Numerical modeling of sub-surface drainage systems in Citraland, West Surabaya

S Dwiuntoroadi\textsuperscript{1*}, U Lasmino\textsuperscript{2}

\textsuperscript{1} Graduate Student of Hydroinformatics, Department of Civil Engineering, Institut Teknologi Sepuluh Nopember
\textsuperscript{2} Lecturer in Departement of Civil Engineering, Institut Teknologi Sepuluh Nopember

*Corresponding author's e-mail: sih.dwiuntoroadi@pu.go.id

Abstract. Flooding occurs when the existing drainage system is unable to accommodate the water flow, that is due to a decreased drainage system capacity, increased flow of water, or a combination of both. On January 31, 2019, two hours of heavy rain caused Citraland housing to be flooded up to one meter high. This study aims to overcome the existing flooding problems through the assessment of sub-surface drainage systems for hilly areas in the Citraland residential area, Surabaya. Annual rainfall data from the rain stations around the residential area will be processed according to the proportion of the area to get a rain analysis plan that will be used in modeling. Plan rainfall data, area data and types of land cover, and catchment area data are analyzed hydrologically to get the design discharge. The hydraulic data of the dimensions of the existing drainage system will be analyzed for the capacity in flowing of Flow Plan. The Drainage System is then modeled using the Storm Water Management Model (SWMM) application. Through using topographic data and land cover, four alternative solutions have been modeled which include the addition of water reservoirs in various housing locations to overcome existing flooding. The results of this study are the second scenario through the addition of one water reservoirs which can handle flooding most effectively because it reduces 34.61\% of the inundation volume that occurs. In addition, the fourth scenario through the addition of three water reservoirs can reduce 57.82\% of the inundation volume that occurs.

Keywords: flood, drainage, SWMM, water reservoirs

1. Introduction
Flooding or occurrence of inundation in an area in a residential or urban area still occurs in many cities in Indonesia, one of which occurs in the city of Surabaya. During the rainy season, the western part of Surabaya city has puddle points that disturb residents’ activities. On January 31, 2019, heavy rain for two hours caused the Citraland area to be flooded up to 1 meter.

The purpose of this research is to conduct a flood simulation using a numerical model through the assessment of a sub-surface drainage system in the residential area of Citraland Surabaya. It is hoped that this research can help various parties including the government of Surabaya in an effort to reduce and even overcome the flood inundation that occurs.
2. Literature Study

Flooding or inundation occurs when the system that accommodates the inundation is not able to accommodate the flowing flow. This is the result of three possibilities that occur: system capacity decreases due to a reduction in the channel cross-sectional area, increased flow of water flow due to increased rainfall or get additional streams, or a combination of both. The system mentioned here means drainage network system of an area. Meanwhile, the drainage system in general can be defined as a series of water structures that functions to reduce and/or remove excess of water (flooding) from an area or land, so that land can function optimally, so the drainage system is an engineered infrastructure in an area to cope with inundation flood (Suripin, 2004).

According to Mulyanto (2012), drainage is a science of drying the soil. Drainage is derived from the word 'to drain' which is a term used to express systems related to handling the problem of excess water, both above and below the land settlement. The definition of drainage is not limited to the technique of excessive water disposal but is more broadly related to its relation to aspects of life that are within the urban area. All matters concerning excess water in the city area can certainly cause quite complex problems. The increasingly complex problems of urban drainage in the planning and construction depend on the ability of each planner. Therefore, in the work, it is required cooperation with several experts in other related fields.

SWMM is a rainfall-runoff model used for simulating the quantity and quality of surface runoff from urban areas. Surface runoff is generated from rain catchment areas. The surface runoff load is then channeled through pipelines, open drains, storage systems, and pumps. The EPA SWMM.5.1 program can model and analyze the quantity and problems of urban runoff. SWMM shows the quantity produced in each sub-watershed, water discharge, and flow depth. By using EPA SWMM, the conditions occurring in the field can be modeled by including the parameters recorded under field conditions. The collection of technical data including channel length, channel dimension, and channel slope is done by direct observation in the field. (SWMM User Manual, 2015)

3. Research Methods

3.1. Study Area

![Figure 1. Study Area Location (QGIS)](image1)

![Figure 2. Land Use Digitizing (QGIS)](image2)
The study area is located in the Citraland residential area, West Surabaya with an area of 0.483 km$^2$ (figure 1).

3.2. Spatial Analysis
Spatial analysis is conducted to get contour information for research location. Digital Elevation Model (DEM) from DEMNAS which has scale 1:50.000 is used for this process. Satellite image and observation are used to digitize the land use (Figure 2) which later will be used for determine Impervious percentage and CN number.

3.3. Hydrology Analysis
Hydrological analysis will produce a rain plan that will be included in the model as input, with a return period of 2 years, 5 years, and 10 years.

3.4. Hydraulic Analysis
The SWMM program is used to model existing sub-surface drainage systems. From the model, it will be analyzed using a rain plan which is calculated through a hydrological analysis to determine the flood points to be overcome.

3.5. Flood Management Scenarios
The scenario to be examined considers the location of the water reservoir based on land availability, flood location, contour and slope of the land, as well as the amount of flood volume that can be reduced.

