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Study of the Effectiveness of Making a Retention Pond for Urban Flood Management: A Case Study of the Barabai River, South Kalimantan

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ABSTRACT

The upstream of the Barabai River is experiencing land conversion from forest to agricultural and mining areas. In 2021, floods and river overflows will inundate nearly 75% of Barabasi City. The solution given is to build a Retention Pool so that the flow of the Barabai River before entering Barabai City is diverted to the Retention Pool. By conducting hydrological and hydraulic flow analysis with the application of HEC RAS with unsteady flow conditions, the water level profile along the Barabai River can be displayed including the flow behavior in the retention pond during flooding. As a result, the retention pond is only effective at accommodating 25% of the discharge during a flood. By optimizing using the HEC RAS program, alternatives to inundation or flooding in Barabai City are obtained, namely: widening the Barabai river 2x, expanding the regulation pool to 95 ha, building a second retention pond of 40 ha, and normalizing the Barabai River that enters Barabai City.

INTRODUCTION

The Barabai River is a tributary of the state and is part of the Barito River Basin with a catchment area of 550 km^2 and a length of the main river of 113.35 km. In the lower reaches of the Barabai River through Barabai City, South Kalimantan Province, there has been a narrowing. When there is heavy rain upstream, there will be floods and overflows of river water downstream which inundate almost 75% of Barabai City (Prabowo 2018). Floods and overflows in Barabai City occur regularly every year starting in 2018, 2019, and 2020 so there is moderate vulnerability to buildings in Barabai City (Muslim et al. 2017). For flood control, drainage has been built, but its effectiveness is only 62.75% (Anam et al. 2015). Normalization or widening of the Barabai River is no longer possible in urban areas. The only way is to make a temporary reservoir in the event of a flood. The planned flood discharge that occurs needs to be studied hydrologically because 4 rivers enter the lower reaches of the Barabai River, namely the Kahakan River, Udung River, Kuli River, and Kitir River with varying river lengths (Ls) and river slopes (So), which certainly have an impact on time concentration (Tc), and the amount of flood discharge that occurs are presented as fluctuating in the form of a calibrated flood hydrograph (Chay 2002, Harto 1993). To regulate the incoming discharge, it is necessary to build a threshold in the Barabai river and side spills in the regulation pond so that the function of the reservoir pond is effective (Anis et al. 2017). The discharge that enters the Barabai River is regulated with a certain threshold elevation so that there is no overflow in the Barabai River. Similarly, the elevation and width of the side spillway (B) that will enter the regulation pool are set at a certain elevation so that the regulation pool can accommodate a certain volume of flood discharge. The elevation of the side spillway must be higher than the elevation of the threshold light that enters the lower reaches of the Barabai River (AH). Setting the threshold height and volume of regulation pool regulation is an important part that needs to be analyzed and optimized so that there will be no more flooding in Barabai City (Cahyono 2010, Czahchor et al. 2010). The threshold elevation was made higher than the elevation of the side spillway entering the Regulation Pond and then analyzed by HEC RAS. Analysis with HEC RAS for the Barabai river has been carried out with flood discharges at the 100th return period (Faizal & Nizam 2005, Hauer et al. 2021).

RESEARCH SIGNIFICANCE

Inflow modeling using HEC RAS, the flow behavior is made unsteady, and then the flow behavior in 2 places is evaluated, namely in the lower reaches of the Barabai

River and in the Regulatory Pond (Istiarto 2012) by analyzing and simulating threshold elevation, the elevation of side beam crest, and the width of side spillway. So, the purpose of this study is to obtain the most effective regulatory pool construction (optimum area and height) including complementary building models (shape and elevation of the threshold lighthouse and side spillway including the width) to reduce flooding that occurred in Barabai City.

The components for perpetual flow were developed for subcritical flow calculations. Hydraulic calculations for cross-sections, bridges, culverts, and other hydraulic structures developed for permanent flow components are combined with non-permanent flow calculations. Components for perpetual flow are used for reservoir models and hydraulic linkages with reservoirs. HEC – RAS is now able to perform one-dimensional water table profile calculations for continuous flow changes in natural and artificial channels. Subcritical, supercritical, and combined system flow profiles of the water table can be analyzed (Istiarto 2012). The water level profile calculated from one cross-section to the next is solved by an energy equation called the Standard – Step method. The energy equation used can be seen as follows (Rizal 2014):

$$\boldsymbol{Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e} \quad \ldots(1)$$

The energy loss height (h_e) between the 2 cross-sections is due to friction loss and loss due to narrowing or widening. The high energy loss equation is as follows (Rizal 2014):

$$\boldsymbol{h_e = L.S_f + c.\left[\frac{\alpha_2 v_2^2}{2g} - \frac{\alpha_1 v_1^2}{2g}\right]} \quad \ldots(2)$$

(a). The overflowing barabai river

(b). Flow on the channel

(c). Flow on intake

(d). Overflowing stream to the city of barabai

Fig. 1: The condition of the area during the flood on November 15, 2021, in the Barabai River.

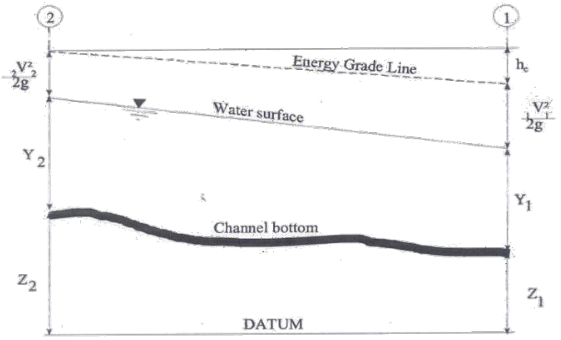

Fig. 2: Components in the energy equation. (Source: Chow et al. 1989).

