Eco-drainage system planning with SWMM model: a case study of Sawah Liat drainage, Kuranji watershed in Padang City, Indonesia

A Junaidi1, H Putra1,2, B Istijono1, N Nurhamidah1 and M Utama2

1Civil Engineering Department, Andalas University, Padang, Indonesia
2Board of River Basin Sumatra V, Ministry of Public Works and Housing, Padang, Indonesia

E-mail: ahmad_junaidi@eng.unand.ac.id

Abstract. Sawah Liat drainage is one area of drainage that the flow of water discharged into the Kuranji River in Padang City. It is a very vulnerable area to the flooding. Flooding was caused by high rainfall, land-use change, and river flooding. This area does not yet have a drainage network system. This research is to plan a new drainage system using the eco-drainage concept of adding a retention pond in the drainage network system. EPA-SWMM model was used to simulate the planned drainage network model and assisted with Global Mapper and ArcGIS for spatial analysis. Six simulation models are performed by combining two models of the drainage network, two land cover models, and two models of rainfall. The results showed that the drainage network models with retention ponds are more effective against controlling flooding. With simulation using a 5-year rainfall return period, there was no flood. For simulations using rainfall data on March 22, 2016, the depth of flooding could be decreasing from 0.2 m to 0.9 m. The retention pond can reduce the 5-year flood volume of 120,200 m³ or 59% of the total 203,710 m³

1. Introduction

Flood is a natural phenomenon caused by a hydrologic cycle, which was partially descended rain will become surface runoff and partly into infiltration. This surface runoff is sometimes called flooding. The amount of flood is influenced by one of the changes in land cover of an area; the higher the land-use change from the wetland to dry land, the surface coefficient also increases. Floods in large-scale and excessive can cause damage to the environment and even harm to humans who live in areas prone to flooding.

Padang city is very susceptible to flood, the main cause of floods in Padang is river overflow and incomplete drainage network system that can accommodate excess rainwater [1]. Rapid land-use changes within the city of Padang will lead to an increase in flooding areas in the lowlands [2]. The actions taken by the community or government to control the flood of the region is to create a drainage system. In this study, the area under consideration is the Sawah Liat drainage of Padang. This drainage area has a sub-catchment area of 145.05 ha — topographic conditions of hills and many basins. The location is right on the west side of the Kuranji river. Sawah Liat drainage is part of the Kuranji block where the flow of water discharged into the river Kuranji.
1.1. Background
On March 22, 2016, the Sawah Liat drainage area was hit by floods of 77.83 ha with 270 mm rainfall and puddles as high as 0.25m - 2m for ± 3 hours. Flooding was caused by high rainfall, land-use change, and river flooding. Flood conditions can be seen in figure 1 [3].

![Figure 1. Flood on March 22, 2016, in Sawah Liat, Nanggalo, Padang City [3].](image)

This area does not have a drainage system, so when heavy rain happens, floods or puddles will occur very often. Therefore, this research is planned new drainage system by using an eco-drainage concept that is adding retention pond in one drainage system, which planning, according to PU Decree No. 12 the Year 2014 [4]. In addition to the flood control, retention pond serves as a water absorption to maintain soil water content, so that dry season does not occur drought. In contrast to the conventional system in the dry season will occur drought because water is not retained first but directly discharged into the river.

1.2. Research objectives
The main objective of this research is to simulate the planning of a new drainage system with eco-concept (eco drainage) in the Sawah Liat drainage area by using the EPA SWMM 5.1 program. Therefore, the secondary objectives of this research are:

- To conduct land-use digitisation from google earth into map form through ArcGIS 10 application by the division of agricultural area as pervious area and residential area as impervious area.
- To plan the canal trajectory and retention pool points based on flow patterns, land cover conditions, and topography using ArcGIS 10 applications.
- To determine the capacity of drainage and retention ponds based on SWMM application simulations results.
- To conduct a simulation to show the response of new drainage network designs with retention ponds and designs in 2010 without conventional retention pools against various changes to both plan rainfall and land cover.

