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Assessment of Structural and Non-Structural Flood Control in Gunting River, Jombang Regency, East Java Province

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ABSTRACT Gunting River which is located in Jombang Regency of East Java Province, Indonesia encounters frequent flood event almost every year. It causes many problems in transportation, health, and economic activity. Thus, flood control which has been implemented in this area needs to evaluate. Design flood was analyzed using HEC-HMS 4.0 Software, while the hydraulic modeling used the unsteady flow simulation model by HEC-RAS 5.0.3 Software. The flood control simulation was conducted with 2 and 10-years return period. The simulation results with the normalization for 2-years (Q_2) and 10-years return period (Q_{10}) can effectively accommodate the exceed of flood discharge and lower the depth of runoff depth. The combination of normalization and embankment for can drain the maximum discharge up to 508.75 m^3/s, and decrease run-off depth of 2.65 m. The land conservation of 17.8 km^2 of the upper area in the watershed has lower the flood depth up to 0.16 m.

KEYWORDS Conservation; normalization; flood control; Gunting River

1 INTRODUCTION

Almost every year, the Gunting River overflows and inundating several areas surrounding the river. Flood cause problems such as obstructing the main transportation road of Surabaya–Madiun, and Malang–Babat, disrupting trade activities in Mojoagung Market and hampering the education and business activities in locations around the area that has become the flood's regular. The flood is worse by the climate condition that has increasing rainfall each year. The upstream part of the watershed has gone a change from water catchment forest into agricultural and plantation area. The matter that should be known in the flood control of area surrounding the Gunting River is the amount of flood potential on Gunting Watershed which includes the location of flood prone area, flood water level in river channel, and the runoff inundation depth. This research studied the steps on flood control by creating a simulation that could reduce the river surface level height and reduce the height of the runoff water.

2 FLOOD CONTROL MANAGEMENT

2.1 River

The combination of the stream and the water flow inside it is called river. The long stream on the earth surface in where the water that came from rain flows is called river stream. One of the river's functions is to collect the rainfall in a certain area and channel it into the sea (Sosrodarsono & Masateru, 1985).

2.2 Land Use Change

Change in land use affects the condition of the watershed. The environment of the rivers in Java Island has been degraded. Many problems were found such as flood, erosion, and degradation due to the land use change (Nugroho, 2009). Land use is a factor created by human intervention. This is hard to avoid due to the development in the densely populated area (Sri Harto, 2000)

2.3 Flood

The cause of flood are human related activities such as change in watershed condition, slum area, damage in flood control construction, inadequate planning in flood control system; and natural factor such as rainfall, erosion and sedimentation, inadequate river or drainage capacity (Kodoatie & Sugiyanto, 2002)

2.4 Flood Control System

Flood control depends on many aspects; this is conducted through two approaches, structural and non-structural (Kodoatie & Sjarief, 2006). Structural controlling is such as by building a levee, flood canal, the interconnection between river streams, or retention dam. Non-structural controlling is through the spatial plan, greening, or reforestation (Sudjarwadi, 2008).

3 RAINFALL AND RUNOFF ANALYSIS

3.1 Rainfall

The amount of watershed rainfall that could be considered to represent the amount of entire rainfall that occurred in the watershed is analyzed by entering the rainfall data on a watershed. The amount of rainfall is obtained by calculating average point rainfalls using Thiessen Polygon method (Sri Harto, 2000).

3.2 Frequency Analysis

Frequency analysis is used to determine the amount of rainfall and design flood discharge on a certain return period. The return period is described as a hypothetical time period in which the rainfall or discharge on a certain amount would be equaled or exceeded in that certain time period (Limantara, 2010).

3.3 Rainfall Hourly Distribution

One of the empirical formula to obtain rainfall distributions is the Alternating Block Method (ABM). The design rainfall is distributed into hourly rainfall. If the available data is daily rainfall data, it needs to change into hourly rainfall with rainfall distribution model (Chow, et al., 1988). ABM method can be used to derive hyetograph from daily rainfall, while analysis rainfall duration can be approached using the Kirpich model (Sujono, 2014).

3.4 Land Use

The spatial distribution of land use change is very decisive on the amount of rain water that would infiltrate into the soil and the amount of rain water that would be transformed into surface runoff. Curve Number (CN) of land use is a function of the watershed characteristic, such as soil type, land cover crop, land use, moisture, and land processing procedure. If the land consists of several land use and soil types, the $CN_{composite}$ would be calculated (Chow, et al., 1988).

3.5 Synthetic Unit Hydrograph

GAMA I Synthetic Unit Hydrograph was developed based on the hydrological behavior of 20 watersheds in Java Island. GAMA I Synthetic Unit Hydrograph also functions well for the rest of Indonesian areas, even though it was derived from watersheds in Java Island (Sri Harto, 2000).

