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To cite this article: R A Sulhan *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1073** 012019

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# Flood analysis of Buntung River and the structural measures in Sidoarjo Regency

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**Abstract.** Sidoarjo Regency as one of the downstream areas of the Brantas River Basin is prone to flooding. This study aims to simulate the flood discharge and inundation in Buntung River, a river passes through Sidoarjo City area with several time return periods and to discuss its physical flood mitigation. Data needed in this study are Rainfall Data for 3 Rain Stations, topography map, cross section of river stream, and land use map. Based on these data, a flood flow analysis plan is then performed using the Nakayasu synthetic hydrographs method. The inundation is simulated using HEC-RAS with 10, 25, and 50 years return periods. Based on the calculation, Buntung River flood discharge with return period of 10, 25, and 50 years return periods is 151,342, 196,923, and 233,981 m<sup>3</sup>/s respectively. The inundation extend of 25 years return period is reaching 0,53 m height above the bank along Sta. P0 to P1. The study reveals that the existing cross section cannot accommodate the design flood for at least 25 years return period. Therefore, normalization is essential for river improvement. The channel is design with river cross-sectional shape of double trapezoidal. The size of the earth dike is 0.60 m above the flood water level with 3.0 m width and 1:2 channel slope. The designed river channel improvement increase the channel depth from -3,56 m to -4,07 m in Sta. P1. The normalized channel could accommodate the design flood and would be beneficial for increasing the urban area safety from flood disaster.

## 1. Introduction

Rapid development, particularly in metropolitan city, increases the risks of flooding. Some of the causes of flood are decreasing of the soil capability to infiltrate the water due to impermeable surface and sedimentation that reduces the channel capacity. Furthermore, prolonged rain is unfortunate especially for flat river in relatively plane catchment. For flood countermeasures, combination of structural and non-structural efforts must be carried out [1]. Structural measure consists of construction of hydraulic structures to increase carrying capacity of the river, such as levee, river normalization, and shortcut. Non-structural, such as flood simulation by various hydrology and hydraulic models, forecasting and warning as well as awareness awareness and law enactment can be more effective to minimize the flood damage.

Sidoarjo Regency in Indonesia is located in the downstream areas of the Brantas River Basin. Sidoarjo are is a buffer of Surabaya metropolitan city. Tambak Oso Village, Waru District, Segoro Tambak Village, and Sedati District were reported to experience inundation. Afvour Buntung is vulnerable from flooding in these area. The river morphology is meandered, eroded in some places, and shallow due to sedimentation. These condition would have a major impact on the occurrence of flood.



There has been several researches regarding flood disaster mitigation combining inundation simulation combined with the hydraulic structure [2,3]. In Buntung River, Ikhsan has studied the drainage system and simulate the flood using 25 years return period and propose construction of levee [4]. However, it did not use hydraulic simulation model. Azzahra studied the stream pattern and sedimentation of Buntung River [5]. It was mentioned that tides affect the flood highly in the downstream of Buntung River.

In this study, the flood and overtopping simulation in Buntung River using several return periods is carried out. As non-structural countermeasures. By understanding the river overflowing in particular rainfall amount, early warning can be designed carefully. As for physical countermeasures, levee and normalization are studied with 25 years return period in order to prevent the flood plain river being inundated.

## 2. Methods

The study area is Buntung River with length, L of 4 km that passes through Sidoarjo Regency and Surabaya City. The catchment area, A is 15864.93 Figure 1 shows the map, photo, and catchment area of Buntung River. The required data are daily rainfall data of 2009-2018 from Ketegan, Bono, and Wonorejo Stations, flood report, catchment map, river cross sections, and tides data at the river estuary. Rainfall data are pre-processed using double-mass curve method and arithmetic means to obtain areal rainfall [6]. Design rainfall (mm/day) with return period of 10, 25, and 50 years are analyzed by using Log-Pearson Type III distributions [7]:

$$\log X_T = \overline{\log X} + K \cdot s$$

Where  $\overline{\log X}$  is average logarithmic of daily rainfall (mm/day), K is constant, and s is standard deviation (mm/day). Flood hydrograph is analyzed by Nakayasu synthetic hydrograph method [8]:

$$T_g = 0,4 + 0,058 \times L$$

$$T_r = (1 - 0,5) \times T_g$$

$$T_p = T_g + 0,8 \times T_r$$

$$T_{0,3} = \alpha \times T_g$$

$$Q_p = \frac{CA \cdot R_o}{3,6 \cdot (0,3T_p + T_{0,3})^{2,4}}$$

$$Q_t = Q_p \left( \frac{t}{T_p} \right)^{2,4}$$

$$Q_r = Q_p \cdot 0,3^{(t-T_p)/T_{0,3}}$$

$$Q_t = Q_p \cdot 0,3^{[(t-T_p)+(0,5 \cdot T_{0,3})]/(1,5T_{0,3})} \text{ and } Q_t = Q_p \cdot 0,3^{[(t-T_p)+(1,5T_{0,3})]/(2 \cdot T_{0,3})}$$

