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Evaluation of Structural Mitigation Effort for Flood Control in Rongkong River

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Abstract.

One of the alternative flood structural mitigation planned for Rongkong River is the construction of embankments and river normalization. However, river normalization has a weakness where the widening of the cross section of the river can cause an increase in sedimentation. The purpose of this study is to examine the effectiveness of the planned flood control in reducing flood runoff using the flood overflow hydraulic model. Rongkong basin was divided into 14 subbasin to create a distributive model. Design rainfall was analyzed using frequency distribution analysis with GEV method at various return period. Flood discharge was analyzed using HEC-HMS software with the SCS and Snyder methods on the 20-year return period. Hydraulic modelling was analyzed using HEC-RAS 1D with unsteady flow condition under existing and design cross section. Based on the results of flood modeling with a flood discharge Q20 of 1,046.78 m^3/s resulted in a flood reduction of 100% and an increase in the average flow velocity of 18% from 1.82 m/s to 2.14 m/s. The use of Q20 as a design flood discharge in the normalization plan and construction of the Rongkong River embankment is considered too large because it causes construction costs to be very expensive. It is recommended to use Q10 in accordance with the regulation of the Ministry of Public Works and Housing, which is stated that the flood design for embankments of the river near the regency/city capital area must be able to pass the flood discharge of Q10 – Q20. It is needed to conduct a design review of the plan of normalization and construction of the embankment.

Keywords: Flood control, river morphology, hydraulic modelling, HEC-HMS, HEC-RAS

Abstrak

Salah satu alternatif mitigasi struktural banjir yang direncanakan untuk Sungai Rongkong adalah pembangunan tanggul dan normalisasi sungai. Namun normalisasi sungai memiliki kelemahan dimana pelebaran penampang sungai dapat menyebabkan peningkatan sedimentasi. Tujuan dari penelitian ini adalah untuk menguji efektivitas pengendalian banjir yang direncanakan dalam mengurangi limpasan banjir dengan menggunakan model hidraulik limpasan banjir. DAS Rongkong dibagi menjadi 14 Sub DAS untuk membuat model secara distributif. Curah hujan rencana dianalisis menggunakan analisis distribusi frekuensi dengan metode GEV pada berbagai periode ulang. Debit banjir dianalisis menggunakan software HEC-HMS dengan metode SCS dan Snyder pada kala ulang 20 tahun. Pemodelan hidraulik dianalisis menggunakan HEC-RAS 1D dengan kondisi aliran tidak tunak pada penampang eksisting dan rencana. Berdasarkan hasil pemodelan banjir dengan debit banjir Q20 sebesar 1.046,78 m^3/s menghasilkan reduksi banjir sebesar 100% dan peningkatan kecepatan aliran rata-rata sebesar 18% dari 1,82 m/s menjadi 2,14 m/s. Penggunaan Q20 sebagai debit banjir rencana dalam rencana normalisasi dan pembangunan tanggul Sungai Rongkong dinilai terlalu besar karena menyebabkan biaya konstruksi menjadi sangat mahal. Direkomendasikan untuk menggunakan Q10 sesuai dengan peraturan Kementerian Pekerjaan Umum dan Perumahan Rakyat yang menyatakan bahwa desain banjir untuk tanggul sungai di dekat wilayah ibukota kabupaten/kota harus dapat melewati debit banjir Q10 – Q20. Selain itu juga perlu dilakukan kajian desain terhadap rencana normalisasi dan konstruksi tanggul.

Keywords: Pengendalian banjir, morfologi sungai, pemodelan hidraulik, HEC-HMS, HEC-RAS

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1. Introduction

Floods are one of the natural disasters that occurred around the world that cause enormous economic losses (Tam, et al., 2014). Indonesia is one of the countries that have a high risk of flood due to its topographic and geographical condition (Riyando, et al., 2018). Floods cause material losses and disrupt community activities (Prastica, et al., 2018). Flood runoff causes a huge loss to the construction, economy, and casualties (Farid, at al., 2021). Flood is a condition where water cannot be accommodated in the river channel or the flow of water is obstructed, so that water overflows and inundates the surrounding area (flood plain) (Suripin, 2003). Flood disasters often occur in the rainy season when rainfall is high. High rainfall intensity that occurred in a short time can cause higher runoff discharge (Farid, at al., 2021).

Another factor that contributes to the cause of the flooding is a change in land use. Land use changes can lead to changes in the hydrologic characteristic, one of them is an increase in surface runoff that will intensify floods (Farid, at al., 2018). Land-use changes upstream of the river due to the development of the area can also cause an increase in erosion that results in reduced capacity of the river (Setio, et al., 2019). Rongkong River has a high potential for flooding every year, flood events are caused by sedimentation in the river which causes a reduction in the river's capacity to pass flood discharge. The source of sediment comes from the erosion of agricultural land upstream and mass landslides that occur on hillsides, mountains, and river cliffs (Puslitbang Lingkungan Hidup, UNHAS 2017).