Nakayasu Synthetic Unit Hydrograph was developed in Japan. The unit hydrograph has been researched in some of the Japan rivers. This Synthetic Unit Hydrograph used in some reservoir project in Java such as in the Brantas River (East Java) project (Chow, et al., 1988).

4 METHODOLOGY

4.1 Research Location

The Gunting River is administratively located in Jombang Regency. The area size of Gunting Watershed is 183.93 km^2. Gunting Watershed consists of 5 sub-basins (Catak Banteng, Pancir, Balong Suru, Gunting Hulu, and Gunting Hilir). Pancir River and Balong Suru River meet in Gunting Hulu River. Catak Banteng River disembogues in the junction of Gunting Hulu River and Gunting Hilir. Gunting Watershed area is shown in Figure 1.

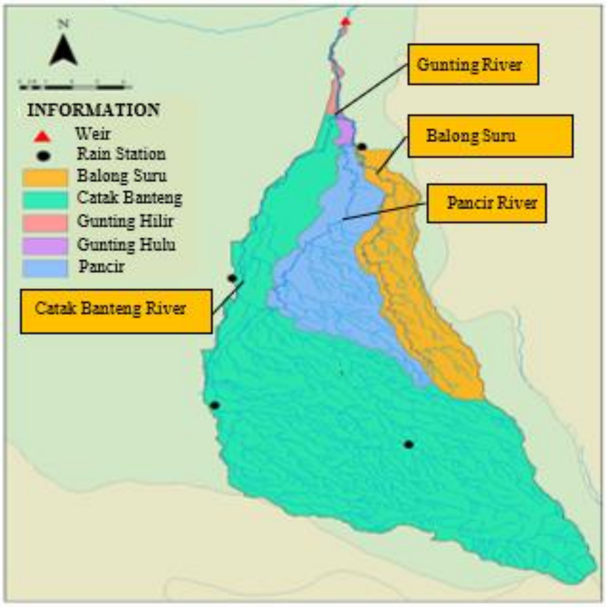

Figure 1. Gunting Watershed Area

4.2 Analysis of Watershed Rainfall

Rainfall analysis is used to calculate the amount of rainfall in the watershed. Watershed rainfall is analyzed with Polygon Thiessen method. The rainfall data used were from 4 manual rain gauges. The watershed areal rainfall was obtained by multiplying rainfall data of each station with Thiessen coefficient to find the annual maximum daily rainfall series.

4.3 Design Rainfall

Frequency analysis of the annual maximum daily rainfall was used to discover the design rainfall on return period of 2, 5, 10, 25, and 50 years.

4.4 Rainfall Distribution

This research area used the daily rainfall data. To obtain the depth of hourly rainfall from the design rainfall, the hypothetical rainfall distribution model was used. The daily rainfall data were hourly distributed using ABM method (Chow, et al, 1988).

4.5 Curve Number (CN) Determination

The $CN_{composite}$ value was determined with the land use and soil type map. The CN value calculation was used to obtain the amount of effective rainfall. Land that consists of several land use and soil type was over-layered with Arc-GIS program.

4.6 Synthetic Unit Hydrograph (SUH)

Synthetic Unit Hydrograph is used to transform rainfall runoff based on the physical characteristic of the watershed, into river discharge (Sri Harto, 2000). Observed discharge data and automatic rainfall data were not available; therefore, the Synthetic Unit Hydrograph was used. The GAMA I SUH was used Catak Banteng Sub-basin, Pancir Sub-basin, and Balong Suru Sub-basin because of the matching watershed parameter; whereas the Nakayasu SUH was used for Gunting Hulu Sub-basin and Gunting Hilir Sub-basin because the parameter of main river length could be used (rivers do not have stream order data or only consists of one main river).

4.7 Hydrological Simulation Analysis

The hydrological simulation analysis was performed using HEC-HMS 4.0. This hydrological simulation was aimed to find the watershed and discharge parameter that cause a flood. According to Sujono (2014), the HEC-HMS modeling consists of:

a) Basin models, the construction of the basin models used 5 (five) sub-basin with a control point on Balongsono Weir,
b) Control specifications used to determine the time the simulation starts and ends,
c) Time series data, filled with the distribution of 2-years return period design hourly rainfall.
d) Paired data, filled with data from GAMA I Synthetic Unit Hydrograph and Nakayasu Synthetic Unit Hydrograph.
e) The simulation result is compared with the measured discharge. Calibration is needed to be done if there is a difference between the simulation result and measured discharge. Design discharge is calculated after the calibrated parameter is obtained.

