Flood control study using 1D/2D numerical model in Cipabuan Channel, Sabi River Watershed, Tangerang City

V Pratiwi1,2*, B P Yakti3, A Rizaldi 3, I R Moe 4, D P Koesrindartono 5
1Doctoral Program of Civil Engineering, Civil and Environmental Engineering Faculty, Institut Teknologi Bandung, Jl. Ganesha 10 Bandung, Indonesia
2Civil Engineering Department, Computer Sciences and Engineering Faculty, Universitas Komputer Indonesia, Jl. Dipati Ukur 112-116 Bandung, Indonesia
3Center for Water Resources Development, Institute for Research and Community Services, Institut Teknologi Bandung, Jl. Ganesha 10 Bandung, Indonesia
4Directorate General of Water Resources, Ministry of Public Works and Housing, Jl. Pattimura No. 20, Kebayoran Baru, Jakarta Selatan, Indonesia
5Public Works and Spatial Planning Agency, Jl. KS. Tubun No. 96 Tangerang, Indonesia

*vitta.pratiwi@email.unikom.ac.id

Abstract. The flood that occurred in Tangerang City still remains an issue that has not been resolved. The flood arose from Bogor through the Cisadane River. Cipabuan Channel is one of the channels in the Sabi River watershed who often overflows. Sabi River itself is a tributary of the Cisadane River. In this study, the flood control simulation in Cipabuan Channel was carried out using a 1D-2D numerical model. Simulation is carried out with 4 scenarios based on the design flow of the 10 year return period. For scenario 1, flood control is carried out using retention pond in the downstream of Cipabuan Channel, scenario 2 is carried out by using two retention ponds in the upstream and downstream of Cipabuan Channel, scenario 3 using retention ponds in the downstream of Cipabuan Channel and bypass channel to Cisadane river, and scenario 4 performed by using retention pond in the downstream of Cipabuan Channel and normalization on the Channel. Simulation results show the effectiveness of flood reduction for each scenario, in scenario 1 flood can be reduced by 9%, scenario 2 flood can be reduced by 32.52%, scenario 3 flood can be reduced by 77.34% and for scenario 4 flood can be reduced by 95%. From these results, it can be concluded that scenario 4 where flood control is carried out using a retention pond in the downstream of Cipabuan Channel and normalizing the River can reduce flooding significantly.

1. Introduction
Tangerang City undergoes flooding every year, particularly during the wet season when most of a region's average annual rainfall occurs. Several countermeasures have been made but not be able to achieve maximum results. The worst flood that ever happened was in early February 2007. Bapennas informed that in Tangerang City and Regency at least 3000 houses were submerged, 13 people died and 42.278 people were forced to live in refugee camps. The value of damage to infrastructure in the Jabodetabek area is estimated at IDR 327 billion with a loss value of IDR 525 billion.

Floods in the city of Tangerang can be classified into 4 typologies based on the cause flooding, namely:

1. Flood due to overcapacity of the river as a drainage channel because of river siltation or sedimentation;
2. Flood due to overcapacity of the drainage channels or the absence of drainage channels;
3. Flood due to a broken dike
4. Flood due to runoff from the upstream area

Looking at the typology based on the causes of flooding, it can be concluded that the main factor of the flood is due to inadequate drainage system conditions (river capacity and drainage channels). This conclusion is in line with the results of rainfall analysis and land use analysis which reinforces the notion that the drainage system is inadequate, causing overcapacity and be the main factor of flooding in Tangerang City.

One of the causes of the flood was the overflow of the Sabi River. It was flooded several areas in the Tangerang City which lead to economic losses and disrupts community activities. Cipabuaran Channel is one of the channels in the Sabi River watershed that often overflows. In this study analyze the flood control was carried out by reducing the flood discharge that enters Sabi River by doing flood control in Cipabuaran Channel.

The aim of this study is to answer several existing problems and provide the flood control, namely:
1. To investigate the flood inundation, flood elevation and flood depth of Cipabuaran Channel
2. To build the correct flood inundation model for the Cipabuaran Channel
3. To provide the solution of flood control for the Cipabuaran Channel

The models are widely used for flood research such as flood damage assessment [1], flood risk mapping [2], and flood related engineering [3]. Based on FEMA (Federal Emergency Management Agency), software for flood modelling has been determined. Software that is commonly used and accepted by FEMA is HEC-RAS, MIKE FLOOD (1D MIKE 11/ MIKE 21 2D), and TUFLOW [4].