The government through BBWS Pompengan – Jeneberang has conducted a technical study of the flood control plan, one of which is the construction of embankments and normalization of the downstream Rongkong River. This work aims to increase the capacity of the Rongkong river so that it can drain flood discharge and prevent runoff to protect community settlements and public facilities. Some of the sub-districts that are prone to flooding due to the runoff of the Rongkong River include South Baebunta, West Malangke, and Sabbang (BBWS, Pompengan Jeneberang, 2013).

The purpose of this study is to examine the effectiveness of planned flood control in reducing flood runoff using the flood overflow hydraulic model. In this study, flood modeling was analyzed using HEC-RAS. HEC-RAS is an advanced software for river flow hydraulic analysis (Najafi, et al., 2015). Hydraulic analysis components used in HEC-RAS for this study is one-dimensional unsteady flow simulation. One-dimensional hydraulic calculations are capable of simulating unsteady flow through a full network of natural and constructed channels (US Army Corps of Engineers, 2016).

2. Study Area

The study area of this research is Rongkong River in North Luwu Regency, South Sulawesi Province which is included in the Pompengan Larona River Area and is located in the Rongkong Basin under PUPR Ministerial Regulation No. 04/PRT/M/2015. The area of Rongkong Basin is 1807 km^2 with the length of Rongkong River is around 104 km and ends in Bone bay which is affected by tides. Rongkong Basin map can be seen in **Figure 1(a)**.

The upstream part of the Rongkong River has a slightly steep to steep slope, while the downstream has a gentle to flat slope. Land slope map is shown in **Figure 1(b)**. This condition causes the upstream flow velocity to be quite heavy to transport sediment and causes sedimentation in the downstream due to changes in slope which causes a decrease in flow velocity. This sedimentation causes the capacity of the downstream Rongkong River unable to pass the flood discharge within a certain return period and eventually causes flood overflow.

Normalization of the river is planned with a double cross-section as can be seen in **Figure 2(a)**, where the width of the main channel is between 40 - 120 m,

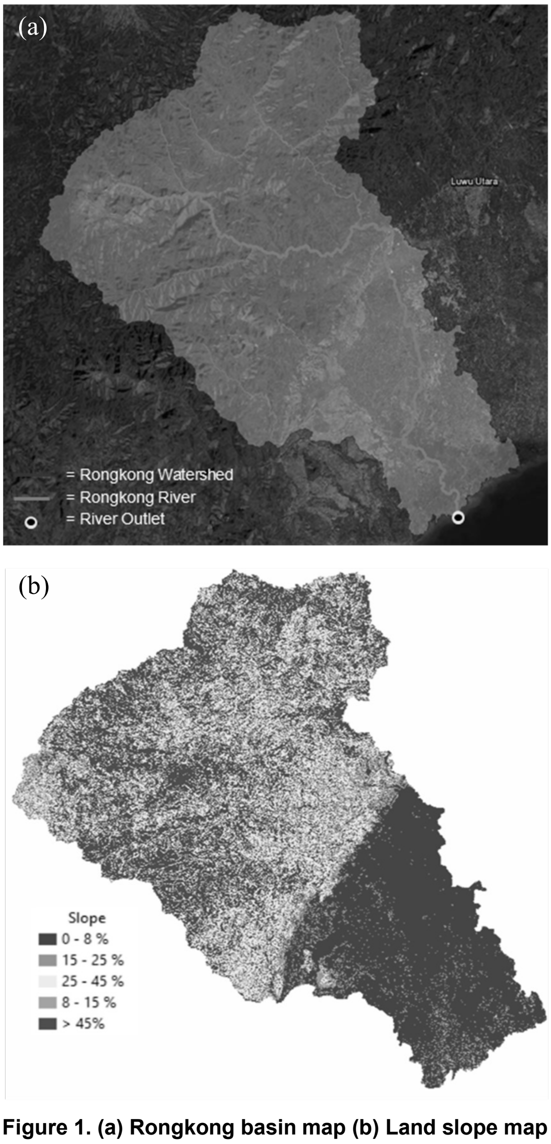

Figure 1. (a) Rongkong basin map (b) Land slope map

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while the banks on the left and right of the river are 20 m wide. The total length of the embankment planned is 54 km as can be seen in **Figure 2(b)** and the height of the embankment varies from upstream to downstream with an average planned height of 5 m.

