Urban Flood Management In Surabaya City: Anticipating Changes in the Brantas River System

Cahyono Susetyo
March, 2008
Urban Flood Management in Surabaya City: Anticipating Changes in the Brantas River System

by

Cahyono Susetyo

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: Urban Planning and Management

Supervisors
Ir. M.J.G. Brussel (First Supervisor)
Dr. D. Alkema (Second Supervisor)

Thesis Assessment Board
Dr. A. Sharifi (Chair)
Prof. Dr. A. van der Veen (External Examiner)
Ir. M.J.G. Brussel (First Supervisor)
Dr. D. Alkema (Second Supervisor)
Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.
Abstract

Concentration of people, activities, and transportations, made hazard management in urban areas became a very complex system. Hazard threats in urban areas may vary, depending on its internal or external characteristics. A city may face earthquake hazard, while other city facing flood hazard, and some city even facing two or more hazard threats at the same time. These presences of hazard threats can be induced by natural causes, man-made causes, or even combination of both causes. External changes around the city can also created new hazard problems, which some times totally unpredicted before.

An example of a city that facing a new flood hazard is Surabaya City, which located in the Delta Brantas Region. In this region, Brantas River, the longest river in East Java Province, was divided into two rivers; Surabaya River, the main river in Surabaya City, and Porong River, a man-made diversion channel that built to protect Surabaya from flooding. In present condition, most of Brantas River water was safely discharged to the sea through Porong River, and only 2% of Brantas River discharge entering Surabaya City through Surabaya River. This established river flow configuration is threatened by the presence of the Mud Flood disaster in Sidoarjo, a nearby municipality from Surabaya, which can reduce the capacity of Porong River. As the result, larger proportion of Brantas River discharge can entering Surabaya City, and threatened to cause new flood problems in Surabaya.

This study was carried out to analyze the possible impact of changes in Brantas River System to flood problems in Surabaya City using 1D2D flood modelling in SOBEK software, which was developed by Delft Hydraulics. Different flood scenarios were developed by adjusting the flood modelling parameters, and then, Flood Hazard Analysis and Flood Risk Analysis were performed to determine the extent of flood problems caused by changes in Delta Brantas region. The result of the flood modelling show that Surabaya City facing an increasing flood hazard due to changes in Brantas River System.

Flood mitigation measures scenarios then developed, which consists of two groups; Structural Measures and Non-Structural Measures. Structural measures were developed using two methods, which are Regulatory Structures adjustment and Channel Improvement. Each measure then simulated to assess their impact on flood hazard reduction. The results show that regulatory structures adjustment is only effective if discharge of Surabaya River is not exceeding 20% of Brantas River Discharge. The model shows that another structural mitigation measure, the channel and flow improvement, can give a greater impact on flood hazard reduction.

Non-Structural mitigation measures also developed by catchment area improvement and development control. Although these two measures were not simulated using 1D2D flood modelling, they also can provide a significant impact on flood hazard reduction and play an important role on Urban Flood Management in Surabaya City.

Keywords: 1D2D flood modelling, Flood Hazard, Flood Risk, Structural Measures, Non-Structural Measures.
Acknowledgements

Alhamdulillah, praise to ALLAH, the most gracious, the most merciful, I can finish my thesis and my 18 month of study in ITC on time. I would like to acknowledge my wife, Ony Devita Shintyasari for her enormous support she gave to me during the completion of my study in Enschede. I would like to dedicate this thesis to my son, Arkaan Javier, for being an amazing child. I also would like to thanks to my family, both in Bandung and Lawang, for their total support.

I want to give a special gratitude for my supervisors, Ir. M.J.G. Brussel and Dr. D. Alkema for their supports and knowledge they gave to me during the completion of my thesis. Indeed, their experiences are very valuable, and having discussions with them are a great pleasure for me. I am sure that the knowledge they share with me are going to be very useful for my future development. Their patience when facing unexperienced person such my self also an important quality that all lecturers should have.

I also want to give my appreciation to ITC-UPM staffs who have gave me a lot of new things to learn, and having the opportunity to study at ITC is one of the greatest achievement I have in my life. Special thanks to UPM’s Program Director, Mr. Emile Dopheide, who made every administrative issue during my study is very easy to be solved. Another person who gave me a great contribution is Mr. Amien Widodo, head of Unit of Disaster Study at 10th Nopember Institute of Technology, Surabaya, for his support during my fieldwork.

Finally, special gratitude for my UPM friends, who have been a really great friends, and surely they made my study at ITC was very colourful. Also for my Indonesian friends, who came together with me to Enschede, and hopefully we can go back home and give a huge contribution to the development of our nation.