The main objective of this research is to simulate the planning of a new drainage system with eco-concept (eco drainage) in the Sawah Liat drainage area by using the EPA SWMM 5.1 program. Therefore, the secondary objectives of this research are:

- To conduct land-use digitisation from google earth into map form through ArcGIS 10 application by the division of agricultural area as pervious area and residential area as impervious area.
- To plan the canal trajectory and retention pool points based on flow patterns, land cover conditions, and topography using ArcGIS 10 applications.
- To determine the capacity of drainage and retention ponds based on the debit of SWMM application calculation results 5.1.
- To conduct a simulation to show the response of new drainage network designs with retention ponds and designs in 2010 without conventional retention pools against various changes to both plan rainfall and land cover.
There are several assumptions taken for this study:
- Assumed no flow from outside the research site such as overflow of the river
- Assumed runoff water does not contain sediment
- The research did not discuss the design details

1.3. Research location
This location discussion in this study is limited as follows:
- Location Areas of Sawah Liat drainage located in District Nanggalo, Padang with coordinates 0°54'40,74" S, 100°22'19,61" E. Administratively the boundaries of the study location are as follows:
  - North: bordered by Kuranji River
  - South: bordering by Lolong Drainage Area
  - West: bordered by Kandis Drainage Area
  - East: bordered by the Kuranji River

![Figure 2. Research location [3].](image)

2. Material and Methods
The method used to collect secondary data is by documentation method by collecting data and information required from sources mostly from mater similar documents related to the problem under study. Data collection is divided into two primary and secondary data. Primary data is taken directly from the field, while secondary data is obtained from related institutions such as BWS Sumatera V, Provincial Water Resources Development Office, Public Works Office of Padang City, Central Bureau of Statistics of Padang City, etc. And for the simulation of the channel drainage design network is used the Storm Water Management Model (EPA SWMM 5.1).

3. Urban drainage
Drainage is to drain, dispose of, or divert water [5]. In general, drainage is defined as a series of water structures that function to reduce and remove excess water from a region or land so that the land can be functioned optimally. Drainage is also interpreted as an effort to control the quality of groundwater associated with salinity. Thus, drainage is not only related to surface water but also groundwater.

  Drainage and retention ponds planning should consider topographical, land use, flow patterns for which slope planning is attempted to follow the gravity flow pattern and for retention ponds placed at the lowest elevation such as basins.

3.1 Introduction to SWMM
Modelling in this research using EPA SWMM 5.1. The Storm Water Management Model (SWMM) is a rainfall-runoff model used to simulate the quantity and quality of surface runoff from urban areas. Surface runoff is generated from rainfall in the catchment area that is excesses rainfall. The runoff
loads are then canalised through pipelines, open drains, storage systems, pumps, etc. SWMM calculates the quantity and quality of surface runoff from each catchment area, and the flow of flow, flow, and water quality in each pipeline and during the simulation period [6].

EPA SWMM 5.1 is a 1-dimensional flow model that uses the Saint Venant equation as its regulatory equation. The Saint Venant equation consists of the equation of the momentum and the equation of momentum and energy equation in which:

Continuity Equation:
\[
(\frac{\partial Q}{\partial x}) + (\frac{\partial A}{\partial t}) = 0
\]  

Momentum Equation:
\[
\left(\frac{1}{A} \ast \frac{\partial Q}{\partial t}\right) + \left(\frac{1}{A} \ast \frac{\partial}{\partial x}\right) \ast \left(\frac{Q^2}{A}\right) + \left(g \ast \frac{\partial y}{\partial x}\right) - g(s_f - s_i) = 0
\]

3.2 Surface flow concept in SWMM

Sub catchment surfaces are defined as nonlinear reservoirs. Water enters through precipitation and disappears through evaporation and infiltration. The difference between the reduction of water entering with the water evaporated and stored by infiltration is the amount of surface flow that occurs.

The flow simulation model in figure 2.

