93.39	93.39	93.39
Main (Bt. Mahat Up)	5600	Q_{50}	93.14	93.14	93.14	93.14
Main (Bt. Mahat Up)	5398.76	Q_{50}	91.91	91.91	91.91	91.91
Main (Bt. Mahat Up)	5200.164	Q_{50}	92.01	92.00	92.01	92.01
Main (Bt. Mahat Up)	3999.394	Q_{50}	90.84	90.84	90.84	90.84
Main (Bt. Mahat Up)	3797.555	Q_{50}	91.04	91.04	91.04	91.04
Main (Bt. Mahat Up)	3600.472	Q_{50}	90.69	90.69	90.69	90.69
Main (Bt. Mahat Up)	2998.726	Q_{50}	88.97	88.43	88.43	88.43
Main (Bt. Mahat Up)	2800.252	Q_{50}	89.80	89.32	89.32	89.32
Main (Bt. Mahat Up)	2602.475	Q_{50}	89.56	88.99	88.99	88.99
Main (Bt. Mahat Up)	2388.46	Q_{50}	89.49	88.70	88.70	88.70
Main (Bt. Mahat Up)	1994.395	Q_{50}	89.14	88.08	88.08	88.08
Main (Bt. Mahat Up)	1799.477	Q_{50}	89.19	87.52	87.52	87.52
Main (Bt. Mahat Up)	1578.913	Q_{50}	89.06	86.05	86.05	86.05
Main (Bt. Mahat Up)	1384.871	Q_{50}	89.12	83.83	83.83	83.83
Main (Batu Kisok)	649.7089	Q_{50}	87.75	84.69	82.67	81.62
Main (Batu Kisok)	495.1637	Q_{50}	87.69	80.51	79.84	79.19
Main (Batu Kisok)	307.1649	Q_{50}	87.34	82.92	81.88	81.13
Main (Batu Kisok)	153.8967	Q_{50}	85.15	81.25	80.28	79.58

