Analysis of flood inundation in North Sunter on the North Sunter Polder system performance

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Abstract. More than 40% area in Jakarta is below mean sea level which it causes inundation to occur every year in Jakarta. In order to solve this problem, the government developed Jakarta flood control management. Polder system is one of drainage system for areas that cannot drain water by gravity. There is one polder system located at North Jakarta named North Sunter Polder System. However, the inundation still occurs every year in that area. Based on the problem, the aim of this study is to analyse the cause of flood inundation in the area, it can be known by simulation using the HEC-HMS and HEC-RAS applications. Based on the simulation results it is known that the cause of flood inundation in the North Sunter Polder system is due to the less optimum pump operation in the polder system. So that to overcome the flood inundation can be done by increasing pump capacity and changing the pump operating elevation.

1. Introduction

Jakarta as the capital city and one of the most populous cities in Indonesia is often flooded. It is happened due the plains of Jakarta which were mostly below mean sea level and have fairly flat contours, so many plains in Jakarta cannot drain water by gravity. To resolve the flood inundation problem in Jakarta, a drainage system plan was made. The main idea in the planning of the drainage system was originally planned in the Dutch colonial era, but it was actualized in a study conducted by NEDECO in 1973 [1].

Based on the masterplan of the drainage system in Jakarta from NEDECO, it can be seen that to resolve the inundation problem in Jakarta is by making a polder system. The polder system is a drainage system made for areas that cannot drain water by gravity [2]. From the NEDECO masterplan, it can be seen that some areas in Jakarta that cannot drain water by gravity are made into polder systems. One of them is the North Sunter Polder System located in the northern part of Jakarta. North Sunter is one of the economically strategic areas in Jakarta. This is due to the large number of industrial companies and labor in the region [3]. Although this economically strategic area is formed in a polder system, in fact the inundation still occurs in this area.

In 2019 there were inundation in various places in the North Sunter area. On January 30, 2019 based on data from the BPBD DKI Jakarta, floods occurred at Gaya Motor Street and Swasembada Raya Street. Because inundation that often occur in the North Sunter region that are economically strategic, it is necessary to do research to find out the causes of inundation in the North Sunter Polder System. In this case the research was based on the last flood that occurred in the area which was on January 30, 2019. Based on the existing problems the authors assumed several possibilities that caused flooding in the North Sunter Polder System, namely pumps that are not able to work, compressed inlets, non-integrated channels, lack of main channel capacity, and lack of micro-drainage capacity. For the
assumption of the causes of flooding in the North Sunter Reservoir Polder system, it can be investigated using simulations using the HEC-HMS and HEC-RAS application to determine the causes of inundation in the North Sunter Polder system.

2. Material and method

2.1. Study area
North Sunter located in Tanjung Priok district, North Jakarta. The North Sunter Polder System has a service area of 1,159.04 ha. North Sunter Polder System is bordered by Java Sea in the north, North Sunter reservoir street in the south, Laksamana Yos Sudarso Street in the east, and West Sunter reservoir street in the west. The map of catchment boundary of North Sunter Polder system is presented in Figure 1 [4].

![Figure 1. Catchment boundary of North Sunter Polder System](image)

The components of North Sunter Polder System consist of main channel, reservoir, and pump. Based on the design planning of North Sunter Polder System, the catchment area is divided into 9 sub-catchments area. Eight of nine sub-catchment area has one main channel. Every sub-catchment flow through the main channel to the North Sunter Reservoir and pumped directly to the sea. The sub-catchment and the components of North Sunter Polder System is presented in Figure 2. The North Sunter Reservoir has an area of 30.31 ha with an average depth of 5 m. There are five pumps in North Sunter Polder System with two different capacities. Three pumps have a capacity of 2,475 m3/s, while the other two have a capacity of 5 m3/s and all the pumps have different operating elevations. The operating elevations of the pumps in North Sunter Polder System are tabulated in Table 1.

| Pump | Capacity (m3/s) | Operating Elevation (m) |
|------|----------------|------------------------|
|      |                | On | Off |
| 1    | 2.475          | -1 | -1.1 |
| 2    | 2.475          | -0.5 | -1 |
| 3    | 2.475          | 0 | -0.5 |
| 4    | 5              | 0.1 | 0 |
| 5    | 5              | 0.1 | 0 |

Table 1. Operating elevation of pumps
Figure 2. The sub-catchments and components of North Sunter Polder System

The data used in this study are mostly obtained from the design planning of North Sunter Polder System itself. Some data like channel cross-section are obtained from field survey. The measurement of cross-section from every main channel are based on the station from the design planning. A program with geographic information system is needed to achieve the geographical data like area and length. In this study a program called ArcMap is used to find the geographical data from the study location, that is area of sub-catchments and length of the main channel. The sub-catchment properties data from ArcMap and field survey are tabulated in Table 3.