From the hydraulic model software above, HEC-RAS is a commonly used software and has a free license, the software was once used to model 2D flood propagation from collapsing dams [5]. As a comparison HEC-RAS, MIKE 21, and TUFLOW were compared, the result show that the HEC-RAS yielded an overestimate result, MIKE 21 gave quite good results and TUFLOW gave underestimate results [6].

In this study, 1D-2D modelling of flood in Cipabuaran Channel is conducted to predict the flood inundation and flood depth in order to create the flood control system and expected to reduce flooding that often occurs.

2. Methods
Generally, the flood modelling stage scheme is illustrated in the flow chart as follows.
Figure 1. Flood Modelling Scheme

1-D model simulation will bring out results in the form of water level and river discharge.

After conducting a water hydraulic modelling simulation on the river (1-D Model) then proceed to modelling the flow in the land (2-D Model). The modelling results will obtained the flow of water, water level in a two-dimensional direction. With the presence of topographic data (DEM = digital elevation model), the size of the inundation area, the depth of the inundation and the length of the inundation can be determined based on several return periods.

The basic equation in hydraulic modelling is continuity and momentum equations. These equations are developed in such a way with the addition of several parameters or variables that are adjusted to the characteristics of the object to be investigated to improve the accuracy of the results in the simulation to be carried out. Following equations are mathematical expression of continuity and momentum equations [7].

Governing Equations:
Continuity Equation
\[
\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_1
\]  
(1)

Momentum Equation
\[
\frac{\partial Q}{\partial t} + \frac{\partial (uQ)}{\partial x} = gA \frac{\partial (h)}{\partial x} - \frac{gn^2|Q|^2}{4r^3A}
\]  
(2)

where :
A = Area
Q = Discharge
q_1 = Lateral Flow
u = Velocity
h = water depth

While the inundation simulations uses the following equations:
\[
\frac{\partial h}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0
\]  
(3)

\[
\frac{\partial q}{\partial t} + \frac{\partial (p^2h)}{\partial x} + \frac{\partial (pq)}{\partial y} + gh \frac{\partial c}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{c^2h^2} = \frac{1}{\rho_w} \left[ \frac{\partial}{\partial x} \left( h\tau_{xx} \right) + \frac{\partial}{\partial y} \left( h\tau_{xy} \right) \right] = 0
\]  
(4)

\[
\frac{\partial q}{\partial t} + \frac{\partial (q^2h)}{\partial y} + \frac{\partial (pq)}{\partial x} + gh \frac{\partial c}{\partial y} + \frac{gp\sqrt{p^2+q^2}}{c^2h^2} = \frac{1}{\rho_w} \left[ \frac{\partial}{\partial y} \left( h\tau_{yy} \right) + \frac{\partial}{\partial x} \left( h\tau_{xy} \right) \right] = 0
\]  
(5)
Where :

- $C(x,y)$ = Chezzy Coefficient
- $\rho_w$ = Water Density
- $\zeta(x,y,t)$ = Water Elevation
- $\tau$ = Effective Stress
- $p,q$ = Flux Density
- $h$ = Water Depth
- $g$ = Gravitational Acceleration

2.1. Study Area

Tangerang is a city located in Banten Province which has an area of 164.55 km$^2$ or around 1.59 percent of the area of Banten Province. This city is one of eight regencies / cities in Banten Province located in the West of the State Capital of Indonesia and crossed by 3 watersheds. The Cisadane watershed is the largest watershed. The flood location in this study is the Cipabuaran Channel. Cipabuaran Channel is one of the River in the Sabi River watershed. Sabi River itself is a tributary of the Cisadane River. Based on BPS (Badan Pusat Statistik) the highest rainfall in the Tangerang occurred in January with an average value of 329.60 mm [8].