Cahyono Susetyo
Enschede, March 2008
# Table of contents

1. Introduction .................................................................................................................. 1
   1.1. Research Background .......................................................................................... 1
   1.2. Background and Justification ............................................................................ 1
   1.3. Research Problem .............................................................................................. 2
   1.4. Research Objective ........................................................................................... 3
   1.5. Research Objective ......................................................................................... 4
   1.6. Research Methodology .................................................................................... 4
   1.7. Research Layout .............................................................................................. 7
2. Study Area .................................................................................................................... 1
   2.1. Overview .......................................................................................................... 1
      2.1.1. Topography .................................................................................................. 2
      2.1.2. Land use ...................................................................................................... 2
   2.2. Climate and Weather ....................................................................................... 3
   2.3. Brantas River Basin ......................................................................................... 4
   2.4. Flood Problems ............................................................................................... 6
      2.4.1. Past Flood Events ..................................................................................... 6
      2.4.2. River and Drainage Network .................................................................... 8
   2.5. Data Requirement Analysis .............................................................................. 9
      2.5.1. Available Data .......................................................................................... 9
      2.5.2. Required Data ......................................................................................... 10
   2.6. Data Collection .................................................................................................. 10
      A. Policies and Regulation .................................................................................. 11
      B. Water Discharge ............................................................................................. 11
      C. Discharge Capacity ....................................................................................... 12
      D. River Cross Sections ..................................................................................... 12
      E. Additional Height Points ................................................................................ 13
3. Literature Review ......................................................................................................... 15
   3.1. Urban Flood Management .............................................................................. 15
      3.1.1. Structural Defence .................................................................................... 15
      3.1.2. Non-Structural Measures ......................................................................... 17
   3.2. Hydrodynamic Modeling ................................................................................. 17
      3.2.1. 1D Flood Modelling ................................................................................. 17
      3.2.2. 2D Flood Modelling ................................................................................ 18
      3.2.3. 1D2D Flood Modelling .......................................................................... 20
   3.3. Digital Terrain Modeling .................................................................................. 21
      3.3.1. Digital Elevation Model (DEM) ............................................................... 21
      3.3.2. Digital Surface Model ............................................................................. 21
      3.3.3. DEM Interpolation Methods ................................................................... 22
      3.3.4. DEM Quality Assessment ...................................................................... 25
4. Digital Terrain Modeling .............................................................................................. 27
   4.1. Introduction ...................................................................................................... 27
4.2. DEM Construction .......................................................... 28
  4.2.1. TIN .......................................................... 28
  4.2.2. IDW .......................................................... 29
  4.2.3. Kriging ....................................................... 29
4.3. DEM Accuracy Assessment ............................................. 33
4.4. DSM Construction ....................................................... 34
5. Flood Management Policies .................................................. 37
  5.1. Policies of River and Water Management ......................... 37
    5.1.1. National and Regional Policies .......................... 37
    5.1.2. Brantas River Basin Management ....................... 38
    5.1.3. Brantas Delta Region Management ..................... 43
  5.2. Flood Mitigation Measures ......................................... 44
    5.2.1. Management Boundaries ................................ 44
    5.2.2. Institutional Hierarchy and Coordination ............. 45
    5.2.3. Structural Defence ...................................... 46
    5.2.4. Non-Structural Measures ................................ 48
6. Flood Modelling .......................................................... 53
  6.1. Introduction ....................................................... 53
  6.2. Model Schematisation ............................................. 54
  6.3. Boundary Conditions .............................................. 57
    6.3.1. Inflow Discharge ...................................... 57
    6.3.2. Rainfall Intensity ....................................... 58
    6.3.3. Sea Tide .................................................. 59
    6.3.4. Surface Roughness ...................................... 60
  6.4. Model Calibration .................................................. 61
  6.5. Model Sensitivity .................................................. 62
7. Flood Risk Analysis ..................................................... 67
  7.1. Introduction ....................................................... 67
  7.2. Flood Hazard ..................................................... 69
    7.2.1. Factors Influencing Flood Hazard ...................... 69
    7.2.2. Flood Depth .............................................. 70
    7.2.3. Flood Duration .......................................... 71
  7.3. Flood Hazard Mapping ............................................. 72
    7.3.1. Conditional Method ..................................... 72
    7.3.2. Weighted Sum ........................................... 75
  7.4. Vulnerability Analysis ............................................ 78
    7.4.1. Flood Risk Analysis .................................... 80
8. Flood Mitigation Scenarios .............................................. 85
  8.1. Introduction ....................................................... 85
  8.2. Structural Measures Scenario .................................... 85
    8.2.1. Regulatory Structures Adjustment ..................... 86
    8.2.2. Channel and Flow Improvement ......................... 88
  8.3. Non-Structural Measure Scenario ................................ 91
    8.3.1. Catchment Area Improvement ......................... 91
    8.3.2. Development Control ................................. 92
9. Conclusion and Recommendation................................................................. 95
9.1. Delta Brantas River System........................................................................ 95
9.2. Flood Risk Analysis ................................................................................... 96
9.3. Flood Mitigation Measures......................................................................... 97
9.4. Recommendation to Surabaya City’s Government..................................... 98
9.5. Recommendation for Future Studies ......................................................... 99
## List of figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>Delta Brantas River Network</td>
<td>3</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Conceptual Framework</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>Surabaya City, East Java, Indonesia</td>
<td>1</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Land Use of Surabaya City</td>
<td>3</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Brantas River Basin</td>
<td>5</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Past Flood Events in Surabaya City</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>River and Drainage Network in Surabaya City</td>
<td>8</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Flood Forecasting and Warning System Control Room</td>
<td>11</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>An Example of Regulatory Structure (Lengkong Barrage)</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Additional Height Point Data</td>
<td>13</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>TIN Interpolation Method</td>
<td>22</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>IDW Power Parameter</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Example of Semivariogram</td>
<td>25</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>DTM Overall Methodology</td>
<td>27</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Elevation Data Overview</td>
<td>28</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Cross-Validation of IDW Interpolation</td>
<td>29</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Variogram Models</td>
<td>30</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Gaussian Variogram Model and Cross-Validations</td>
<td>30</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>Spherical Variogram Model and Cross Validations</td>
<td>31</td>
</tr>
<tr>
<td>Figure 4.7</td>
<td>Circular Variogram Model and Cross Validations</td>
<td>31</td>
</tr>
<tr>
<td>Figure 4.8</td>
<td>Comparison of Interpolation Methods</td>
<td>32</td>
</tr>
<tr>
<td>Figure 4.9</td>
<td>Visual Comparison of IDW and Spherical Kriging</td>
<td>34</td>
</tr>
<tr>
<td>Figure 4.10</td>
<td>DSM Boundary</td>
<td>35</td>
</tr>
<tr>
<td>Figure 4.11</td>
<td>DSM Construction Scheme</td>
<td>35</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>Institutional Framework in Brantas Basin Management</td>
<td>40</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Flood Control Scheme of Brantas River Basin</td>
<td>42</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>Brantas River Basin</td>
<td>44</td>
</tr>
<tr>
<td>Figure 5.4</td>
<td>Flood Mitigation Hierarchy</td>
<td>46</td>
</tr>
<tr>
<td>Figure 5.5</td>
<td>Structural Defense Adjustment During Flood Event</td>
<td>48</td>
</tr>
<tr>
<td>Figure 5.6</td>
<td>Flood Proofing Methods</td>
<td>50</td>
</tr>
<tr>
<td>Figure 6.1</td>
<td>1D2D Combination in SOBEK</td>
<td>53</td>
</tr>
<tr>
<td>Figure 6.2</td>
<td>Y-Z Cross Section Profile</td>
<td>54</td>
</tr>
<tr>
<td>Figure 6.3</td>
<td>Channel Interpolation Method</td>
<td>55</td>
</tr>
<tr>
<td>Figure 6.4</td>
<td>1D2D Connection</td>
<td>56</td>
</tr>
<tr>
<td>Figure 6.5</td>
<td>FLOOD MODELING SCHEMATISATION</td>
<td>56</td>
</tr>
<tr>
<td>Figure 6.6</td>
<td>Hydrograph for Brantas River Downstream</td>
<td>57</td>
</tr>
<tr>
<td>Figure 6.7</td>
<td>Sea Tide Adjustment</td>
<td>61</td>
</tr>
<tr>
<td>Figure 6.8</td>
<td>Model Calibration</td>
<td>62</td>
</tr>
<tr>
<td>Figure 6.9</td>
<td>Monthly Discharge of Delta Brantas Rivers (m³/s)</td>
<td>63</td>
</tr>
<tr>
<td>Figure 6.10</td>
<td>Model Sensitivity Analysis (Flood Depth)</td>
<td>64</td>
</tr>
<tr>
<td>Figure 6.11</td>
<td>Depth and Flood Extent Sensitivity</td>
<td>65</td>
</tr>
<tr>
<td>Figure 7-1</td>
<td>Flood Risk Parameters</td>
<td>67</td>
</tr>
</tbody>
</table>
Figure 7-2 Overview of Risk Analysis................................................................. 68
Figure 7-3 Flood Depth Definition................................................................. 70
Figure 7-4. Flood Hazard Zoning Method .................................................... 73
Figure 7-5. Flood Hazard Zoning ................................................................. 74
Figure 7-6 Weighted Sum Method ............................................................... 75
Figure 7-7 Flood Depth Classification ......................................................... 77
Figure 7-8 Flood Duration Classification .................................................... 77
Figure 7-9 Flood Hazard Classification ....................................................... 77
Figure 7-10 Flood Hazard Analysis (2 Years Return Period) ......................... 78
Figure 7-11 Element at Risk Vulnerability .................................................. 81
Figure 7-12 Flood Risk Maps (2 Years Return Period) .................................. 82
Figure 7-13 Flood Risk Variation ................................................................. 83
Figure 8-1 Adjusted Regulatory Structures .................................................. 87
Figure 8-2 Impact of Structure Adjustment ............................................... 87
Figure 8-3 Surabaya City's 1950 Land Use Plan ......................................... 89
Figure 8-4 Existing and Proposed Channel ............................................... 90
Figure 8-5 Development Control Zones ..................................................... 93
Figure 8-6 Development Control Parameters ............................................ 94
Figure 8-7 Development Control Zones ..................................................... 94
List of tables

Table 2-1 Rainfall Measurement of Surabaya City (1955 – 1998) ................................................................. 4
Table 4-1 DEM Accuracy for Different Interpolation Methods ............................................................ 33
Table 5-1 Main Structural Defense ........................................................................................................ 47
Table 6-1. Estimated Maximum Daily Rainfalls (mm/hours) .................................................................. 58
Table 6-2. Design Rainfall Intensities (mm/hour) ................................................................................... 58
Table 6-3 Rainfall Hydrograph ................................................................................................................. 59
Table 6-4. Design Sea Tide Level (m) ....................................................................................................... 60
Table 6-5. Manning Coefficient for Urban Areas ..................................................................................... 60
Table 7-1 Vulnerability Value for Element at Risk ................................................................................... 80
Table 8-1 Regulatory Structure Adjustment ........................................................................................... 87
1. Introduction

1.1. Research Background

Concentration of people, activities, and transportations, made hazard management in urban areas became a very complex system. Hazard threats in urban areas may vary, depending on its internal or external characteristics. A city may face earthquake hazard, while other city facing flood hazard, and some city even facing two or more hazard threats at the same time. These presences of hazard threats can be induced by natural causes, man-made causes, or even combination of both causes.

Flood in urban area have a strong relationship with both natural and man-made causes. Flood in urban area can be considered as a natural hazard when it is caused by natural causes, such as extreme rainfall, heavy storm, and typhoon. On the other side, flood in urban areas can be considered as man-made causes when lack of garbage disposal system made people throw away their waste into the river and reducing or blocking the river flow.

Flood problem in urban areas can be influenced by many factors, such as drainage network within the city, rainfall, and water discharge of rivers passing through the city. In theory, there are five causes and types of urban flooding (Parkinson 2005), which are, 1) Lack of drainage infrastructure, 2) Blockage of the drainage system, 3) Flooding in low-lying areas, 4) Backup due to elevated downstream water levels, and 5) Inundation caused by high river water levels.

To study all those five factors for flood hazard assessment will require a large amount of time and efforts, and it is difficult to study all urban flood causes in the same time. Authorities in urban areas sometimes analyze each of those factors separately, even sometimes only analyzing the one which considered is the most important factor. Flood hazard assessment may left out one or more factors, because limitations resources during flood hazard assessment. Some flood hazards might be unpredicted, and therefore, no flood mitigation will be prepared for these unpredicted flood hazards.

1.2. Background and Justification

Flood is a big problem in Indonesia, where most of its major cities are located in coastal areas. Indonesia’s capital city, Jakarta, was repeatedly suffers from flood disaster, and there is a big possibility that other cities in Indonesia also facing the same problem. Other major city in Indonesia facing the same problem as Jakarta is Surabaya City, capital of East Java Province, which have similar characteristics with Jakarta. Surabaya is located in low-lying land in coastal area, and surrounded by extensive land use conversion that can increase the discharge of rivers that entering the city.
Every year, several parts of Surabaya, especially in squatters and slums, suffers from a flood and affected a lot of people who already been in a poor conditions. In general, there are two factors that caused high flood risk in Surabaya. Firstly, Surabaya has a very high rainfall rate, with yearly average rainfall around 141.1 mm. Rainfall above 200 mm occurs in February, March, April, November, and December (Ferita 2006). Secondly, the presence of Surabaya River, that runs through the city. This river is a branch from the Kali Brantas River, the second largest river in Java Island.

Water flows in the Kali Brantas upstream of Surabaya are regulated by Perum Jasa Tirta through a series of storage reservoirs and regulator structures. The large flows in the Kali Brantas are mainly released via a man-made flood diversion channel called Kali Porong which starts at Lengkong Barrage in Mojokerto and flows directly to the sea. Division of flows into the Kali Surabaya and Kali Porong is made by operating the gates at Mlirip Weir and Lengkong Barrage. This regulatory system of Kali Brantas is called Delta Brantas System, with two main functions. First function is to protect Surabaya from flooding if water discharge of Kali Brantas increases, and second function is as a water level regulator in the dry season to maintain flows to the Porong Main Canal feeding the large Delta Brantas irrigation system.