2.2. Daily rainfall
The rainfall calculation is done based on rain gauges that affect the study area. In this case, Thiessen Polygon method used to determine the rain gauges that affect North Sunter area. The result from Thiessen Polygon method is that rainfall in North Sunter area affected by two rain gauges, Tanjung Priok and Kemayoran. Tanjung Priok rain gauge affect the rainfall in North Sunter around 91.66% of the area, meanwhile Kemayoran rain gauge is around 8.34%. The rainfall used in this study is daily rainfall during inundation, which was on January 30, 2019. The daily rainfall from two rain gauges is multiplied by the percentage affect of each rain gauge to determine the regional rainfall. The regional rainfall in North Sunter on January 30, 2019 is tabulated in Table 2.

Table 2. Regional rainfall in North Sunter on January 30, 2019

| Rain Gauge       | Rainfall on January 30, 2019 (mm) | Percentage (%) | Regional Rainfall (mm) |
|------------------|------------------------------------|----------------|------------------------|
| Tanjung Priok    | 127.6                              | 91.66          | 124.2                  |
| Kemayoran        | 86.6                               | 8.34           |                        |

2.3. Rainfall distribution
Based on regional rainfall that has been obtained from the affect of two rain gauges, then the rainfall is distributed into hourly rainfall using Wanny rain distribution. In Wanny rain distribution, it must be known how long the rain occurred in North Sunter on January 30, 2019. Based on rainfall history data that occurred in North Sunter on January 30, 2019, the rain starts from 01.00 to 04.00, so the rainfall pattern that is used in this study from Wanny rain distribution is 3 hours rain pattern. The hourly-rainfall distribution is tabulated in Table 5.
Table 3. The sub-catchment properties data

| Sub Catchment | Area (ha) | Station (m) | Shape | TW (m) | BW (m) | y (m) | S     |
|---------------|----------|-------------|-------|--------|--------|-------|-------|
| SC 1          | 100.28   | 0 - 572     | Rectangular | 10.3   | 10.3   | 2.5   | 0.00018 |
|               |          | 572 - 1946  | Trapezoidal  | 7.7    | 4.8    | 1.64  | 0.0002  |
| SC 2          | 115.32   | 0 - 499     | Trapezoidal  | 5.28   | 4.8    | 3.24  | 0.0039  |
|               |          | 499 - 1455  | Trapezoidal  | 3.94   | 2.48   | 2.8   | 0.0011  |
| SC 3          | 160.12   | 0 - 1053    | Rectangular  | 4.75   | 4.75   | 2.88  | 0.0004  |
| SC 4          | 170.96   | 0 - 1480    | Rectangular  | 6      | 6      | 4.2   | 0.00013 |
|               |          | 1480 - 2120 | Rectangular  | 6.28   | 6.28   | 2.38  | 0.00143 |
|               |          | 2120 - 2780 | Trapezoidal  | 4.57   | 3.4    | 2.36  | 0.0002  |
| SC 5          | 198.66   | 0 - 1560    | Rectangular  | 6      | 6      | 3.7   | 0.000384|
|               |          | 1560 - 2220 | Rectangular  | 4.7    | 4.7    | 2.2   | 0.00034 |
|               |          | 2220 - 3870 | Rectangular  | 5.1    | 5.1    | 2.95  | 0.00061 |
| SC 6          | 67.85    | 0 - 183     | Trapezoidal  | 17.86  | 17.43  | 4     | 0.005   |
|               |          | 183 - 1585  | Trapezoidal  | 12.86  | 12     | 3.5   | 0.00071 |
| SC 7          | 157.57   | 0 - 982     | Rectangular  | 12     | 12     | 3.6   | 0.00081 |
|               |          | 982 - 1477  | Trapezoidal  | 9.66   | 7.4    | 2.9   | 0.00061 |
|               |          | 1477 - 2634 | Trapezoidal  | 12.66  | 11.83  | 3.6   | 0.00242 |
|               |          | 2634 - 3232 | Rectangular  | 11     | 11     | 3.2   | 0.00033 |
|               |          | 3232 - 3593 | Trapezoidal  | 24.6   | 22     | 5.2   | 0.00069 |
| SC 8          | 61.3     | 0 - 165     | Rectangular  | 2.8    | 2.8    | 1.2   | 0.00303 |
|               |          | 165 - 290   | Rectangular  | 2.8    | 2.8    | 1.2   | 0.00184 |
|               |          | 290 - 644   | Rectangular  | 2      | 2      | 1.07  | 0.00209 |
|               |          | 644 - 1047  | Rectangular  | 1.7    | 1.7    | 0.89  | 0.00124 |

