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FLOOD ROUTING ANALYSIS OF THE WAY SEPUTIH RIVER, CENTRAL LAMPUNG, INDONESIA

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ABSTRACT: Lampung is currently vulnerable to flooding. There were 16 flood events in Lampung with the latest major flood, which occurred in February 2018, inundated 10 sub-districts. One of the main causes of flooding in Lampung is flash flooding caused by heavy rainfall on the upstream area. The villages along Way Seputih (Seputih River), one of the main rivers in Lampung, Indonesia, have been affected by flash flood for the last three years. One of the possible solutions to control the flood from causing heavy causalities is to create a flood route model of Way Seputih, which is the main focus of this study. In this study, a hydraulic model of Way Seputih is built by using HEC-RAS 4.1 software to simulate the effect of extreme rainfall and how it causes flooding along the Way Seputih. The hydraulic model is based on field topographic measurement, simulated tides, and synthetic hydrographs generated by rainfall data and validated by field water surface elevation measurement. The output of HEC-RAS 4.1 in form of water surface elevation time series of locations along the Way Seputih is then used to build a flood route model. By using this model, the flooding time interval between villages along the Way Seputih can be predicted which can be used as the basis for an early warning system or planning for flood defense infrastructures such as dikes and pump systems.

Keywords: Flood Routing, HEC-RAS, Way Seputih

1. INTRODUCTION

Flood is one of the most commonly occurring natural disasters in Indonesia. According to Badan Nasional Penanggulangan Bencana/BNPB [1], flood and storm have been alternately ranked as a natural disaster with the highest occurrence for the last four years, ranging from 523 to 978 events per year for the flood.

The flood may occur due to various causes. While lengthy high rainfall and poor water absorption rate of the land soil are the most well-known, the overflow of main rivers due to the high intensity of rainfall at the upstream area can also cause flooding on the downstream area. This type of flood is often called flash floods [2]. As an archipelagic country that has a relatively steep ground contour due to its mountainous topography, several places in Indonesia are prone to the flash flood. The most recent event of flash flooding occurred in Jayapura, Papua which causes 104 causalities and 9,641 people evacuated [1].

On the western side of Indonesia, the province of Lampung has been struck by flash flooding every year for the last three years. According to BNPB [1], there were a total of 16 flood events in Lampung in 2018 alone. One of the major flood events is in February 2018 where flood inundates 10 sub-districts of Lampung.

The Way Seputih (Seputih River), which has its watersheds in the Seputih-Sekampung River Area, is one of the rivers that was flooded in February 2018 Lampung flood event. A study presented in the Decree of Minister of Public Works [3] stated that Way Seputih has the length of the mainstream of + 244.23 km. The river also has seven points of potential flood location, namely: Way Seputih, Way Terusan, Way Pegadungan, Way Pengubuan, Way Waya, Way Raman, and Way Sukadana. The location of Way Seputih. The location of Way Seputih is shown in Fig.1.

While it is difficult to completely prevent flooding on one area, flood control countermeasures can still be taken by minimizing the chance and causalities of flooding up to a certain level [4]. One of the methods to predict flooding is by flood routing. Flow routing or Flood routing is a method to determine the flow propagation between points in a channel [5]. Flood routing can provide the timing and height of floods which are measured at the measurement posts before the flood ‘wave’ moves to the next location. This timing and height information can help whether a warning should be given and how evacuation on the area should be planned which in the end may reduce the impact of flooding on the local population.

However, a proper hydraulic analysis is required to build a flood route model. One possible way to analyze the hydraulic behavior of Way Seputih is by using a computational model. Based on the importance of flood control described above, the overarching aim of this study is to make a flood route model for Way Seputih based on a computational hydraulic model.