At Gunungsari in Surabaya, the Kali Surabaya is divided into two rivers, Kali Mas and Kali Wonokromo. Kali Mas flows through the city to the north coast, and Kali Wonokromo flows straight to the east coast of Surabaya, discharging into the Madura Strait (BAPPEKO 2000).

1.3. Research Problem

There is an immediate threat of flooding in Surabaya because of the possibility of increase in river flow entering Surabaya. This threat is caused by the presence of Mud Flood disaster in Porong, Sidoarjo, neighbouring municipality of Surabaya City. This flood hazard in Surabaya due to Mud Flood disaster is already became a public concern, because from the big flood disaster in the year 2002 in Jakarta, flooding experts agreed that one of the main causes of Jakarta flood disaster was increasing discharge of the 13 rivers that flow through the capital originate (The Jakarta Post, February 2002).

Kali Surabaya River is one part Delta Brantas System, a network system consists of Kali Brantas River, Kali Surabaya River, Kali Porong River, and two river regulator structures. First, Mlirip Weir as a regulatory structure for river flow entering Kali Surabaya and Second, Lengkong Barrage as a regulatory structure for river flow entering Kali Porong. The presence of Mud Flood disaster in Porong is threatening to reduce the discharge capacity of Kali Porong. If this happened, there is a need to develop new water discharge regulations for Mlirip Weir and Lengkong Barrage to re-distribute water discharge from Kali Brantas. This new regulations could have a significant impact to flood hazard disaster in Surabaya City because if too many water were re-distributed to Kali Surabaya, more water will entering the city and can caused a flood within the city. Overview of this problem can be seen in figure 1.1.
This flood hazard in Surabaya City due to re-distribution of river discharge within Delta Brantas system can be unavoidable, if the capacity decrease of Kali Porong were so severe, and left no other choice to the authorities than to release excessive water to Kali Surabaya. These possibilities to regulate river discharge within Delta Brantas system and its impact to flood hazard in Surabaya must be carefully examined to find the best possible solutions. As a conclusion for this research problem discussion, problem statement in this study is “What is the impact of changes in river Brantas River System to flood hazard in Surabaya City”.

1.4. Research Objective

The main objective of this study is to identify potential flood hazard within Surabaya City due to river flow regulations in Delta Brantas River Network System. More specific research objectives of this study are:
1. To analyze present Delta Brantas river network system.
2. To have better understanding about existing river regulator structures.
3. To analyze flood risk in Surabaya City.
4. To explore possible flood mitigations in Surabaya.
1.5. Research Objective

To achieve objectives of this research, there are some questions to be answered. For each objective, research questions are;

1. To analyze present Delta Brantas river network system.
   - What is the current capacity of rivers within Delta Brantas system?
   - What are the possibilities to change river flow regulations?

2. To have better understanding in the river regulator structures.
   - What kind of authorities do affected municipalities have in changing river regulations?
   - Would be adjustments of river flow regulations solve the problems?
   - What are the effects of different river flow regulations?

3. To analyze flood risk in Surabaya City caused by changes in Brantas River system.
   - Which part of Surabaya will be affected by different water regulations?
   - What is the possible worst-case scenario of flooding in Surabaya due to changes in river flow regulations?

4. To explore possible flood mitigations in Surabaya.
   - What are the possible mitigation measures can be taken by municipality to reduce flood hazard?
   - What extent each mitigation measures will be effective?

1.6. Research Methodology

This study consists of five different phases that interconnected each other. One phase should be completed before continuing to the next phase. This kind of methodology ensures that before jumping to the next step, all the required data and information already gathered. The main phases of this study are;

1. Data requirement assessment.
   There are generally two types of date sets that are used in this study for the input of the model; spatial and non spatial data. Spatial data include Digital Elevation Model (DEM), one-dimensional channel network, man-made structures and land cover map which is transformed into spatial map showing surface roughness coefficients. Non spatial data are inflow discharge and water level.

   For 1D-2D flood modelling, there are four parameters needed for the input which are (Bin Usamah 2005);
   - Digital Elevation Model to represent topography and river cross sections.
   - Roughness data to represent the resistance to water flow on.
   - Embankment and other artificial structure to make the model work as close as to the real world condition.
   - Boundary data in which time series of flow or water levels or Q-H relation can be defined.

2. Fieldwork data collection.
   When some of required data are still not available, then the possibilities to gather those data through fieldwork will be investigated. If there is a strong indication that it is not possible to gather the data through fieldwork, then other methods of analysis that suitable to available data
must be selected. List of all required data which are already available and which are going to be gathered during fieldwork must be completed before conducting fieldwork. The fieldwork phase will be used to collect data and information required in the study, such as river discharge, capacity of river network, existing river regulator structure, land use, and previous flooding events in Surabaya.

3. Flood modelling development.
For this purpose, 1D-2D SOBEK flood modelling will be used to simulate flood hazard in Surabaya. 1D-2D flood modelling means that it not only simulate water flow inside the river network, but also simulate overland flow if water volume is exceeding river capacity. In general, 1D-2D flood modelling consists of (Tennakoon 2004);
- Construction of Digital Terrain Model and river network.
- Boundary conditions set-up.
- Surface roughness identification.
- Model calibration

4. Flood Risk Analysis
After flood model for Surabaya is constructed, next phase is to develop different flood scenarios to gain a better understanding about possible flood events. This type of scenario development is known as “alternative scenario”. The purpose of alternative scenarios is to broaden people’s thinking about the future to account for uncertainty by exploring not one, but a range of possible futures (Wollenberg 2000). Flood scenarios will be developed by changing the values of the model, and in this study, value changes will be applied to river flow regulations. Accurate and reliable flood risk maps are ideal tools for decision makers to reduce social and economic losses from eventual flood events (Tennakoon 2004). In this study, the extent of possible flood hazard in Surabaya City due to changes in river flow regulations will be identified.

5. Exploration of possible mitigation measures for flood management.
Last phase of this study is to identify possible solutions to manage flood in Surabaya city. There are some possible ways to manage flood, either by building dikes, changing river flow regulations by adjusting river regulator structures within the city, or by defining retention areas which in general, remaining non-developed lands in urban floodplains are low-lying and they may be acting as retention or detention ponds to ease the flood level in the surrounding neighbourhood (Tennakoon 2004). Overall research methodology is presented in the next page.
Figure 1.2 Conceptual Framework

1st Phase

DATA REQUIREMENT ASSESSMENT

DATA AVAILABILITY

2nd Phase

AVAILABLE DATA

FIELDWORK

3rd Phase

LANDUSE HEIGHT POINT BUILDING FOOTPRINTS HYDROGOGICAL DATA

DEMO CONSTRUCTION DSM CONSTRUCTION

4th Phase

1D/2D FLOOD MODELLING

FLOOD RISK ANALYSIS

5th Phase

FLOOD MITIGATION SCENARIOS

CONCLUSION AND RECOMMENDATION
1.7. Research Layout

The first chapter of this thesis discusses the overview and the introduction of the research, which includes detailed explanations on research background, research problems, research objectives and questions and, conceptual framework for this research.

Chapter two explains the study area, flood problems, and issues related to data requirement and collection. The explanation about the study area concerns on climate condition, topography, and spatial characteristics. Last part of this discusses on data requirement and collection during fieldwork.

Chapter three discusses literature reviews related to this study. In general, this chapter is divided into three main subtopics: Urban Flood Management, Hydrodynamic Modelling, and Digital Terrain Modelling. The first subtopic contains detailed explanation on the concepts of flood management in urban areas, and how is it applicable in the study area. The second subtopic discusses hydrodynamic modelling, with reviews and discussions on 1D2D flood modelling. In general, this sub topic will discuss the procedures, advantages, and disadvantages of different in flood modelling. The third subtopic is about Digital Terrain Modelling (DTM) and DTM requirement for 1D2D hydrodynamic modelling purpose. Another discussion in this subtopic is about interpolation approaches than can be applied to construct DTM.

Chapter four discusses Digital Terrain Modelling construction with different data sources. First subtopic is about generating Digital Elevation Model (DEM) but different point interpolation methods and quality assessment for each method. Second subtopic is about generating Digital Surface Model (DSM) by adding an elevation values to DEM. Source of this elevation values is man-made features, which can be higher or lower than elevation observations. Resulted DSM then will be used as an input in the 1D2D flood modelling

Chapter five discusses policies and regulations related to flood hazard management, either at national, regional, or local scale. A special emphasize was put on the flood management in Delta Brantas Region where Surabaya City located. Changes of Brantas River system also occurs in Delta Brantas due to the presence of mud flood disaster in Sidoarjo, neighbouring municipality of Surabaya City. Last part of this chapter discusses theoretical aspects of flood mitigation measures.

Chapter six discusses the hydrodynamic modelling of the river and main drainage channels in Surabaya City using SOBEK’s 1D2D flood modelling. Detailed explanation focuses on parameters used in flood modelling, for instance boundary condition, surface roughness and etc. Further discussion is about model calibration and model sensitivity.

Chapter seven discusses flood risk analysis based on results from 1D2D flood modelling and other required parameters, such as land use, buildings, and other elements at risk from flood hazard.

Chapter eight discusses possible flood mitigation using different methods described in the literature review part. First part of this chapter is about existing regulations related to flood and river management in Surabaya City. Second part of this chapter is analyzing the possibilities to implement
regulations to reduce flood hazard. Third chapter is description about the best possible solutions and its impacts to flooding problem in Surabaya City.