The normalization and construction of the embankment are designed using the flood discharge at a 20 year return period which is 3939 m^3/s based on design data. Flood discharge used is based on the regulation of the Ministry of Public Works and Housing, which is stated that the flood design for embankments of the river near regency/ city capital area must be able to pass the flood discharge of Q10 – Q20 [13].

3. Material and Methods

The stages in this study consist of literature study review, data collection, analysis and modeling, suggestions, and conclusions. Rainfall data is obtained from 3 stations which is DAS Rongkong (2010-2019), Sabbang (2010-2019), and Lamasi-Padang-Kalua (1979-2019) which can be seen in **Figure 3**. Observed discharge data is obtained from 1 station which is Rongkong Narobo (2003-2019) as can be seen in **Figure 4**.

Basin parameters such as basin area, river length, length to centroid, slope, CN, and etc. were analyzed using Geographic Information System (GIS). The hydrologic analysis consists of regional rainfall analysis using the isohyet method, design rainfall analysis at various return periods using frequency distribution analysis, effective rainfall analysis using SCS-CN method, hourly rainfall distribution using satellite data based on historical flood events, and flood design discharge analysis using HEC-HMS based on Synthetic Unit Hydrograph (SUH) method which is Soil Conservation Service (SCS), and Snyder

Hydraulic modeling was analyzed using HEC-RAS 1D with unsteady flow conditions. The boundary condition used upstream of the model is flood discharge and tidal

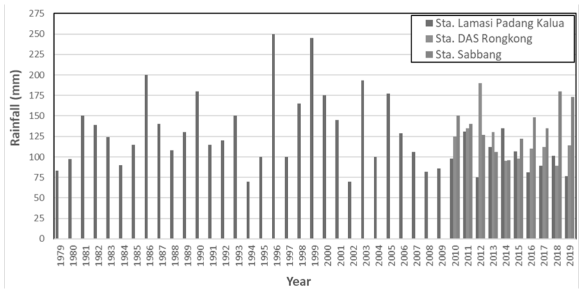

Figure 3. Maximum daily rainfall data

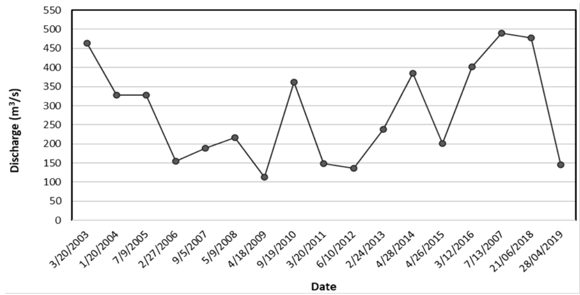

Figure 4. Maximum observed discharge data

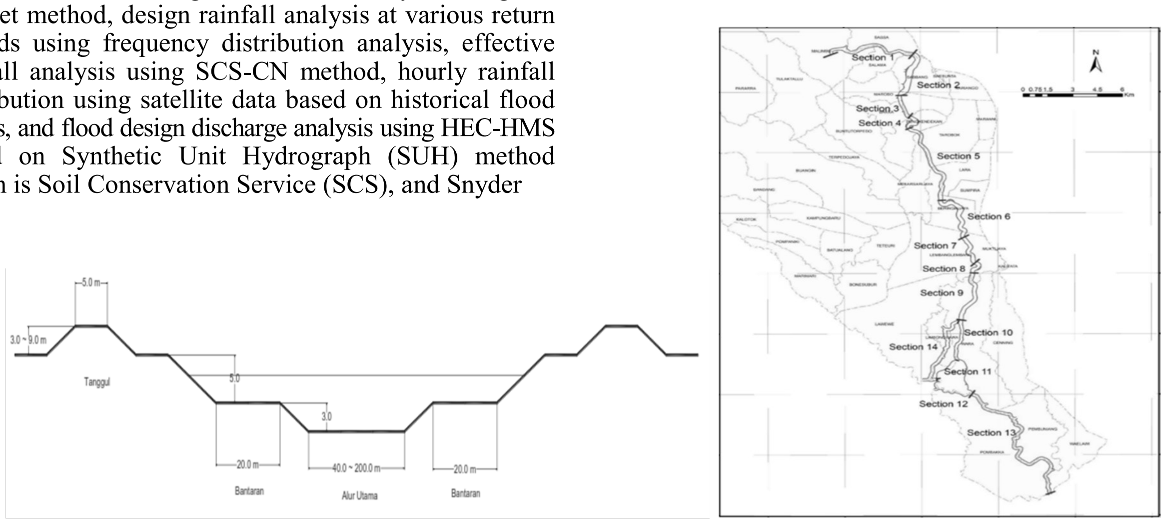

Figure 2. (a) Typical design of embankment and normalization (b) Flood control plan map