Determination of the total ow rate and velocity coefficient for a cross-section requires dividing the flow into units because the flow velocity is not uniformly distributed. In HEC – RAS the approach used is to divide the area in the embankment area using the boundaries of the n values that exist in the cross-section (the location where the value of n changes) as the basis for division (Fig. 3). The discharge calculated in each of the sub-areas in the embankment area is used by the Manning formula. Since HEC-RAS is a one-dimensional program for determining the water level profile, only one water level and average energy is calculated for each cross-section. For a given water level, the average energy is obtained by calculating the flow energy portion of the 3 subsections of a cross-section (left of the embankment, middle, and right of the embankment). Fig. 3 shows how the average energy will be obtained for a cross-section with the composition of the main flow and the right area of the embankment (no left area of the embankment).

MATERIALS AND METHODS

Data Collection

The data inputted in this study from the Central Kalimantan River Basin (BBWS) III agency include 1) Rainfall data 1 daily and water level data (AWLR) for data input in the HEC-RAS application Rainfall data 1 daily from the nearest Rain Station for at least the last 10 years. 2) Observation data or minimum field discharge measurements when flooding occurs in 5 rivers. 3) Elevation digital model (DEM) owned by the Information & Geospatial Agency, land use map based on aerial photography in 2015 from data from the Department of Public Works & Spatial Planning (PUPR) of South Kalimantan Province as well as land maps belonging to the 2016 Agricultural Land Resources Research and Development Agency, which are used to hydrological analysis and modeling. 4) Data from the measurement of the cross-section and long section of the Barabai River from upstream to downstream. 5) Regulation pool planning data which includes inundation area and a peak elevation of the regulation pool. 6) Data on types of supporting buildings in the entry of flow to the retention pond.

Data Processing Stage

The activity stages include: 1) Analysis of the design flood hydrograph of 5 (five) rivers using HEC-HMS, 2) Inputting the long and cross-section data of the Barabai River into the HEC RAS program, 3) Entering the input data for the regulatory pool to be made, 4) Entering input spillover data for the entry of Barabai River water into the retention pond, 5) Entering boundary conditions at the upstream and downstream of the Barabai River (upstream is the flood hydrograph of each river, downstream is the bottom slope of the Barabai River).

Analysis Stage

In the next analysis, the following things were carried out: 1) Performing a flow hydraulics analysis with HEC RAS with unsteady flow conditions, 2) displaying input results on all cross rivers and regulatory ponds and side spillways, 3) optimizing the output results of the HEC RAS program, 4) determine alternative inundation or flood management, 5) proposed recommendations for flood management in Barabai City.

RESULTS AND DISCUSSION

Modeling of flow behavior in retention ponds is strongly influenced by the input of discharge data entering the river which is expressed in the form of a flow hydrograph for 24 hours (Martin & Fransiskus 2015, Noor 2013). The input does not always flow downstream but can be seeped into the soil and this depends on the physical properties of the soil. The flow that enters the largest regulation pool from the Barabai River is then added to the flow from the Kahakan River, Udung River, Kuli River, and Kitir River whose results are presented in a schematic form in Fig. 4.

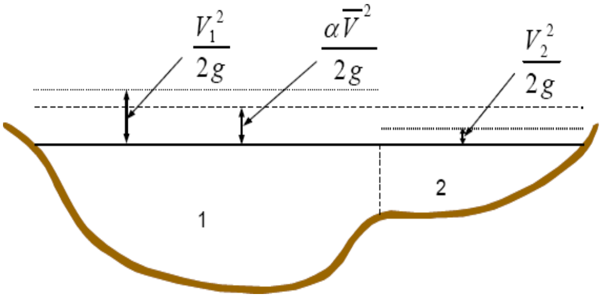

Fig. 3: Average energy distribution in HEC RAS. (Source: Chow et al. 1989).

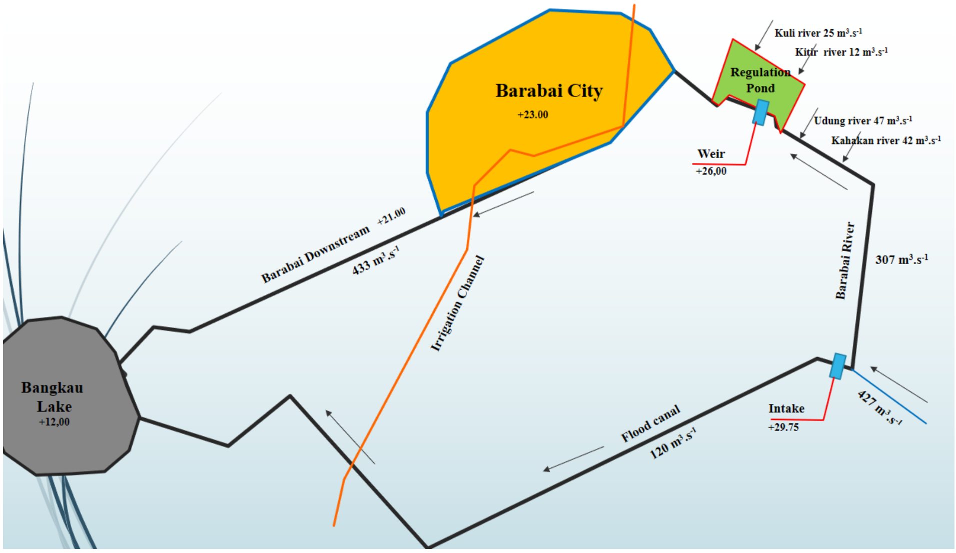

Fig. 4: Flow scheme in the Barabai Sungai River. (Source: Consultant Study Results, 2021).