Chapter nine is about achieved conclusions as an answer to research questions and recommendations to flood management in Surabaya City and possible further study.
2. Study Area

2.1. Overview

Surabaya, the second largest city in Indonesia, is the capital city of the province of East Java. Its main activities are manufacturing and trading with major air and seaport facilities. Surabaya also plays a role as a centre of development for eastern part of Indonesia. Surabaya is located between 112° 30’ to 113° E longitude and 7° 0’ to 7° 30’S latitude. It situated in the south and west of the Madura Strait, north of Kabupaten Sidoarjo and east of Kabupaten Gresik. It has an area of 327.41 km\(^2\) and is divided administratively into Districts (Kecamatan) and Sub-Districts (Kelurahan). Currently, there are 31 Districts and 163 Sub-Districts within Surabaya City.

![Figure 2.1 Surabaya City, East Java, Indonesia](image)
In Regional context, Surabaya City plays a role as a center of development in East Java Province. Surabaya and its surrounding regencies formed a greater urban area known as “Gerbang Kertosusila” or GKS, which is an acronym for the regencies (Kabupaten) of Gresik, Bangkalan, Mojokerto, Surabaya, Sidoarjo and Lamongan.

In the context of GKS, development of Surabaya City is a part of Surabaya Metropolitan Area (KMS), which plays a role as:
- Center of economic activities in East Java, Bali, and other Eastern Indonesia regions, with the presence of Tanjung Perak Port as its main support.
- Center of regional development in East Java Province
- Urban Center for social-economic activities in “Gerbang Kertosusila” region.

Recent urban development has spread south from Surabaya to Sidoarjo, where both industrial and residential growths have been vigorous. To the west, Gresik is emerging as a major industrial centre as well, with significant residential development to be expected.

2.1.1. Topography

Surabaya can be divided into two topographic areas: lowland plain and rolling plain. The lowland plain has an elevation of up to 5 m above low tide level (datum Low Water Spring = LWS) and prevailing slope 0 - 2%; it is located in the southern, eastern and northern portion of the city. A large part of this area is at an elevation below the highest tide level (+ 3.22 LWS).

The remaining area is rolling plain which is located in the western portions of Surabaya City. The elevation is more than 5 m above low tide level (LWS) and the slope is 2–15 %. Slope characteristics made most inundated areas are located in the eastern and northern part of Surabaya City, where flat slope made water discharge to sea is relatively slow. For northern part of Surabaya, damage caused by flood is relatively higher than in the eastern part, because northern part of Surabaya City is dominated by built-up areas, whereas in eastern part, open space and conservation areas dominated existing land use.

2.1.2. Land use

Land use in Surabaya City consists of both urban and rural activities. Urban land use consists of housing, commercial, industrial, offices and public service buildings, while rural activities consists of agricultural fields and fish ponds. The urban area is mainly in the central, southern and northern part of the city, but spreading to newly developing areas to the west and east of the city centre. Build up areas in Surabaya City in 2001 made up 63% of the whole city, while the rest are non-built-up areas such as agricultural, fishery, and vacant land. Fishery is a biggest component of non-built-up areas in Surabaya City.

There is a constant expansion of land in Surabaya City due to sedimentation process in the eastern coast regions and the presence of an island (Galang Island) in the northern region of Surabaya. This expansion causes the morphologic form of eastern coast of Surabaya City constantly changed.
2.2. Climate and Weather

Surabaya has a typical equatorial climate, and can be classified as a Type IV climate, which is a tropical climate with relative abundant rainfall and sunny day. Another rainfall characteristic in Surabaya City is that there is a significant difference of rainfall between during dry season and rainy season. Therefore, rainfall data during rainy season can be considered more important to be included in flood management than rainfall data in dry season.

- Dry season : May - October
- Wet season : November - April

From November to February, the northern monsoon gives rise to heavy rains during the wet season. The southeast trade winds carry air from Australia during the dry season. Monthly mean temperatures vary between a low of 21 °C in August to 34 °C in April. In the wet season average monthly humidity reaches 80 %, while in the dry season it falls to a low of 66%. The month with the highest average rainfall is January with over 300 mm, while the lowest is August with 23 mm.

Another distinctive characteristic of rainfall in Surabaya City is that storms almost always occur in the afternoon or early evening. Analysis of hourly data for Perak station for the peak months of the 1998/99 wet season (December and January) shows that 45% of the total rainfall occurred between 15:00 and 17:00, and 87% between 15:00 and 21:00.

There are ten daily rainfall stations in the Surabaya City, and each station recorded maximum daily rainfall since year 1950 to the year 1998. Recorded rainfall for each station can be seen in table 2.1.
Table 2-1 Rainfall Measurement of Surabaya City (1955 – 1998)

<table>
<thead>
<tr>
<th>No</th>
<th>Rain gauge</th>
<th>Maximum Recorded Daily Rainfall (mm)</th>
<th>Return Period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.25</td>
</tr>
<tr>
<td>1</td>
<td>Larangan</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>2</td>
<td>Kebon Agung</td>
<td>187</td>
<td>65</td>
</tr>
<tr>
<td>3</td>
<td>Gubeng</td>
<td>250</td>
<td>77</td>
</tr>
<tr>
<td>4</td>
<td>Wonorejo</td>
<td>197</td>
<td>63</td>
</tr>
<tr>
<td>5</td>
<td>Keputih</td>
<td>175</td>
<td>73</td>
</tr>
<tr>
<td>6</td>
<td>Kedung Cowek</td>
<td>178</td>
<td>75</td>
</tr>
<tr>
<td>7</td>
<td>Sememi</td>
<td>175</td>
<td>76</td>
</tr>
<tr>
<td>8</td>
<td>Banyu Urip</td>
<td>175</td>
<td>78</td>
</tr>
<tr>
<td>9</td>
<td>Gunung Sari</td>
<td>200</td>
<td>77</td>
</tr>
<tr>
<td>10</td>
<td>Perak</td>
<td>149</td>
<td>76</td>
</tr>
</tbody>
</table>

|     | Average    |                                      | 74   | 94 | 119 | 136 |

Source: Surabaya Drainage Master plan

From table 2.1, it can be seen that there is a relatively little variation across the study area, with the highest and lowest values within approximately +/-10% of the average. The results of the daily analysis also do not indicate any clear geographic pattern, and it is considered appropriate to average the results for all stations, as shown at the foot of Table 2.1. Perak is close to the average for low return periods but shows lower rainfall for higher return periods. It was also found that analysis of the daily rainfall series over the period for which short duration gave slightly lower values than the full series; this implies that the short duration rainfall values may be on the low side. For design purposes, the short duration results for Perak were factored by the ratio from the daily analysis for each return period, and then divided by the duration to give rainfall intensities.

2.3. Brantas River Basin

Surabaya City is situated on the lower reach of Bantams River Basin, which is located on East Java Province, Java Island. In geographical term, Surabaya City is located between 110° 30’ and 112° 55’ East Longitude and between 7° 01’ and 8° 15’ South Latitude. Bantams River Basin is bounded by Mt. Broom (2,393 m) and Mt. Seer (3,676 m) in the east, and a series of mountainous area (elevation 300 to 500 m) in the south. In the middle reach, the Basin is bounded by the Arjuno mountain complex consisting of Mt. Arjuno (3,339 m), Mt. Butak (2,868 m) and Mt. Kelud (1,731 m). Mt. Wilis (2,169 m) and its ridges bounded the western area of the Basin, and the lower reach of Brantas River Basin, including Surabaya, is located around Madura Strait. The basin covers nine regencies or districts: Sidoarjo, Mojokerto, Malang, Blitar, Kediri, Nganjuk, Jombang, Tulungagung, Trenggalek and five urban centers or municipalities; Surabaya (capital of East Java), Mojokerto, Malang, Kediri, Blitar.

Watershed area of Brantas River Basin is about 11,800 square kilometers, and stretches up to 320 kilometers from its spring at Mt. Arjuno to the Delta Brantas Region, where Brantas River divided into two rivers, the Surabaya River and the Porong River, both of which drain into the Madura Strait.
The Brantas River flows clockwise with Mt. Arjuno and Mt. Kelud as its center. At the end of its southward journey, the Brantas River joins the Lesti River on the left bank and Metro River on the right bank at a point where it starts its westward flow and upstream of the Sutami multipurpose dam. The total catchment area at the Sutami dam site is about 2,050 km² including 625 km² of the Lesti River basin. The average river bed slope in the upper reaches is around 1 in 200.

The Brantas River, where it turns north-northwestward, joins with the Ngrowo River where the catchments area is around 3,600 km². As a result of past drainage works (to reduce flood flows in Brantas), water from about 1,300 km² of the Ngrowo basin drains into the ocean to the south. Only about 177 km² of the Ngrowo River basin now drains into the Brantas River. At this point the river slope is of the order of 1 in 1000. The tributaries in this reach originating from the southern slope of Mt. Kelud carry large amounts of sediment erupted from Mt. Kelud.

After joining the Ngrowo River, the Brantas River flows in a northwesterly direction up to Kertosono and then turns eastward up to Mojokerto, where it branches into the Porong and Surabaya Rivers. The Brantas River catchment area at this location (Lengkong Dam site) is about 8,650 km². In this reach the tributaries are Widas, Konto, and others originating from Mt. Arjuno. The average bed slope here is about 1 in 2000. The Porong and Surabaya Rivers flow through a flat plain at an elevation of 25 m. Porong River acts as a flood diversion channel while Surabaya River provides the water supply to Surabaya City and acts as the main drain for the urban area.