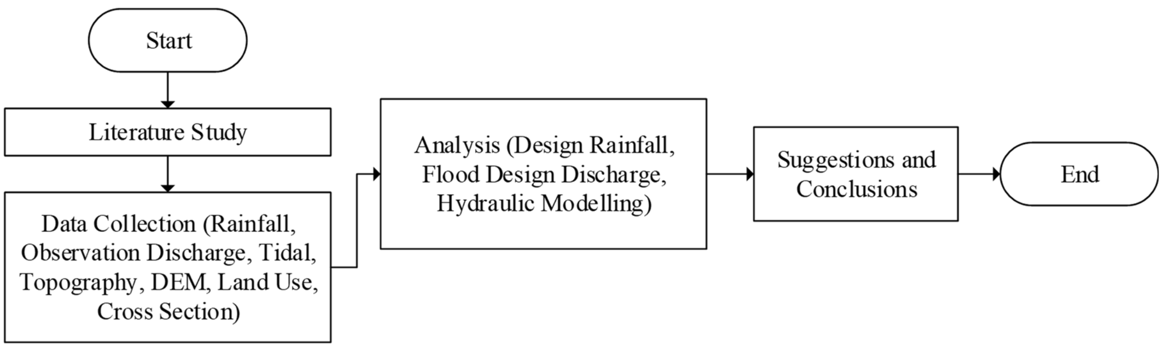

Figure 5. Flow chart of the study

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stage elevation downstream of the model. The geometric data is obtained from Rongkong River Flood Control Survey, Design, and Investigation (SID) Study. The flow chart of this study is described in **Figure 5**.

4. Results and Discussions

4.1. Basin property analysis

Basin property data was analyzed using GIS-based on Digital Elevation Model (DEM) data. To be able to produce a distributive model, Rongkong Basin was divided into 14 sub-basins and the results can be seen in **Figure 6(a)**.

4.2. Design rainfall analysis

Generalized Extreme Value (GEV) was chosen as a method for frequency distribution analysis to produce design rainfall at various return periods. Analysis was performed on the maximum daily rainfall data at each station used. The results can be seen in **Figure 6(b)**.

4.3. Regional rainfall analysis

Regional rainfall was analyzed by creating an isohyet map using GIS. The isohyet map was created based on the 20 year return period design rainfall. Isohyet's map of regional rainfall can be seen in **Figure 7(a)**. Based on the map, design rainfall was calculated on each sub-basins, the results can be seen in **Figure 7(b)**.

4.4. Hourly rainfall distribution analysis

Due to the lack of observed hourly rainfall data, the analysis of the hourly rainfall distribution was conducted using Global Precipitation Measurement (GPM) satellite data based on historical flood events that have occurred 2010-2020. From the results of the analysis the distribution of hourly rainfall can be seen in **Figure 8(a)**.

4.5. Effective rainfall analysis

The calculation of effective rainfall is done by first calculating the infiltration value. The infiltration calculation in this study was done using the SCS method based on the value of CN (Curve Number). CN values are obtained by combining soil texture maps based on HWSD (Harmonized World Soil Database) maps shown in **Figure 12** and Rongkong Basin land use maps shown in **Figure 13** to get CN values on each existing sub-basins as can be seen in **Figure 8(b)**.

4.6. Flood design discharge analysis

The flood design discharge was analyzed using HEC-HMS with SCS SUH and Snyder SUH method with