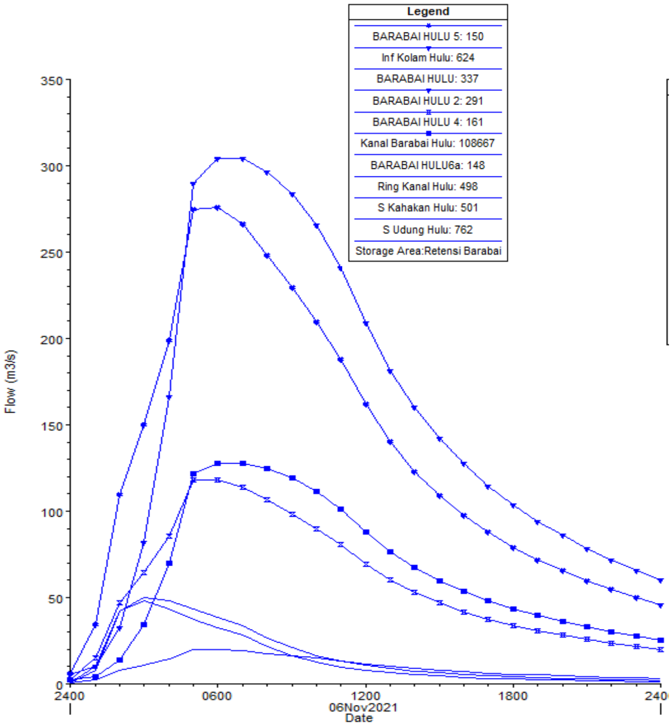

Fig. 5: Calibrated flood hydrograph. (Source: Calculation Result, 2021)

The results of the flood hydrograph calculation have been calibrated by observing flood events on the 15th. November 2021, the results of which are presented in Fig. 2. Validation of the discharge value has been carried out on all STA as the results of the measurement of the discharge at the time of the incident from STA 188 to STA 272 which were compared with the results of the HEC RAS modeling. The total flood discharge that enters the lower reaches of the Barabai River is 579.24 m^{3}.s^{-1} which is the accumulation of 4 rivers. All accumulated discharges from the Barbai River, Kahakan River, Udung River, Ulin River, and Kitir River are planned to enter the holding pond for several hours. The storage pond is planned with an inundation area of 58 ha, then the highest elevation of the regulation pond is planned to be +18 m. The flow that enters the reservoir first passes through the side spillway with a width of 8 m and a height of 3 m. In determining the discharge that enters the downstream of the Barabai River, a hydrological analysis is carried out to obtain flood hydrographs for the 5 rivers mentioned above. Frequency analysis can be calculated using the Gumbel or Pearson log method. The results of the hydrograph analysis must pay attention to the suitability of the relationship between parameters (Yan et al. 2013). The results of the calculation of the peak flood discharge were calibrated based on the results of flood observations in the five rivers mentioned above so that the hydrograph parameters of each river were obtained. Furthermore, these parameters can be used to calculate the flood hydrograph (Zhang & Singh 2006) in the 5 rivers, so that the result is that the peak flood time (Tr) occurs at the 6th h with varying peak discharge quantities which are presented in Fig. 5.

Furthermore, the results of the calculation of the flood discharge plan are entered as the upstream boundary condition in the HEC RAS program, while the downstream boundary conditions use the data of the downstream river bed slope. In accordance with the storage pond development plan, it must be ensured that the size and dimensions of the planned storage pond include the dimensions of the side girder. Furthermore, from the dimensions of the reservoir Komal, the inundation area will be obtained which will be included as input in the HEC RAS program. Similarly, the width of the next side girder is used as input in the HEC RAS program.

The results of the measurement of the situation map and river cross-section are first entered into the HEC RAS program. In this study, the total length of the river studied was 20 km and there were 150 cross rivers included in the HEC RAS. The results are presented in Fig. 6. Running is carried out using unsteady flow conditions with the aim of getting an overview of the flow behavior pattern in the river, side spillway, and the holding pond within 24 hours. The results of the analysis in the HEC RAS program will show the water level profile along the Barabai River including the water level profile in the side spillway and storage pond. In the reservoir pond, a graph or table will be obtained showing the relationship between time and the highest elevation of the reservoir pond and a graph showing the relationship between time and the flow rate entering the regulation pond. Based on initial calculations, it was determined that the regulation pool needed to be at least +44 meters above sea level or 26 meters high to accommodate the maximum flood discharge of 579.24 m^{3}.s^{-1}.

After running based on the data that has been entered in the HEC RAS program, the results show that the peak discharge occurs at 16.00 WIB, and to accommodate flood

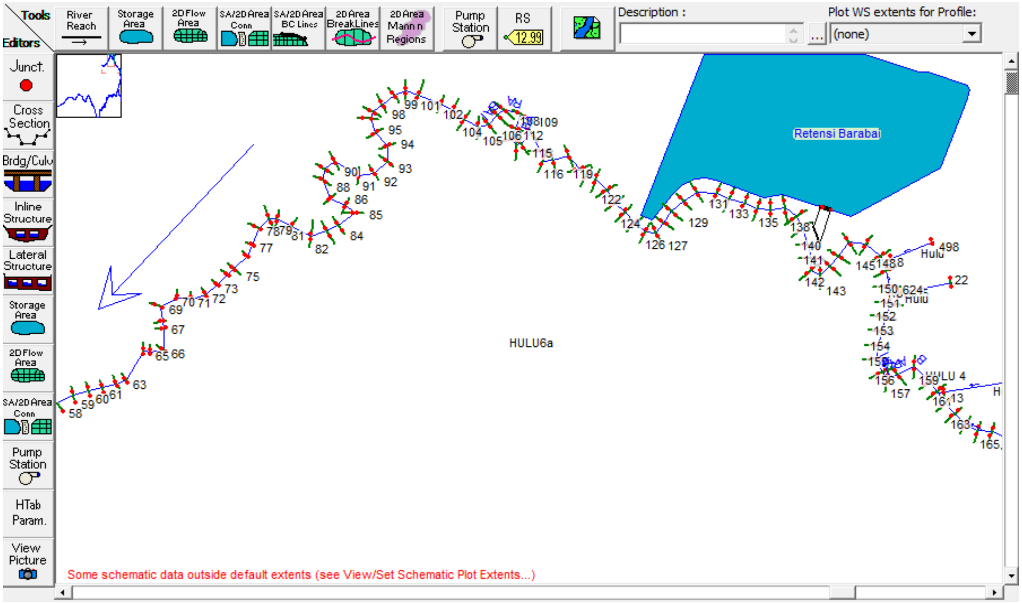

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Fig. 6: Barabai River modeling with Hec Ras Program. (Source: Calculation Result, 2021)

