Application of the Polder System in Flood Management in Urban Areas a Case Study

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Abstract

Water management is crucial, especially in the rainy season. Over time, climate change causes an increase in rainfall which results in increased surface runoff. In addition, the increase in surface runoff is caused by the conversion of land functions from green land to watertight land such as roads, urban areas, buildings, and others. This chain event resulting flood. However, considering the condition of the land surface in the capital, which has fallen and is almost level with sea level, the usual solution cannot be utilized. By utilizing the polder system which is a closed system of water flow flowing with the help of a pump and the flow of water in the system can be monitored and regulated in and out, it is expected to be a solution to flood problems in the capital city. For this study, a case was taken in the KBN 2 area which is one of the Sunter-Cakung Polder areas. The area of KBN2 itself, broadly and largely, is the largest contributory area of runoff in the Sunter-Cakung polder system. From the results of the analysis obtained, with the application of the polder system by making a storage pond as high as 5 meters and an area of about 5 Ha in the downstream of the river and the existing pump operation of 1 unit with 1 m^3/s capacity, the area that was previously affected by the flood, was reduced quite widely.

Keywords
Flood, Polder, Retention Pond, Urban Areas and Pump

1. Introduction
Water is a very important resource for the life of living things, especially humans. Water management is crucial, especially in the rainy season. In the rainy season, the amount of water is large and sometimes difficult to control. Over time, climate change results in an increase in rainfall which results in increased surface runoff. In addition, the increase in surface runoff is caused by the conversion of land functions from green land to impermeable lands such as roads, urban areas, buildings, and others. Due to the increase in surface runoff, the channels that were previously able to accommodate the surface runoff are no longer able to and resulting in the appearance of puddles. This event is often referred to as a flood condition. To overcome these problems, there are several solutions, either by normalizing rivers, building water reservoirs, or increasing river capacity, which are solutions that are often used in the capital. However, considering the condition of the land surface in the capital, which has fallen and is almost level with sea level, the usual solution cannot be used because the old solution of water still uses gravity as its driving force and if the drain is higher, the water cannot be made to the outside, resulting in inundation. Therefore, the Polder System is the answer to these problems.

The Polder system itself is defined as a closed system of water flow flowing with the help of a pump and the flow of water in the system can be monitored and regulated in and out of the closed system. In its application, a simple polder system has been applied since ancient times such as in China for irrigation purposes where the water flow system is closed and can be regulated as well as to protect the irrigation area inside from water from outside the system (Tang et.al. 2019). In its development, the Polder system was used in the Netherlands to overcome the problem of flooding (Rusetski 2019). The use of polders in the Netherlands is caused by the sea level being higher than the land elevation of the Netherlands so that all wastewaters cannot be channeled into the sea and the influence of sea tides on the plains of the Netherlands. The existence of this problem makes Polder the solution (Baan and Klijin 2004; Hoes and Van De Giesen 2015). In its implementation the polder system has been applied in various locations in Indonesia in dealing with flood problems such as in the Muara Angke area, Jakarta (Sari et al. 2019), Semarang (Pratiwi and Wahyu 2021), Ancol, Jakarta (Prastica 2018).

In this research, the location/study area used is the Sunter-Cakung area where the main channels are the Cakung Lama River and the Cakung Drain. Based on observations, several areas of Sunter–Cakung experienced high enough puddles of water to inundate residents' houses as seen in Figure 1.

Figure 1. Location of flood in the Sunter-Cakung area

In this study, a Numerical Model is used with the help of HEC-HMS and HEC-RAS to model flood events and the implementation of the polder system in overcoming flood events in the Sunter-Cakung area. With this research, it is hoped that this Polder System will become an alternative solution in dealing with existing flood problems.

1.1 Objectives

The main objectives of this research include:

- Determine the flood discharge in the Sunter-Cakung area
- Determine area and location impacted by flood discharge in the Sunter-Cakung area
- Seeing the effect of the Polder system application in reducing flood inundation in the Sunter Cakung area
- Determine the system and its configuration for effective flood control in Sunter-Cakung