Basin parameters, T, and Q are depicted in Figure 1 and Figure 2. Flood hydrograph is calculated by make a superposition from unit hydrograph from hourly rainfall distribution. Rt:

$$Rt = \frac{R_{24}}{5} x \left( \frac{5}{t} \right)^{2/3}$$

Where R24 is designed rainfall (mm/day), t is time step (h).

In order to simulate the overflowing, HEC-RAS 5.0.1 1D hydraulic model is applied. By using this model, it is easier and timely to estimate water level profile, water flow velocity, and Froude number. Afterward, the intended water level during rainfall is determined in particular return period, i.e. 25 years. According to this scenario, the river capacity is design to meet the specific discharge. Menu of Channel Modification in HEC-RAS is applied to simulate the best scenario by considering existing cross section as well as local condition [9].

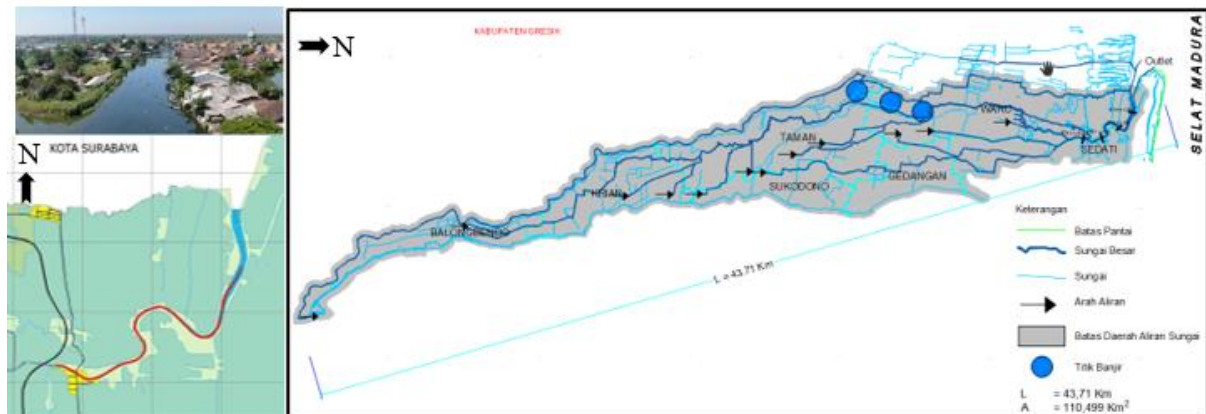


Figure 1. Map, photo, and catchment area of Buntung River (Source: BBWS Brantas).