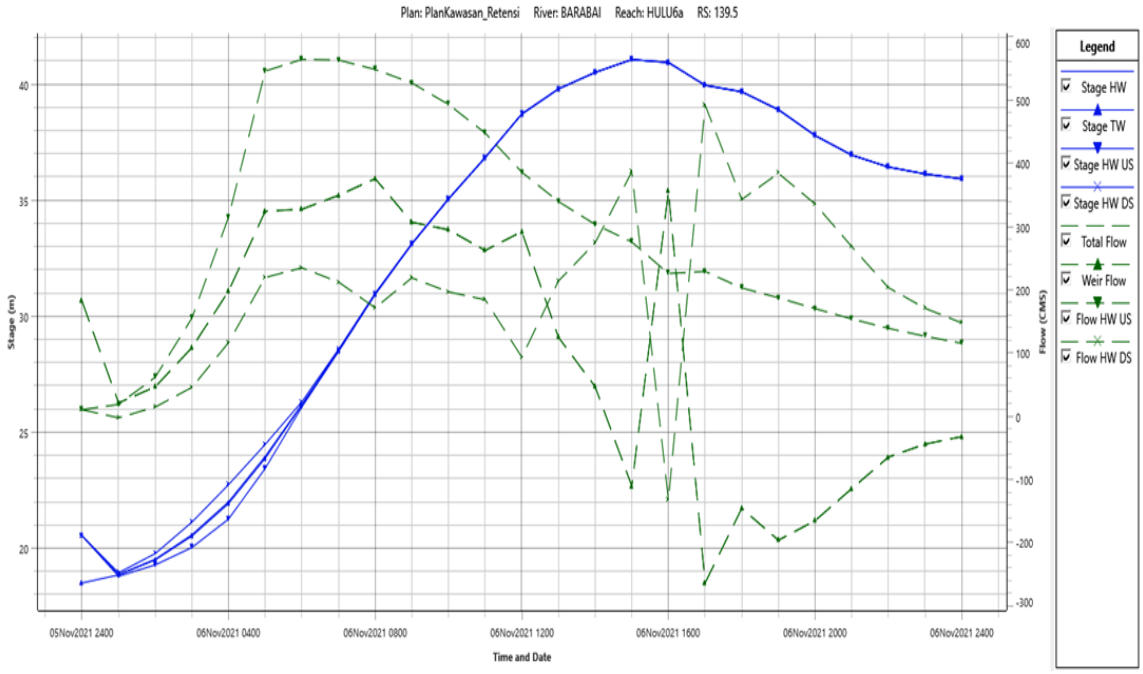


Fig. 7: Simulation of flow in regulation pool with 40% discharge. (Source : Calculation Result, 2021)

discharges from 5 rivers for 24 hours the required reservoir pool elevation is +48 m. Based on the plan, only a maximum elevation of +25 m is provided or the height of the storage pool is only 7 m. As illustrated in Fig. 7, the HEC RAS application's results also revealed a connection between the water level profile on the side spillway and the storage pond. The water level elevation during flooding above the side spillway crest is between +18 and +25, as can be observed on the side spill. This shows that due to the installation of the side spillway, there will be an overflow of water up to +25 m, meaning that the guard height of the side spillway must be even higher. So based on the modeling of the flow through the side perforation and the storage pond, it can be seen that the storage pond is no longer able to accommodate all the flood discharges that occur. The side spillway and regulation ponds that are planned are only able to accommodate about 40% of the flood discharge that occurs within 24 hours after the downstream river recedes and then flows into the downstream river. So the remaining 60% of the discharge must still be channeled downstream of the Barabai River which enters Barabai City. Efforts are being made to re-calculate the capacity of the regulation pool to accommodate flood discharge with reference to the planned elevation of +25 m, so that new hydraulic flow behavior will also be obtained, both in the regulation pool and on the side ledge. Then the water level profile in the lower reaches of the Barabai River will be based on the discharge capacity that can be stored by the regulatory pool. After re-modeling, it was found that the regulation pool was only effective at accommodating 40% of flood discharge. The remaining 60% of the discharge flows downstream of the Barabai River. The results of the modeling of flow behavior and rating curve in the regulation pool as well as the flow behavior sideways are presented in Fig. 7. From the picture, it can be seen that the water level has met the top elevation of +25. It is also necessary to examine the intake, it needs to be screened because it affects the incoming discharge (Rizal et al. 2020) and (Rizal et al. 2021) and the need for water balance for irrigation (Salim & Rizal 2020).

After 40% can be absorbed by the regulation pond, then 60% of the flood discharge flows to the lower reaches of the Barabai River and through Barabai City with a flow profile presented in Fig. 7. In the Fig., it appears that there is still quite a high runoff when the Barabai River water enters Barabai City. At 0-5 km the average water level elevation is around +35 but at 5-8 km the average water level elevation drops to +22, so, there is a significant difference. The very high elevation of the water table indicates that the distribution of the puddle is quite wide, but in this HEC RAS only one-dimensional modeling is presented, so visualization of the inundation area or inundation zoning needs to be reworked in the 2-dimensional HEC RAS modeling. In detail, at STA 139 to STA 62, there are quite extreme inundations