2. Methods

To achieve the research objectives, here is the research methodology Flowchart

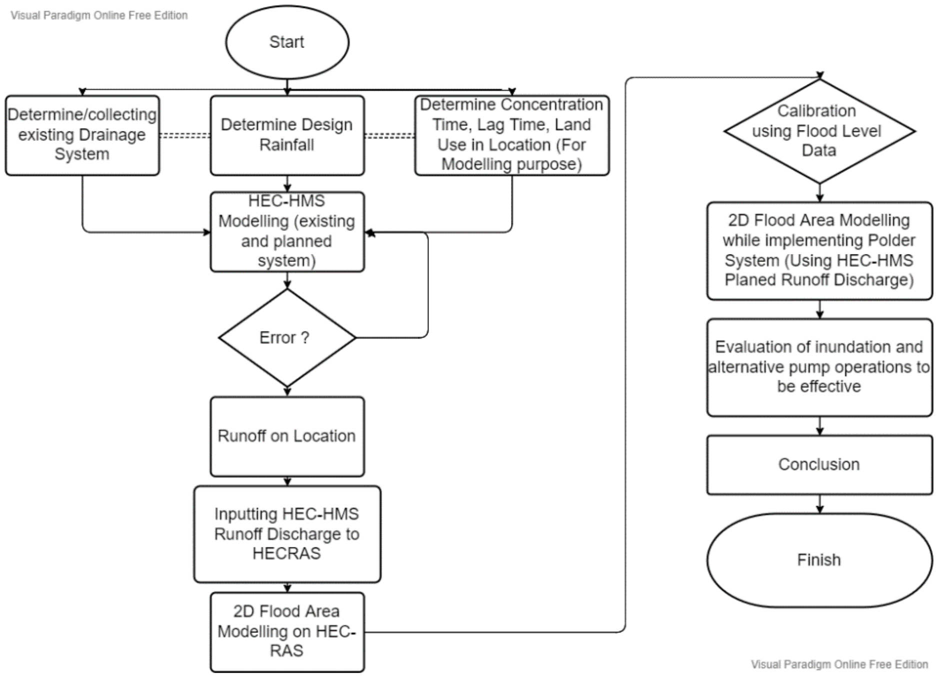


Figure 2. Research flowchart

From Figure 2, it is shown that there are several steps to find impact of polder system implementation to reduce flood inundation areas in location. Basically there are 3 main steps to model it, first one is Hydrological modelling using HEC-HMS to find runoff discharge of existing drainage system and planned system using polder system. After that the second part is to model of existing flood areas using HEC-RAS. This part is the most essential part because if this model not calibrated and verified, the planned solutions won't be valid. For this study, calibration and verification process are not by the amount of discharge on certain river on the system (Hydrologic calibration). This happens due to limitation of data gathered. Instead of using hydrologic calibration, this study using hydraulic calibration matching the height of inundation between 2D modelling and actual observation. The last part after the model is calibrated and verified, using the calibrated model, polder system will be implemented to see the effects of this polder system to lessen the flood inundation in study location.

3. Data Collection

For this study, there are several data needed such as existing drainage system, rainfall, and land data (slope, areas, and land use). These data used to help flood modelling process.

3.1 Rainfall Data

For the purposes of hydrological analysis, rainfall data is required from a rainfall measuring station located in a water catchment area, or if there is none, then rainfall data is taken from locations around the area under review. In this study, the Thiessen polygon method was used to determine the effect of rain stations around the study area. The Cakung polder system uses 3 rain posts, namely Pulo Gadung Rain Post, Rorotan Rain Post, and Kodamar Rain Post. The duration of the rain observations obtained is for 10 years from 2011-2020 for the three rain posts. According to SNI 2415 (2016) at point 4.1.2 it is explained that in determining the design rain value, it is necessary to have the maximum annual daily rainfall data from the data obtained. Based on this, Figure 3 shows the value of the maximum annual rainfall at the three rain posts.