4.8 Hydraulic Analysis Simulation

The hydraulic analysis was conducted with HEC-RAS 5.0.3 program. The process stages in HEC-RAS are modeling of river geometry, river hydraulic modeling by establishing the upstream boundary, downstream boundary, initial condition, and the program simulation (Istiarto, 2014). River geometry modeling was conducted by the Arc-GIS 10.3 software with HEC-GeoRAS. The US Army Corps of Engineers (USACE) has developed a GIS extension for ArcMap called HEC-GeoRAS [15], which was used to prepare the geospatial information for the hydraulic model and process the results (El-Naqa & jaber, 2018). The river geometry construction was by digitizing the river layer as river axis and exported the RAS data, so it can be processed in the HEC-RAS 5.0.3 program. The scenario on flood controlling used the structural and non-structural types. The structural flood controlling simulation with the return period of 2 years and 10 years were by normalization (river planned width of 25 m) and levee combination normalization (freeboard height is 0.8 m from the flood surface level). Non-structural flood controlling was by conservation of upstream watershed (shrubs and empty land changed into forestry area). The conservation area was of 17.8 km^2 or 9.68 % from the total area of Gunting Watershed.

5 RESULTS AND DISCUSSIONS

5.1 Analysis of Watershed Rainfall

Watershed maximum daily rainfall analysis with Polygon Thiessen are shown in Table 1.

Table 1. Annual maximum daily rainfall

Year	Annual maximum daily rainfall, P (mm)				
	Gunting Hilir	Gunting Hulu	Catak Banteng	Pancir	Balong Suru
2002	105	105	82	88	87
2003	95	95	77	55	57
2004	134	134	79	90	95
2005	143	143	73	83	81
2006	122	122	83	89	87
2007	91	91	182	76	115
2008	70	70	69	62	63
2009	95	95	82	88	81
2010	87	87	71	86	80
2011	82	82	81	69	69
2012	75	75	81	69	69
2013	100	100	77	101	69
2014	104	104	52	63	53
2015	60	60	156	86	73
2016	177	177	82	95	71

5.2 Analysis of design rainfall

Frequency analysis on annual maximum daily rainfall on each sub-basin showed that the data was compatible with Normal Log and Log Pearson III distribution. The results for design rainfall on several return periods are shown in Table 2.

Table 2 Design rainfall of each sub-basin

Return period (years)	Design Rainfall (mm)				
	Gunting Hilir	Gunting Hulu	Balong Suru	Pancir	Catak Banteng
2	97	97	75	80	78
5	125	125	89	92	103
10	143	143	97	98	126
25	167	167	106	103	163
50	186	186	113	107	197

5.3 Rainfall Distribution

Gunting Watershed use daily rainfall measurement. The daily rainfall data were hourly distributed using ABM method. The rainfall duration to describe the ABM pattern was of 5 hours. The example of Gunting Hilir Sub-basin hourly rainfall with a return period of 2 years and 10 years are shown in Figure 2 and Figure 3.

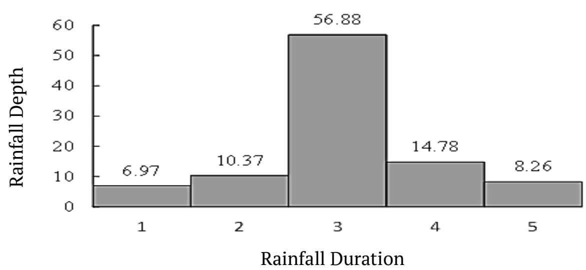

Figure 2. ABM 2-years return period Gunting Hilir Sub-basin

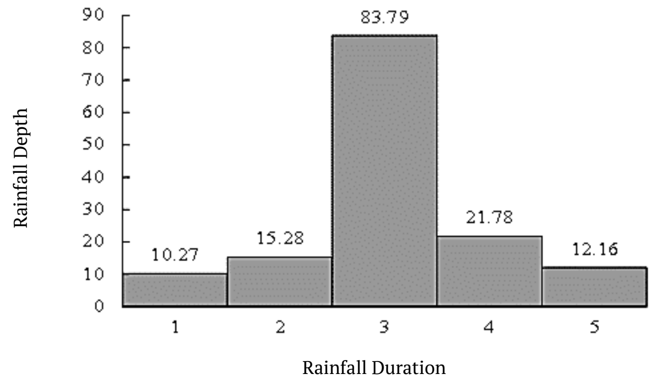

Figure 3. ABM 10-years return period Gunting Hilir Sub-basin

5.4 Curve Number (CN)

Curve Number was determined based on the soil type and land use map that was overlaid with ArcGIS 10.3 software. The CN was calculated to obtain the amount of effective rainfall. The calculation result of $CN_{composite}$ and initial abstraction (Ia) is shown in Table 3.