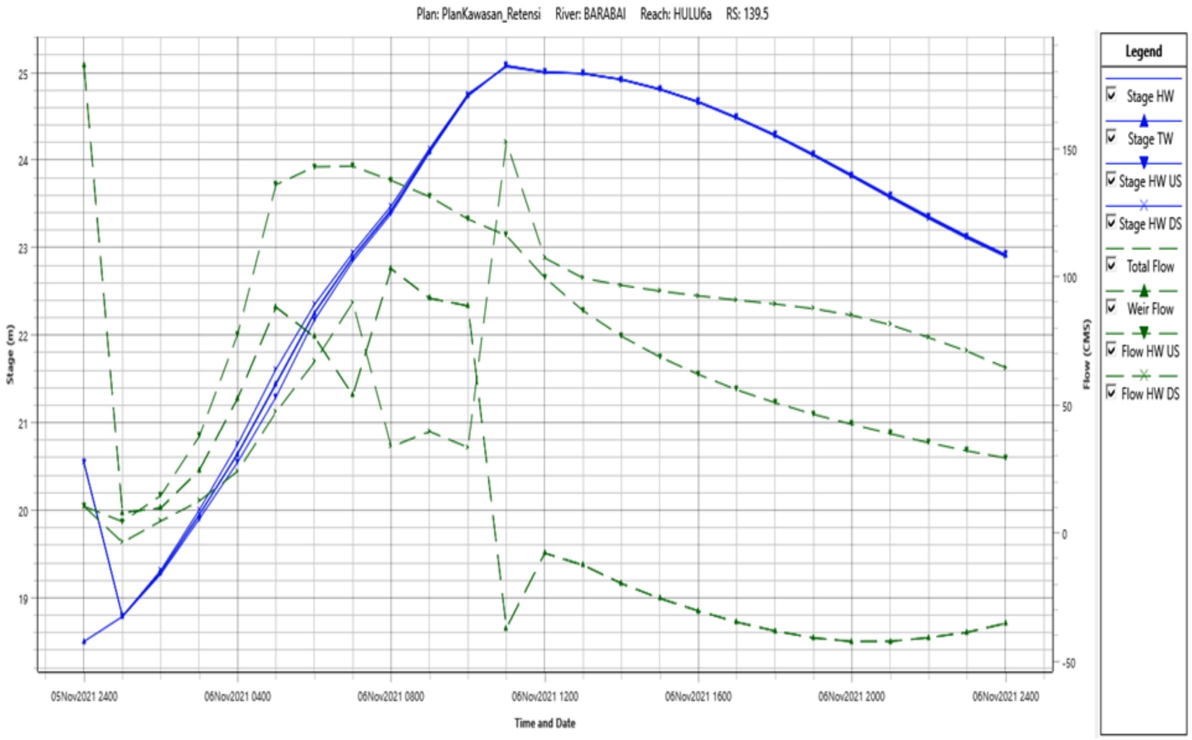


Fig. 8: Simulation of flow profile on side spillway with 40% discharge. (Source: Calculation Result, 2021)

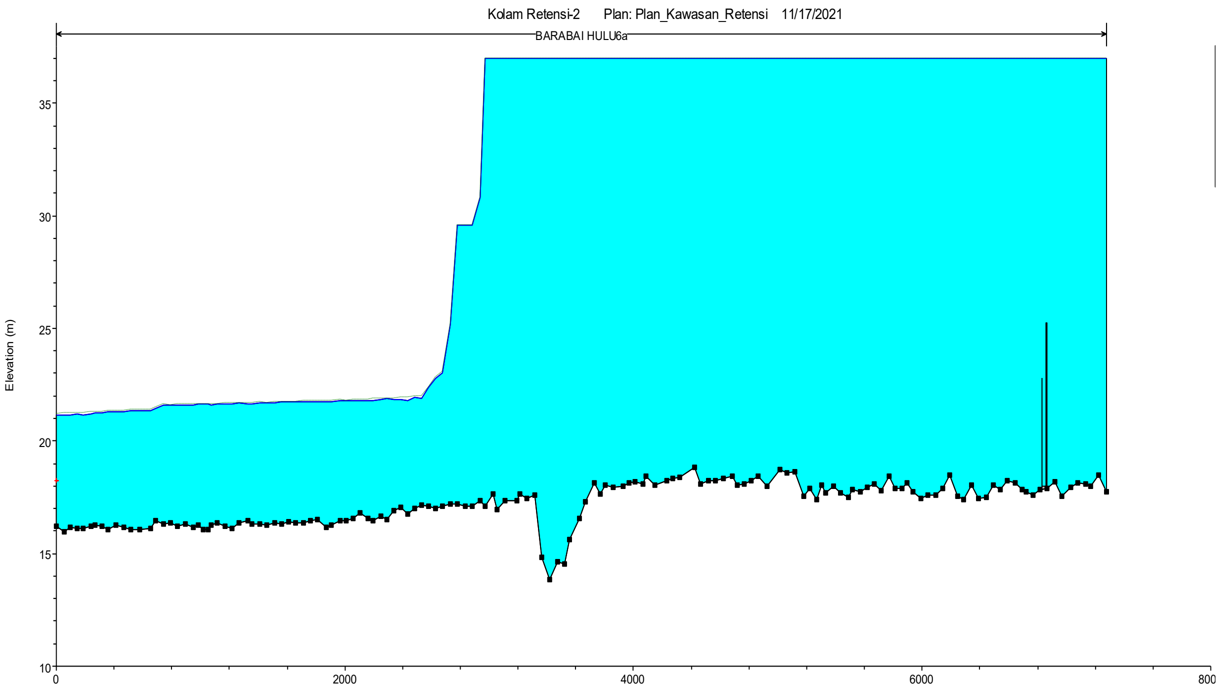
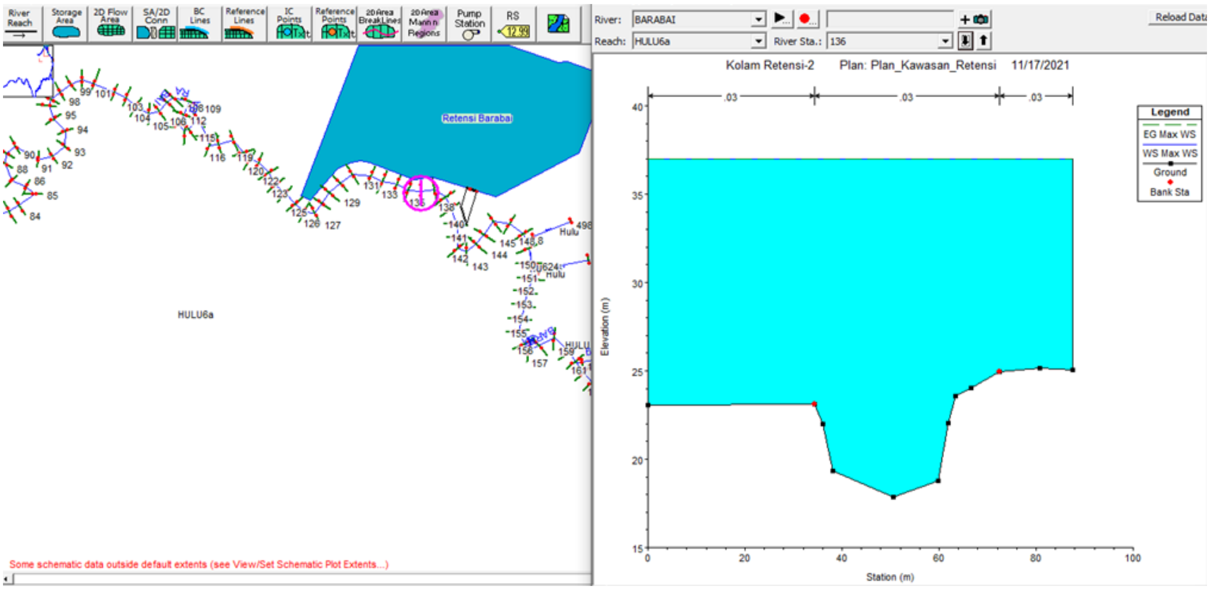