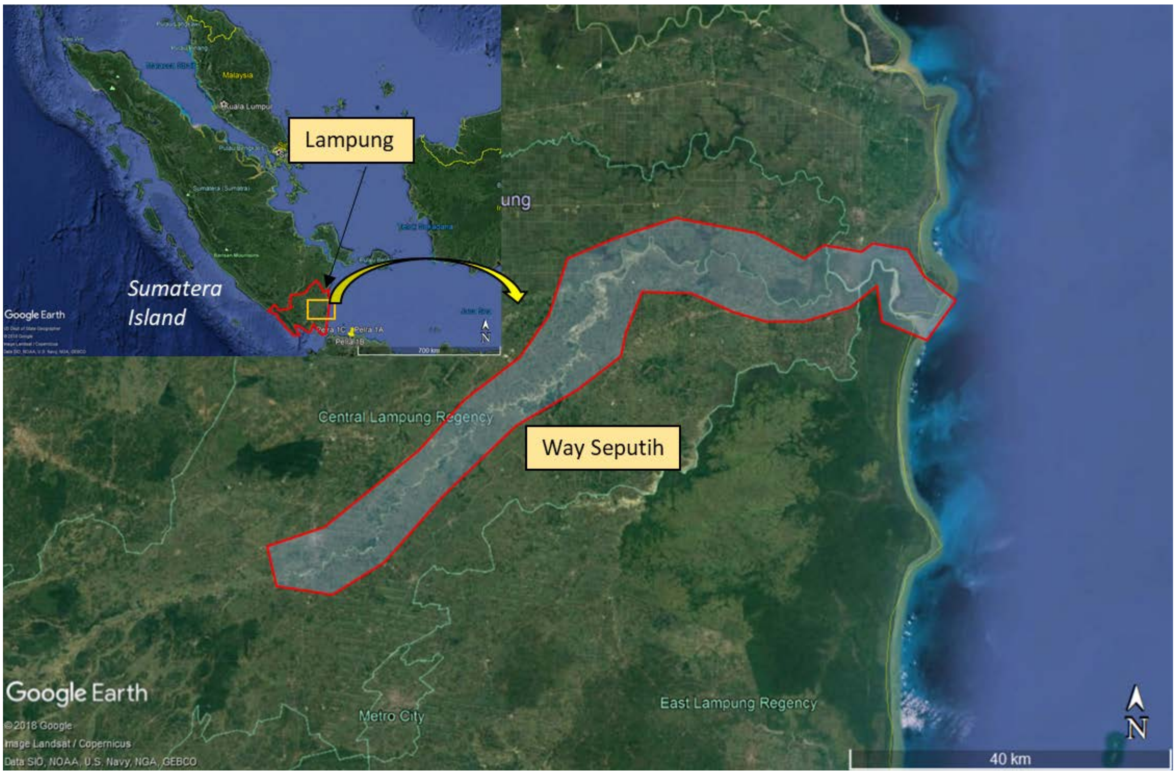


Fig.1 Location of Way Seputih (Source: Google Earth, 2019)

The modeling software used in this study is HEC-RAS 4.1 which is a one-dimensional hydraulic computational software [6]. Chapter 1 describes the background of this study along with the aim and objectives. Chapter 2 explains the methodology used to carry out the study and the environment data processing required to perform the hydraulic analysis. Chapter 3 shows how the hydraulic model is set up and calibrated. Chapter 4 presents the hydraulic analysis result and its discussion. Chapter 5 Finally, the study result is concluded in Chapter 6.

2. METHODOLOGY

This study is conducted in four phases: (1) data acquisition, (2) data processing, (3) model setup (4) output analysis and flood routing, which are shown in Fig.2. On the data acquisition phase, data required for HEC-RAS analysis that comprises of water surface elevation measurement on the Way Seputih, tide model, river topography, and rainfall data are collected. The acquired data are then processed in the next phase in which the output are water surface elevation time series, river topography, and hydrographs. Using the processed data, the HEC-RAS 4.1 Way Seputih model is then set up and calibrated before the effect of extreme rainfall to the channel is simulated. Finally, the output of simulation which includes flood duration and water surface elevation is then used to make a flood route model.

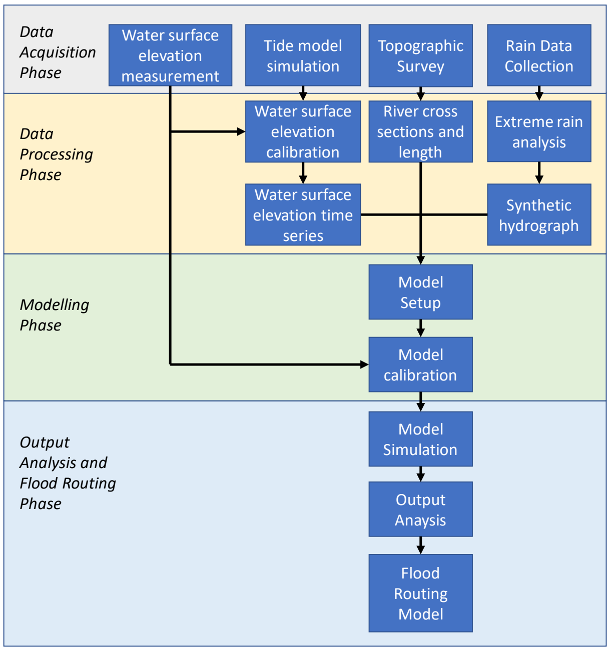


Fig.2 Flowchart of flood route model creation

Tide model simulation is done using RMA2, which is a two-dimensional hydrodynamic modeling software based on the finite element method and a part of the Surface-water Modeling System (SMS) software [7]. The model setup is shown in Fig.3 with tidal boundary condition shown as BCD1 to BCD5 obtained from NAOTIDE while