3.6. Study Flowchart

![Study Flowchart](image-url)
4. Results

4.1. Rain Station Influence
There are several rain stations around the study site, including Kandangan, Banyu Urip, Gunungsari, and Kebon Agung rain stations. By using data on the location of the Surabaya city rain station and the location of the study, a rain station that affected the research area was determined using the Thiessen polygon method. Through the use of QGIS application, it is determined that the study area is 100% affected only by one rain station, namely the Kandangan rain Station.

4.2. Rainfall Plan
Of the 10-years of rainfall data at the Kandangan rain station, test is carried out to determine distribution types use, which is Normal, Log-Normal, Gumbel, or Log-Pearson III. And from the test, the one suitable for use in Kandangan rain station is the Pearson III Log distribution and the result is presented on table 1.

| Return Period | Log $\bar{x}$ | k   | Sd  | Log Q | R (mm) |
|---------------|--------------|-----|-----|-------|--------|
| 2             | 1.97         | -0.116 | 0.084 | 1.9604 | 91.29  |
| 5             | 1.97         | 0.79  | 0.084 | 2.0365 | 108.78 |
| 10            | 1.97         | 1.333 | 0.084 | 2.0821 | 120.82 |

4.3. Chi-Square and Smirnov-Kolmogorof Test
There are 2 ways to test the suitability of the distribution with existing data, namely using the Chi-Square and Smirnov-Kolmogorof tests. These tests are used to determine the relationship between the depth of rain and the value of probability. From the Chi-Square test the theoretical Chi value > the calculated Chi value = 3.841 > 2 so that the hypotheses tested can be accepted. Meanwhile, from the Smirnov-Kolmogorof test, the value of Do > Dmax = 0.41 > 0.1304 is obtained, so the hypothesis being tested can also be accepted.

4.4. SWMM Modelling
Modeling with SWMM is done by entering the required data on components from SWMM such as Rain Gage, Junction Node, Conduit, and Sub-catchment. The result is like in Figure 4.
4.5. Existing Drainage Analysis
With all the hydraulic data entered along with the rainfall data from the previous hydrology analysis. The simulation was carried out, with the result that there were 10 nodes that flooded with a total flood volume of 5256 m$^3$ (2-year return period), 8613 m$^3$ (5-year return period), and 10870 m$^3$ (10-year return period).

4.6. Scenario 1 Analysis
Scenario 1 includes the addition of a water reservoir at location number 1 (red circle, figure 4) of 750 m$^3$ over an area of 250 m$^2$. As shown in Figure 5, the scenario resulted in the decrease of the flooding by shifting back the flood occurring by at least one hour. Scenario 1 results in a reduction in total flood volume of 9.28% (2-year return period), 7.29% (5-year return period) and 6.20% (10-year return period).

**Figure 4.** Drainage Model modelled in SWMM, numbers indicate the locations of reservoirs.
4.7. Scenario 2 Analysis
Scenario 2 includes the addition of a water reservoir at location number 2 (red circle, figure 4) of 3000 m$^3$ over an area of 1000 m$^2$. Figure 6 shows a different result from scenario 1, which is the flooding reduced by decreasing the flow of water coming out of the node, instead of shifting back the time it occurred. It also means that the flood remains in the same time period, but with less water and lower depth. Scenario 2 results in a reduction in total flood volume of 34.61% (2-year return period), 25.83% (5-year return period) and 23% (10-year return period).
4.8. Scenario 3 Analysis
Scenario 3 includes the addition of a water reservoir at location number 3 (red circle, figure 4) of 3000 m³ over an area of 1000 m². Similar to scenario 2, Figure 7 shows the decrease of flooding occurring by decreasing the water coming out of the nodes. This also means that the flood remains in the same time period, but with less water and lower depth. Scenario 3 results in a reduction in total flood volume of 16% (2-year return period), 8.29% (5-year return period) and 6.39% (10-year return period).

Figure 7. Graph showing the decrease of flooding occurring on scenario 3 in one of the nodes

4.9. Scenario 4 Analysis
Scenario 4 includes the addition of three water reservoirs at all locations, number 1 to 3 (red circle, figure 4) of total 6750 m³ over an area of 2250 m². Scenario 4 results in a reduction in total flood volume of 57.82% (2-year return period), 40.59% (5-year return period) and 35.04% (10-year return period).

4.10. Result
The result of modelling and simulation of the scenarios is shown in the following table:

| Table 2. Comparative tables of total flood volume reduced by m³ and percentage |
|---------------------|---------------------|---------------------|
| Return Period       | 2-years m³ | 2-years % | 5-years m³ | 5-years % | 10-years m³ | 10-years % |
| Scenario 1          | 488        | 9.28%     | 628        | 7.29%     | 674        | 6.20%     |
| Scenario 2          | 1819       | 34.61%    | 2225       | 25.83%    | 2500       | 23.00%    |
| Scenario 3          | 841        | 16.00%    | 714        | 8.29%     | 695        | 6.39%     |
| Scenario 4          | 3039       | 57.82%    | 3496       | 40.59%    | 3809       | 35.04%    |
5. Conclusion

Based on the results of the analysis and discussion above, several conclusions can be drawn:

1. By using the rainfall calculation for the return period of 2, 5, and 10 years and SWMM modeling, it was found that flooding occurred at several node points was caused by the channel which is not large enough to drain the planned rainfall.

2. The second scenario through the addition of one water reservoir can handle flooding most effectively because it reduces 34.61% of the inundation volume that occurs. Besides, the fourth scenario through the addition of three water reservoirs can reduce 57.82% of the inundation volume that occurs.

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