Fig. 9: Profile of the water level passing through the city of Barabai with a discharge of 60% of the Planned Discharge. (Source: Calculation Result, 2021)



River: BARABAI

Reach: HULU6a

River Sta.: 136

Kolam Retensi-2 Plan: Plan_Kawasan_Retensi 11/17/2021

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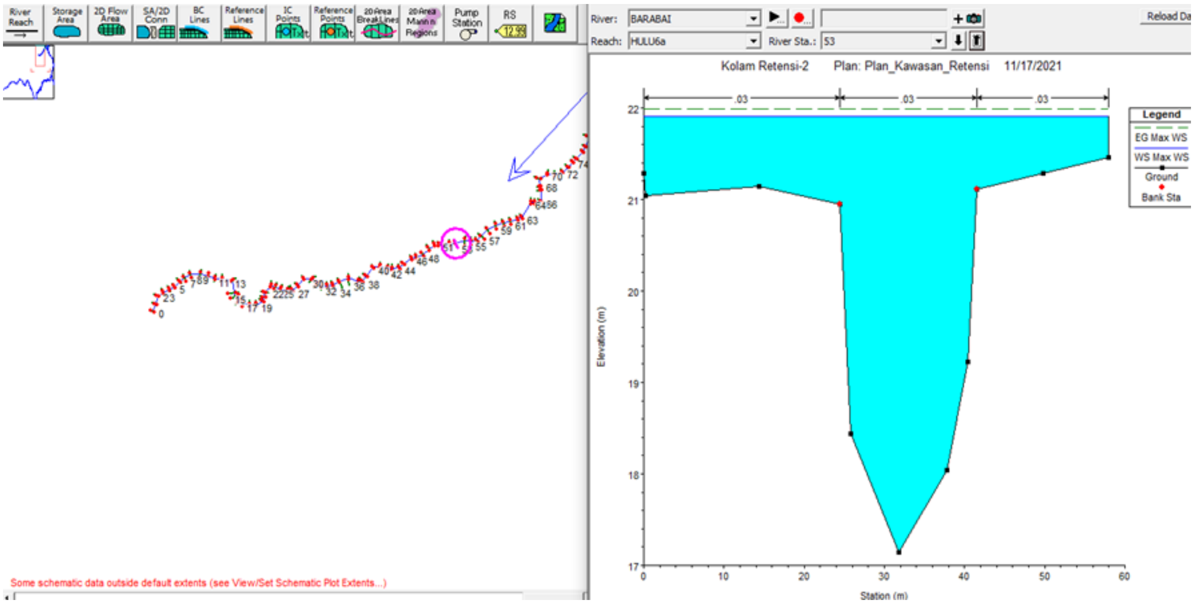
Fig. 10: Water level profile at STA 138 with 60% discharge. (Source: Calculation Result, 2021).



River: BARABAI

Reach: HULU6a

River Sta.: 53

Kolam Retensi-2 Plan: Plan_Kawasan_Retensi 11/17/2021

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Fig. 11: Water level profile at STA 53 with 60% discharge. (Source: Calculation result, 2021).

up to an altitude above +35. Then at STA 53, it started to decline at an elevation of +23 to STA 0 at an elevation of +21, as shown in Fig. 8 and Fig. 9. The cross-section of the river which is quite small is an indicator of the occurrence of water overflow in the Barabai River that passes through Kota Barabai. Care must be taken in reviewing the Barabai River's maximum storage capacity in the form of an estimate of the percentage of flood discharge that can flow without flooding. Furthermore, the rest needs to be given a solution by making a reservoir upstream of the Barabai River. Based on field verification, it is possible to carry out river normalization because there is a violation of river boundaries. There are 10 cross-sections. In field visualization, it is clear that there are river border violations.