**Figure 2.3 Brantas River Basin**
The climate in the basin is dominated by tropical monsoons. The rainy season is normally from November to April, and the dry season is from May to October. The annual mean temperature in the basin ranges from 24.2°C to 26.6°C. The average rainfall over the basin is around 2,000 mm of which more than 80% occurs in the rainy season. Variation of rainfall is large. In wet years it is around 2,960 mm, and in dry years (one in three years on average) it is around 1,370 mm. The average rainfall in the higher elevation, especially in the southern and western slopes of Mt. Kelud is between 3,000 mm and 4,000 mm. The yearly mean relative humidity ranges from 75% to 82%. The average annual surface water potential in the Brantas basin is estimated to be approximately 12 billion m³ while the average annual flow that can be regulated is estimated to be about 3 billion m³ or 25% of available surface water. The average annual flow in the upstream reach is around 823 m³/s, midstream 3,859 m³/s and downstream is 5,300 m³/s (total of Surabaya and Porong river gages).

2.4. Flood Problems

Major factors in the increase in severity of flooding in Surabaya are land development and increased urbanisation. However, the impact of proposed developments on drainage and flooding is not considered when building permits are issued. Developers are not required to provide adequate drainage for their developments or to bear the costs of improvements to the primary and secondary drainage systems which their development necessitates.

2.4.1. Past Flood Events

According to Surabaya Drainage Master plan Report (SDMP, 2000), due to an unusually heavy flood caused by La Nina, a detailed survey of flooding was carried out during the end of the 1998/99 wet season. Flooding caused by intense rainfall has been identified in 148 separate areas throughout Surabaya. The results of the survey showed that area affected by flooding in Surabaya City is up to 14.5% of the total area. Built-up areas (housing, commerce, industry, public facilities, roads etc.) Within Surabaya city that were affected by 1999 flood is 15,826 ha or 22.7% of the total built-up areas in Surabaya City.

Some thirteen flood areas in more 100 ha each were identified. The worst affected flood area is Tenggilis Mejoyo area, which has an area of 286 ha and floods to a depth in excess of 70 cm with a duration of more than 6 hours. Information collected during the community survey of 600 households in the flood areas identified found 43% affected by flooding inside their homes every year, with a further 27% affected by flooding in some years. The average frequency for flooding inside the home was 16 times per year, the average duration 11 hours and the average depth 16 cm. In the worst cases the frequency was 50 to 60 times per year, the duration 2 to 5 days and the depth 50 to 100 cm. Since nearly all flooding occurs during a period of 4 months (December to March) this means that, on average, during the wet season these people get flooded inside their homes once a week. Of these 600 households 87% were affected by flooding every year in the street outside their homes. The average frequency for flooding in the street was 30 times per year, the average duration 12 hours and the average depth 24 cm. In the worst cases the frequency was 70 to 85 times per year, the duration 3 to 7 days and the depth 70 to 110 cm.
Figure 2.4 Past Flood Events in Surabaya City

Map showing flood events indicated by different colors for various time intervals.
2.4.2. River and Drainage Network

Surabaya originally developed as a sea port with the original harbour along the banks of the Kali Mas. During the Dutch colonial period, main regulator structures were built at Gunungsari and Jagir to maintain river levels upstream for irrigation, and the Kali Wonokromo was excavated as a diversion channel to dispose of flows from the Kali Brantas to the Madura Straits in the east. Navigation locks were constructed at Gunungsari to allow small boats to pass upstream into the Kali Surabaya. The Kalibokor and Gunungsari Canals functioned mainly as supply canals for irrigating rice fields and supplying fisheries to the west and east of the city, which was located around the Kali Mas. Being situated very near the coast, the Kali Mas, Kali Wonokromo and the low-lying agricultural areas along the coast were subject to the effects of tides.

Figure 2.5 River and Drainage Network in Surabaya City

As the city developed into a major maritime trade centre the urban area grew westwards and eastwards, taking up land previously used for agricultural purposes. New drains were constructed to dispose of runoff from the new urban areas to the Madura Straits to the east. However, the network of irrigation canals remained, and became incorporated into the built-up areas.

In the late 1970's a new electrically operated gated regulator structure was built at Gunungsari, now operated by Jasa Tirta, inc., a semi-government institution. The navigation locks at Gunungsari and Mlirip upstream in the Kali Surabaya are now disused, and the river is no longer used for freight transport. Recently, a modern container terminal has been constructed at Perak Port, to take large
ocean going vessels, although the old harbour along the Kali Mas still remains for more traditional craft sailing between Surabaya and the outer islands of the Indonesian archipelago.

The Jagir barrage and Wonokromo weir regulate the intake to the Ngagel water treatment plant, which commenced operation in 1922. The Gunungsari barrage maintains water levels for the intake from the Kali Surabaya to the modern Karangpilang water treatment plant, phase I of which opened in 1990. Major extensions (Karangpilang II) have recently been completed. A small Water Treatment Plant on Jalan Kayoon also exists, with its intake just upstream of the inflatable rubber weir at Gubeng. The layout of the main drainage system for Surabaya City consists of the following 4 types of facilities:

a) Main drains to carry flood flows originating outside Surabaya directly to the sea (K.Surabaya and K. Wonokromo),

b) Collection of internal drainage from urban areas through tertiary, secondary and main drains, assisted where gravity flow is not possible by drainage pump stations,

c) Sea defence embankment with tide gates to prevent backflow in main drains during high tides (East coast area),

d) A series of main and secondary irrigation canals from Gunungsari and Gubeng regulator structures. At present these have a dual function in the wet season, as they receive drainage inflows.

2.5. Data Requirement Analysis

Data requirement analysis was based on two main aspects; First, requirements for analyzing existing policies and regulations regarding flood management in Surabaya City, and Seconds requirements to construct 1D2D flood modelling.

2.5.1. Available Data

1. Elevation dataset.
   Height points and contour lines were acquired from official city map issued in the year 2002 by City Planning Agency of Surabaya City. Specifications of this elevation dataset are;
   - Method: GPS and Direct Levelling
   - Height point unit: cm
   - Contour interval: 0.5 m
   - Coordinate System: User TM 3, Zone 49.2 Datum WGS ’84.
   - Horizontal Reference Point: BPN 1201085, 1201095, 1201102
   - Vertical Reference Point: TTG.1030, TTG.1038 and BPN 1201108.

2. River Network and Main Drainage System for Surabaya City.
   River Network and Drainage System was compiled from Surabaya Drainage Master Plan (SDMP), issued by Planning Bureau of Surabaya City in the year 2000. This map is developed under CAD environment, and don’t have any spatial reference.
3. Land use Map and Road Network of Surabaya City.
Existing land use map and road network of Surabaya City were acquired from official land use map issued by Planning Bureau of Surabaya City in the year 2005. Coordinate system of this map is UTM Zone 49 South, Datum WGS ’84. This map has 1:5000 scale.

4. Past flood events in Surabaya City.
Past flood events are acquired from Bureau of Water and Flood Management of Surabaya City. Available flood maps are from the year 2002 to the year 2005.

2.5.2. Required Data
This thesis requires following data to be collected during fieldwork phase;

1. Regulations for Delta Brantas River Network.
2. Local and Regional Policy of Urban Management in Surabaya City and Delta Brantas River Network.
3. Water discharge
   - Brantas River
   - Kali Surabaya
   - Kali Porong
   - Rivers inside Surabaya City
4. Discharge Capacity.
   - Brantas River
   - Mlirip Weir
   - Lengkong Barrage.
   - Kali Surabaya River.
   - Kali Porong River.
   - Rivers and primary channels in Surabaya City
5. Cross-sections for rivers and primary channel in Surabaya City
6. Additional Height Points

2.6. Data Collection
The source of data collection during fieldwork is divided into primary and secondary sources. Both data were derived by the author himself and with helps from colleagues. The fieldwork focused on collecting primary and secondary data from various sources. The data requirement list was prepared based on the available data, collected by the previous students and new data required for this study. The data requirement covered some expectations on data accuracy and precision. However it was changed and improved due to some limitations and availability of the required information. Since all the required information is available in different sources or offices, detailed information regarding on the sources for each data were prepared with helps from the local officers.
A. Policies and Regulation

Main sources of policies and regulations are Jasa Tirta, inc, Bureau of Water and Flood Management of Surabaya City, and Bureau of Water Resource of East Java Province. There are total 13 formal regulations about river and flood management related to Surabaya City. Responsibility for flood control in Surabaya is divided between at least seven different authorities. This fragmentation of responsibility causes difficulties in co-ordination of planning and implementation of improvements to the drainage systems.

For flood management, Jasa Tirta, inc. has installed a Flood Forecasting and Warning System (FFWS) to anticipate floods in the Brantas River Basin. By means of FFWS all hydrological data within the Brantas River Basin, including water level and rainfall could be monitored in order to prepare flood forecasting.