![Figure 2. Study Location (Cipabuaran Channel)](image)

2.2. Model Setup

River Network

River network patterns influence each other on the river that are reviewed are very necessary in carrying out a hydrodynamic model simulation. In this simulation, Cipabuaran Channel has been integrated into one system. Following (Figure 3) is the appearance of river network patterns for existing conditions.
Figure 3. River Network

Boundary Condition
The boundary conditions used in 1-D hydrodynamic modelling are inflow hydrographs, water level elevation data, and rating curves of river cross sections. For 2-D modelling requirements, DEM data is obtained from public works and spatial planning services office of Tangerang City. The following (Figure 4) are the boundary conditions used in the model.

Figure 4. Boundary Conditions

The discharge hydrograph in the picture above is obtained from the results of lumped hydrology model. The hydrograph was conducted by using SCS method and simulated by using HEC-HMS The Hydrologic Modelling System (HEC-HMS) is designed to simulate the complete hydrologic processes of dendritic watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing [9].
3. Results and discussion

3.1. Existing Condition
Existing conditions are modelled using a design flow of 10 year return period with river conditions without flood control.

![Figure 5. Existing Condition (2-D)](image)

3.2. Flood Control Condition
The Flood Control Condition is carried out with 4 scenarios based on the design flow of the 10 year return period. For scenario 1, flood control is carried out using retention pond in the downstream of Cipabuarian Channel, scenario 2 is carried out by using two retention ponds in the upstream and
downstream of Cipabuaran Channel, scenario 3 using retention ponds in the downstream of Cipabuaran Channel and bypass channel to Cisadane river, and scenario 4 performed by using retention pond in the downstream of Cipabuaran Channel and normalization on the River. The following (Fig 7) is a flood control scheme on the Cipabuaran Channel.

**Figure 7. Flood Control Scheme**

For scenario 1 with a downstream retention pond planned to reduce flooding with a 10-year return period, the pond has a storage capacity of 49,680 m$^3$.

For scenario 2 with a downstream and upstream retention pond planned to reduce flooding with a 10-year return period, the downstream pond has a storage capacity of 49,680 m$^3$ and the upstream pond has a storage capacity of 61,200 m$^3$.

For scenario 1 with a downstream retention pond planned to reduce flooding with a 10-year return period, the pond has a storage capacity of 49,680 m$^3$.

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For scenario 3 with a downstream retention pond and bypass channel to Cisadane River planned to reduce flooding with a 10-year return period, the downstream pond has a storage capacity of 49,680 m$^3$ and the bypass channel dimension 1.6 x 1.6 m.

**Figure 8. Comparison between existing and normalized Cipabuaran Channel profiles**

For scenario 4 with a downstream retention pond and normalization of Cipabuaran Channel planned to reduce flooding with a 10-year return period, the downstream pond has a storage capacity of 49,680 m$^3$ and the comparison of Cipabuaran Channel profiles after normalization can be seen in the following figure.
Figure 9. Scenario 1 (2-D Cipaburan Channel)

Figure 10. Scenario 2 (2-D Cipaburan Channel)
Figure 11. Scenario 3 (2-D Cipabuaran Channel)

Figure 12. Scenario 4 (2-D Cipabuaran Channel)

Table 1. Recapitulation of flood control effectiveness

| Flood Control Condition | Effectiveness of Flood Reduction |
|-------------------------|---------------------------------|
| Scenario 1              | 1%                              |
| Scenario 2              | 16%                             |
| Scenario 3              | 37%                             |
| Scenario 4              | 95%                             |
Based on the results of simulations, it can be seen that flood reduction with scenario 4 shows the most effective results, but for the selection of flood control further analysis is needed where the cost component must be considered so that flood control can be applied.

For further studies, further calibration of the observation data is needed. Comparison with observed data requires first that the modelled quantity is measurable. In the case that observed data do not exist, the second technique of benchmarking with other (validated) models is an option. As third option, even in the absence of validated models to refer, falsification through expert knowledge and expert judgement can be applied which implies comparing model results with experts’ expectations. [10]

4. Conclusion

Simulation results show the effectiveness of flood reduction for each scenario, for scenario 1 flood can be reduced by 9%, scenario 2 flood can be reduced by 32.52%, scenario 3 flood can be reduced by 77.34% and for scenario 4 flood can be reduced by 95%. From these results it can be concluded that scenario 4 where flood control is carried out using retention pond in the downstream of Cipabuan Channel and normalizing the River can reduce flooding significantly.

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