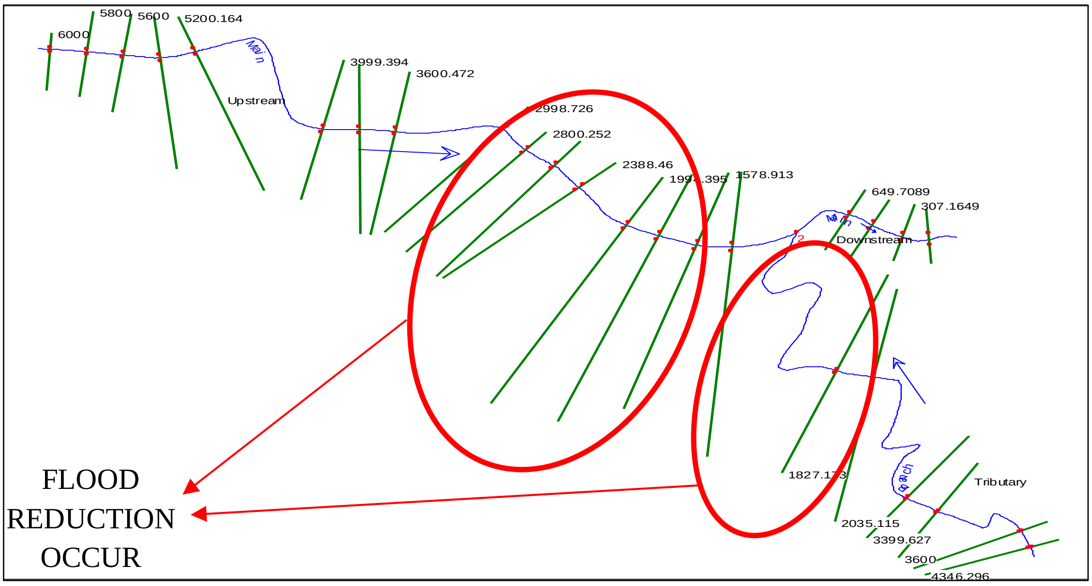
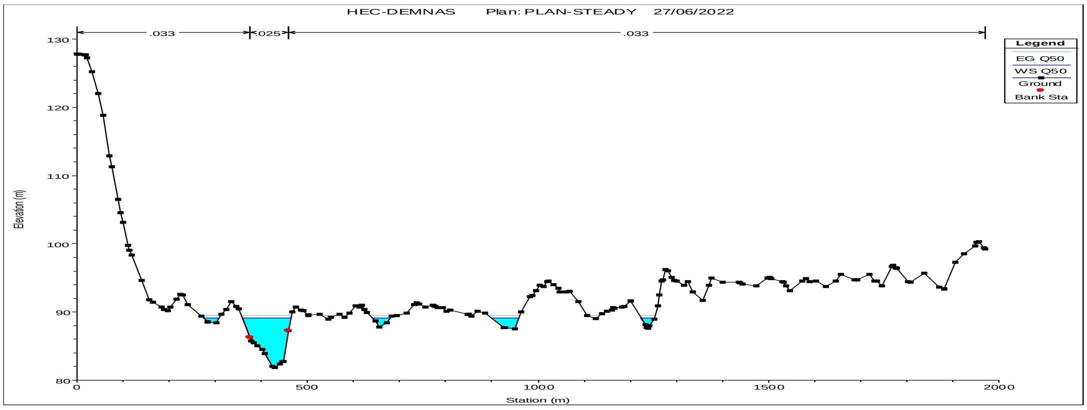
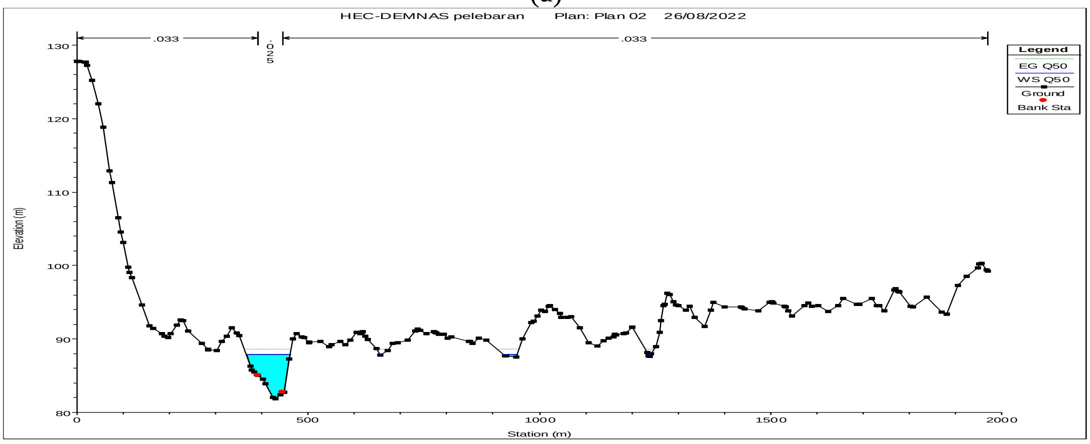


Figure 12. Flood Reduction Area after widening at the location of Batu Kisok.

According to Table 4, the affected flood reduction after widening is located only around Batu Kisok, as shown in Figure 12. After the widening at the cross-sections, sta. 153.897, sta. 307.165, sta. 495.164, and sta. 649.709, the result shows a significant flood reduction at cross-sections of sta. 1994.395, sta. 1799.477, sta. 1578.913, and sta. 1384.871 (see Figure 13, Figure 14, Figure 15, Figure 16), slightly reduced at sta. 2998.726, sta. 2800.252, sta. 2602.475, sta. 2388.46, sta. 2035.115, and sta. 1827.173. However, it can be seen in Table 4 that the variety of cross-section widening does not affect the flood reduction at the abovementioned cross-sections. The reduction of water elevation was already seen on the widening of ± 45 m, showing that the water elevations have the same value on widening by ± 60 m and ±75 m. Even with this result, it still can be said that the narrowing location at Batu Kisok could contribute to one of the factors that caused flooding in Batang Mahat. It shows that the problem of flooding in Batang Mahat is not only focused on one aspect in a particular location but also takes thorough study in every segment of the Batang Mahat River.