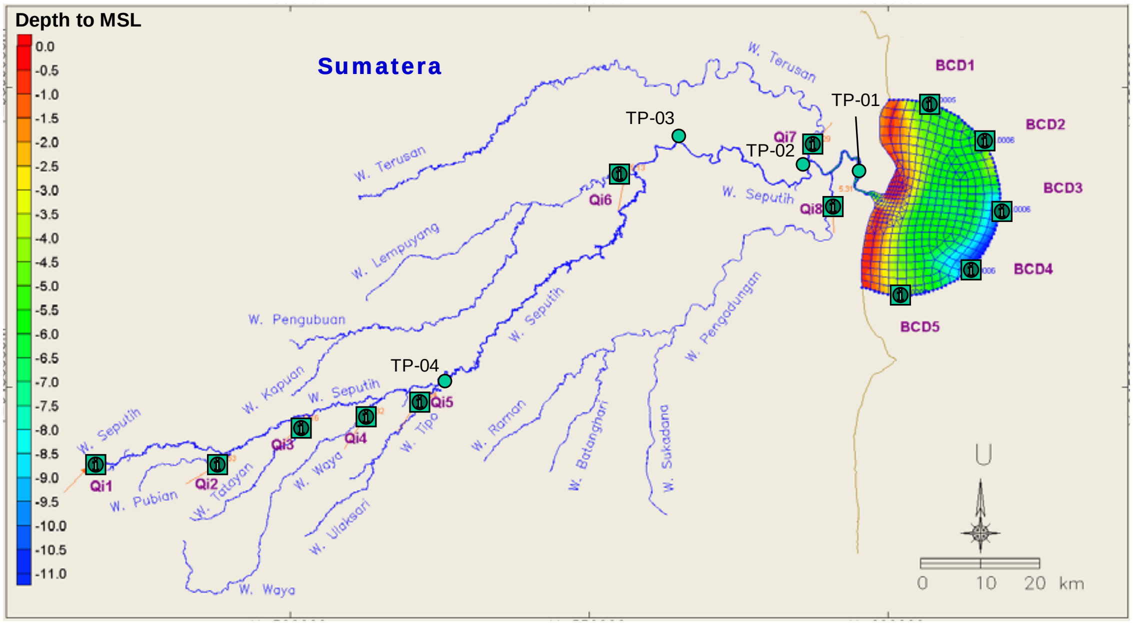


Fig.3 SMS model setup and water surface elevation observation points (TP)

flow input Qi1 to Qi7 is obtained from National Center of Water Resources Research and Development (Puslitbang Air). To ensure that the initial flow and the tidal data is appropriate, the model is run for a month in July 2015 and calibrated based the water surface elevation on measurement points on the Estuary of Way Seputih River (TP-01), Mataram Ilir Village (TP-02), Nabung Ilir Village (TP-03), Gunung Sugih Village (TP-04). The calibrated RMA2 model will be used as the tide input on HEC-RAS 4.1 simulation later.

The topographic survey was conducted on the Way Seputih main channel and did not include the sub-channels. The total length of the measured channel is 280 km with an example of a measured cross-section of the channel as shown in Fig.4. This measured channel length and cross sections were used as the geometry input on the HEC-RAS 4.1 model.

Recorded hydrographs are not always available since river flow recorder station is relatively rare in Indonesia [8], hence synthetic hydrographs that are based on rainfall, river catchment area, and river length are used as simulation input. Rainfall data is obtained from the Local Technical Implementation Unit of Natural Resources Management Office of Way Seputih-Sekampung with data ranging from 1990 to 2014. The data recapitulation in the form of maximum annual rainfall is shown in Fig.5.

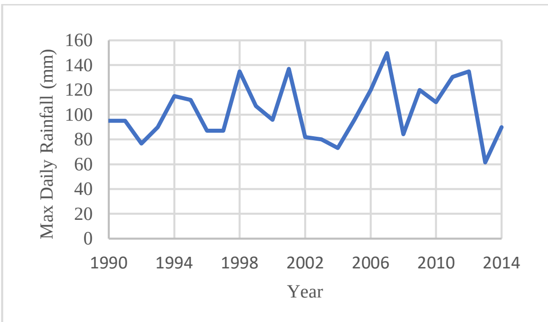


Fig.5 Maximum Daily Rainfall on Way Seputih between 1990 and 2014 (Source: National Center of Water Resources Research and Development (Puslitbang Air))