![Figure 3. Stream simulation model [6].](image)

4. Hydrological analysis

The hydrological analysis was performed to obtain the rainfall value of the plan with a certain return period. The return period is determined based on table 1. The frequency analysis is performed to determine the distribution type, including Normal Distribution, Normal Log Distribution, Pearson Log Distribution III, and Gumbel Distribution. Furthermore, the determination of the type of distribution used will be tested matches based on Chi-Square Test and Kolmogorov-Smirnov. Once the distribution is set, the rainfall value of the design plan can be calculated. To create the hour-time rainfall distribution pattern with Alternating Block Method (ABM) method, which later as input rain gauge on EPA SWMM 5.1 [7].

| City Typology   | Water Catchment Area (ha) |
|-----------------|---------------------------|
|                 | <10  | 10-100 | 101-500 | >500   |
| Metropolis      | 2 Th | 2-5 Th  | 5-10 Th | 10-25 Th |
| Big city        | 2 Th | 2-5 Th  | 2-5 Th  | 5-20 Th  |
| Medium City     | 2 Th | 2-5 Th  | 2-5 Th  | 5-10 Th  |
| Small town      | 2 Th | 2 Th    | 2 Th    | 2-5 Th   |
The total area of research is 145.05 ha and included in the category of big cities, then for drainage planning used a rainfall 5-year return period.

5. Spatial analysis
Processing of spatial data using Global Mapper 19 and Arcgis 10 software. The spatial analysis is done among others to determine:

- Map contour /DEM/topography of research location downloaded through Global Mapper 19 application. The data type used is SRTM Worldwide Elevation Data (3-arc-second Resolution).
- We are fetching the satellite imagery map of the research location from Google Earth 2018.
- Determine flow patterns using Global Mapper 19.
- Determining the land use of the research location
  ✓ The land use in this research is divided into two areas: pervious and impervious areas. The pervious region is a water-infiltrate area, whereas the impervious regions of the region can not miss the water. The steps to determine the previous and impervious regions are as follows:
    ✓ Direct observation of research location
    ✓ Image usage imagery is taken from google earth
    ✓ Doing digitisation of land use google earth to a map with the help of ArcGIS software with the distribution of agricultural areas as pervious area and the residential area as an impervious area.
- We are planning the canal tract and retention basin paths based on flow patterns, contours, and land use.
- Sub catchment division for each canal
Determine the percentage of the impervious area of each sub-catchment

6. Flow calculation
The flow debit is calculated using the SWMM 5.1 application. The calculated debit is:

- Total flow discharge from the research area to predict the volume of flooded inundation. The prediction of flooding is made by comparing the calculation of the runoff rate and the volume of the research area per contour. If the runoff rate is greater than the value of the volume of the research area, then it is indicated that the contour is flooded then the puddle area is mapped using ArcGIS 10 software [8]
- The flow rate per sub-catchment using the impervious plan is 80%. Subsequently, the result of the debit calculation is used for the hydraulic design of the canal cross-section.

7. Flood simulation
There are six simulation models for this study is shown in table 2.

| Simulation Model | Land Use | Drainage Network |
|------------------|----------|------------------|
|                  | 2017* | Future** | New Design*** | 2010 Design |
| Simulation 1 - 4 uses rainfall data for the five-year return period | ✓ | ✓ | ✓ | ✓ |
| 1                | ✓ | ✓ | ✓ | ✓ |
| 2                | ✓ | ✓ | ✓ | ✓ |
| 3                | ✓ | ✓ | ✓ | ✓ |
| 4                | ✓ | ✓ | ✓ | ✓ |
| Simulation 5 - 6 uses rainfall data on March 22, 2016 | ✓ | ✓ | ✓ | ✓ |
| 5                | ✓ | ✓ | ✓ | ✓ |
| 6                | ✓ | ✓ | ✓ | ✓ |
** Existing Land Use used in this research is derived from the Google Earth imagery map (July 23, 2017).

** Based on Law 26 of 2007 on Spatial Planning, the proportion of public green space in urban areas is 20 per cent so that the future land use condition is 80% of the housing [9].