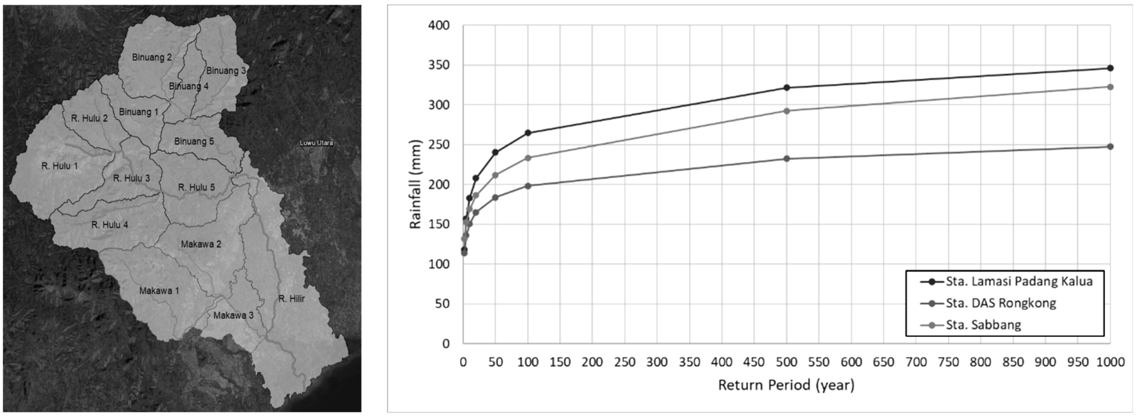
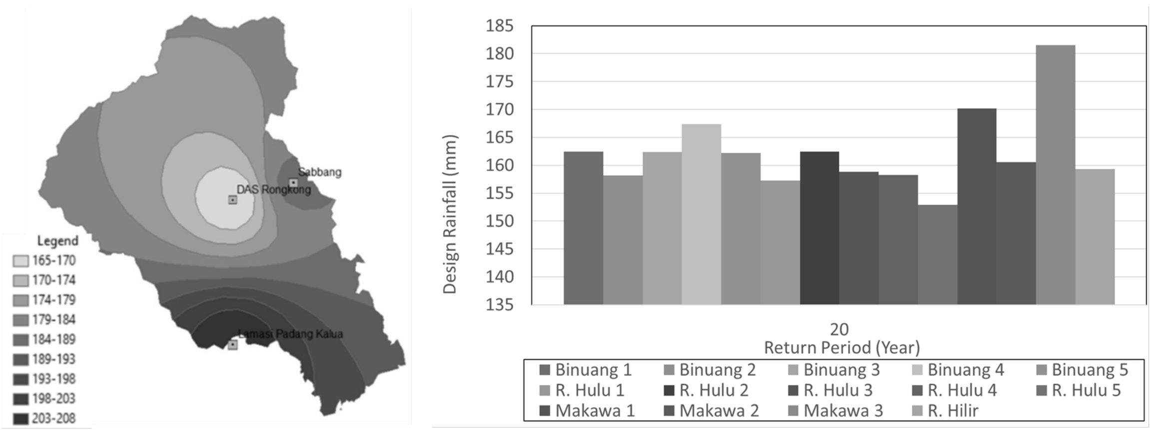


Figure 6. (a) Sub-basins map (b) Design rainfall at various return periods on each station



(a) (b)

Figure 7. (a) 20 year return period isohyet map (b) Design rainfall on each sub-basins

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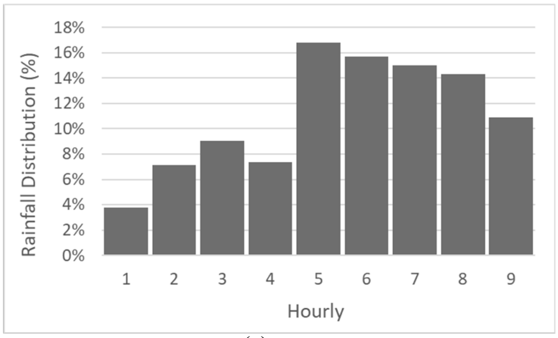
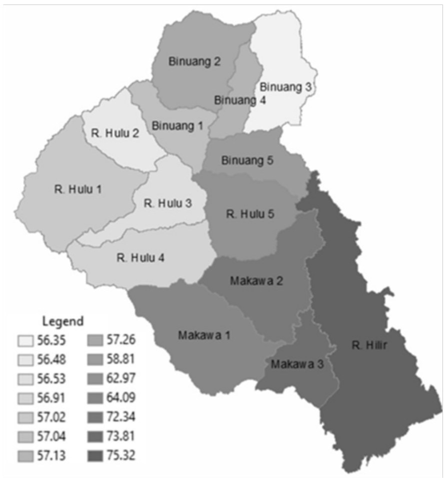
various return periods. The inputs used in modeling flood discharge with HEC-HMS are river network schemes, basin parameters, hourly rainfall, and CN value for infiltration. The basin network scheme can be seen in **Figure 9**.

Flood peak discharge was calibrated using frequency distribution of observed discharge data located at Junction-5 by adjusting the time lag parameter on both SCS SUH and Snyder SUH methods. Calibration was analyzed on 20 year return period flood peak discharge.



