Simulation of Catchment Area, Water Storage and Pump Capacity in Polder Drainage System

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Abstract. Tidal flooding that occurs on the northern coast of Semarang City is caused by high rainfall, sea water level rise, and is exacerbated by land subsidence. Handling of tidal flooding is recommended with a polder system. Tidal flood management is made of several alternative retention ponds located in the Banger region so that water can flow in the new retention pond at the pump into the river so that the water goes to the sea. The purpose of this study is to formulate a correlation between catchment area, retention pool and pump capacity. Rainfall-runoff as well as hydraulic parameters were computed and simulate using SWMM software Version 5.1. Based on the analysis results, it clearly shows that, the flood discharge of 24 m³/s can be overcome by integrated pond structure with pump configuration. Alternative 1 retention pool 1 with a storage volume of 15,000 m³, Alternative 2 combined ponds 1 and 2 with a storage volume of 11,400 m³, Alternative 3 combined 3 ponds 1, 2 and 3, storage volume of 14,200 m³, alternative 4, is a combination of the three retention ponds above, with a storage volume of 64,300 m³. The water level in the pond is maintained not to overflow when pumping is carried out with the addition of the pool area, it will further reduce the capacity of the pump that is turned on with certain configurations on the pump operation schedule.

1. Introduction
The flooding that occurred in the city of Semarang, Central Java was caused by the channel and the river being unable to accommodate water due to high rainfall and tidal waves. The cause is the narrowing of the river due to irregular buildings, siltation of the river caused by sedimentation while the cause of high sedimentation include environmental damage in the upstream or catchment areas. Based on current flood, the flood inundation area was developing in several areas including around the mouth of the Plumbon River, Siangker River around Ahmad Yani Airport, Karangayu, Krobokan, Bandarharjo, along roads in Mangkang, Tugu Muda - Simpang Lima to Kali Semarang, Kali Banger, in Genuk from Kaligawe to the Demak border [1].

On the other hand, sea water level rise also has contribute the occurrences of flood problem in this area. The rate of sea water level rise recorded at the tidal port of Tanjung Emas Semarang Port is 5.43 cm/year. However, the government has carry out several mitigation measures, to prevent water flow into community settlements change (deformation) of the ground surface vertically down from a high reference plane. Land subsidence is basically a change (deformation) of the ground surface vertically down from a high reference plane. According to previous study, it has mentioned the high tides and land subsidence are the main threats in Semarang that could cause high potential of flooding.
Rob's flood in Semarang cause assures to prevent water flows into community settlements [2]. Land subsidence is basically damage to infrastructure and residential areas besides that it also has an impact on the lives of communities, households and individuals simultaneously [3]. The problem caused by the tidal flood is that productive land is no longer functioning defence, damage to public infrastructure and increasing conditions in slum areas. To overcome this problem, the Semarang City Government has decided to construct the drainage system using the Banger Polder system. Thus, this study was conducted to determine the characteristics of catchment areas, channels (long storage) and retention pools. Then, simulations on hydraulic analyses were carried out to evaluate the effectiveness of the polder system operations and formulate a correlation between catchment area, retention pool and pump capacity.

2. Literature Review
Polder is a system of handling urban drainage by isolating the catchment area against the entry of water from outside, both in the form of runoff or subsurface flow. Flood water level in the system will be control according to the plan properties of the polder system include: a. The polder area is restricted groundwater preventing the water from outside flows into the catchment area, b. In the polder there is no free surface flow as in the natural catchment area, but it is equipped with a control structure at its disposal (with a drain or pump) to control the outflow, c. water level in the polder is independent of the surface water in the surrounding area and is assessed based on land elevation, soil properties, climate, and plants. The polder system component consists of 1) Roving embankments and or sea defence, or other insulation constructions 2) Field drainage system 3) Conveyance system 4) Reservoirs and outfall systems 5) Recipient waters [4].

Based on this configuration, the polder system working by isolated hydrological system unit which mean the area is not affected by the surrounding system, surface and groundwater can be controlled in such a way, regions that are often flooded in natural conditions (flood areas). The polder system is a closed water system with embankment elements, pumps, channels, retention ponds, landscape arrangements, and dirty water installations. This polder system must work a unified system and be integrated with a more macro drainage system master [5].

2.1. Sea Water Level Rise
Global warming has an impact on weather, sea levels, beaches, agriculture, wild animal life and human health. When the atmosphere warms, the sea surface layer will also warm up, so the volume will increase and increase the sea level. Changes in sea level will greatly affect life in the coastal area. A 100 cm rise will sink the Netherlands, 17.5% of Bangladesh, and many islands. When the ocean reaches the mouth of the river, flooding due to tides will increase on land [6]. Add some info on seawater level rise in Semarang/Indonesia.

2.2. Land subsidence
Indications of land subsidence in Semarang can be seen clearly from several data sources and field observation. Based on measurements and data on land subsidence, hilly areas in Semarang City shows smaller value compared to coastal areas. From field observations, land subsidence in the former swamp and pond areas shows the greatest subsidence, for example in Tanah Mas housing, Tanjung Mas Beach, the rate of subsidence ranged from 5.5 to 7.23 cm/year [7].