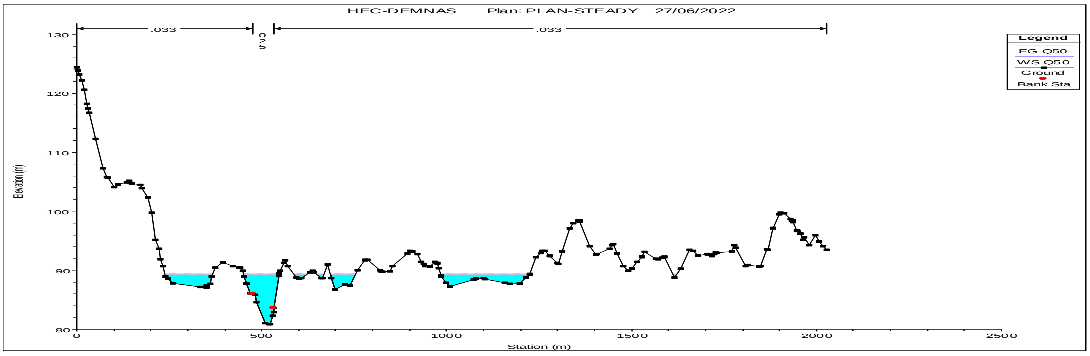
(a)



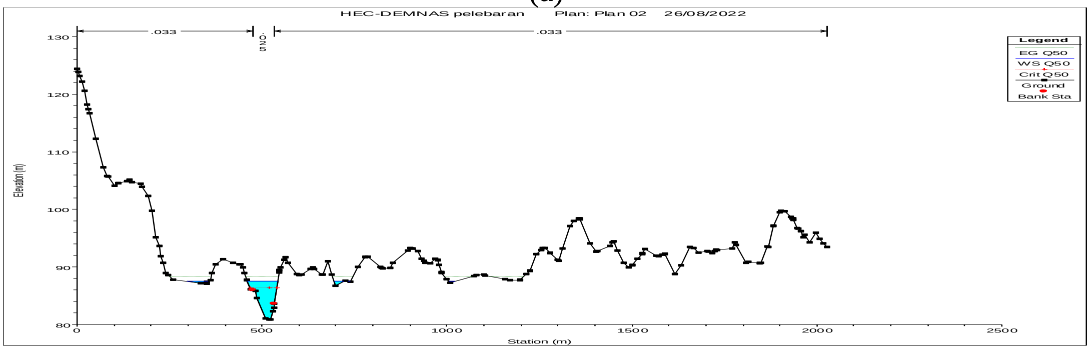
(b)

Figure 13. (a) Cross-section sta.1994.395 at Bt.Mahat (upstream) with the discharge of Q_{50} before the widening (b) Cross-section sta.1994.395 at Bt.Mahat (upstream) with the discharge of Q_{50} after the widening

In addition, the deep riverbed at Batu Kisok can be caused by several factors, including the high flow velocity that occurs in scouring, which causes the riverbed to deepen. Table 5 shows the velocity of each cross-section in Batang Mahat.

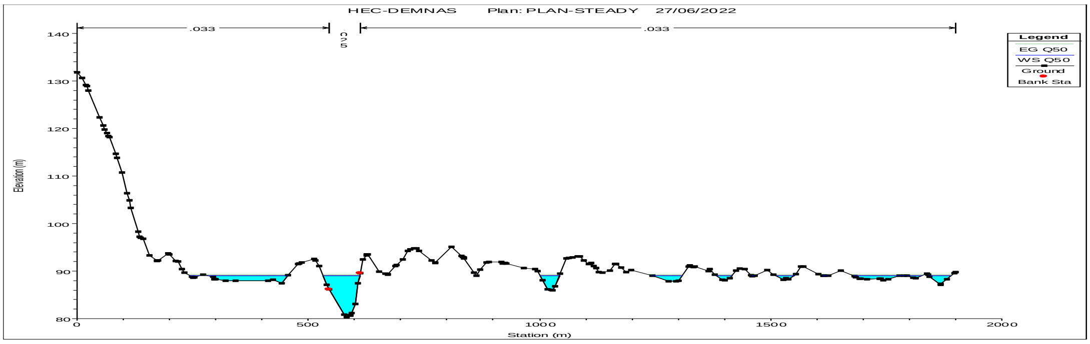


(a)