(a)



(b)

Figure 8. (a) Hourly rainfall distribution (b) CN values map

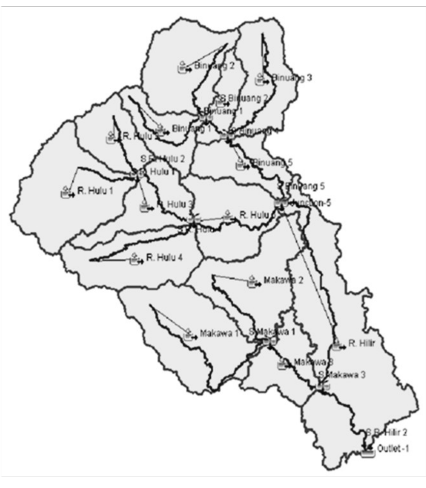


Figure 9. Rongkong basin hydrological model scheme in HEC-HMS

From the calibration, Snyder SUH was chosen as the flood design discharge that will be used for hydraulic modeling. The calibration results can be seen in **Figure 10** and **Table 1**.

Based on the analysis result using Snyder SUH the flood discharge hydrograph obtained at Junction-5 and Outlet-1 both is shown in **Figure 11** and **Figure 12**. The flood peak discharge for both review points is shown in **Table 2** and **Table 3**.

4.7. Hydraulic modeling analysis

Modeling is carried out on 2 conditions which are existing condition and design condition. The 20-year flood design discharge obtained from calculation before is used as a boundary condition in HEC-RAS 1D unsteady flow at the upstream of the model. The boundary condition used downstream of the model is tidal data using Highest High Water Level (HHWL) elevation. The river network scheme and boundary used for modeling can be seen in **Figure 13** and the boundary condition is shown in **Table 4**.

The results of the hydraulic modeling using HEC-RAS 1D on the elongated profile of Rongkong River existing conditions are shown in **Figure 14**. From the results, there was a flood runoff that occurs slightly upstream and from the middle to downstream of the river. The flood occurs at Sta. 54000-48000 and at Sta 32000-0.

The height of the flood runoff at some of the review points can be seen in **Table 5**. The average height of the flood runoff is about 2 m and the average of the flow

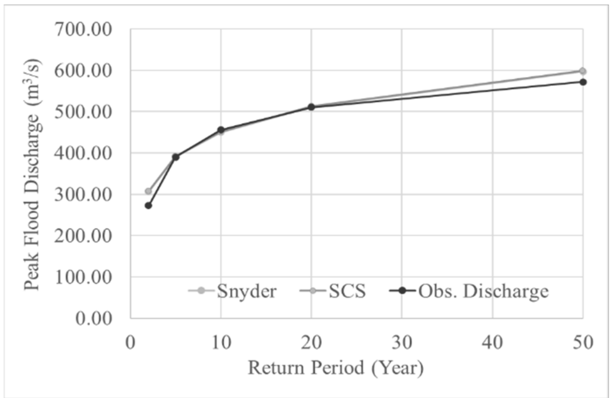


Figure 10. Peak discharge calibration

Table 1. Calibrated flood peak discharge on 20 year return period

Return Period	Peak Flood Discharge (m^3/s)		
(Year)	SCS	Snyder	Obs. Discharge
2	306.86	306.12	272.60
5	391.18	389.99	390.15
10	451.20	449.76	455.67
20	512.65	510.96	510.66
50	599.19	597.16	571.96

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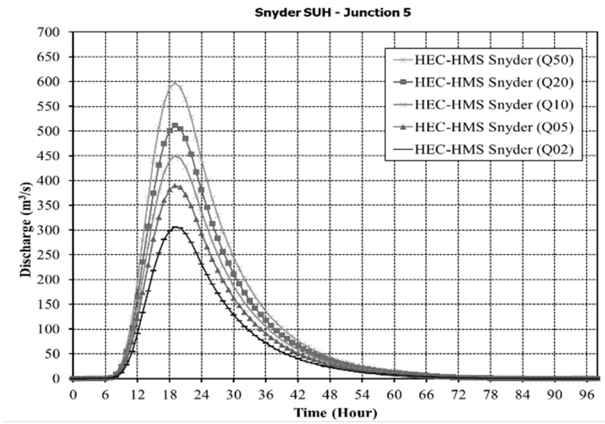

Figure 11. Snyder SUH flood discharge at junction-5

Table 2. Snyder SUH peak flood discharge at junction-5

Return Period (Year)	Peak Discharge (m^3/s)
2	306.12
5	389.99
10	449.76
20	510.96
50	597.16