2.3. SWMM (Storm Water Management)
SWMM is a model that is able to analyse the problems of quantity and quality of water related to urban runoff. Storm Water Management was developed by the EPA (Environmental Protection Agency - US), since 1971 by Huber and Dickinson. SWMM is classified as a dynamic flow rain model that is used for simulations with continuous time span or momentary flood events. This model is most widely developed for simulations of hydrological and hydraulic processes in urban areas [8].
2.4. Pumps
Pumps are used to drain water from low elevation to high elevation, the pump also serves to maintain the water level in the retention pond. If the pump is used to raise water from long storage into the sea with the elevation difference \( H_s \) so it does not cause flooding, then the power used by the pump to raise water as high as \( H_s \) is equal to height \( H_s \) plus energy loss during jetting, energy loss is proportional to the addition of elevation, the effect is the same as if the pump raised the water as high as \( H = H_s + \Sigma hf. \)

The power used to raise water can be calculated by using equations 1, 2 and 3.

\[
D = \frac{Q H \gamma}{\eta} \left( \frac{kgf m}{d} \right) \quad (1)
\]

\[
D = \frac{Q H \gamma}{75 \eta} \quad (HP) \quad (2)
\]

\[
H = H_s + \Sigma hf \quad (m) \quad (3)
\]

where:

- \( D \) is pump power (1 Nm / d = 1 watt = 75 HP),
- \( Q \) is flood discharge (m\(^3\)/s),
- \( H_s \) is static suction height (m),
- \( \Sigma hf \) is energy loss (m),
- \( \gamma \) is water density (1000 kgf/m\(^3\)),
- \( \eta \) is pump efficiency (%).

3. Methodology

3.1. Study Area
This research is located in the eastern Semarang district precisely in the catchment area of the banger as shown in Figure 1.

![Figure 1. Research Location Map](image)

3.2. Data Collection
The primary data obtained by making observations and direct measurements in the field. Primary data used consists of polder area data, drainage channel capacity, and pump capacity. Secondary data is data obtained from government agencies, private sector and related agencies.
study consisted of rainfall data, topographic data, RBI topographic maps, land use data, drainage system data, land subsidence data and tidal data [10-11].

3.3. Hydrological Analysis Method
Steps to determine the location of the rain station, rainfall data and catchment area, then calculate the flood discharge plan with several stages including: a. calculating average rainfall, conducting alignment tests, determining methods that meet the distribution test, calculating rainfall intensity and planning discharge flood calculation of average rainfall using the Thiessen polygon method. b. rain frequency analysis, c. rain data alignment test, d. rain intensity using A Prob software version 4.1 that was developed by Sherly et al. [12].

3.4. Flood Plan Discharge Analysis
After hydrological analysis by processing the planned rain data, the next step is to create a flood model in the Grace River Basin using EPA SWMM software Version 5.1. EPA Storm Water Management Model (SWMM) is a dynamic Rainfall-Runoff simulation model, used for single events or continuous simulations for urban areas. The SWMM component routes runoff from sub-bases through pipes, channels, reservoirs, pumps and regulators the result is flow, speed and depth of flow. The EPA SWMM model in various parts of the earth is used for planning and design analysis related to flood discharge in urban and non-urban areas. Currently SWMM 5.1. has been developed to model specific hydrological problems related to the "Low Impact Development (LID) control" like the following seven kinds of green infrastructure: a. Pavement translucent, b. Rain garden, c. Green roof, d. Roadside park, e. Rain barrel, f. Infiltration trench, g. Grass channel [13].

Analysis of the Existing Pond and Pump Capacity and Scenarios for Addition of Retention Pools:
• Alternative 1st (Pond 1)
• Alternative 2th (Ponds 1+2)
• alternative 3th (Ponds 1+2+3)
• alternative 4th (Total Area in 1 Pond (1+2+3)).your

4. Results and Discussion
4.1. Hydrological Analysis
Hydrological analysis is the first step to get the magnitude of the planned flood discharge in a plan catchment area water storage simulation and pump capacity.

4.2. Distribution of Regional Rainfall
The nearest rainfall station used namely Maritime, Karangroto and Pucanggading. To distribute rainfall intensity in the catchment area, we use the Thiessen method with the help of ArcGIS 10.5 software [14]. Based on the map the Banger River Basin Area is 670 Ha. The most area affected was Maritime Rain Station [15].