Table 3 $CN_{composite}$ value on each sub-basin

Sub-basin	Normal Condition		Wet Condition	
	CN (II)	Ia	CN (III)	Ia
Gunting Hilir	79.83	12.83	90.10	5.58
Gunting Hulu	77.74	14.55	88.93	6.33
Catak Banteng	72.51	19.26	85.85	8.37
Pancir	72.25	19.51	85.69	8.48
Balong Suru	66.54	25.54	82.06	11.11

5.5 Synthetic Unit Hydrograph (SUH) Analysis

This research used GAMA I SUH and Nakayasu SUH to transform rainfall into runoff. The selection of GAMA I Synthetic Unit Hydrograph and Nakayasu SUH was conducted based on the watershed parameter. The GAMA I Synthetic Unit Hydrograph is shown in Figure 4, while Nakayasu SUH is shown in Figure 5.

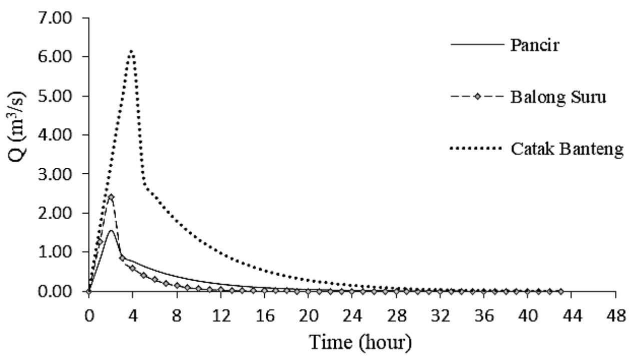

Figure 4. GAMA I SUH figure in each sub-basin

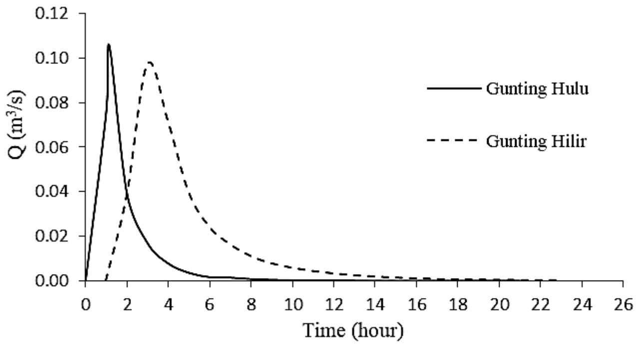

Figure 5. Nakayasu Synthetic Unit Hydrograph figure in each sub-basin

5.6 Hydrological Flood Routing

Hydrological flood routing in Gunting River was modeled using HEC-HMS 4.0 program. The Gunting Watershed model scheme is shown in Figure 6 and Figure 7.

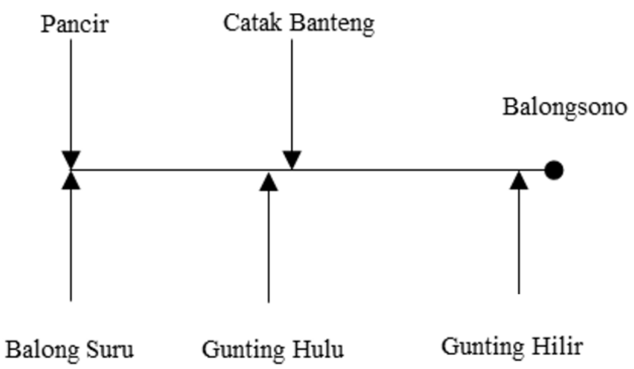

Figure 6. Hydrological modeling scheme

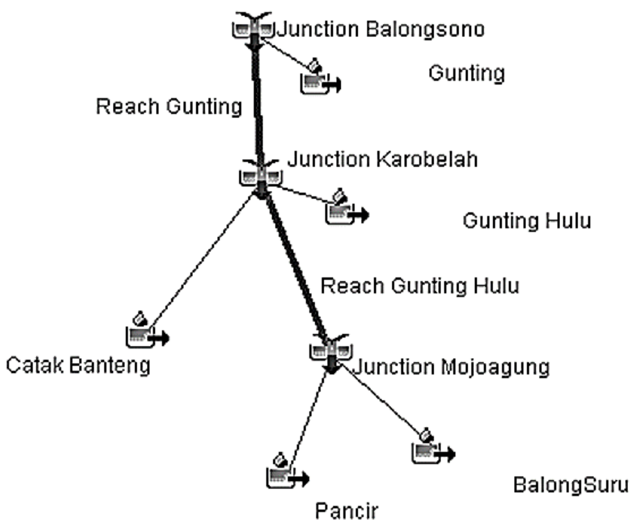

Figure 7. HEC-HMS 4.0 modeling scheme

The created basin model was used for flood simulation on January 30th, 2017 with a control point in Balongsono Weir. The result of measured flood discharge was 233.17 m³/s. The flood discharge on model simulation on January 30th, 2017 was 282.5 m³/s. The difference between measured discharge and simulation discharge was 49.33 m³/s. The simulation result is shown in Figure 8.