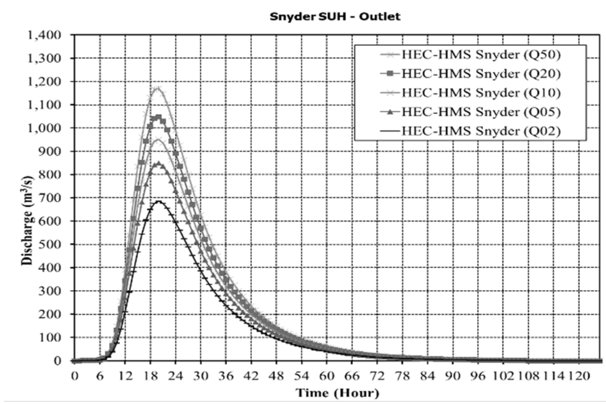

Figure 12. Snyder SUH flood discharge at Outlet-1

Table 3. Snyder SUH peak flood discharge at outlet-1

Return Period (Year)	Peak Discharge (m^3/s)
2	684.46
5	848.74
10	951.16
20	1046.78
50	1169.91

velocity is 1.82 m/s. Flooding occurs due to sedimentation in the river which causes a reduction in the river's capacity to drain the flood downstream of the river.

The results of the hydraulic modeling using HEC-RAS 1D on the elongated profile of Rongkong River

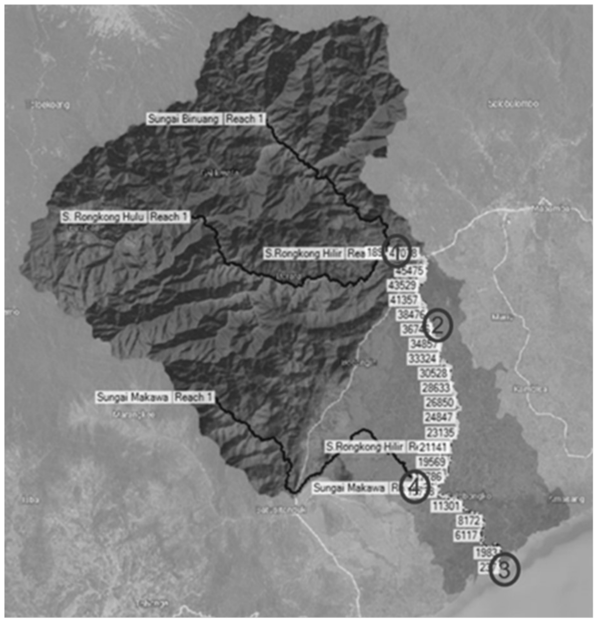

Figure 13. River network scheme in HEC-RAS

Table 4. Boundary condition

Boundary	Description
1	Flow hydrograph
2	Lateral flow hydrograph
3	Flow hydrograph
4	Stage hydrograph

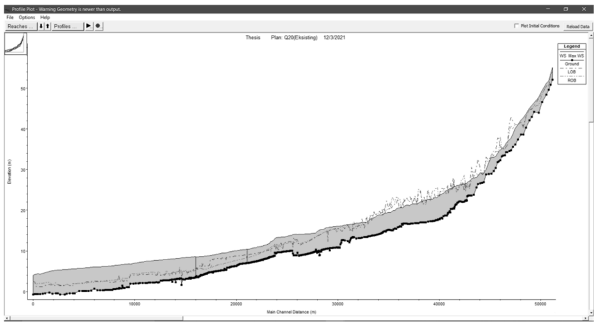

Figure 14. Elongated profile of Rongkong river existing

Table 5. Flood runoff height at existing condition

No.	River Sta.	LOB	ROB	WS. Elev.	Runoff
1	50293	48.66	48.60	49.55	0.95
2	49934	46.44	45.82	47.97	2.15
3	48421	40.65	40.24	42.86	2.62
4	32745	15.66	15.44	16.98	1.54
5	26974	11.98	12.25	14.15	1.90
6	19446	8.44	7.94	9.74	1.80
7	13485	4.08	4.38	7.08	2.70
8	8860	3.04	2.9	6.66	3.76
9	1690	1.73	2.33	5.23	2.90
10	237	2.33	2.46	4.71	2.25
11	91	2.54	2.45	4.32	1.87

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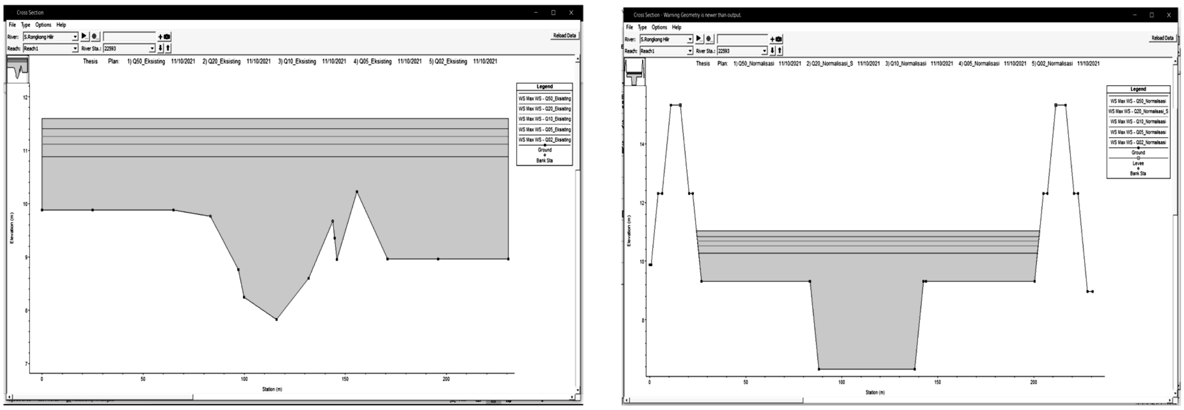