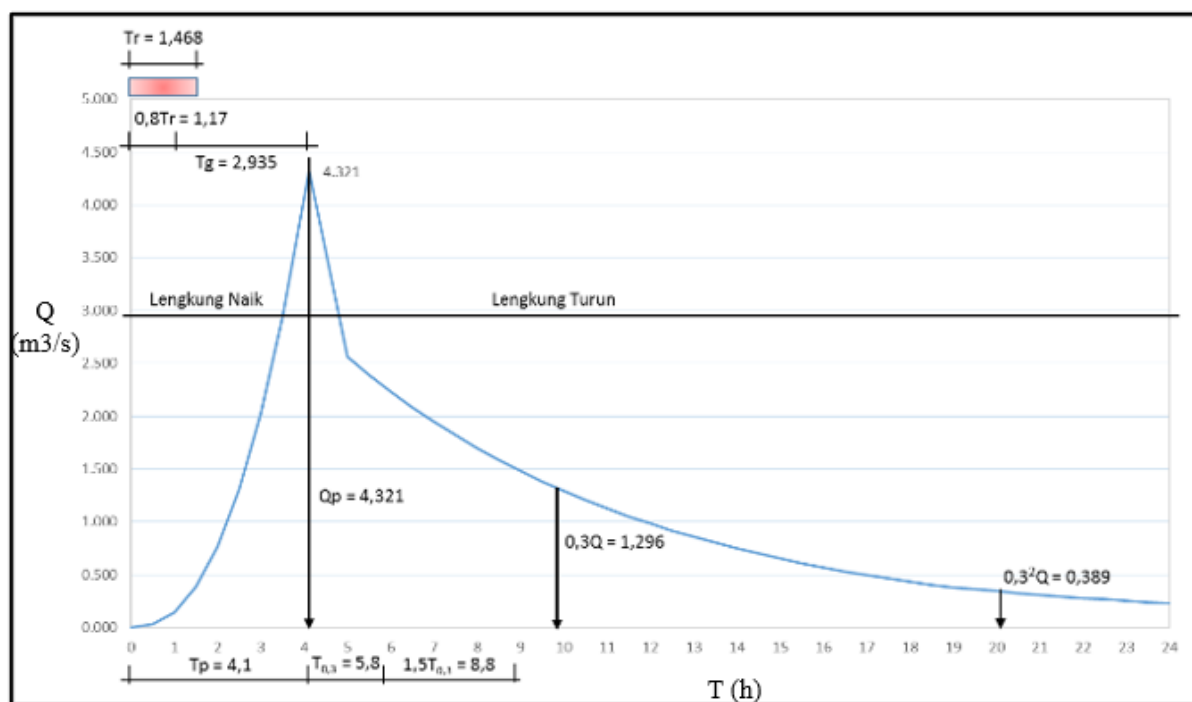
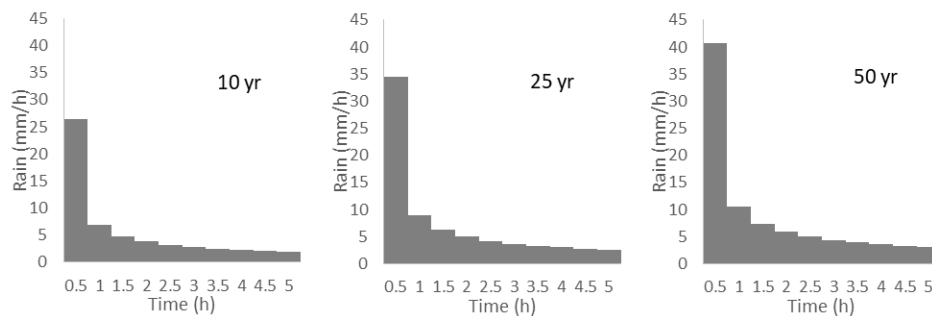


Figure 2. Unit hydrograph elements.

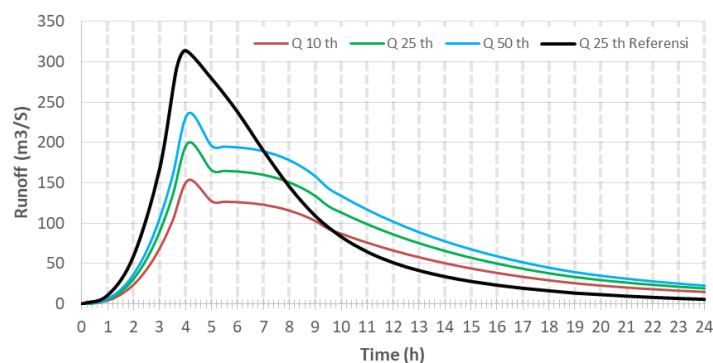
### 3. Results and discussion

#### 3.1. Rainfall-runoff transformation

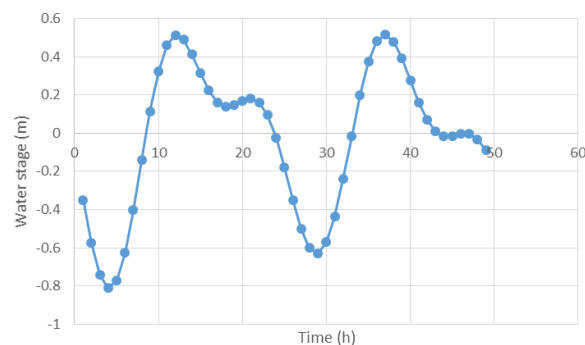
Analysis of hydrology shows that the design rainfall for 10, 25, and 50 years return period are 141.356 mm/day, 158.975 mm/day, and 177.520 mm/day respectively. The rainfall intensity hourly distribution is given in Figure 3. These data are introduced to the Nakayasu model and the results are shown in runoff as illustrated in Figure 4. Due to lack of flood observation data, validation of flood simulation is conducted by comparing the analysis with the reference from past study, i.e. simulation carried out by Ikhsan [4] which is shown by black curve in Figure 4. It can be concluded that the simulation could provide the plausible result despite slightly lower value of the calculation.