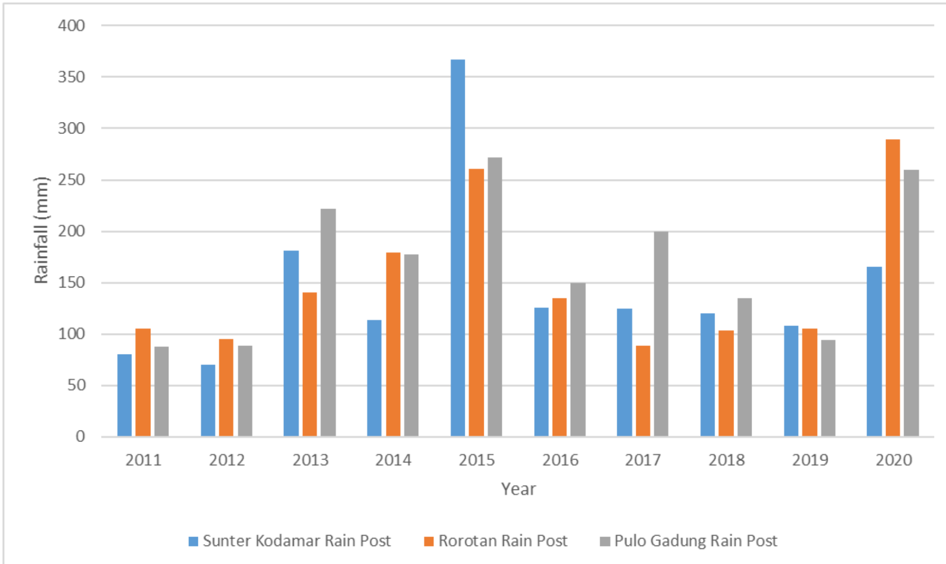


Figure 3. Maximum rainfall each of rain post

Before determining the design area rainfall, each of rain posts maximum rainfall data have to be tested of outlier test, this test used to find whether there are outlier data. Based on test result shown in Figure 4, The Sunter Kodamar Post has top outliers while the other 2 posts such as the Rorotan Rain Post and Pulo Gadung have no outliers. Therefore, this outlier needs to be removed. However, the standard amount of data from the frequency analysis process to determine the design rainfall value is 10, due to outlier data removal, the amount of data at the Sunter Kodamar rain post is only 9. Therefore, it is necessary to replace the data. For this study, it is assumed that the lack of data is replaced by another 9-year average maximum rainfall value. so that at the Sunter Kodamar Rain Post which originally had an outlier value of 367 mm, it was replaced with a value of 121 mm.

Outlier Test

Sunter Kodamar Station Skewness: 2.30348

Lower outlier Ok

Upper Outlier Test

From Water Resources Council (1981), if:

Skewness >+ 0.4; Needs Upper Outlier Test

Skewness < -0.4; Needs Lower Outlier Test

if -0.4 < Skewness < +0.4; needs Upper and Lower Outlier Test

Skewness of Sunter Kodamar Station= 2.30348 > 0.4, so needs Upper Outlier Test

Upper Outlier Threshold can be found by:

Yh= Y average + Kn.Sy

From calculation these parameters found:

Y average = 4.8107

Kn = 2.036

Sy = 0.4622

So Yh 5.81215

so upper outlier threshold is 334.337 mm

Maximum Daily rainfall on set data in Sunter Kodamar Station is:

367 mm > 334.337 mm

So Sunter Kodamar Post has Upper Outlier

Figure 4. Outlier Test Result of Sunter Kodamar Rain Post

After all data has been tested and verified, next step is to determine design rainfall for modelling, for this study, 25 year return period is used for design and modelling. Here are results of Frequency Analysis of each rain post.

Table 1. Frequency analysis result in Sunter Kodamar rain post

Period Year (Year)	**t**	**Methods**				
		Normal Distribution	**Log normal**	**Gumbel I**	**Pearson III**	**Log Pearson**
2	0	121	116.6	116.5	119	118.8
5	0.84	149.2	146.6	156.4	148.4	149
10	1.28	163.9	165.1	182.9	164.9	166.2
20	1.64	176	182.3	208.2	179.2	181
25	1.75	179.6	**187.6**	216.3	183.5	185.4
Maximum Deviation		16.79	11.59	14.15	14.53	14.53
Delta Critical (Sig. Level 5 %)		40.9	40.9	40.9	40.9	40.9

Table 2. Frequency analysis result in Rorotan rain post

Period Year (Year)	**t**	**Methods**				
		Normal Distribution	**Log normal**	**Gumbel I**	**Pearson III**	**Log Pearson**
2	0	150.1	135.6	140.4	135.5	129.3
5	0.84	210.1	198.2	225.6	201.1	189.8
10	1.28	241.5	241.7	282	245	241.2
20	1.64	267.5	284.8	336.1	286.7	300.5
25	1.75	275	298.7	353.2	**299.9**	321.6
Maximum Deviation		19.27	16.89	16.21	15.75	17.05
Delta Critical (Sig. Level 5 %)		40.9	40.9	40.9	40.9	40.9