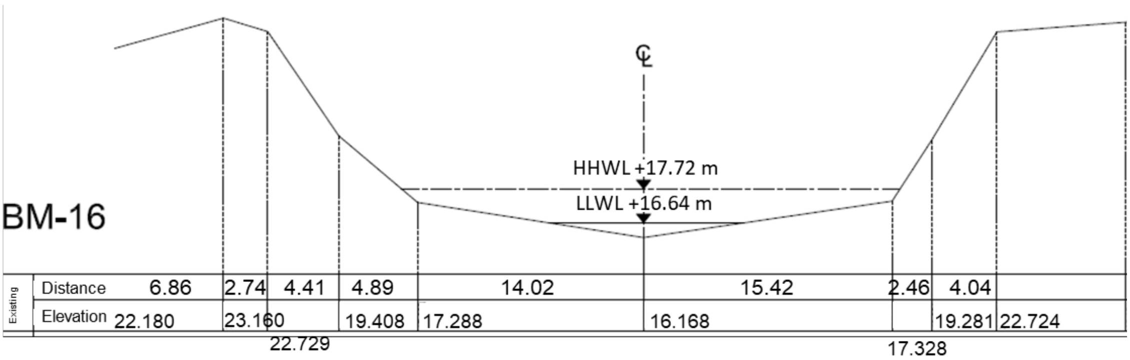


Fig.4 Typical cross-section of Way Seputih

For the purpose of flood routing in Way Seputih, extreme rain hydrographs are created on seven points at the upstream of Way Seputih, which comprises of (A) Upstream of the main channel (B) Way Pubian (C) Tributaries of the main channel (D) Way Tatayan (E) Way Waya (F) Way Tipo, and (G) Way Bilu. This maximum annual rainfall data is then used to obtain the extreme maximum rainfall, which has 10-yearly and 100-yearly return period using Gumbel's Method [9]. The result of extreme maximum rainfall calculation is shown in Table 1.

Table 1 Extreme rainfall maximum flow result based on Gumbel's Method

Point	Location	10-yearly return period flow (m^3/s)	100-yearly return period flow (m^3/s)
A	Upstream of the main channel	296.29	390.53
B	Way Pubian	261.21	344.29
C	Tributaries of the main channel	105.48	139.03
D	Way Tatayan	282.64	372.55
E	Way Waya	281.55	371.10
F	Way Tipo	241.72	318.61
G	Way Bilu	237.88	313.55

In this study, Nakayasu's equation method [6] is used to create the synthetic hydrographs on the designated locations with the equation as follows:

- Curve when 0 < t < Tp

$$Q_d = Q_p \left(\frac{t}{T_p}\right)^{2.4};$$

- when Tp<t<($T_p + T_{0.3}$)

$$Q_d = Q_p . 0.3^{\frac{t-T_p}{T_{0.3}}};$$

- when (Tp + T0.3) < t < (Tp + T0.3 + 1.5To.3)

$$Q_d = Q_p . 0.3^{\frac{t-T_p+0.5T_{0.3}}{1.5T_{0.3}}};$$

- when t > ($T_p + T_{0.3} + 1.5T_{0.3}$)

$$Q_d = Q_p . 0.3^{\frac{t-T_p+1.5T_{0.3}}{2T_{0.3}}}$$

Note

Q_d = Quantity of flow (m^3/s)

Q_p = Peak flow of the flood (m^3/s)

= $\frac{C\,A\,R_o}{3.6\,(0.3\,T_p+T_{0.3})}$

L = Length of the river (km)

C = Runoff coefficient

A = Catchment area (km^2).

R_o = Unit rain (mm)

T_p = Time lag from the beginning of the rain to the maximum flow (hour) : $t_g + 0.8\,t_r$

t_g = Time of concentration (hour), when: L > 15 km, $t_g = 0.4 + 0.058\,L$

$T_{0.3}$ = Time needed from the peak flow to 30% of the peak flow: $\alpha \times t_g$

α = 2.0 for typical runoff area

= 1.5 for the slow rising part of hydrograph and the quickly declining part

= 3.0 for the quickly rising part of hydrograph and the slow declining part

An example of Nakayasu synthetic hydrograph used in this study is shown in Fig.6.

3. MODEL SETUP AND CALIBRATION

The HEC-RAS 4.1 model was set-up using the measured topography for the river geometry, calibrated tide from the previous phase as the stage hydrograph input, and river flows as the flow hydrograph inputs as shown in Fig.7. There are 17 sub-watersheds with each becomes the input source for the main channel. During the model calibration, the HEC-RAS 4.1 model uses constant, no-rain flow from each sub-watershed and channel manning coefficient used as the calibrating