*** New drainage network design is planned based on future land use conditions

8. Result and discussion

The rainfall data used in this research is taken from Pos Khatib Sulaiman. Because the data is available only seven years from January 2010 to December 2017, it is used Peak Over Threshold method and obtained 50 series of data [7]. Based on the results of selected frequency analysis, Log Pearson distribution type III. From the calculation of Log Pearson III distribution type obtained rainfall five years return period of 159 mm. The Heytograph pattern with Alternating Block Method can be seen in figure 4.

![Figure 4](image)

**Figure 4.** Photograph of 5 years returns period.

From the calculation of ArcGis obtained total Impervious area is 71.3 ha (49.15%) and Pervious 73.75 ha (50.85%). From the land use analysis, it is concluded that land is still dominated by agricultural land, as in figure 4.

![Figure 5](image)

**Figure 5.** Land use site location.

In the new drainage network, design planning in this study use two outlets where the surface flow is partially dumped into the retention pond and partly into the river. The layout design of the canal trace and retention pool can be seen in figure 5.
The cross-section design for the channel drainage is determined with a rectangular shape because it is most economical. The design data can be seen in Table 3.

Table 3. The new design of channel drainage.

| Canal Name | L(m)  | b(m) | H(m) | Initial Elev. | Final Elev. | S     | n     |
|------------|-------|------|------|---------------|-------------|-------|-------|
| C1         | 1,012.31 | 2    | 1.5  | 27.80         | 12.00       | 0.015608 | 0.017 |
| C2         | 214.95  | 2.5  | 2    | 10.00         | 8.60        | 0.006513 | 0.017 |
| C3         | 357.86  | 3.5  | 2.5  | 10.00         | 8.40        | 0.004471 | 0.017 |
| C4         | 123.55  | 3    | 3    | 8.60          | 8.10        | 0.004047 | 0.017 |
| C5         | 471.09  | 2.8  | 2    | 11.80         | 11.00       | 0.001698 | 0.017 |
| C6         | 388.67  | 2    | 1.5  | 15.60         | 9.20        | 0.016467 | 0.017 |
| C7         | 175.24  | 2    | 1.5  | 14.60         | 8.60        | 0.034238 | 0.017 |
| C8         | 237.02  | 2.2  | 1.6  | 12.40         | 8.80        | 0.015188 | 0.017 |
| C9         | 216.50  | 3    | 2    | 9.00          | 8.20        | 0.003695 | 0.017 |
| C10        | 222.95  | 1.5  | 1    | 15.20         | 10.60       | 0.020632 | 0.017 |
| C11        | 555.79  | 3.8  | 3    | 8.20          | 3.80        | 0.007917 | 0.017 |
| C12        | 491.28  | 2    | 1.8  | 9.40          | 6.20        | 0.006514 | 0.017 |
| C13        | 637.42  | 3.8  | 3    | 11.00         | 8.20        | 0.004393 | 0.017 |

Figure 6. Sketch of the new channel drainage.

Table 4. The total area of the retention pond.

| Name | Total Area (m²) | Depth (m) |
|------|----------------|-----------|
| Pool 1: SU1 | 29,100.00 | 2         |
| Pool 1: SU2 | 17,000.00 | 2         |
| Pool 1: SU3 | 6,100.00  | 3         |
| Pool 1: SU4 | 1,000.00  | 2         |
| Pool 2: SU5 | 15,000.00 | 3         |
| Pool 2: SU6 | 15,000.00 | 3         |
The 2010 drainage design network was obtained from the Padang City Drainage Technical Review Report, Directorate General of Human Settlements, and has not been built yet [10]. The drainage system used is still conventional, yet applying an eco-friendly concept whereby the total surface flow is discharged into the river as the final outlet. The 2010 drainage network layout can be seen in figure 7.