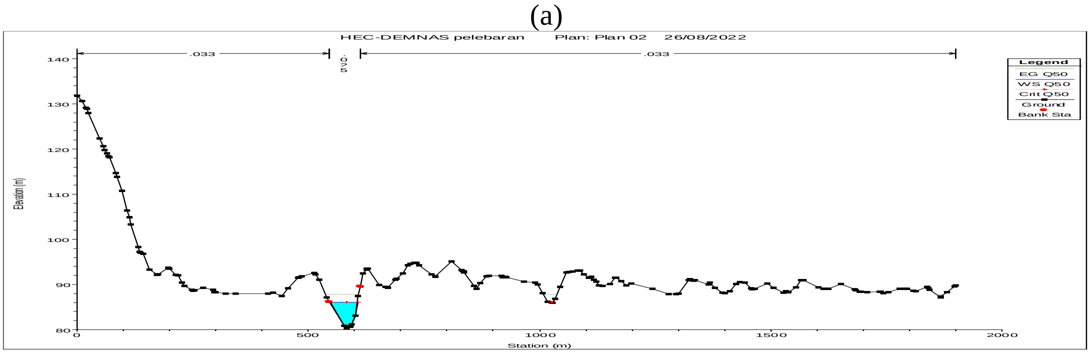


(b)

Figure 14. (a) Cross-section sta. 1799.477 at Bt.Mahat (upstream) with the discharge of Q_{50} before the widening (b) Cross-section sta. 1799.477 at Bt.Mahat (upstream) with the discharge of Q_{50} after the widening.



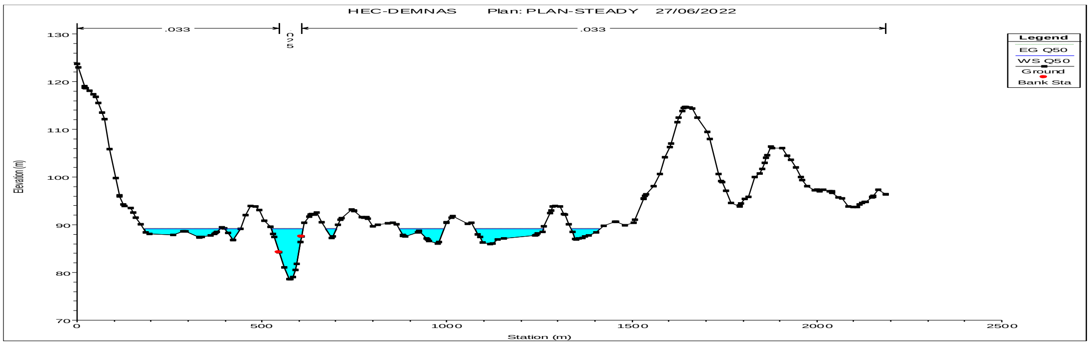
(a)



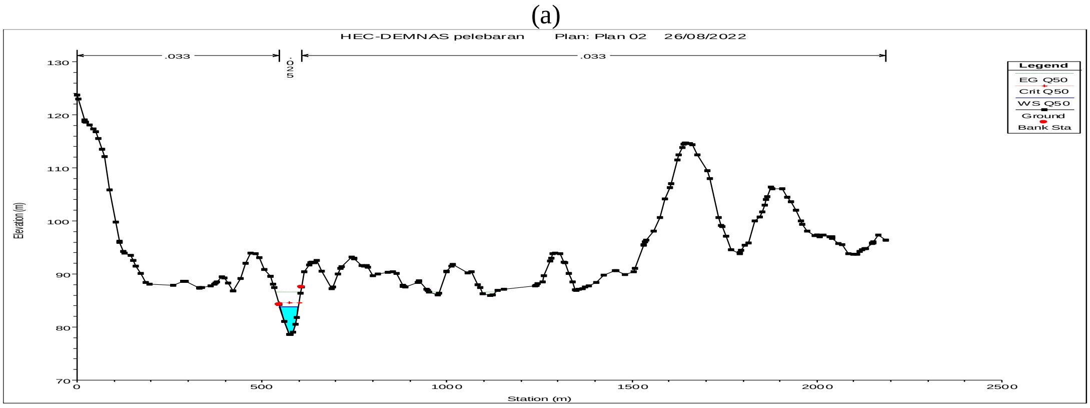
(b)

Figure 15. (a) Cross-section sta. 1578.913 at Bt.Mahat (upstream) with the discharge of Q_{50} before the widening (b) Cross-section sta. 1578.913 at Bt.Mahat (upstream) with the discharge of Q_{50} after the widening.