**Figure 3.** Rainfall intensity hourly distribution.



**Figure 4.** Flood hydrograph as upstream boundary condition.



**Figure 5.** Tidal stage as downstream boundary condition (right).

### 3.2. Simulation of inundation from river overtopping

Runoff from Nakayasu becomes an upstream (P81) boundary condition of hydraulic model/HEC-RAS. As for the downstream (P0), the boundary condition is set as stage/flow hydrograph which is obtained from tides data. Friction coefficient or Manning's  $n$  values is 0,035 representing rough natural stream. Contraction and expansion coefficients are 0.1 and 0.3 respectively. The results of the simulation is shown in Figure 6 for upstream (P80), middle (P30), and downstream (P0).

For model validation, comparison with the inundation occurrence is presented. According to the flood report, on 22 February 2017 and 15 December 2018, flood occurred at Kedungrejo and Ketegan area respectively. The recorded rainfall was up to 21 mm/day and 110 mm/day respectively. The inundation depth in Buntung River vicinity ranges from 0.15 m to 0.5 m. This report conform to the simulation from HEC-RAS, though the simulation shows little higher value. This may be attributable to

the location of flood survey report that are located higher than the simulated points of simulation. Nevertheless, the simulation would result in more safe countermeasures.

### 3.3. River normalization as structural measure

In order to overcome the flooding, channel cross section normalization is designed. The proposed dimensions of the river is a double trapezoidal cross section. By trial and error of new cross section in HEC-RAS Channel Modification, the ideal cross section to alleviate flood can be obtained. Trial is conducted to reduce the water level at least 0.88m, 0.81m, and 0.53m at downstream, middle stream, and upstream respectively. Figure 7 shows the result of channel modification. After being trialed, the channel with width of 21 m, bank slope of 1:2, and dyke height of 0.6 m is sufficient to convey the design flood with 25 years return period.

This study has shown the effect of normalization and dyke structure to reduce the occurrence of river overflowing in 25 years return period rainfall. However, there is still possibility that Buntung River experiences inundation in the upcoming years when the rain occurs with probability of less than 4%. Therefore, it is necessary to evaluate the robustness of these non-structural and structural countermeasures by studying the benefit and cost of the measures. Intangible benefit, such as the flood damage reduction as well as public willingness to pay the structural measure would be beneficial for operational purposes [10,11].