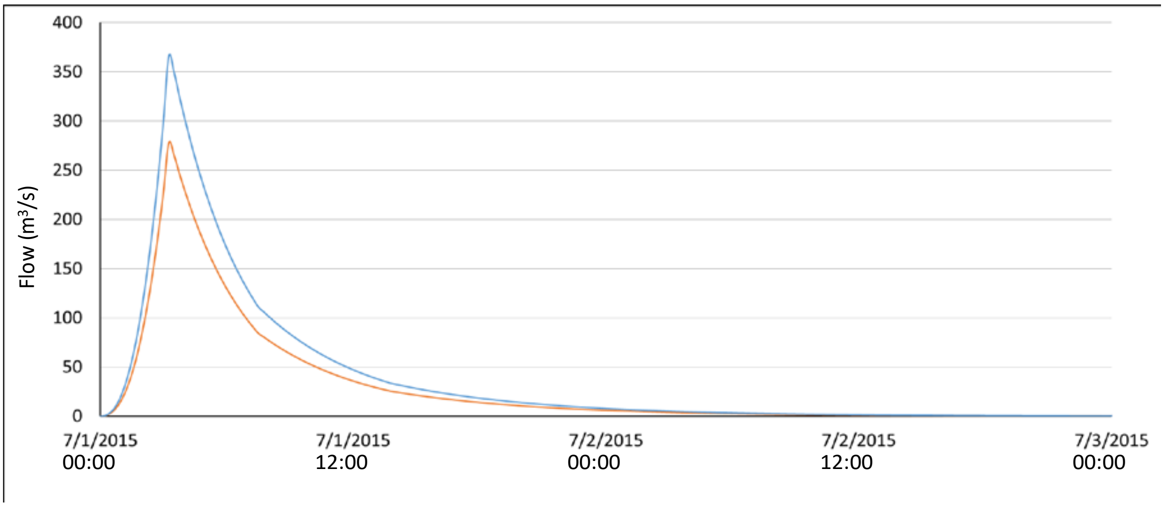
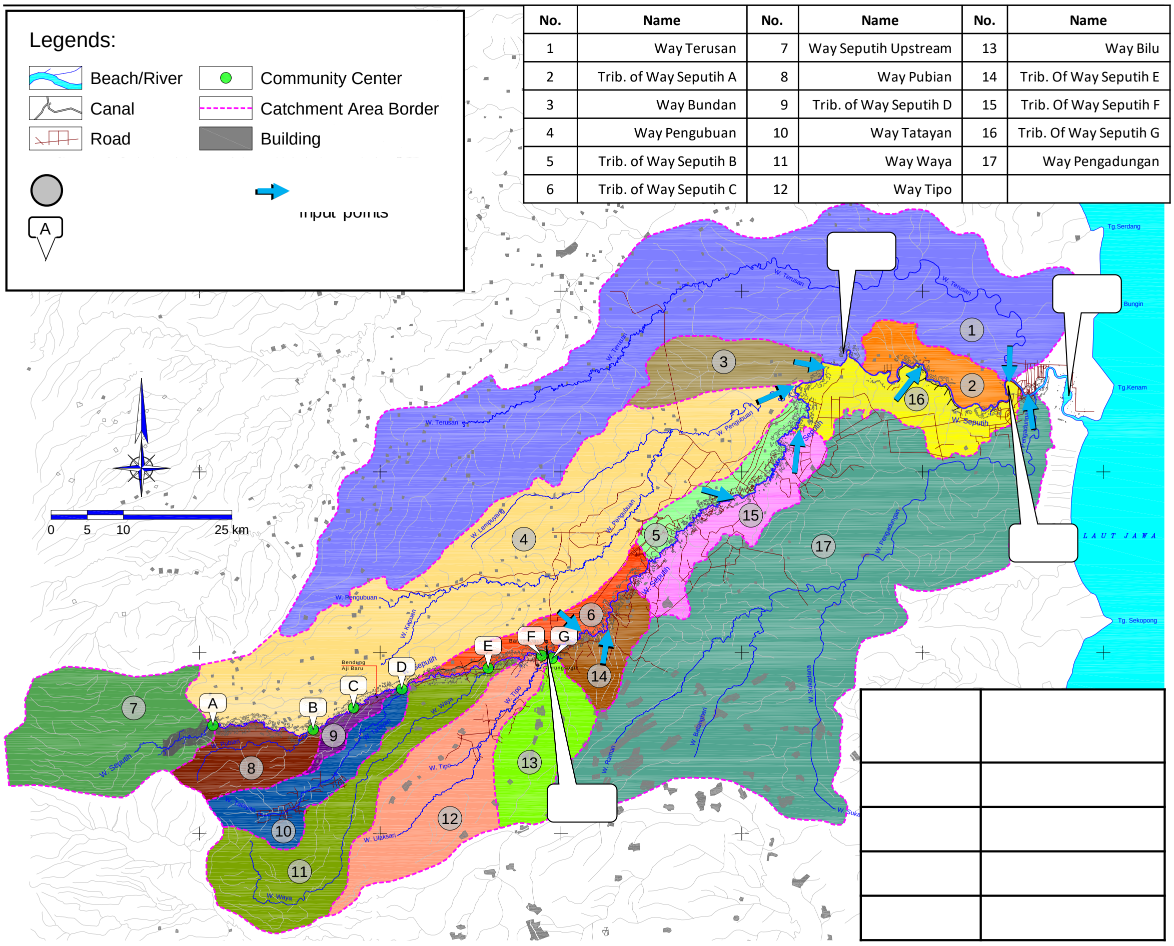


Fig.6 Example of an extreme 10 and 100-yearly return period rain from the Way Tatayan sub-watershed.



No.	Name	No.	Name	No.	Name
1	Way Terusan	7	Way Seputih Upstream	13	Way Bilu
2	Trib. of Way Seputih A	8	Way Pubian	14	Trib. Of Way Seputih E
3	Way Bundan	9	Trib. of Way Seputih D	15	Trib. Of Way Seputih F
4	Way Pengubuan	10	Way Tatayan	16	Trib. Of Way Seputih G
5	Trib. of Way Seputih B	11	Way Waya	17	Way Pengadungan
6	Trib. of Way Seputih C	12	Way Tipo		

Fig.7 Model configuration of Way Seputih for HEC-RAS 4.1 simulation. The Way Seputih watershed are divided into 17 different colored areas.

parameters. The model calibration result shows a good agreement between the model water surface elevation with a no-rain scenario and the measured water surface elevation as presented in Fig.8. From the calibration process, it was obtained that the constant flow is 4 m^3/s with the manning coefficient ranging from 0.2 to 0.3 [10]. This minimum constant flow agrees with the study by Mulyo [11] The diminishing effect of the tide towards upstream can also be seen at TP-04 where the influence of tide is no longer present.