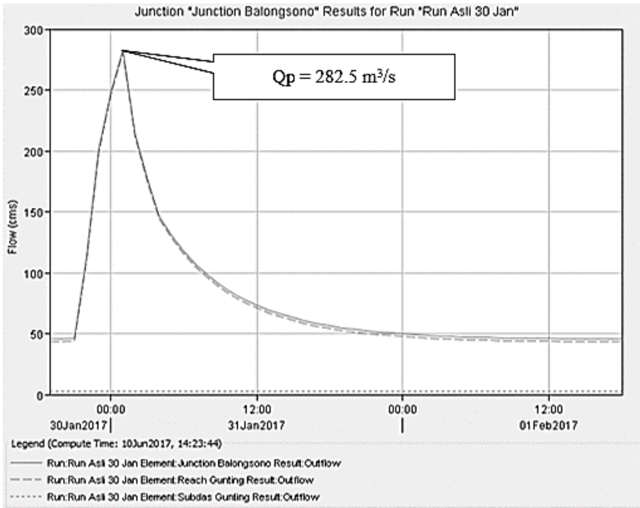

Figure 8. Flood discharge simulation result on January 30th, 2017

Flood discharge from model simulation has a different result with the measured flood discharge. Calibration was then needed to be conducted to obtain a value that closes between peak flood discharge at simulation and measured peak flood discharge. Recording of peak flood discharge in Balongsono Weir on January 30th, 2017 was with Q = 233.17 m³/s. Calibration result is shown in Figure 9.

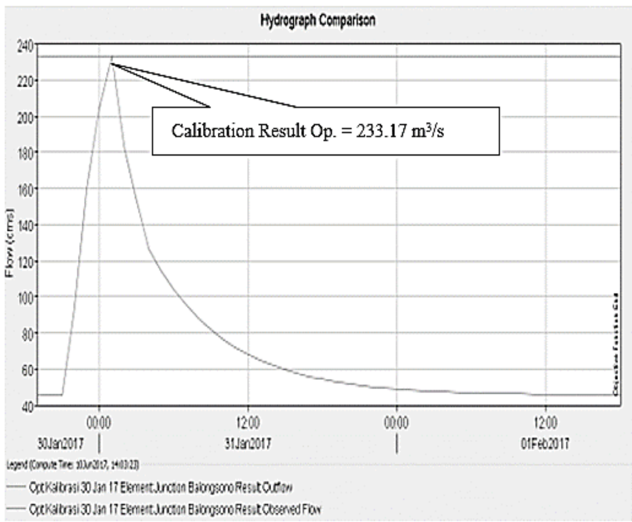

Figure 9. January 30th, 2017 calibration result

The calibrated hydrology model was used for the design flood discharge calculation. The modeling simulation result is shown in Table 4 and Figure 10.

Table 4. Design flood discharge

Design flood discharge (m^3/s)				
Q2	Q5	Q10	Q25	Q50
297.4	429.9	548.2	740.5	920.7

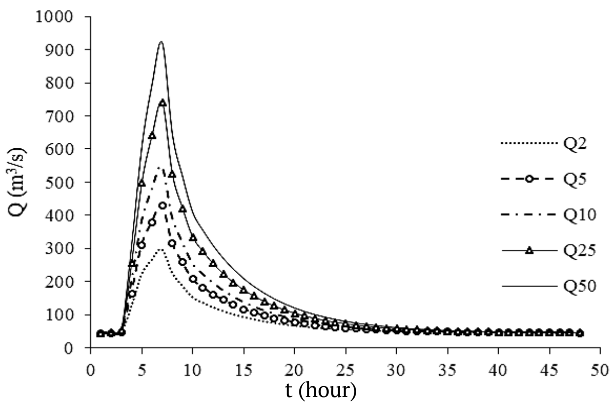

Figure 10. Design flood hydrograph of Gunting River

5.7 Hydraulic Flood Routing

The length of Gunting River modeling is ± 7.45 km, with the upstream on the river station 7,450.22, and the downstream on river station 0. Balongsono weir is in Gunting River downstream as the control point. The boundary condition applied was at the downstream boundary condition used the rating curve data from the Balongsono Weir; the upstream boundary condition used the outflow hydrograph values that were obtained from Pancir Sub-basin and Balong Suru Sub-basin. The lateral inflow was from Catak Banteng Sub-basin and Gunting Hulu Sub-basin. The scheme of the Gunting River is shown in Figure 11.