Table 3. Frequency analysis result in Pulo Gadung rain post

Period Year (Year)	**t**	**Methods**				
		Normal Distribution	**Log normal**	**Gumbel I**	**Pearson III**	**Log Pearson**
2	0	168.7	156.2	159.4	166	157.8
5	0.84	226.8	217.4	241.7	225.8	224.9
10	1.28	257.1	258.5	296.2	258.6	268.5
20	1.64	282.2	298.1	348.5	286.6	309.6
25	1.75	289.5	310.8	**365.1**	294.8	322.5
Maximum Deviation		13.33	17.43	9.08	13.57	14.87
Delta Critical (Sig. Level 5 %)		40.9	40.9	40.9	40.9	40.9

From this Frequency Analysis Result Design Rainfall of 25-Year Return Period in each rain post has been determined. In Table 1-3 shows several results of 25-Year Return Period Frequency Analysis result, based on SNI 2415;2016 using Kolmogorov-Smirnov Test, the most suitable method is the method that has the lowest Maximum Deviation. In this case, the selected method for each rain post in order are Log Normal with amount of 187.6 mm for Sunter Kodamar Rain Post, Pearson III with amount of 299.9 mm for Rorotan Rain Post, and Gumbel I with amount of 365.1 mm for Pulo Gadung Rain Post. However, to model the flood, Area Design Rainfall is needed. To determine that we can use Polygon Thiessen Method. For this Study area influenced by each rain post are 6.27 Km^2 for Sunter Kodamar Rain Post, 5.43 Km^2 for Rorotan Rain Post, and 6.71 Km^2 for Pulo Gadung Rain Post. After area influenced by every rainpost are known, we can determine the Area Design Rainfall. Area Design Rainfall for 25 Year Return Period is 285 m.

3.2 Existing Drainage System Data

Existing Drainage System data obtained from Satelite data and also direct observation in location of study. This data needed to model the existing flood and calibration and verification process of model. This existing drainage system data consist of flow configuration in field of study and tributary area of each drainage system which include drainage length, area, slope, and many more.

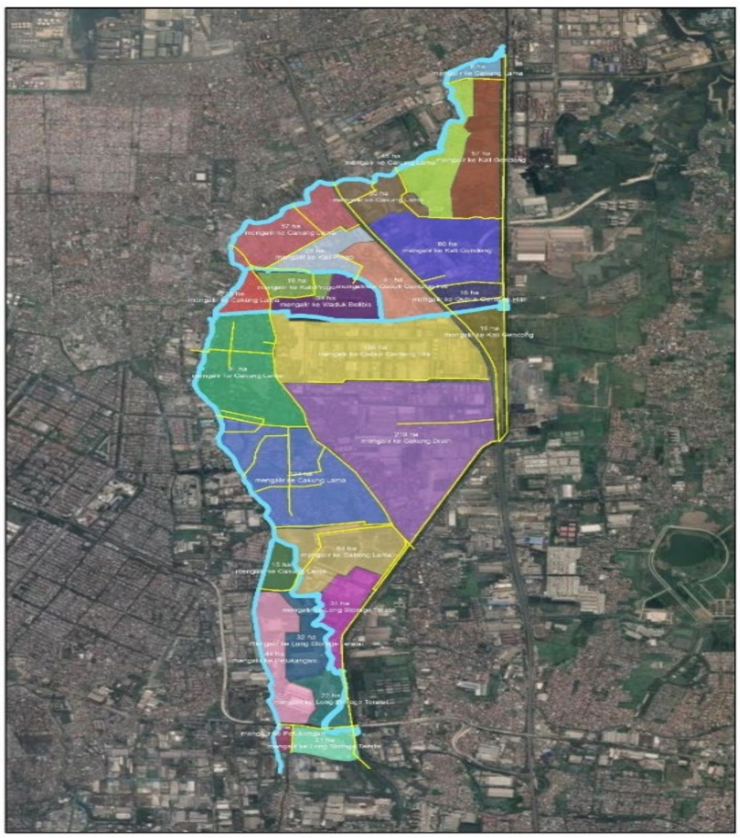
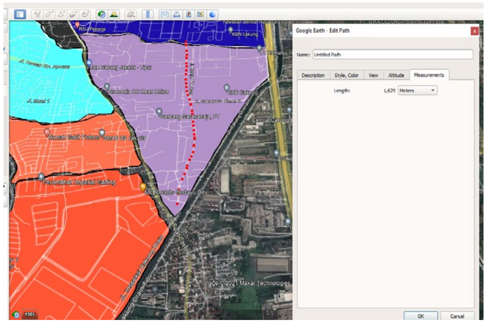