Figure 2.6 Flood Forecasting and Warning System Control Room

B. Water Discharge

Water discharge data were acquired from two main sources; Measurement station under Jasa Tirta, inc. and from Surabaya Drainage Master Plan Document (SDMP). Measurement stations for water discharge observed during fieldwork are:
1. Lengkong Station, as measurement station for Brantas River.
2. Perning Station, as measurement station for Kali Surabaya.
3. Gunungsari Station, as measurement station for Water entering Surabaya City.
4. Porong Station, as measurement station for Kali Porong.
5. Jagir Dam, as measurement station for Kali Wonokromo.
6. Gubeng Dam, as measurement station Kali Mas.
C. Discharge Capacity

There are no exact information can be collected during fieldwork regarding discharge capacity for river and main drainage channels. Information about discharge capacity will be derived from river regulatory structures, such as water gates and pump stations. For rivers, regulatory structures that can be use to calculate discharge capacities are:

1. Lengkong Barrage, as regulatory structure for Kali Porong.
2. MLirip Weir, as regulatory structure for Kali Surabaya.
3. Gunungsari Dam, as regulatory structure for Kali Surabaya.
4. Jagir Dam, as regulatory structure for Kali Wonokromo.
5. Gubeng Dam, as regulatory structure for Kali Mas.

Figure 2.7 An Example of Regulatory Structure (Lengkong Barrage)

D. River Cross Sections

River cross sections are acquired from Jasa Tirta, Inc, and SDMP documents. Cross sections from Jasa Tirta, Inc. are for Main River, while cross sections from SDMP are for primary drainage channel inside Surabaya City. Each river/channel has average 4 cross sections. Cross sections data acquired during fieldwork are still in drawing format, not table format. Therefore, each cross section must be converted into table format to be usable during flood modelling.
E. Additional Height Points

Additional height points are required to fill the gaps between available height points. This information was acquired from existing ground control points. During fieldwork, some 700 observations were collected, with coordinate system and accuracy exactly similar to the available height points. Collected height points can be seen in figure 2.9.

Figure 2.8 Additional Height Point Data
3. Literature Review

3.1. Urban Flood Management

Flood management in urban areas is a complex decision-making process. Its main purpose is to define and implement all measures that can reduce the risk from flooding which human, natural and economic resources are subjected (Oliveri and Santoro 2000). In urban areas, objects that can be exposed to flood hazard are more various and have more complicated relationship each other compared to another type of land use, i.e., rural or agricultural.

Urban flood problem seems to be difficult to handle in developing countries. The reason for this is that firstly, developing countries have small, vulnerable economies and are common to be severely damaged when flood disaster strikes. Secondly, limited amount of resources to cope with flood hazard, particularly to investigate and evaluate possible strategies made government in developing countries often underestimate the existing flood hazard (Hansson, Danielson et al. 2008). Quality of human resources also limits the possible measures that can be implemented by government to protect the residents and their belongings in urban areas.

There are two main aspects in urban flood management; structural mitigation and non-structural measures. Structural mitigation measures are an effort to modify the characteristics of a flood (i.e., the volume and timing of flood waters, their extent and location, their velocity and depth), so that damage or susceptibility to people and properties can be reduced.

Non-structural measures are an effort to manage flood hazard by applying actions and regulations that can either reduce flood hazard, or to minimize the impact of flood in case disaster is unavoidable. (e.g. real-time forecasting and alert systems, information and training campaigns, tax adjustments, flood insurance programs).

3.1.1. Structural Defence

The main objective of structural defence in urban flood management is to mass-balanced the systems of water flow, cycling, and containment in each part of the urban area by water flowing out of that part. According to (Hansson, Danielson et al. 2008), two main concepts of structural defence strategies in flood management are using traditional measures or using wider ecosystematic measures.

Traditional measures are common structural measures in flood management. It utilises hydraulic structures, which can be used to manage, either to divert, slow, or stop the flow water. Flood management using structural defence is the utilization of an existing flood protection system or development of new systems to minimize flood hazard. Flood protection system in urban areas needs to be continuously improved, because the growth of a city and its surrounding areas made flood hazard also continuously increase. Continuous improvement of the flood protection system requires a
reassessment of the growing flood hazards and an up-to-date evaluation about flood hazards depending on the newest information available about land use, climate, river, and channel characteristics. (Plate 2002).

The use of structural mitigation measures in flood management is primarily concerning how to avoid flood or reducing damage resulted by disasters. A structural measure infrastructure for flood management includes dykes, dam, reservoir, or methods to improve infiltration of rainfall into the ground. Structural measures can be done by using existing infrastructures or building structures increase the capacity of flood protection system. The main component of structural defence is the hydraulic structures that can change the water system balance, which in some cases can increase the allowable amount of water in the river before flood occurs.

Traditional structural defence also have drawbacks. For example, dykes may provide relatively good protection against small to medium floods. But, if a dyke breaks in the case of larger flooding events, dyke more likely to act not as a protection but instead, can increase the effect of the flood. Some views also consider DAM as potential threat that could devastate river ecosystems and the construction of a DAM in first place is regretting the right of people affected by it.

Structural defence of flooding in urban area can also use wider ecosystem measures, such as renaturalisation, that can improves the porosity and absorption of water into the soil, with or without improvement of water penetration to the ground. One widely known method of renaturalisation is re-wetting a formerly drained to be functioned as a reservoirs. This can only be efficiently achieved using detailed knowledge of the occurring organic and mineral soil substrates, the terrain characteristics, and the available surface and groundwater resources (Hansson, Danielson et al. 2008). Land use management can also plays an important role in renaturalisation, because different land use types may have different characteristics. Evapotranspiration rates can be differs because crops have different vegetation cover, leaf area indices, and root depths. Interception rates during flood or storm can also different for different land use types (De Roo, Schmuck et al. 2003).

Another approach to structural defence of flooding is mentioned in (De Roo, Schmuck et al. 2003), which stated that basically there are three approaches possible to implement in reducing flood hazard:

A. Reduce the amount of water flowing to downstream areas, by
   1. Changing land use, for example reforestation;
   2. Building new reservoirs;
   3. Building new polders;
   4. Improving management of reservoirs towards flood control.
B. Reduce or prevent damage as much as possible, by
   1. Building dykes;
   2. Increasing dyke-heights;
   3. Increasing floodplain storage, by increasing floodplain width or deepening the floodplain;
   4. Relocation of vulnerable build-up areas to areas with less or no flood risk.
C. A combination of both.
3.1.2. Non-Structural Measures

Because structural defence approach requires a significant amount of resources to be operational, which most developing countries can not afford, approaches to avoid loss of life and limit disruption and damage from flooding have changed significantly in recent years. Worldwide, there has been a move from a strategy of flood structural defence to non-structural approach and risk management (Pender and Neelz 2007).

Non-structural measures concerns mainly on non-engineering actions such as restricted development planning, regulating human activities in order to mitigate flooding (Hansson, Danielson et al. 2008). With this approach, flood hazard is reduced by changing the spatial characteristics of a city and its surrounding areas and the behaviour of its residents.

Non-structural approach can also utilize an Early Warning System (EWS) to avoid or reduce damage during flood event. The presence of EWS in flood management is very important because when government and resident of a city are informed on flood management and coping strategies, they are better prepared for adequate countermeasures. For instance, government can quickly changes the configuration of regulatory structures to avoid flood, and residents can building houses on stilts and choosing safe escape routes (Hansson, Danielson et al. 2008).

Although an Early Warning System is a very good approach to reduce the flood risk by a non-structural measures, there is a problem with implementation of an EWS, which is a warning system can be very complicated due the uncertainty in the flood forecast used within the decision-making chain for issuing flood warnings (Moore, Bell et al. 2005). Combining an EWS with a management of structural defence can be a very effective method to either avoid the flood or reducing the damage in the event of flood disaster.

3.2. Hydrodynamic Modeling

Hydrodynamic modelling urban flood management is a method to develop a digital representation of water movement inside or outside channels within a city. This model can give authorities a better understanding about the extent of flood hazard. Flood modelling and forecasting requires not only rainfall–runoff information, but also requires channel flow routing and forecast updating (Moore, Bell et al. 2005). There are a set of tiered methodologies in hydrodynamic modelling, and each appropriate for different tasks and applications over different scales. The most widely used hydrodynamic model for assessing flood hazard in urban areas are one-dimensional (1D) and two-dimensional (2D) flood modelling (Pender and Neelz 2007).

3.2.1. 1D Flood Modelling

In the 1D approach, water flow is assumed to occur in one dominant spatial dimension aligned with the centre line of the main river channel. The geometry of the problem is represented in the model by channel and floodplain cross-sections perpendicular to the channel centreline. Measured distances between these cross-sections are also required by the computer model (Pender and Neelz 2007).
According to (Horritt and Bates 2002) 1D Flood model is capable of capturing the downstream propagation of a flood wave and the response of flow to free surface slope, which can be described in terms of continuity and momentum equations as:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$  \hspace{1cm} (1)

$$S_0 = \frac{n^2 P^{4/3} Q^2}{A^{10/3}} - \frac{\partial h}{\partial x} = 0$$  \hspace{1cm} (2)

Q is the volumetric flow rate in the channel, A the cross sectional area of the flow, q the flow into the channel from other sources (i.e. from the floodplain or possibly tributary channels), $S_0$ the downslope of the bed, n Manning’s coefficient of friction, P the wetted perimeter of the flow, and h the flow depth.

One source of the technical requirements in an urban flood model is from (Mark, Weesakul et al. 2004), which stated that data requirement for 1D flood modelling is:

- **Dynamic flow description**: when urban flooding occurs, surface water can flow in both street and pipe systems with flow exchange between these two systems through manholes. This means that simulation of backwater effects is needed in modelling of urban flooding. By using a dynamic wave model, the model includes backwater effects and surcharge from manhole including rapid change of water level.

- **Parallel flow routing**: while surface flooding takes place, water from the pipe system flows through manholes or catch pits to street system. Flow along the street (e.g. right above the pipes) can be in either direction along the streets, i.e. it can flow following a slope of the street or against it. It is not necessary that the flow direction in the street has to be the as the flow direction in the pipe system.