4.3. Rain Frequency Analysis
The frequency analysis in this study used A Prob version 4.1 software which was developed by [16-17]. Based on the analysis, it can be concluded that the rain data alignment test meets the requirements of the Pearson III Log distribution with the smallest maximum difference of 0.090. It was proven in the Smirnov-Kolmogorof and Chi-Quadratic tests, the distribution of Log Pearson III data was declared passed [13]. The magnitude of the return period of rain as in Table 1 and 2.
Table 1. Regional Maximum Rainfall at the Maritime Rain Station

| No | Year | Date       | Maximum Rainfall (unit) |
|----|------|------------|-------------------------|
| 1  | 2006 | 28 January | 156.50                  |
| 2  | 2007 | 6 November | 78.40                   |
| 3  | 2008 | 19 February| 96.10                   |
| 4  | 2009 | 25 December| 104.50                  |
| 5  | 2010 | 11 December| 168.60                  |
| 6  | 2011 | 2 January  | 89.00                   |
| 7  | 2012 | 4 February | 96.00                   |
| 8  | 2013 | 23 February| 135.30                  |
| 9  | 2014 | 23 January | 120.50                  |
| 10 | 2015 | 13 February| 119.00                  |
| 11 | 2016 | 11 April   | 74.00                   |
| 12 | 2017 | 28 October | 99.50                   |
| 13 | 2018 | 17 February| 138.50                  |

Table 2. Rainfall of Banger Catchment Area

| Return Period | Log Pearson III (unit) |
|---------------|------------------------|
| 2             | 104                    |
| 5             | 131                    |
| 10            | 147                    |
| 20            | 163                    |
| 50            | 182                    |
| 100           | 196                    |
| 200           | 211                    |
| 500           | 229                    |
| 1000          | 243                    |

4.4. Analysis of Rain Intensity

Based on the analysis, the results obtained is a concentration time for 1 hour. The hydrograph used was an hourly rain data analysis (Figure 2).

Figure 2. Hydrograph Rain of Banger Catchment Area

4.5. Flood Plan Discharge Analysis

4.5.1. Retention pond

In planning this Banger drainage system is planned with a polder system. The pump station was built to pump out the water from the retention pond [16]. Plans for retention pools can be seen in Figure 3.
4.5.2. Modelling the Polder Plan on the Banger Catchment Area

The depiction of the watershed sub-area is carried out by dividing residential areas and roads according to the drainage channel in the existing conditions (Figure 4). In addition, the description of the sub-watershed is also determined based on the direction of flow and elevation in the existing concession.

Figure 4. Banger Sub DAS on SWMM Model

Figure 5 show Alternative Pool Storage for Alternative 1, 2, 3, and 4. Alternative 1 polder system in the Banger watershed is by analyzing retention pond 1 capacity with pump 1. With a pool depth of 3 m and a storage volume of 15 m$^3$, the pump is set to turn on at a water depth of 2.5 meters, and is turned off at a depth of 0.5 meters. The inflow discharge that enters the pond is 24 m$^3$/s. Alternative 2 combined plan of 2 reservoirs, namely retention pond 1 and pump 1, with a retention pool 2 and pump 2 added with the depth of retention pool 2 is 3 m and the volume of storage is 11.4 m$^3$, with inflow
discharge into pond 1 is 12 m$^3$/s and the planned pump capacity is 4 m$^3$/s. The pump is set to turn on at a water depth of 2.5 m, and is turned off at a depth of 0.5 meters.

Alternative 3 combined plan of 3 reservoirs, namely retention pond 1 and pump 1, with a retention pool 2 and pump 2 added, and a retention pool 3 and pump 3. With a depth of retention pool 3 which is 3 m and a storage volume of 14.2 m$^3$, with inflow discharge into pond 3 is 10 m$^3$/s and the planned pump capacity is 9 m$^3$/s. The pump is set to turn on at a water depth of 2.5 m, and is turned off at a depth of 0.5 m.

In alternative 4 conditions, there is 1 pool whose volume is a combination of the three retention pools above, with a pool area of 21.39 ha and a total volume of 64.3 m$^3$. With a pool depth of 3 m and a storage volume of 64.3 m$^3$, the inflow discharge into pond 1 is 23 m$^3$/s. The pump is set to turn on at a water depth of 2.5 meters, and is turned off at a depth of 0.5 meters. Wastewater from alternatives 1, 2, 3, and 4 discharged into the Banger River then assisted with a pump existing Banger River, water is discharged into the East Flood canal.

![Figure 5. Alternative Pool Storage for Alternative 1, 2, 3, and 4](image)

5. Conclusions
The polder system is the most appropriate treatment for tidal flood control in the Banger watershed, with the concept of isolating sea water flow and controlling water elevation with pumps, canals, ponds, dikes. Catchment area of the Banger River Basin, which is 520.22 ha. Based on the rainfall record in Maritim rain station, and after analysis of the rain area by the Thiessen method, that the rain of the Banger catchment area varied between 74 mm and 168.6 mm, while the rain plan with a 50-year return period is 182 mm, which has been statistically tested with the distribution of log Pearson III distribution. Based
on the results of the hydrological analysis using SWMM software, it was found that the Banger catchment area inflow that entered the reservoir was 24 m³/sec with a 50-year flood return period. With the addition of the pool area, it will further reduce the capacity of the pump that is turned on with certain configurations on the pump operation schedule, this can be seen in the configuration of the combined pump.

6. References

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