As a visualization, the water level profile is presented at STA 138, it appears that the water level profile is

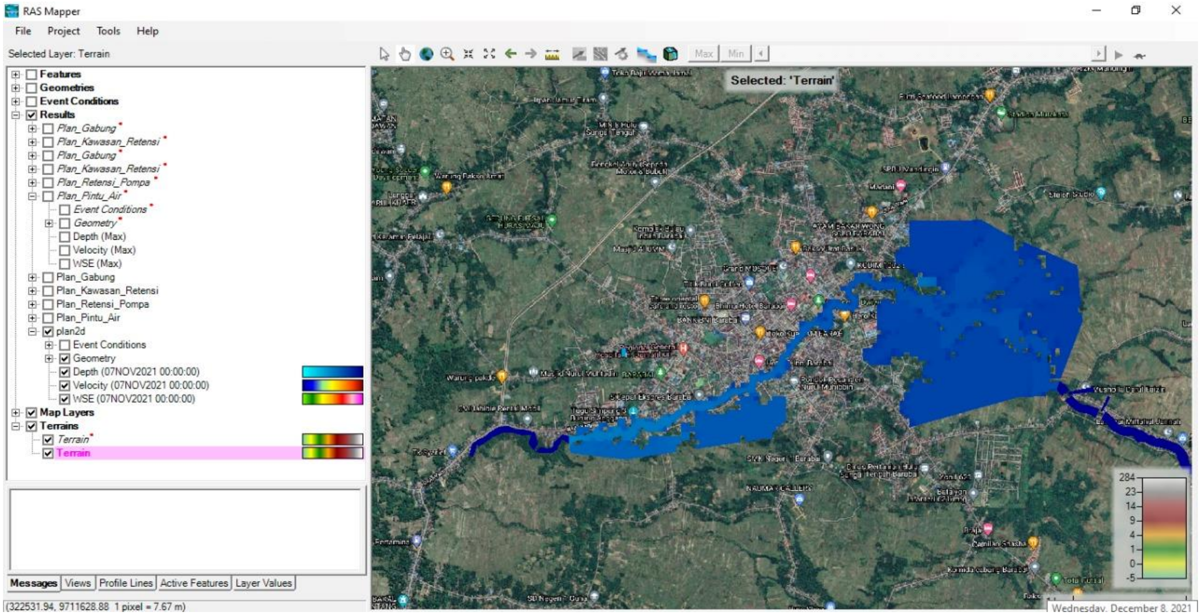
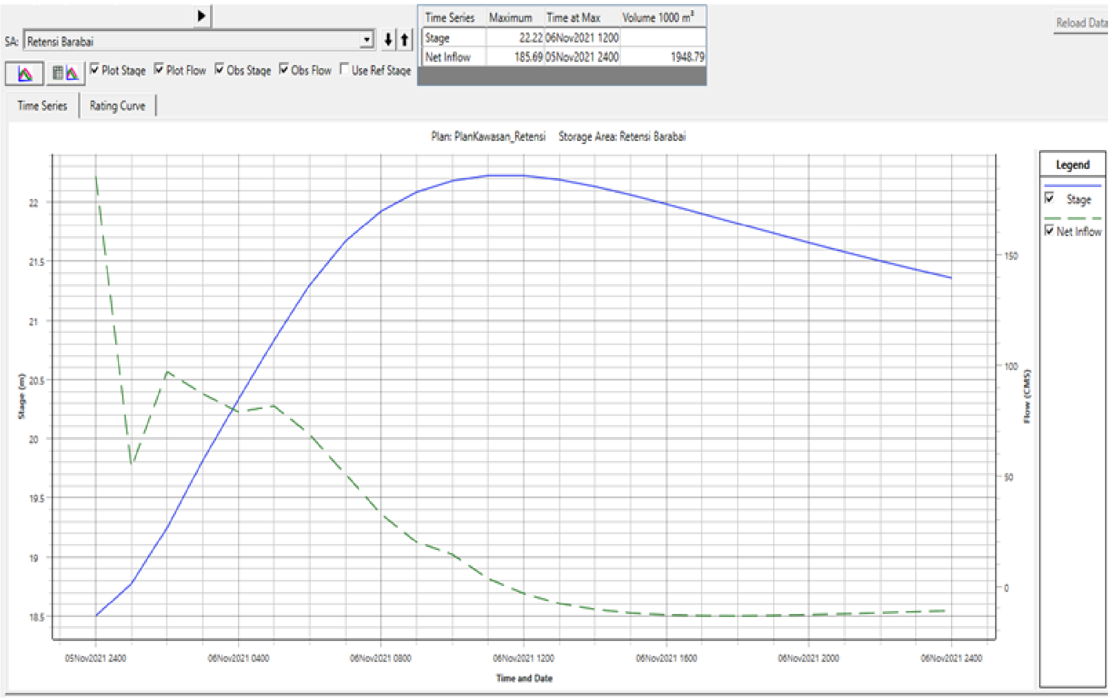


Fig. 12: Areas experiencing inundation in Kota Barabai. (Source: Calculation result, 2021)

quite high, namely 5 meters above the river embankment elevation as shown in Fig. 10. Visualization of water level conditions is also presented in Fig. 11. At STA 53 the water level profile is also high but lower than STA 138 only 2 m above the embankment. This is possible because the cross-sectional area of the river at STA 53 is larger than that of STA 138.

After conducting a study using HEC RAS 1D, almost all cross sections of rivers passing through Barabai City overflowed. The solution given is to do another analysis to



Time Series	Maximum	Time at Max	Volume 1000 m³
Stage	22.22	06Nov2021 1200	
Net Inflow	185.69	05Nov2021 2400	1948.79

Fig. 13: Result of f1ow simulation in retention pond with expansion and addition of retention pond.