- **GIS interface**: GIS is important in simulation urban flooding. It is used as a tool to provide data and display simulation results. Surface storage for simulating surface flooding can be calculated by the application of GIS together with the DEM the study area, i.e. find area–elevation relation from DEM. In addition, results of the simulation can be easily understood in form of flood inundation maps. Model output in term of water along the streets are transferred to GIS and with interpolation routine, water surface is able developed. Flood inundation maps can be generated by overlaying of water surface and introducing flood depth map which is an method to visualise flood situations.

The main drawback of 1D flood modelling approach is an inaccuracy in the treatment of street channels and in the case of water flow on a surface. Both cases still considered as one dimensional. When the channels are overtopped, the flow of water is not only no longer 1D, because water move around 2D plane.

### 3.2.2. 2D Flood Modelling

As an addition to 1D flood modelling, 2D flood modelling can be use to analyze flow behaviour on a surface, both for water dept and velocity. 2D-modelling of out-channel floods clearly has the
potential to revolutionise understanding of high-magnitude spatial and temporal hydraulics and high-magnitude flow phenomena, geomorphological and sedimentological processes, and hence rapid fluvial landscape change. This potential for new understanding is because of the now wide availability of high-resolution DEM data for large and often inaccessible areas, and the availability of remotely-sensed data (Carrivick 2006).

Models to predict flood inundation based on the 2D shallow water equations are classed here as 2D approaches and solve for water level and depth-averaged velocities in two spatial dimensions. Unlike 1D models there is no need to prescribe a particular direction for the flow in 2D models. This brings advantages in terms of providing more detail on the nature of floodplain inundation but also introduces a number of limitations, e.g., difficulties in including hydraulic structures such as weirs and bridges in the models, longer computer run times and greater data requirements (Pender and Neelz 2007).

The system of 2D flood model consists of three equations: one equation for continuity and two equations for the conservation of momentum in the two orthogonal directions (Mignot, Paquier et al. 2006).

\[
\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0 \tag{3}
\]

\[
\frac{\partial (hu)}{\partial t} + \frac{(hu^2)}{\partial x} + \frac{\partial (huv)}{\partial y} + gh \frac{\partial h}{\partial x} = -gh \frac{\partial z_b}{\partial x} - gn^2 \frac{u \sqrt{u^2 + v^2}}{h^{1/3}} + v_{eff} \frac{\partial}{\partial x} \left( h \frac{\partial u}{\partial x} \right) + v_{eff} \frac{\partial}{\partial y} \left( h \frac{\partial u}{\partial y} \right) \tag{4}
\]

\[
\frac{\partial (hv)}{\partial t} + \frac{(huv)}{\partial x} + \frac{\partial (hv^2)}{\partial y} + gh \frac{\partial h}{\partial y} = -gh \frac{\partial z_b}{\partial y} - gn^2 \frac{v \sqrt{u^2 + v^2}}{h^{1/3}} + v_{eff} \frac{\partial}{\partial x} \left( h \frac{\partial v}{\partial x} \right) + v_{eff} \frac{\partial}{\partial y} \left( h \frac{\partial v}{\partial y} \right) \tag{5}
\]

In equation above, \( h \) is water depth, \( u \) and \( v \) are velocities along horizontal \( x \)- and \( y \)-axes, \( z_b \) is bottom level, \( n \) is Manning’s roughness coefficient, \( g \) is gravity acceleration and \( V_{eff} \) is effective cinematic viscosity. Usually, it is assumed that the viscosity is constant throughout the flow field. Although 2D flood modelling can accurately describe the behaviour of flow on a surface, this model also has a drawbacks. First, calculation method is considerably more complicated than 1D flood model, and second, river and drainage network sometimes has a complicated morphology that can not incorporated sufficient enough in 2D flood model.
3.2.3. 1D2D Flood Modelling

Because both 1D and 2D flood modelling has its own advantage and disadvantages, there are an extensive approaches to integrate 1D and 2D models resulting in hydrodynamic model of floodplains and integrated 1D (channel flow) and 2D (overland flow), or widely known as 1D2D flood modelling. The main idea of 1D2D flood modelling is integrating 1D hydrodynamic modelling technologies, Digital Elevation Models and GIS systems is to take advantage of the best combination of 1D hydrodynamic data for rivers together with 2D terrain data, and presenting them in the GIS as maps (Horritt and Bates 2002).

The integrated one-dimensional and two-dimensional (1D-2D) model development focuses on the extension of model capabilities in order to simulate flooding situations more accurately. This includes improving flood wave propagation over initially dry land, improving the presentation of hydraulic control (levees and embankment) in the floodplain and integration of one-dimensional hydraulic elements (pumps, bridges and regulator gates). The combined 1D-2D modelling opens up the possibilities for studying flood control measures, flood forecasting, and development of flood evacuation plans. Main advantages of 1D2D flood modelling model are (Shaviraachin 2005):

- Flow computation on initially dry land, without using any special drying or wetting procedures.
- Accurate and stable flow computation on very steep slopes, such as dike walls and other manmade structures.
- Especially suitable for short event predictions (hours and days).
- Realistic flood predictions of dike break due to heavy rainfall or other natural hazards.
- Pre- and post-processing within a GIS environment.

There are several software computer package that can perform 1D2D modelling, and one of them is SOBEK, which has been developed by Delft Hydraulics in partnership with the National Dutch Institute of Inland Water Management and Wastewater Treatment (RIZA), and the major Dutch consulting companies. SOBEK a valuable instrument for flood forecasting, navigation, optimising drainage systems, controlling irrigation systems, reservoir operation, sewer overflow design, ground water level control, river morphology regulation, and water quality control. SOBEK can combine river systems, urban systems and rural systems for a total water management solution. The program has been enhanced with facilities to import GIS data into the model and to export computational results to GIS systems for presentation and evaluation. It simulates very well the influence of the existing/planned infrastructure on flooding processes (Shaviraachin 2005).
3.3. Digital Terrain Modeling

To be operational, 1D2D computer models require information on the topography of the river channel and the adjacent floodplain. Topography information is required because in the case of urban floodplains, the effect will also influence channel’s surrounding, such as streets, buildings and other urban infrastructure (Pender and Neelz 2007). This is why a digital terrain modelling must be constructed in flood modelling.

3.3.1. Digital Elevation Model (DEM)

A widely used definition of DEM is a digital representation of ground surface topography or terrain. Another generic terminology for DEM is “a representation of terrain elevation as a function of geographic location” (Yue, Du et al. 2007). The digital elevation model (DEM) represents land elevation data, which are essential for estimation of flood volumes on the surface areas (Mark, Weesakul et al. 2004). In addition, the result presentation in the form of a flood inundation map is based on water levels from the model simulation in conjunction with the DEM. Thus, quality of the model results depends on the quality of DEM. To generate the DEM, spot elevations (X, Y) coordinates and the ground level Z) covering all of the catchments are needed.

The DEM may be developed based on a different interpolation method, which converts elevation information originally stored as a point into coverage, which contain the elevation for the whole area. The size of a 1–5 m resolution is recommended for urban flood analysis since it can cover the width of the road, the width of sidewalks, and houses or buildings. However, using a finer resolution like 1 m does not necessarily provide results which are significantly more accurate in terms of flood levels, but does provide a much better visual presentation of the flood extent. A coarser 5 m DEM can thus be used for quick assessment of the model results, while detailed analyses should be based on the 1m DEM. It also makes sense to create both a fine DEM and a coarse DEM and to use each for various purposes.

3.3.2. Digital Surface Model

For flood modelling purposes, sometimes DEM is not enough, because it only stores the natural terrain elevation, not actual elevation. If water movement on surface need to be simulated accurately, DEM must be corrected, by raising or lowering elevation to include man-made features. The result of this DEM correction called Digital Surface Model (DSM).

It is essential to have an accurate description of the man-made features such as building and street in flood modelling, because man-made features greatly influence the movement of water on a surface. If the DSM is based on spot elevations on the ground level, e.g. on the sidewalk, the streets must be added into the DEM with an elevation which corresponds to the height of the curb, either raising or lowering the value of DEM. Major roads in the study area where floods occur must be included in the DEM, as the streets act as drains for the surface flooding.
3.3.3. DEM Interpolation Methods

A typical procedure is to interpolate and generate the DEM using ground points, and then interpolate it with different interpolation method to have an elevation representation for the whole study area. Each interpolation method has its own advantages and disadvantages, and it is important to study which one is the most appropriate interpolation method to be utilise. Most commonly interpolation methods that will be used to generate Digital Elevation Model for study area are TIN, IDW, and Kriging. A DEM Quality assessment then must be performed for each DEM generated by different methods to decide which one gives the best digital representation for topography of study area.

TIN

TIN is a point interpolation method based on calculation of elevations from digitally extracted Ridgelines (Jordan 2007). Elevations along calculated ridgelines are extracted from the original elevation model and a new DEM is created by TIN interpolation using these ridgeline elevations. Unlike other DEM type, TIN basically is a vector model that supports lines, points and polygon features combined together as a presentation of terrain topology. The original input data will be preserved in generating the terrain model because when constructing DEM with TIN method, there is no transformation i.e. to raster is needed. The TIN structure is dynamic Because nodes can be placed irregularly over a surface, TINs can have a higher resolution in areas where a surface is highly variable or where more detail is desired and a lower resolution in areas that are less variable. This allows changes in its resolution according to surface complexity. For instance, a simple flat surface can be represented with large or coarse TIN resolution, while the high resolution TIN structure is needed to represent a rugged terrain (Zulkarnain 2006).