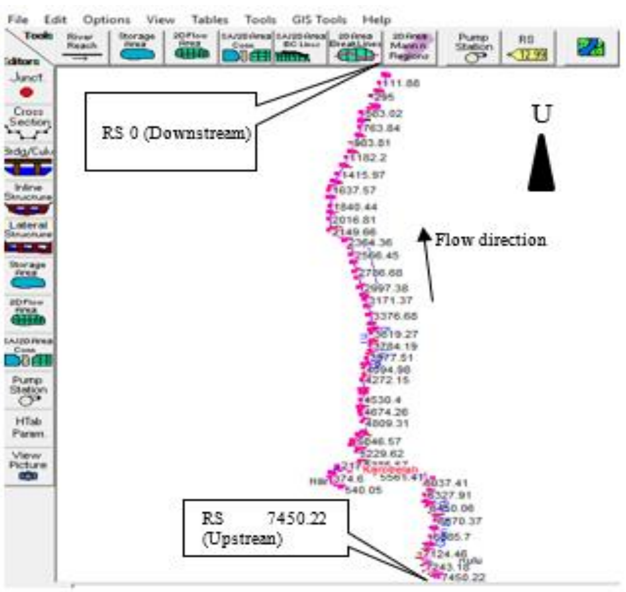

Figure 11 Gunting River scheme

The model simulation was conducted at flood event on January 30th, 2017. The simulation was conducted with various n-Manning value; therefore, it obtained a close value which is n = 0.025 – 0.045. The simulation result showed the runoff length of 3,328 m, the average water level of +31.50 m, and runoff depth of 0.73 m. The measured water level in Balongsono Weir was +27.25 m, and simulated water level in Balongsono Weir was +27.39 m.

5.8 Model Simulation with Design Flood

Design flood used in the model simulation was the 2-years and 10-years return period flood discharge (design flood discharge for small river or river with watershed less than 500 km^2). The height of the runoff was observed to the average land elevation. 2-years return period maximum discharge in Gunting River was of 268.65 m^3/s, with the average water level in the river was of +32.02 m. The result from flood simulation with 2-years return period showed the runoff occurred was of 5,346 m or as much as on the 75 cross section points, with average runoff depth of 1.25 m. Flood simulation with 10-years return period showed maximum discharge of 505.48 m^3/s, with the average water level in the river of +33.36 m. Runoff occurred in all the river cross points with average runoff height of 2.69 m.

5.9 Flood Control System

Gunting River does not have enough capacity for the 2-years and 10-years return period maximum discharge. Flood control countermeasures need to be applied to reduce the overflow. Flood control is conducted structurally (normalization, levee combination normalization) or non-structurally (upstream watershed conservation). Normalization is in the form of adjustment on the river base elevation and river width, by following the availability of river maximum riverbanks width. Addition and elevation of the river levee should pay attention to the surrounding area, so it would not disrupt the settlement. Gunting River location that is on residential area and agricultural fields makes it difficult to obtain large area for retention pond location (not used in flood controlling steps). The flood control simulation on Gunting River is as follow:

a) Normalization

River normalization is conducted by repairing the river cross section that suffers from silting and narrowing. The planning on river cross section is adjusting to the condition on the field, on the shape of a trapezoid. The width of the river for normalization is of 25 m. The result of normalization simulation with 2-years return period discharge showed the maximum discharge of 274.31 m³/s with the average water level of + 32.27 m. Average runoff depth that occurred was of 0.5 m, and the runoff length was of 2,472 m. Normalization simulation with 10-years return period discharge resulted to the maximum discharge of 502.37 m³/s, the average water level of +32.81 m; average runoff depth of 2.05 m, and runoff length of 6,745 m. Examples of normalized river reach are shown in Figure 12 and Figure 13.

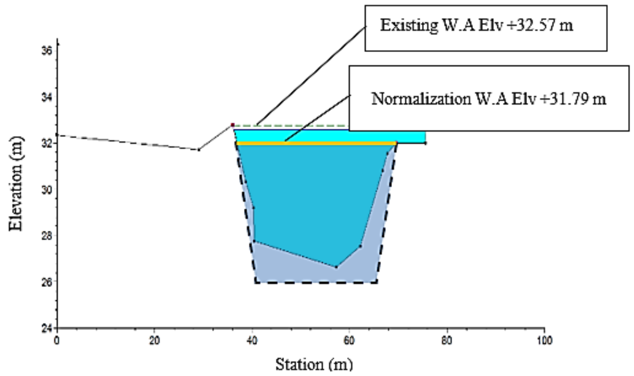

Figure 12. Reduction of water level in Gunting River (RS. 3,977.51) Q_2 with normalization