4. DISCUSSION AND ANALYSIS

As described in Chapter II, simulation scenarios with 10-yearly and 100-yearly return period rains respectively were ran with the extreme rain hydrographs located on the upstream of Way Seputih. The model is run from 05 July 2015 to 09 July 2015 with the rain input for each scenario is given at 0900 AM where the water surface elevation from the tide is on its daily highest.

After the simulations are completed, the water surface elevation is observed in nine different points located in the mid-to-downstream of Way Seputih

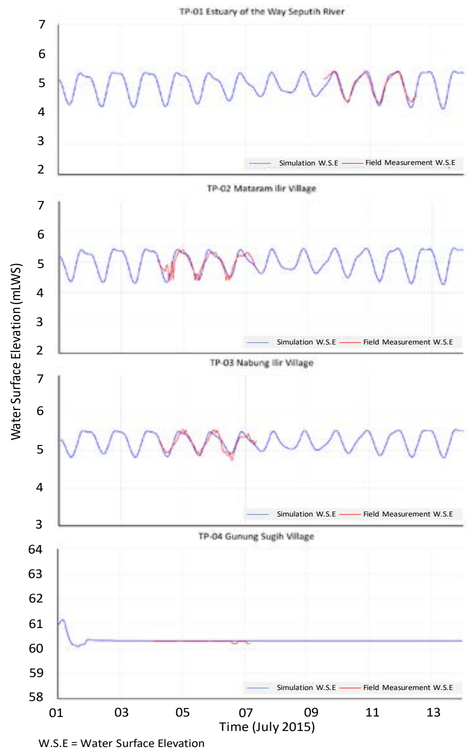


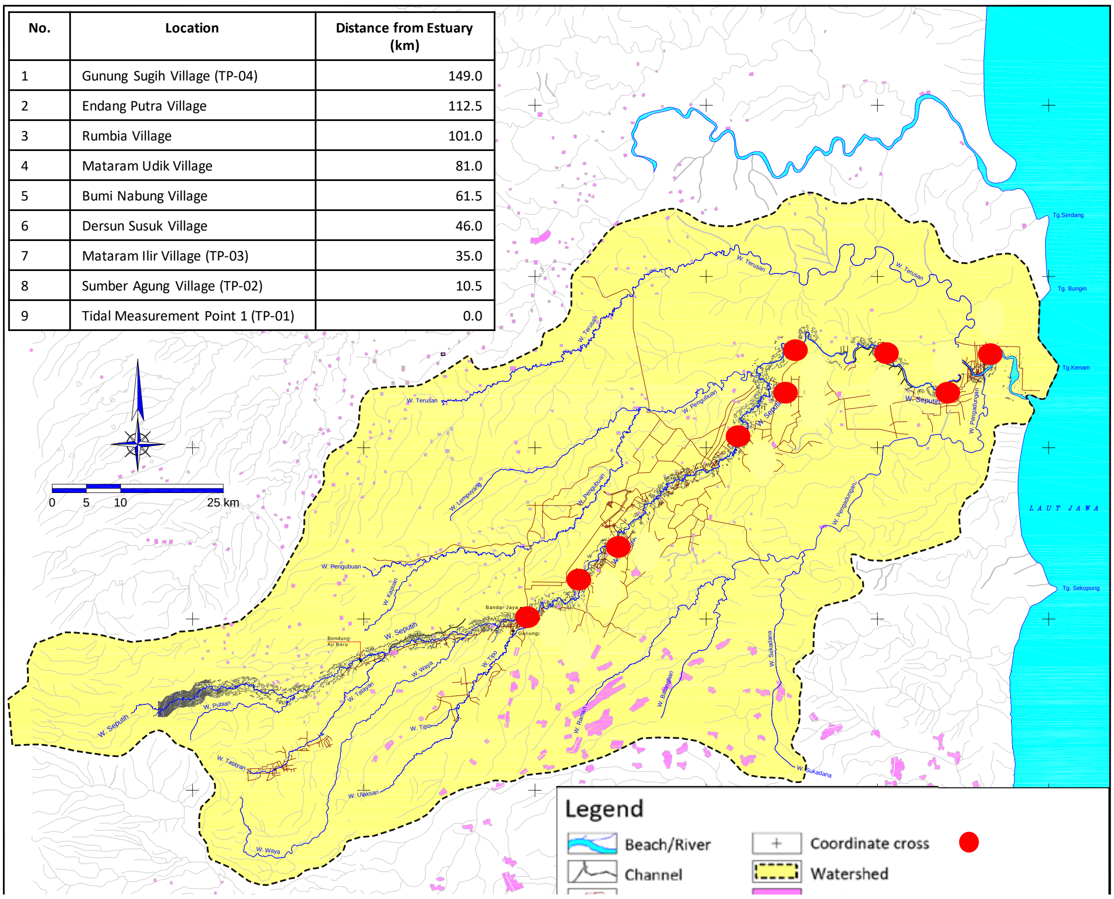
Fig.8 HEC-RAS Way Seputih model calibration.