2.4. Flood hydrograph
Estimation of the flood hydrograph is simulate using HEC-HMS application. The input data as parameter of the simulation are sub-catchment properties, weighted CN, the pumps and reservoir data, and the hourly rainfall distribution [5]. In this study, the simulation used SCS-CN for loss method and kinematic wave for transform method. SCS-CN used based on the available data, but kinematic wave used because of this concept suitable with urban area [6], like North Sunter. The estimation of weighted CN based on 2017 land use map from Badan Informasi Geospasial which is presented in Figure 3 and the weighted CN of each sub-catchment are tabulated in Table 4. The CN number for each sub-catchment was based on runoff curve number table for selected land uses [7]. The outputs of simulation using HEC-HMS are the flood hydrograph for each sub-catchment in North Sunter on January 30, 2019. This flood hydrographs will be used as input in simulation with HEC-RAS application.

Table 4. Weighted CN of each sub-catchment in North Sunter

| Sub-Catchment | SC 1 | SC 2 | SC 3 | SC 4 | SC 5 | SC 6 | SC 7 | SC 8 | SC 9 |
|---------------|------|------|------|------|------|------|------|------|------|
| Weighted CN   | 83   | 84   | 85   | 81   | 84   | 85   | 84   | 85   | 70   |
Table 5. Hourly rainfall distribution

| Date     | Time | % Wanny Rainfall Distribution | Hourly Rainfall (mm) |
|----------|------|--------------------------------|----------------------|
| 30-Jan-19| 0:00 | 0%                            | 0                    |
| 30-Jan-19| 1:00 | 68%                           | 84.32                |
| 30-Jan-19| 2:00 | 24%                           | 29.76                |
| 30-Jan-19| 3:00 | 8%                            | 9.92                 |
| 30-Jan-19| 4:00 | 0%                            | 0                    |
| 30-Jan-19| 5:00 | 0%                            | 0                    |
| 30-Jan-19| 6:00 | 0%                            | 0                    |
| 30-Jan-19| 7:00 | 0%                            | 0                    |
| 30-Jan-19| 8:00 | 0%                            | 0                    |
| 30-Jan-19| 9:00 | 0%                            | 0                    |
| 30-Jan-19| 10:00| 0%                            | 0                    |
| 30-Jan-19| 11:00| 0%                            | 0                    |
| 30-Jan-19| 12:00| 0%                            | 0                    |
| 30-Jan-19| 13:00| 0%                            | 0                    |
| 30-Jan-19| 14:00| 0%                            | 0                    |
| 30-Jan-19| 15:00| 0%                            | 0                    |
| 30-Jan-19| 16:00| 0%                            | 0                    |
| 30-Jan-19| 17:00| 0%                            | 0                    |
| 30-Jan-19| 18:00| 0%                            | 0                    |
| 30-Jan-19| 19:00| 0%                            | 0                    |
| 30-Jan-19| 20:00| 0%                            | 0                    |
| 30-Jan-19| 21:00| 0%                            | 0                    |
| 30-Jan-19| 22:00| 0%                            | 0                    |
| 30-Jan-19| 23:00| 0%                            | 0                    |
| 31-Jan-19| 0:00 | 0%                            | 0                    |

Figure 3. Land use map of North Sunter area
2.5. Determine the causes of inundation using HEC-RAS

HEC-RAS application is one-dimensional flow model which is capable of performing calculation of steady flow, unsteady flow, sediment, and water quality analysis for a network of natural or constructed channels [8]. The analysis that used in this study is unsteady flow analysis. The input data as the parameter of the simulation are network and geometry of channel, data of pumps and reservoir, and flow hydrograph from the simulation with HEC-HMS. In this case unsteady flow simulation used as a simulation run.

The outputs of HEC-RAS simulation are maximum water level of each main channel cross-section during the simulation time which is from January 30, 2019 00:00 until January 31, 2019 00:00 based on the flow hydrograph from HEC-HMS with the existing main channel. The result will show which main channel cross-section has inundation. Then it compared to the inundation area data in North Sunter on January 30, 2019.