Based on Table 5, it can be seen that the velocity at the location of Batu Kisok at the discharge of Q_{50} is the highest among the other area on the upstream and tributary of Batang Mahat. In this location, at the discharge of Q_{50}, the velocity value is 9.16 m/s, while at Q_{normal}, the flow velocity is 7.60 m/s. This value is classified as "fast" according to Mason (1981), who categorized flow velocity into five groups: very fast (>100 cm/s), fast (50-100 cm/s), medium (25-50 cm/s), slow (10-25 cm/s), and very slow (<10 cm/s).



(a)



(b)

Figure 16. (a) Cross-section sta. 1384.871 at Bt.Mahat (upstream) with the discharge of Q_{50} before the widening (b) Cross-section sta. 1384.871 at Bt.Mahat (upstream) with the discharge of Q_{50} after the widening.

In addition, when viewed from the slope factor of the Batang Mahat watershed, which is dominated by areas with steep to very steep slopes of about 66.39%, the inundation location occurs in relatively flat and sloping areas (Figure 17). It happens because the steeper watershed causes more significant surface runoff, resulting in less infiltration. It also results in more runoff and flooding in flatter areas.

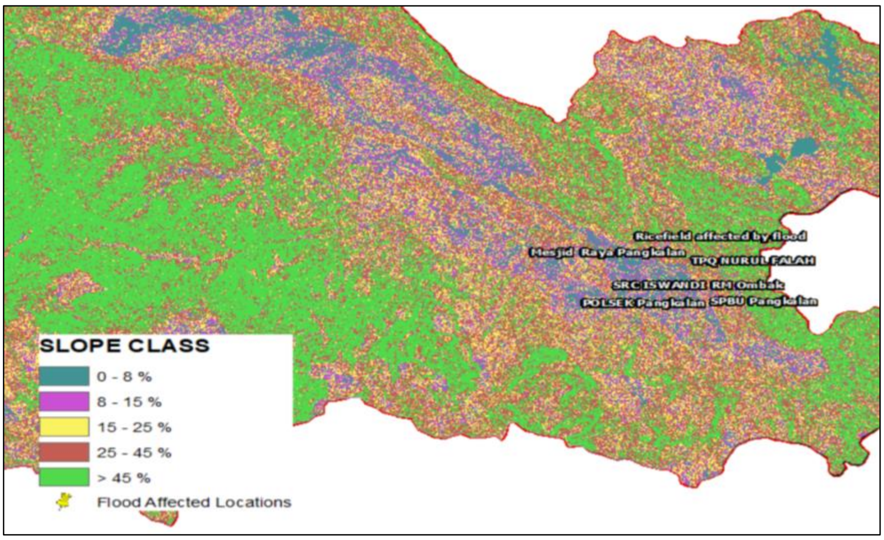


Figure 17. Slope map of Batang Mahat river basin with flood points where flooding occurs.

Table 5. The velocity of Q_{50} year discharge for each cross-section.

RiverCode	ReachCode	Sta.	Profile	Velocity
Branch (Bt. Malagiri)	Tributary	4346.296	Q_{50}	4.538 m/s
Branch (Bt. Malagiri)	Tributary	4209.762	Q_{50}	5.345 m/s
Branch (Bt. Malagiri)	Tributary	3600	Q_{50}	3.066 m/s
Branch (Bt. Malagiri)	Tributary	3399.627	Q_{50}	5.993 m/s
Branch (Bt. Malagiri)	Tributary	2035.115	Q_{50}	5.185 m/s
Branch (Bt. Malagiri)	Tributary	1827.173	Q_{50}	3.420 m/s
Main (Bt. Mahat Up)	Upstream	6000	Q_{50}	4.184 m/s
Main (Bt. Mahat Up)	Upstream	5800	Q_{50}	2.767 m/s
Main (Bt. Mahat Up)	Upstream	5600	Q_{50}	3.578 m/s
Main (Bt. Mahat Up)	Upstream	5398.76	Q_{50}	6.206 m/s
Main (Bt. Mahat Up)	Upstream	5200.164	Q_{50}	4.613 m/s
Main (Bt. Mahat Up)	Upstream	3999.394	Q_{50}	3.987 m/s
Main (Bt. Mahat Up)	Upstream	3797.555	Q_{50}	2.363 m/s
Main (Bt. Mahat Up)	Upstream	3600.472	Q_{50}	3.744 m/s
Main (Bt. Mahat Up)	Upstream	2998.726	Q_{50}	5.885 m/s
Main (Bt. Mahat Up)	Upstream	2800.252	Q_{50}	0.861 m/s
Main (Bt. Mahat Up)	Upstream	2602.475	Q_{50}	2.788 m/s
Main (Bt. Mahat Up)	Upstream	2388.46	Q_{50}	2.725 m/s
Main (Bt. Mahat Up)	Upstream	1994.395	Q_{50}	3.132 m/s
RiverCode	**ReachCode**	**Sta.**	**Profile**	**Velocity**
Main (Bt. Mahat Up)	Upstream	1799.477	Q_{50}	2.498 m/s
Main (Bt. Mahat Up)	Upstream	1578.913	z	2.774 m/s
Main (Bt. Mahat Up)	Upstream	1384.871	Q_{50}	1.983 m/s
Main (Batu Kisok)	Downstream	649.7089	Q_{50}	6.978 m/s
Main (Batu Kisok)	Downstream	495.1637	Q_{50}	5.502 m/s
Main (Batu Kisok)	Downstream	307.1649	Q_{50}	5.944 m/s
Main (Batu Kisok)	Downstream	153.8967	Q_{50}	9.164 m/s