which consists of (1) Tidal Measurement Points 1, (2) Sumber Agung Village, (3) Mataram Ilir Village, (4) Dersun Susuk Village, (5) Bumi Nabung Village, (6) Mataram Udik Village, (7) Rumbia Village, (8) Endang Putra Village, and (9) Gunung Sugih Village. These locations are chosen because the flood risk is higher on highly populated areas, where in this case villages should be the most crowded among other locations along the river. The locations of observation points are shown in Fig.9.

Based on the simulation result, both 10-yearly and 100-yearly rain may cause flooding to the areas located on the downstream of Way Seputih. Recent previous studies regarding the flood events in Way Seputih is rather limited although it can be considered sufficient to validate the result of this study. According to the official document by Ministry of Public Works and Housing [12], the flow of Way Seputih can reach as high as 400 m^3/s, hich is in order with the 100-yearly return period flow acquired in this study. Amin [13] also stated in his study that the Way Seputih upstream is always overflown and inundates the downstream side watershed during the rainy season in October to April.

The water surface elevation increment due to rainfall increases as the observation point moves toward upstream. The largest elevation increases occurred in Gunung Sugih Village that 10-yearly return period rain can increase the water surface elevation up to 10 meters while the 100-yearly rain can increase the water surface elevation by 12 meters. However, the highest elevation increment does not always mean that the location will have the longest flood period. In this study, the location with potentially longest flood duration is located downstream in Sumber Agung village since the river cliff is relatively short compared to other observation points.

The flood duration increment due to extreme rain return period from 10-yearly to 100-yearly varies on each site, with increment ranging from 15% to 50% longer flood duration. The highest increment occurred in Bumi Nabung Village with 15 hours of flood duration up on 100-yearly extreme rain from 10 hours on 10-yearly extreme rain The simulation also shows that not all channel sections are overflown when extreme rain occurred, namely sections near Mataram Ilir Village on 10-yearly rainfall and Dersun Susuk Village is onlyvery close to being inundated during 100-yearly rainfall. This does not automatically mean that the villages are not flooded, as a report of flooding on Mataram Ilir Village [14] and Dersun Susuk Village [15] is still be found. However, Dersun Susuk village flooding can be considered to



No.	Location	Distance from Estuary (km)
1	Gunung Sugih Village (TP-04)	149.0
2	Endang Putra Village	112.5
3	Rumbia Village	101.0
4	Mataram Udik Village	81.0
5	Bumi Nabung Village	61.5
6	Dersun Susuk Village	46.0
7	Mataram Ilir Village (TP-03)	35.0
8	Sumber Agung Village (TP-02)	10.5
9	Tidal Measurement Point 1 (TP-01)	0.0

Fig.9 Location of observation points along Way Seputih for flood route model

be minimal as there is one report to be found regarding the flood. Flood reports from the news have also been found for other observation locations, namely Bumi Nabung Village, Mataram Udik Village, Rumbia Village, Endang Putra Village, Sumber Agung, and Gunung Sugih Village [14].

5. FLOOD ROUTE MODEL

The flood route model has been created based on the analysis done in the previous phase. The model picked nine observation points as shown in Fig.9, in which every point is a residential area in the form of villages except for Point 9. The 10-yearly return period rain flood model shows that the time interval of floods is in hourly order and almost one day as shown in Fig.10. The model shows that it will take 21 hours before a flood from the most upstream observation point (Gunung Sugih Village) reached the river estuary, with 5 hours of the flood time interval from the Gunung Gunung Sugih Village to the next villages (Endang Putra and Rumbia). The interval gets shorter to 3 hours to the next point of Mataram Udik Village and 2 hours to the upcoming point of Bumi Nabung Village.

The 100-yearly return period flood route model has a slightly shorter flood interval between observation points as shown in Fig.11. The only