Figure 5. Sunter Cakung exisiting drainage system

From Figure 5 it is shown the tributary area and Sunter-Cakung existing drainage system. For KBN2 Polder System, there are 3 main channels crossing in this area named Progo Channel, Gubuk Genteng Channel, and Kebun Bulog Channel. It is show also that these 3 channels will be flowing towards Cakung Drain. From Figure 5 also there are several tributary flow areas in KBN 2 coded with different color code. Each tributary area and slope can be figured out using ArcGIS and Google Earth.



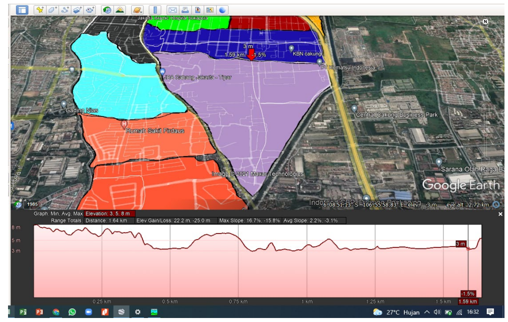


Figure 6. Using Google Earth to determine slope on tributary areas

From Figure 6, by using Google Earth land slope, channel slope and drainage length can be determined. For detailed information from each tributary area shown in Table 4.

Table 4. Tributary area information and data

Tributary	Area	Land Use	Luas (Km^2)	L (m)	Slope (%)	Flow Towards
KBN2	Brick Red	Housing Area	0.15	335	0.5	Cakung Lama
	Dark Green	Housing Area	0.18	331	0.5	Progo
	Blue Sky	Housing Area	0.28	759	0.5	Progo
	Violet	Housing Area	0.34	1094	0.5	Progo
	Pastel	Housing Area	0.41	1086	0.5	Gubuk Genteng
	Dark Blue	Housing Area	0.8	624	0.5	Gendong/ Cakung Drain
	Black	Housing Area	0.18	350	0.5	Gubuk Genteng
	Light Yellow	Housing Area	1.36	864	0.5	Gubuk Genteng
	Dark Yellow	Housing Area	0.19	244	0.5	Kali Gendong
	Violet	Housing Area	2.19	2400	0.5	Cakung Drain

4. Results and Discussion

In this part, this study will elaborate result of polder system implementation in KBN 2 of Sunter-Cakung Polder System. This part will divide into 2 main part which is hydrological modelling and hydraulic modelling.

4.1 Hydrologic Modelling

After all main data are gathered, the first step is to model hydrologic condition on the field. Using HEC-HMS software flow generated flow each tributary area and flow in each drainage channel in KBN2 can be estimated. There are several main parts needed for hydrologic modelling in HEC-HMS, first is area design rainfall that already been calculated in point 3.1, second is basin model of HEC-HMS which is part to model the drainage system in study location which means it needs existing tributary data information which already been defined in Table 4. Here are HEC-HMS modelling and Hydrograph on each drainage channel.

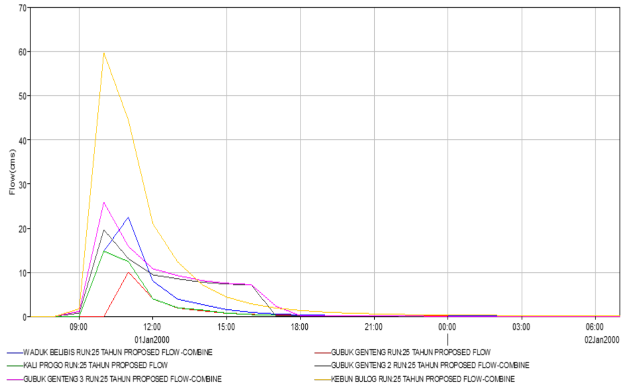


Figure 7. Hydrologic Modelling Result, Basing Model (Left) and Hydrograph of Drainage Channel (Right)

From Figure 7 on right picture, there are several flow hydrographs. This hydrograph represents flow of each drainage channel in Sunter-Cakung Polder System. For KBN2 there are 3 main channels namely Gubuk Genteng, Progo and Kebun Bulog which is shown in the graph. Using this hydrograph, we can model the hydraulic condition.