However, when it comes to determining the optimal flood management in Batang Mahat, it is important to recognize that there is no single perfect solution that can completely solve the problem. According to Junaidi *et al.* (2018), flood management is quite complex, including many technical science disciplines, and also depends on other aspects related to social, economic, environmental, institutions, organizations, and law. Depending on the problem's type, conditions, time, and space, flood management solutions can be structural or non-structural (Qari *et al.*, 2014). As a brief recommendation regarding flood control in Batang Mahat, this research suggests implementing structural measures, such as river normalization and blasting at the Batu Kisok location, to widen the river cross-section. This recommendation is taken by looking at the cross-section and flood simulation results in Batang Mahat. According to the cross-section, the river profile at the upper reach and tributary of Batang Mahat has a more comprehensive river profile but a shallow riverbed.

In contrast, the location of Batu Kisok has a narrow and deep riverbed. Also, water elevation is considerably decreased after widening cross-sections at Batu Kisok. For the non-structural recommendation, it is suggested that the government should improve strict rules for the commercial plantations so that the community can contribute to minimalizing the land use change that can reduce flood damage.

4. Conclusions

In conclusion, the flood in Batang Mahat can be attributed to two potential factors. Firstly, the channel capacity of Batang Mahat is insufficient to accommodate the discharge of flood water. The river is only sufficient to accommodate water discharge at the maximum of about 1329.44 m^3/s ($Q_{5\text{-year}}$ return period). According to the simulations, the flood that occurred in Batang Mahat in 2017 was the flood with the discharge of Q $Q_{5\text{-year}}$ return period (2003.07 m3/s), which inundated an area of about 2.47 km^2 out of 9.26 km^2 area in total. Secondly, the narrowing of the Batu Kisok location acts as a "bottleneck," exacerbating flooding in the upstream area of Batang Mahat. This is evident from the noteworthy reduction in water elevation at cross-sections sta. 1994.395, sta. 1799.477, sta. 1578.913, and sta. 1384.871, as well as a slight decrease at sta. 2998.726, sta. 2800.252, sta. 2602.475, sta. 2388.46, sta. 2035.115, and sta. 1827.173 after widening the cross-sections in Batu Kisok. Furthermore, upon examining the riverbed elevation, it is evident that Batu Kisok exhibits the most significant elevation variation (+75.45 m), which can reach up to approximately 17 m. This elevation discrepancy is attributed to the high flow velocity of around 9.164 m/s during the $Q_{5\text{-year}}$ discharge and 7.60 m/s during the normal flow conditions (Q_{normal}).

The flood incident in Batang Mahat, particularly in the Pangkalan Kota Baru district, can be classified as a significant event demanding immediate attention. Addressing the issue of flooding in Batang Mahat requires a comprehensive examination across all segments of the river, rather than focusing solely on one specific location. Therefore, the government and stakeholders should take into account the findings of this research to determine whether implementing structural or non-structural measures would be more suitable for effective flood management in Batang Mahat.

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