Figure 16. Comparison of the cross-section between existing conditions and design conditions

Table 6. Flood runoff height at design condition

No.	River Sta.	LOB	ROB	WS. Elev.	Runoff
1	50293	51.36	51.68	49.28	0
2	49934	48.44	48.48	48.07	0
3	48421	45.14	45.14	40.34	0
4	32745	20.54	20.54	15.33	0
5	26974	17.92	17.92	12.75	0
6	19446	14.06	14.06	8.17	0
7	13485	13.42	13.42	7.26	0
8	8860	11.87	11.87	6.16	0
9	1690	8.69	8.69	4.41	0
10	237	7.52	7.52	4.10	0
11	91	7.35	7.35	4.02	0

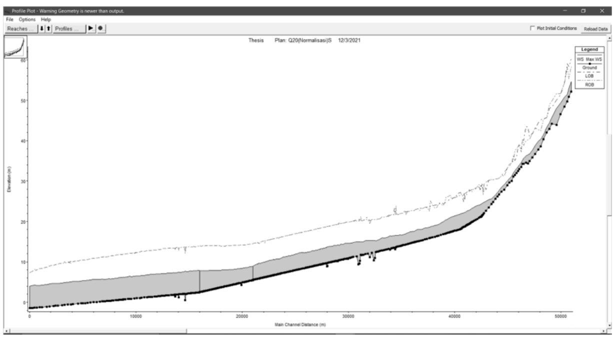

Figure 15. Elongated profile of Rongkong river design conditions

normalization and embankments conditions are shown in **Figure 15**. Based on the results, flood reduction resulted from the plan of normalization and construction of levees by 100% where there was no flood runoff along the modeled river.

However, there is a difference between flood discharge resulting from the analysis in this study which is used in the model with flood discharge design from the data plan. This difference shows that the structural mitigation effort for flood control in Rongkong River with river normalization and construction of embankment is over-designed.

The height of the flood runoff at some of the review points can be seen in **Table 6**. In this condition, there is no flood runoff after normalization and embankment construction are carried out. In **Figure 16** is displayed several cross-sections as a comparison between existing conditions and design conditions.

From the comparison of the cross-section between existing conditions and design conditions shown in **Figure 16**, it can be seen that the existing capacity of the Rongkong River at a certain cross-section was unable to pass the flood discharge on 2 year return period.

5. Conclusions.

The conclusions from this study include the following :

1. There is a difference in flood discharge on the 20-year return period at rongkong river outlets between the results of the analysis which is 1046 m^3/s with the flood discharge used to design the normalization and embankment of the planning data which is 3939 m^3/s. This is due to differences in several methods used in hydrological analysis and in the planning data that has not been explained regarding flood discharge calibration methods.
2. From the results of modeling using HEC-RAS, the existing capacity of the Rongkong River upstream from Sta. 51295-41482 is 724-1491 m^3/s, at the middle from Sta. 41451-21303 is 82-385 m^3/s, and at the downstream from Sta. 21221-91 is 35-80 m^3/s. This shows that the existing Rongkong River is no longer able to pass the Q2 – Q5 flood discharge in the middle and downstream.
3. In the upstream, the capacity is still able to pass the Q50 flood discharge because the cross-section of the river in the upstream part of the river is widened due to the erosion from the river flow.
4. Based on the results of flood modeling using the normalization and embankment condition resulted in a flood runoff reduction of 100% and caused an increase in the average flow velocity of 18% from 1.82 m/s to 2.14 m/s.

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5. The use of Q20 as a design flood discharge in the normalization plan and construction of the Rongkong River embankment is considered too large because it causes construction costs to be very expensive.
6. It is recommended to use Q10 in accordance with the regulation of the Ministry of Public Works and Housing, which is stated that the flood design for embankments of the river near the regency/city capital area must be able to pass the flood discharge of Q10 – Q20.
7. It is needed to conduct a design review of the plan of normalization and construction of the embankment.

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