4.2 Hydraulic Modelling

The second part of analysis is hydraulic modelling which consist of calibration and verification process and also Polder system implantation result in KBN 2 area. For calibration and verification process, Hydrograph shown in Figure 7 will be used as boundary condition of hydraulic modelling. Here is the result of hydraulic modelling.

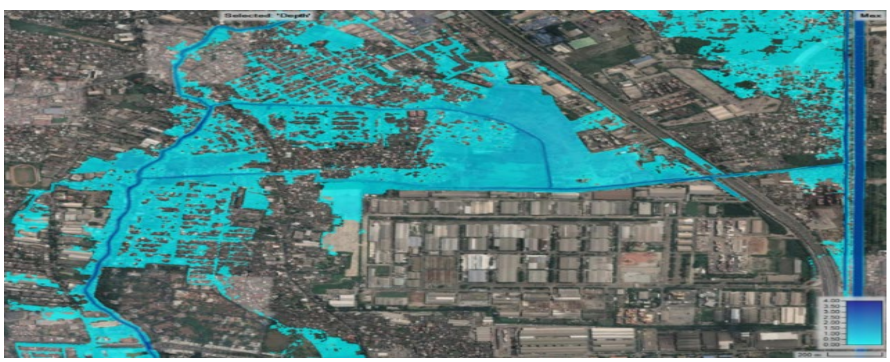


Figure 8. 2D modelling of existing flood inundation on KBN2 area

From Figure 8 above, result of 2D modelling of flood inundation can be seen. From the looks of it flood is a major problem in this area almost all area near the drainage channel are inundated and basically all of them are residential area. This modelling result must be calibrated and verified whether this 2D modelling result are accepted or not. Based on several news and direct observation of inundation height, here are the result of calibration and verification process.

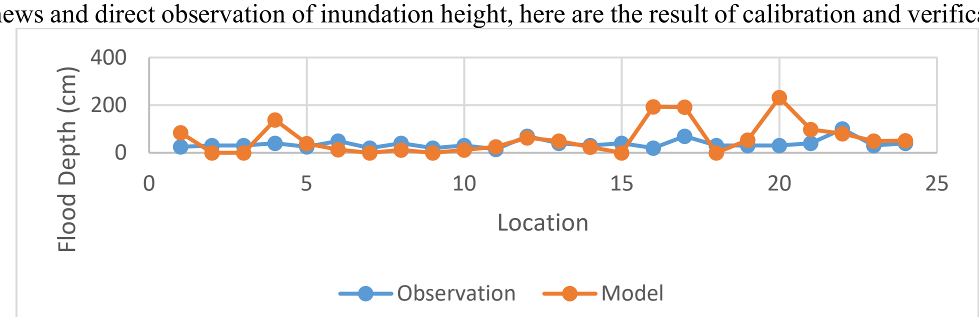
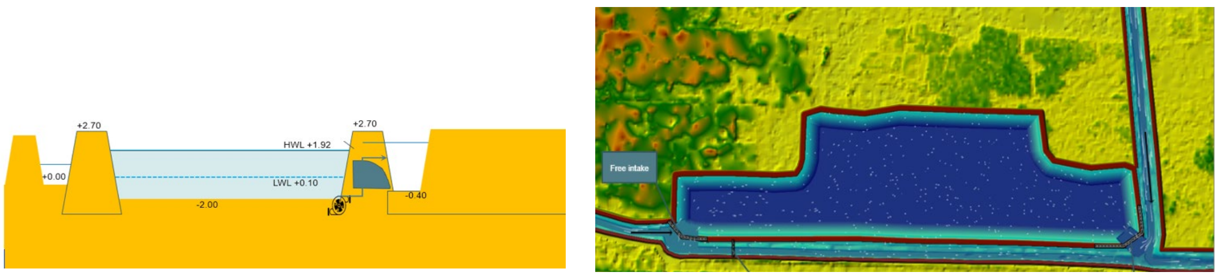


Figure 9. Flood inundation height difference between model and observe

From Table 4 and Figure 9, it is shown that 20 out of 26 location of flood inundation happened in observation are able to be modeled. But if we look closer there is decent amount of difference of inundation height. This tend to happen of calibration used is Hydraulic calibration because of the quality of terrain data used and there is difference made in location's terrain between the day terrain data obtained and now. Because of that Hydraulic Calibration harder to implement but because of lack of flow observation data, this method is used and by the looks of it at least 20 out 26 locations that are flooding can be modeled.