**Figure 7.** The layout of channel drainage network design 2010 and sub-catchment.

The data parameters inputted in SWMM include Subcatchment, Junction, Conduit, Storage Unit, Regulator, and Outlet. The network model on SWMM for new drainage network and drainage network in 2010 can be seen in figure 8 and figure 9 below:

**Figure 8.** The new channel drainage design network model.

**Figure 9.** The channel drainage design model in 2010.
The results of the analysis show that the new drainage network model with retention pond is more effective in controlling flood where the flood does not occur on the 5-years return period rainfall event while drainage without design retention pond in 2010 occurred flooding along the channel. As a news outlet, the retention pond can reduce the 5-year annual flood volume by 120,200 m³ or 59% of the total 203,710 m³.

It was simulated against rain on March 22, 2016. To show the reliability of the new drainage network with a retention pool, with a rainfall of 270 mm. The simulation results show flooding in the channel, but the volume of flooding decreased from 364,620 m³ to 51,244 m³, and flood height decreased from 0.25 m - 2 m to 0.2 m - 0.9 m as in figure 10 below:

![Figure 10. Change in flood volume after a new drainage channel design applied to 270 mm rainfall.](image)

9. Conclusions and recommendations

9.1. Conclusions

Based on simulation result can be concluded as follows:

- Land use in this research is divided into 2(two) that is impervious land for residential land, and pervious land for agricultural land, from the results of land use utilization using google earth image map in 2017, the total area of Impervious is 71.30 ha (49.15%) and Pervious 73.75 (50.85%) it is concluded that land use is still dominated by agricultural land.

- The results showed that the drainage network models with retention ponds are more effective against controlling flooding. With simulation using a 5-year rainfall return period, there was no flood. For simulations using rainfall data on March 22, 2016, the depth of flooding could be decreasing from 0.2 m to 0.9 m. The retention pond can reduce the 5-year flood volume of 120,200 m³ or 59% of the total 203,710 m³.

9.2. Recommendations

- Based on the results of this study, it is necessary to review the design of 2010 made by the Directorate General of Human Settlements because the channel simulation results experienced floods of rain when re-5 years.

- Surely the results of this study are not perfect. Therefore it is recommended that further research using the data of direct measurement results in the field such as topographic data.

- The construction of river dykes along the 3.13 km research area can be realised by the Board of River Basin Sumatera V because it had been halted since 1996. It is to prevent river overflow as happened on March 22, 2016.

Acknowledgements

Thanks to the Civil Engineering Departement of Faculty of Technology, Andalas University, Padang, Indonesia, which has facilitated this research.
References

[1] Junaidi A and Nurhamidah N 2017 Flood Problem in Padang City: The Effectiveness Solution International Journal of Civil Engineering and Technology (IJCET) 8 (10) p1210-1219
[2] Nurhamidah N and Junaidi A 2016 Linear Reservoir-based adaptive land subsidence model: Case of Sumatra peat lowland forest J.Lowland Technology International 18 (3) p173-182
[3] Muhammad A, Goda K, Alexander N A, Kongko W, Muhari A 2017 Tsunami evacuation plans for future megathrust earthquakes in Padang Indonesia considering stochastic earthquake scenarios Natural Hazards and Earth System Sciences 17(12) 2245
[4] Anonymous 2014 Ministerial Regulation no. 12 / PRT / M / 2014 on Implementation of Urban Drainage System (Jakarta: Ministry of Public Works)
[5] Suripin 2004 Urban Drainage System (Yogyakarta: ANDI Publisher) p 408
[6] Rossman L 2015 Storm Water Management Model User’s Manual Version 5.1 (Cincinnati: EPA United States Environmental Agency)
[7] Triatmodjo 2008 Applied Hydrology (Yogyakarta: Beta Offset)
[8] Ariandhy D R, Westy S A and Ihsan 2013 Flood Inundation Prediction Using USSCS Rational Method 1973 Proceeding of IPLBI Scientific Meeting (Makasar: Faculty of Engineering, Hasanuddin University)
[9] Anonymous 2007 Law No.26 on Spatial Planning (Jakarta: Government of the Republic of Indonesia)
[10] Anonymous 2010 Directorate Directorate General of Human Settlements 2010 Padang (Padang: Report on Drainage Technical Master of Padang City)