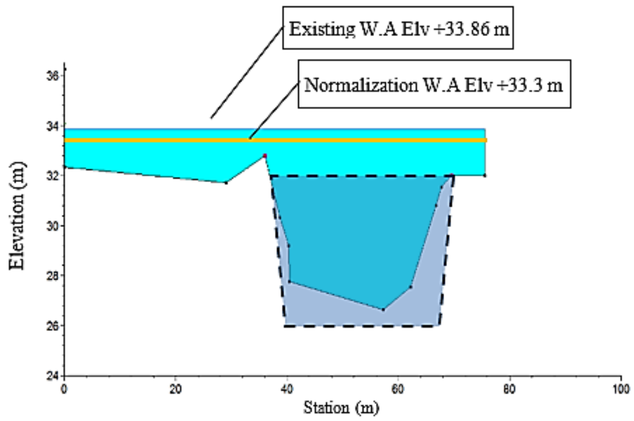

Figure 13 Reduction of water level in Gunting River (RS. 3,977.51) Q_{10} with normalization

b) Normalization and Elevation of the River Levee

River normalization was not entirely succeeded. Other simulations were conducted by combining river normalization and levee construction on the location that is still overflowed. River reaches that have overflowed water were equipped with levee and the levee was elevated. The planning on levee height of the river level was by considering the height of the freeboard of 0.8 m from the flood level as shown in Figure 14.

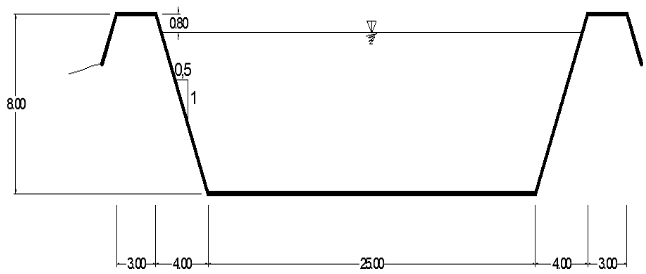

Figure 14 Plan on normalization and Gunting River's levee

Simulation of normalization and levee with 2-years return period discharge resulted to the maximum discharge of 279.01 m³/s and average water level of +31.5 m. Simulation with 10-years return period discharge result to the maximum discharge of 508.75 m³/s, and the average water level of +33.02 m. There was no runoff on the simulation of normalization and levee. Examples of levee combination normalization are shown in Figure 15 and Figure 16.

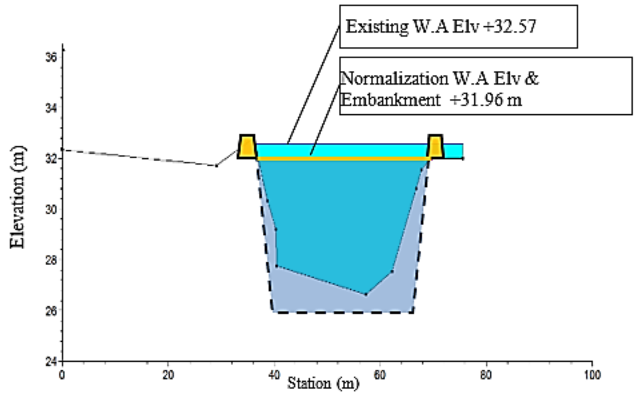

Figure 15 Reduction of water level in Gunting River (RS. 3977,51) Q_2 with levee combination normalization

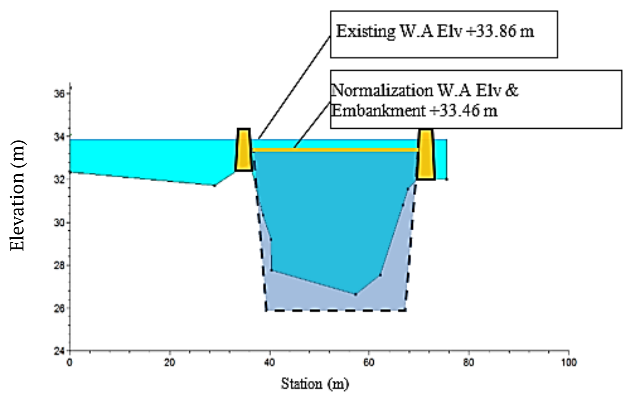

Figure 16 Reduction of water level in Gunting River (RS. 3977.51) Q_{10} with levee combination normalization

c) Conservation on Upstream Sub-basin

Conservation on the upstream part of the sub-basin is one of non-structural flood control efforts. Catak Banteng Sub-basin, Pancir Sub-basin, and Balong Suru Sub-basin are three upstream sub-basins that were improved as green space. The green space improvement was conducted by assuming the shrubs area and empty land to be changed into green space or forest area. The land used for the conservation was of 17.8 km^2 or 9.68 % from the total area of Gunting Watershed. 2-years return period flood in this simulation resulted in a maximum discharge of 249.32 m^3/s, average water level of +31.87 m, average runoff depth of 1.10 m. 10-years return period flood resulted in the maximum discharge of 474.69 m^3/s, average water level of +33.30 m, average runoff depth of 2.53 m. Average runoff height at conservation was declined about 0.14 m on 2-years return period and 0.16 m on 10-years return period when compared with an existing condition. Examples of conservation simulation results are shown in Figure 17 and Figure 18.