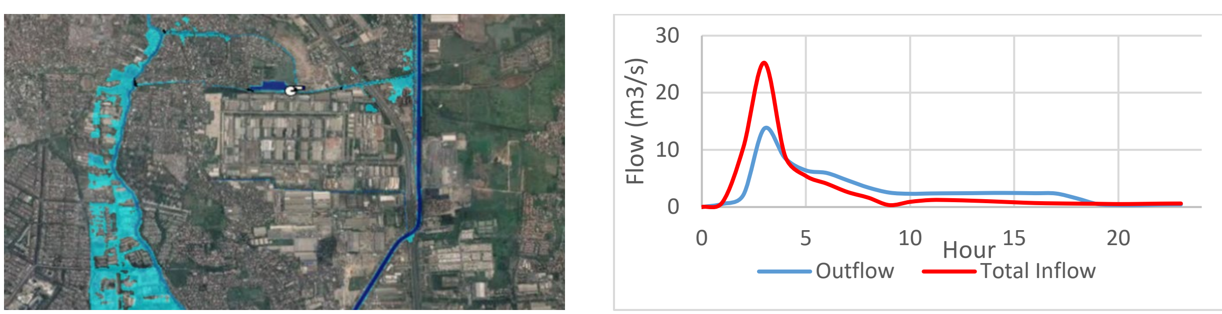
As seen from Figure 8., most of flood inundation happen around junction of Gubuk Genteng and Progo drainage channel and from Satelite data and direct observation, due to small and inadequate of drainage size flood inundation happens. Beside that it is also can be seen there is an effect of backwater from junction meet to upstream of each of Gubuk Genteng and Progo drainage channel. Those 2 are the main reasons of flooding in KBN 2. To solve this flood problem, Polder system is implemented. For this case, beside the junction of 2 drainage channel will be built a water reservoir with free intake from both channel and outlet using pump and as a safety measure there will be an emergency spillway with schematic of water reservoir shown below



(a) (b)

Figure 10. (a) Water reservoir schematic (b) Water reservoir location and shape

By implementing water reservoir located in junction of 2 drainage channel, flood inundation can be solved as shown in Figure 10. Beside finishing the flood inundation problem, this water reservoir also lessen the flow towards the junction by almost half from around 26 m^3/s to 14 m^3/s, this is due to water coming from Gubuk Genteng and Progo are hold in by the water reservoir when there is a risk of flooding so not all water coming from these 2 channel directly flow to downstream instead of it is being held first by water reservoir. This explanation can be seen more clearly in Figure 11. So, it can be concluded that by implementing polder system of closed drainage system, flood inundation in KBN2 can be solved.



(a) (b)

Figure 11. (a) Flood inundation map after polder system implementation
(b) Flow reduction on downstream of junction

5. Conclusion

From this study we can conclude several things:

- From result of analysis Flood flow in KBN2 is around 26 m^3/s which is result of 2 drainage channel of Gubug genteng and Progo Channel
- From Figure 8, it can be seen with existing drainage system, there are several area of flood inundation with happen mostly around the junction between 2 drainage channel of Gubug Genteng and Progo Channel
- By implementing Polder system of building a reservoir with schematic shown in Figure 10 beside junction of 2 drainage channel and 2 pump with capacity of 0.5 m^3/s, flood inundation problem can be solved and by implementing this new system there is reduction of flow to downstream from original amount of 26 m^3/s to around 14 m^3/s.

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Biography

Christian Cahyono S.T., M.T. joined Bina Nusantara University in September 2020 as a Faculty Member of Faculty of Engineering. He served as the Lecturer Specialist S2 in 2021. Since January 2021, he has served as one the Lecturer with expertise in Water Resource Engineering especially in Hydrology and Hydraulics modelling flood events and Water Availability Analysis. He has been a lecturer for almost 2 years with several Water resource project such as Tempe Lake Revitalization, Polder Implementation System in Sunter Cakung area, Water Reliability Analysis in Jatiluhur estate, Selorejo DAM Hydrology event safety and several more. He also been active as a reviewer of International Journal for almost 2 years with main topic of hydrology and hydraulics.