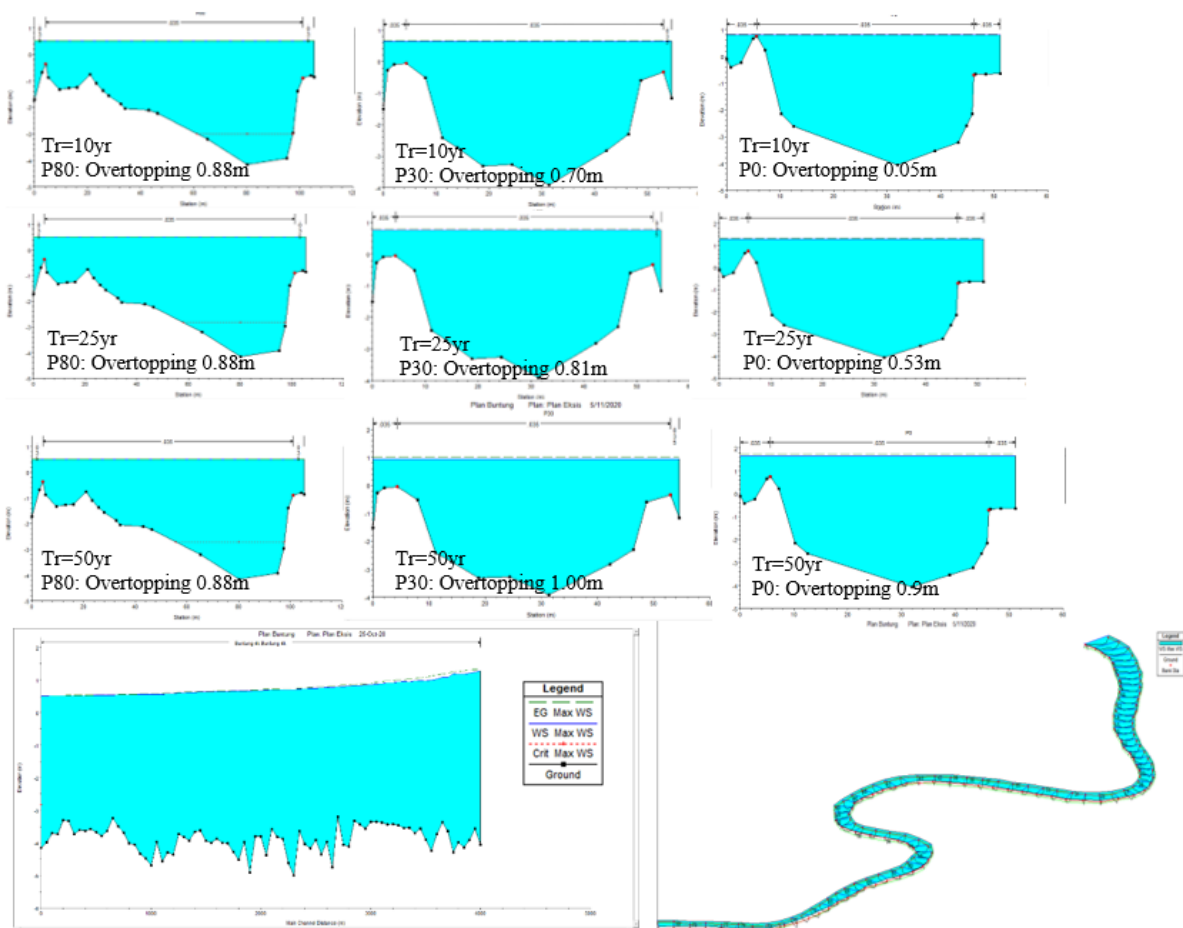
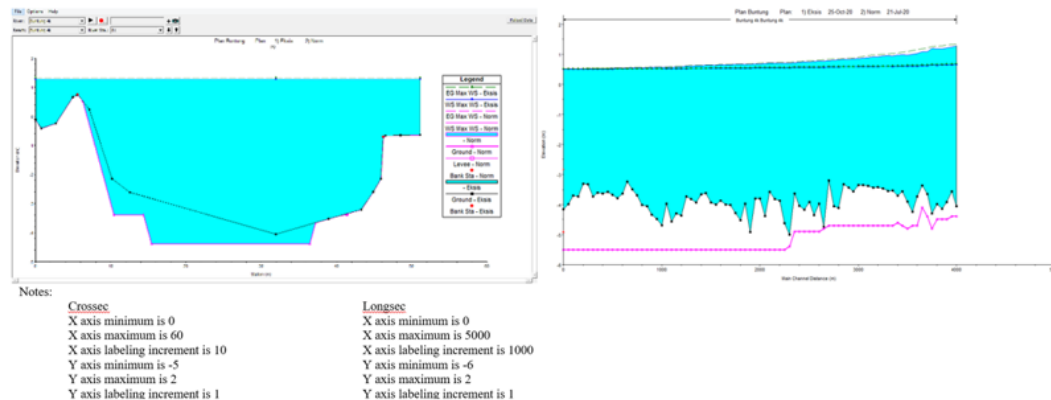


Figure 6. Water stage from hydraulic simulation.



**Figure 7.** Channel modification and water profile for cross section (left) and long section (right) at downstream (P0).

#### 4. Conclusions

Simulation of rainfall-runoff and open channel hydraulic of Buntung River Sidoarjo has been presented. Design flood with return period of 25 years is  $196.923 \text{ m}^3/\text{s}$ . It is found that existing channel capacity cannot accommodate the runoff that causes inundation in surrounding area. Validation with flood report and survey shows that the simulation shows a reliable results. As for the structural measures, river normalization and levee construction is proposed. The channel with width of 21 m, bank slope of 1:2, and dyke height of 0.6 m is sufficient to convey the design flood with 25 years return period. For further study, it is recommended to simulate the submerged area due to inundation as the flood plain is relatively flat. Validation with flood depth from water level recorder or direct survey is necessary to gain the confidence of the modeling. Studying the feasibility of the physical countermeasures by including the intangible cost/benefit of flood damage is recommended to provide integrated flood alleviation in the study site.

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