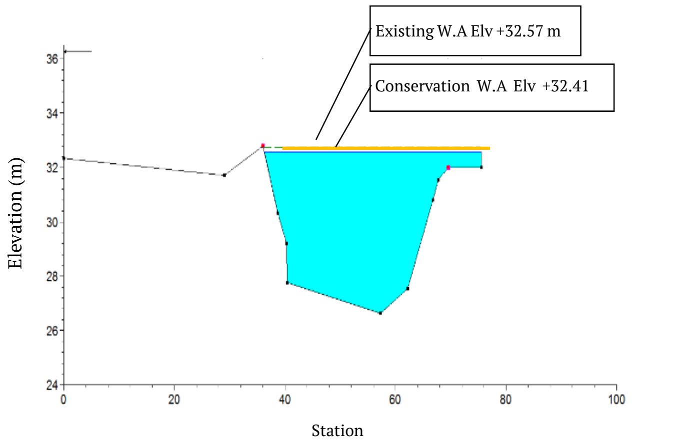

Figure 17. Reduction of water level in Gunting River (RS. 3,977.51) Q_2 with conservation

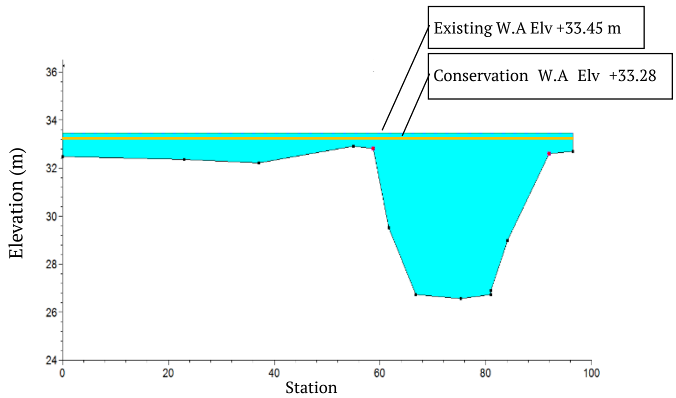

Figure 18. Reduction of water level in Gunting River (RS. 3,977.51) Q_2 with conservation

The simulation result of flood control with normalization, levee combination normalization, and conservation on the 2-years and 10-years return period discharge on Gunting River is shown in Table 5.

Table 5 Comparison of average runoff to an existing condition

Return period discharge	Reduction of average runoff depth		
	Normalization (m)	Levee and Normalization (m)	Conservation (m)
Q_2	0.74	1.25	0.14
Q_{10}	0.65	2.69	0.16

6 CONCLUSIONS AND SUGGESTIONS

6.1 Conclusions

This research resulted in several conclusions as follow.

a) Results of simulation with HEC-RAS 5.0 program showed that 2-years return period flood simulation has a maximum discharge of 268.65 m^3/s and an average elevation of +32.02 m, and runoff occurred on 75 points with runoff length of 5,346 m. 10-years return period flood has a maximum discharge of 505.48 m^3/s and an average elevation of +33.46 m, and runoff occurred in 99 points with runoff length of 7,450 m.

b) Flood control by river normalization with 2-years discharge could store maximum discharge of 274.31 m^3/s, reduce the runoff length into 2,472 m and reduce the runoff depth about 0.75 m. Combination of levee and normalization could store maximum discharge of 279.01 m^3/s, reduce the runoff depth of 1.25 m. Flood control by conservation on the upstream part of the watershed was of 17.8 km^2 or 9.68 % from the total area of the watershed; the runoff still occurred of 4,283 m, but the runoff depth was reduced of 0.15 m. Flood control with 10-years discharge by river normalization could store maximum discharge of 502.37 m^3/s, reduce the runoff length into 6,745 m and reduce the runoff about 0.65 m. Combination of levee and normalization could store maximum discharge of 508.75 m^3/s, reduce the runoff of 2.65 m. Runoff still occurred on the food control by conservation on the upstream part of the watershed of 7,450 m, and the runoff was reduced of 0.16 m.

6.2 Suggestions

Suggestions and recommendations that are related to the result of this research are as follow:

a) A study on the levee reinforcement for the anticipation of a levee breach when large flood discharge occurs is necessary.
b) A study on the application of conservation on the upstream part of the watershed to reduce the sedimentation on the Gunting River is necessary.
c) For the sake of accuracy and comprehensiveness of the research, data on automatic hourly rainfall and water level recording for Gunting Watershed need to be added.

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