After comparing the result, there will be another simulation run, but there will be some changes to the pump's capacity and operating elevation to find out whether the flood inundation is caused by the pumps or channel. In this case, the maximum changes of pump capacity based on the maximum pump capacity in Indonesia which is 10 m³/s. If after doing some changes in pump capacity and operating elevation, there is no flood inundation, then the cause of inundation is caused by a pump that is not optimum.

3. Results and discussion

Flow hydrographs from HEC-HMS simulation results for each sub-catchment in North Sunter Polder System is presented in Figure 4. Meanwhile, the result of HEC-RAS simulation after the flow hydrograph was made into an input in HEC-RAS is presented in Figure 5-7.

![Figure 4. Flow hydrographs of each sub-catchments](image-url)

Based on the HEC-RAS simulation results, it can be seen that there is flood inundation on the main channel in Sub-Catchment 4 Sta.2780 and Sub-Catchment 5 Sta.3870. It can be seen that the water level exceeds the existing bank station. Flood inundation on the main channel in Sub-Catchment 4 occurs at the same location as flood inundation data on 30 January 2019, which is on Gaya Motor Street. Then the flood inundation in Sub-Catchment 5 also occurred at the same location, which is on Swasembada Raya Street. Therefore, the results of HEC-RAS simulation are in accordance with the conditions in the North Sunter Polder System on January 30, 2019.
After knowing the location of the inundation based on HEC-RAS simulation results, some changes will be made to the pump operation. The purpose of this changes is to reducing flood inundation at the study location, so that the cause of inundation could be known in the North Sunter Polder System.

Figure 5. Inundation in Sub-Catchment 1 Sta. 1346 – Sub-Catchment 3 Sta. 0 (a-h)
Figure 6. Inundation in Sub-Catchment 4 Sta. 2780 – Sub-Catchment 6 Sta. 183 (i-r)
The changes in pump operation are carried out by trial and error. There are many changes to pump operations have been carried out by HEC-RAS simulation, but there is only one simulation will be explained. The selection of this simulation is based on best simulation results. In this case the changes in pump’s operation was made by adding one of the pump’s capacity and lower the operating elevation. Adding pump capacity means the volume of water that pumped every second will increase and lowered the pump operating elevation means the pump operation will start earlier. The changes in pump operation is tabulated in Table 6. The results of new HEC-RAS simulation with changes in pump operation presented in Figure 8.
Table 6. Changes in pump operation

| Pump | Capacity (m³/s) | Operating Elevation (m) |
|------|----------------|-------------------------|
|      |                | On  | Off  |
| 1    | 5              | -1  | -1.3 |
| 2    | 2.475          | -0.5| -1.1 |
| 3    | 2.475          | 0   | -0.7 |
| 4    | 5              | 0   | -0.5 |
| 5    | 5              | 0   | -0.5 |

Figure 8. The results of new HEC-RAS simulation after changes in pump operation

Based on the results of the new HEC-RAS simulation in the condition of additional pump capacity and changes in pump operating elevation it can be seen that this condition makes no flood inundation on the main channels in Sub-Catchment 4 Sta. 2780 and Sub-Catchment 5 Sta. 3870. From the results of the simulation, the water level elevation in Sub-Catchment 4 decreased by ±1, 7 m and the water level elevation in Sub-Catchment 5 decreased by ±2.5 m.

From the simulation results it can be concluded that by adding pump capacity and changes in pump operating elevation as shown in Table 6, it is effective in resolving flood inundation problem in the North Sunter Polder System. From these results it can also be seen that the cause of flooding in the North Sunter Polder System is because the existing pump cannot work optimally. This happens due to lack of pump capacity and the length of time the pumping starts so that there is flood inundation.

4. Conclusions

Based on the HEC-RAS simulation result, there is flood inundation on main channel in Sub-Catchment 4 Sta. 2780 and Sub-Catchment 5 Sta. 3870 and the results of HEC-RAS simulation are in accordance with the conditions in North Sunter Polder System on January 30, 2019. Based on the simulation results of HEC-RAS, the causes of floods in the Sunter Reservoir North Polder System occur due to the lack of...
optimum pump operation. So, flood inundation in the North Sunter Polder System can be overcome by increasing the capacity of one pump and lower the pump operating elevation.

Furthermore, it is necessary to do more research and study, starting from field surveys to conducting simulations with applications to determine the causes of flood inundation in the North Sunter Polder System. Then, measurement of the channel cross-section should be carried out at a closer interval to determine the actual channel conditions, because the possibility of flood inundation can be caused by main channel conditions which not detected by the HEC-RAS simulation. And the last, the process of measuring the channel cross-section must be carried out in detail by calculating the sediment conditions that exist in the main channel to obtain the simulation results that are close to the existing conditions.

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