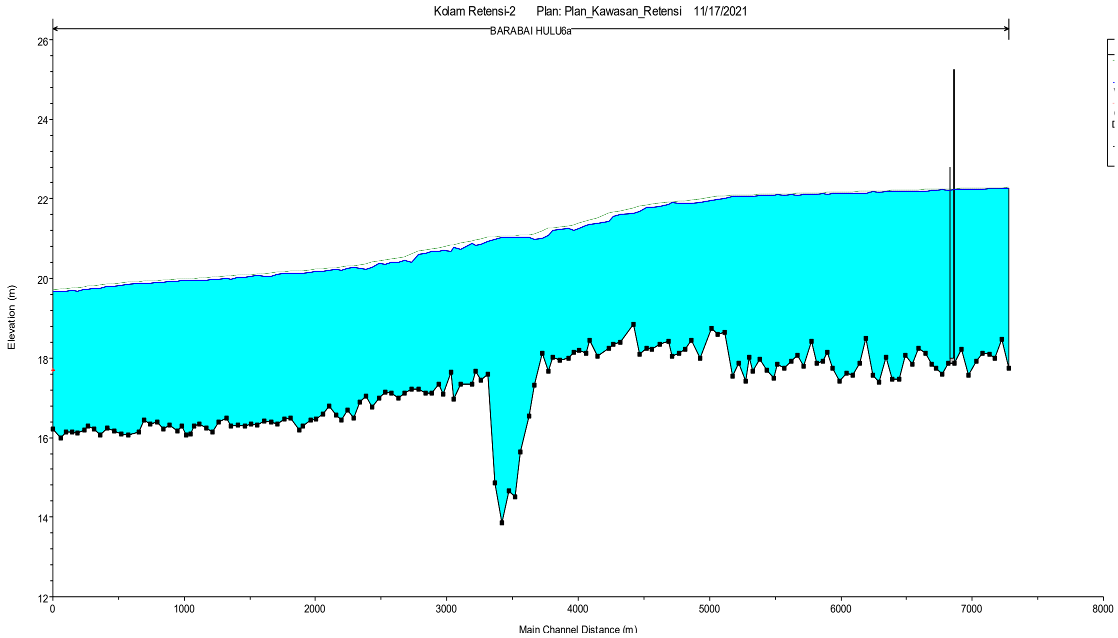


Fig. 14: Long section and cross conditions section after repair. (Source: Calculation result, 2021)

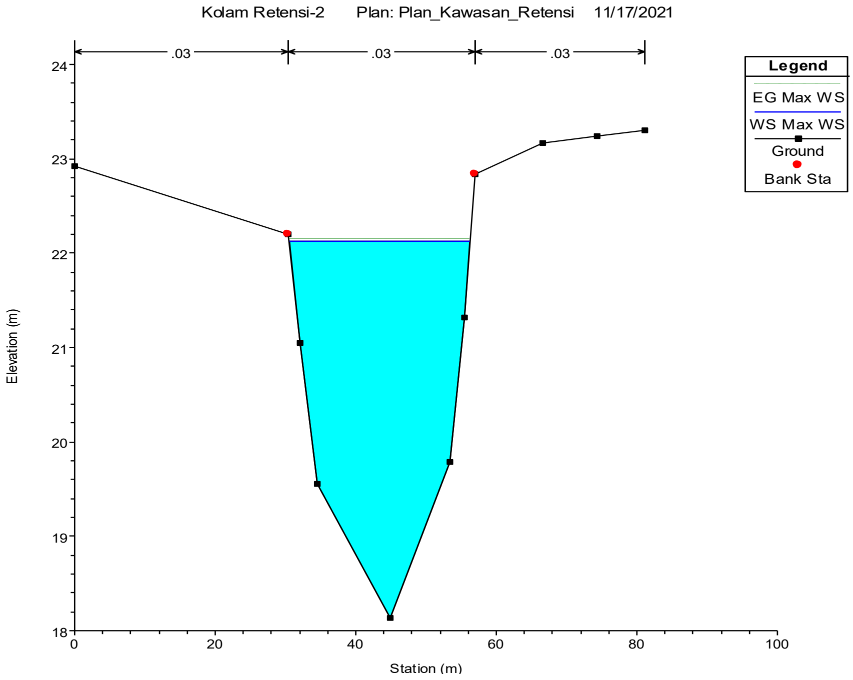


Fig. 15: Long section and cross conditions section after repair. (Source: Calculation Result 2021)

find out the level of overflow or inundation by doing 2D modeling as described previously. In modeling, boundaries of the area to be analyzed must be made. So in this analysis, the study boundary zone uses all areas of Barabai City, South Kalimantan Province. Based on the study, the results are presented in Fig. 12. In the picture, it can be seen that 70% of the Barabai City area experiences inundation during floods. The largest distribution occurs in the eastern river area, especially at the point where the Retention Pool will be built.

Given the explanation in the preceding section, it is clear that despite the construction of a retention pond, the flooding issue in Barabai City has persisted despite multiple modeling iterations (Ljubenkov 2015). So some of the solutions are as follows:

1. The Barabai Canal is maximized so that it can drain a maximum flood discharge of 200 $m^3.s^{-1}$ by widening the Barabai canal 2x from the initial plan, then the planned regulation pool expansion is carried out from an inundation area of 58 ha to 95 ha.
2. The Barabai Canal is maximized so that it can drain a maximum flood discharge of 200 $m^3.s^{-1}$ by widening the Barabai canal 2x from the initial plan, then a 2nd regulation pool is made upstream of the Barabai River with an area of 40 ha and a height of 7 m. Visualization of alternative selection is presented in Fig. 13.
3. The Barabai Canal, which is in the upper reaches of the Barabai River, is widened by 2 meters from the original plan, and the river entering Barabai City is widened by at least 4 meters on each side so that it can drain a maximum flood flow of 200 $m^3.s^{-1}$. After normalizing 4 m to the right cliff and 4 m to the left cliff, it seems that there are no more puddles in Barabai City. After running using the HEC RAS Program, the water level profile is quite good and there are no more puddles, as shown in Fig. 14 and Fig. 15.

CONCLUSION

This study is quite important as a solution to flooding management in Barabai City based on a priority scale. By enlarging the retention pond from 58 ha to 95 ha or by constructing another retention pond in the Barabai River's upstream section, flooding in Barabai City can be prevented. If this is not possible, the Barabai River, which flows through Barabai City, is normalized on both sides.

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