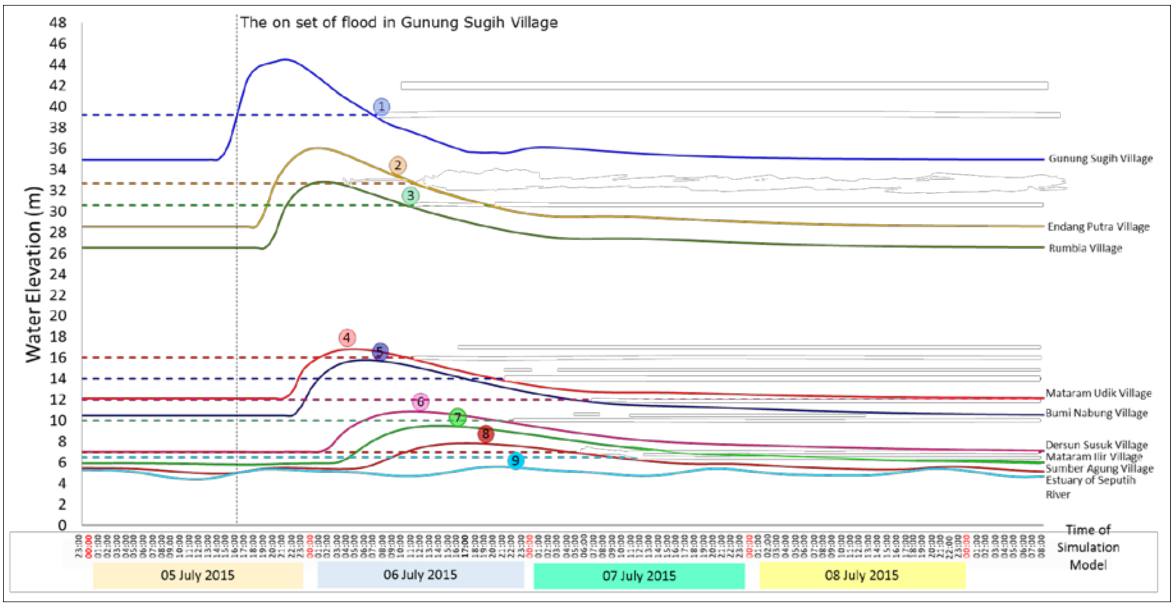


Fig.10 HEC-RAS water surface elevation time series simulation result on nine observation points along Way Seputih for 10-yearly extreme rainfall.

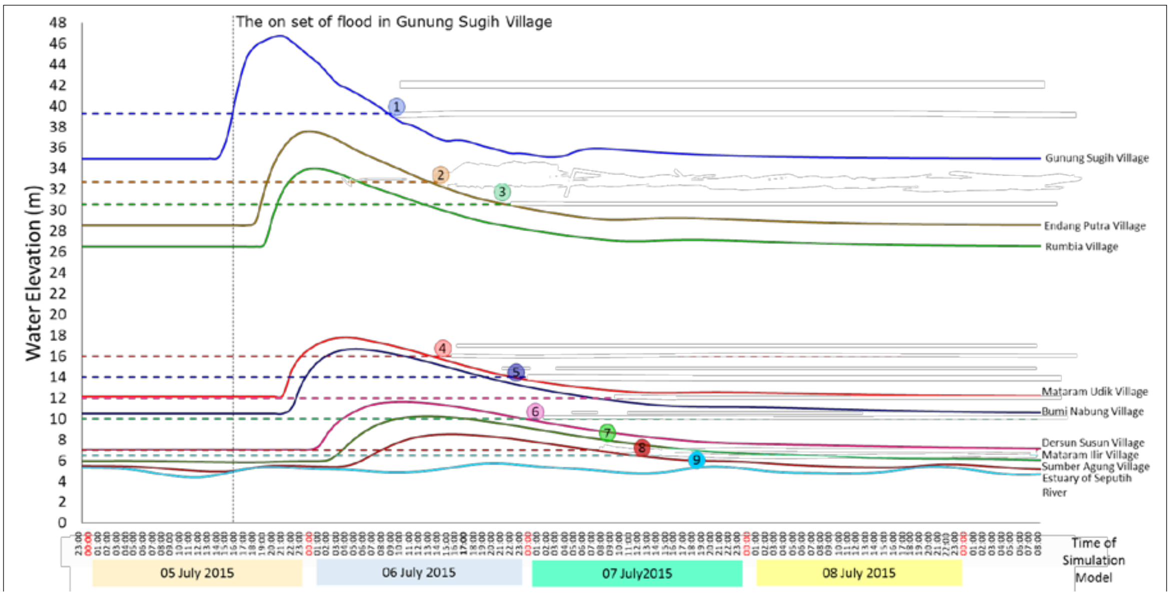


Fig.11 HEC-RAS water surface elevation time series simulation result on nine observation points along Way Seputih for 100-yearly extreme rainfall.

noticeable flood interval difference is between Gunung Sugih Village and Endang Putra Village where the flood interval is 1 hour less than the 10-yearly return period flood route model.

6. CONCLUSION AND RECOMMENDATIONS

A flood route model of Way Seputih has been created based on the hydraulic simulation using HEC-RAS 4.1. The model has given an analytical prediction of how long a flood on the upstream will come down to the downstream area.

The potential use of this model is to design a flood early warning system based on a flood event happening in one of the locations at the upstream of Way Seputih. The shortest flood interval time between the villages chosen in this study is two hours, which should be adequate for a quick evacuation. Another possible use case is to use this flood route model to design a flood defense such as dikes for long term protection and pumping system for eventual flood prevention.

To further validate this analytical model, additional direct observation of water level and/or flow on the more locations along the Way Seputih is suggested. We suggest that this additional observation points should be carried out on locations evenly spaced along the Way Seputih at least on location 1, 3, 4, and 7.

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