Figure 3.1 TIN Interpolation Method

Source: ESRI ArcGIS help
(1) Nodes, the fundamental building blocks of a TIN.
(2) Every node is joined with its nearest neighbours by edges.
(3) DEM constructed from TIN.
Another way to construct a DEM using TIN method is by using a break line of an area linear feature, or the boundaries of area features, which represents important natural or man-made discontinuities in the landscape. There are 3 common break lines used in TIN generation, namely hard break lines, soft break lines and faults. Soft break lines will ensure that the known elevation values along a linear feature are maintained in the TIN. Furthermore, it also can be used to maintain linear features and polygon edges by enforcing the break line as TIN edges. There is no elevation interruption defined by the soft break lines. Hard break lines on the other hand, define location of abrupt surface change for instance, streams, ridges, shorelines and building footprints. The fault break lines are used to represent an interruption in surface continuity, that for instance, caused by man-made features.

**IDW**

DEM can also be generated by using distance-weighted interpolation. A common method is the Inverse Distance Weight (IDW), which implements the spatial correlation assumption, that things that are close to one another are more alike than those that are farther apart. IDW is an exact interpolator, where the maximum and minimum in the interpolated surface can only occur at sample points. The output surface is sensitive to clustering and the presence of outliers. IDW assumes that the surface is being driven by the local variation, which can be captured through the neighbourhood.

To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. This means that a Z-coordinate is interpolated from the adjacent X, Y, Z points for each and every grid cell. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away; this is why the method called Inverse Distance Weight. Main parameters in IDW method are power value (p) and root mean square prediction error (RMSPE) as described in figure below.

![Figure 3.2 IDW Power Parameter](https://example.com/image.png)

From previous figure, weights are proportional to the inverse distance raised to the power value $p$. As a result, as the distance increases, the weights decrease rapidly. How fast the weights decrease is dependent on the value for $p$. The surface calculated using IDW depends on the selection of a power value (p) and the neighbourhood search strategy. The optimal power (p) value is determined by
minimizing the root mean square prediction error (RMSPE). The RMSPE is the statistic that is calculated from cross-validation. In cross-validation, each measured point is removed and compared to the predicted value for that location. The RMSPE is a summary statistic quantifying the error of the prediction surface.

**Kriging**

Kriging is a probabilistic interpolation method that calculates the values of the whole study area based on the value values of observations. The basic interpolation assumption is that, values at a short distance are more likely to be similar than at a larger distance. The elevation value for each pair is compared and expressed as variance or covariance. Then, the spatial structure could be analysed through a semivariance method (Zulkarnain 2006). This method defines the degree of spatial dependence among pairs at a specific distance with following equation:

\[
\gamma(h) = \frac{1}{2} \sum_{i=1}^{m} [(Z(x_i + h) - Z(x_i))^2]
\]

(6)

Where

- \( \gamma(h) \) = semi-variance at distance \( h \)
- \( m \) = number of point pairs within \( h \) distance
- \( Z(x_i) \) = elevation value at position \( i \)
- \( Z(x_i + h) \) = value at \( h \) distance from \( i \)

The dataset is analysed through an experimental semi-variogram and it is used to assign the weights for each elevation sample. An experimental variogram plot is a graph with semivariance values of the elevation data (Y-axis) against the distance between elevation data (X-axis). After building the experimental variogram, an appropriate theoretical function (e.g. Gaussian, Exponential, spherical) is needed to model the spatial variation.

The next step is to determine the values of the required parameters; “Nugget”, “Sill” and “Range”. Nugget is a semivariance as the separation between elevation data approaches zero. This value represents variability at a point that can’t be explained by spatial structure. Sill is a maximum semivariance value that represents variability in the absence of spatial dependence. Finally, range, represents the separation between point-pairs at which the sill is reached (distance at which there is no evidence of spatial dependence). In addition lag refers to the average distance of semi-variogram in x-axis. Formula for calculation variogram and an example of variograms and its parameters can be seen below.

\[
\gamma(h) = \frac{1}{2n} \sum_{i=1}^{n} (Z(x_i) - Z(x_i + h))^2
\]

(7)

Where

- \( n \) is the number of pairs of sample points separated by the distance \( h \).
The prediction variance that is derived together with the prediction result is based on the configuration of the existing measurements around each point to be predicted. The kriging weight must sum to one. The weight values are assigned based on the fitted variogram model (Peter et al., 2005) with an optimization criterion to minimize the prediction variance. The estimated elevation value (point to be predicted) is calculated using next equation:

$$Z_0 = \sum_{i=1}^{N} \lambda_i Z_i$$

Where

$Z_0 = \text{The estimated value}$

$\lambda_i = \text{Weights for measurements participated in the estimation}$

$Z_i = \text{Samples value}$

### 3.3.4. DEM Quality Assessment

The quality of a DEM must be assessed to find out how accurate it represents the real world. For this purpose, there are two general method than can be used; by statistical analysis and by visual assessment. First method, the Statistical Analysis, is basically looking at calculated value on every observation points. Thus, to calculate the difference between calculated and observed values.

The most common statistical method to assess the quality of DEM is The Root Mean Square Error (RMSE), which is based on the assumption that the errors are normally distributed with zero mean. This technique is valid when the errors are free from the systematic error and random in nature. The horizontal accuracy concerns the accuracy of the two-dimensional positional accuracy during the extraction of the elevation data (Zulkarnain 2006). The formula for calculating RMSE is:
Where $Z_i$ is the interpolated elevation value, $Z_j$ is a true value and $n$ is number of samples.

The second DEM Quality assessment method is by using a Visual Assessment, to compare DEM with the actual topology of the area. This method is comparing the overview of generated DEM with the actual visual perception of the whole area. Visual assessment of DEM is simply performing visual assessment to find out how good DEM represents the real topology based on common or expert knowledge about geomorphology of the whole area.
4. Digital Terrain Modeling

4.1. Introduction

Development of flood mitigation measures in flood-prone area such for both structural and non-structural measures requires accurate flood predictions. In this study, three definitions are used to describe digital representation of terrain data. Digital Elevation Model (DEM) is defined as a digital presentation of terrain which contains elevation data, Digital Surface Model (DSM) is digital presentation of terrain which contains mixed object on the surface of earth such as buildings and roads, and last, (Digital Terrain Model) DTM is defined as a broad process of converting natural terrain to digital maps contains various data.

Digital representation of terrain is a vital requirement to simulate flood in 1D2D environment. When water volume is not exceeding channel capacity, water is simulated in 1D flood model, and if water overtopping from channels occurs, water propagation on 2D space is simulated on 2D grid generated from digital terrain data. Topographic data are crucial for flood inundation modeling and it is best to use recent and highly accurate topographic data. There are a lot of information related to terrain that can be used as a parameter in flood modelling, such as terrain elevation, building footprint, and land use. Overall methodology of Digital Terrain Modelling can be seen in following figure;

![Figure 4-1. DTM Overall Methodology](image-url)
4.2. DEM Construction

In this research, DEM is generated using spot height, and then different interpolation methods are used to convert spot height as a point to an elevation coverage data. Interpolation methods used in this study are TIN, IDW, and Kriging. Finally, DEM quality assessment with Root Mean Square (RMSE) method will be utilise to find out which DEM is the most appropriate to represent topographic elevation for study area. DEM generation in this thesis mainly done in ArcGIS environment and some required extensions such as 3D analyst and GeoStatistics.

Available data for DEM generation for this research is Spot Height, which produced by the Government of Surabaya City. Unit of this elevation data is in cm. Detailed descriptions of elevation dataset can be seen in following figure:

![Figure 4-2 Elevation Data Overview](image)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Of Points</td>
<td>56911</td>
</tr>
<tr>
<td>Minimum Value (m)</td>
<td>0.00</td>
</tr>
<tr>
<td>Median Value (m)</td>
<td>6.52</td>
</tr>
<tr>
<td>Mean Value (m)</td>
<td>9.61</td>
</tr>
<tr>
<td>Maximum Value (m)</td>
<td>46.02</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>7.60</td>
</tr>
</tbody>
</table>

4.2.1. TIN

First interpolation method is a TIN, which height points and triangulated height points. The height points are connected with a series of edges to form a network of triangles, and with Delaunay triangle criterion, a new coverage is constructed. TIN interpolation doesn’t require any intermediate parameters, because it constructed a DEM by using triangulation. RMSE for TIN interpolation cannot generated automatically in ArcGIS, because TIN uses an exact elevation of each value. Therefore, elevation data must be split into Calibration dataset and Validation dataset. Calibration dataset was used to generate the TIN, while Validation dataset was used to calculate differences between predicted value and observed value. Mean Error value and RMSE value then manually calculated to assess the quality of generated DEM.

By comparing the values of validation dataset with calibration dataset, two DEM quality indicators were obtained; Mean Error, which is an average difference between calculated value and observed value, and Root Mean Square Error (RMSE), which is the error value combined with number of
validation dataset. For TIN Interpolation, Mean Error Value is -0.015051 while Root Mean Square Error is 0.844.

4.2.2. IDW

Second interpolation method is an Inverse Distance Weight (IDW), which calculated the value of an unobserved location by its distance to an observed location. Main parameter for IDW is power value \((p)\), which is by using ArcGIS Geostatistics, the value for dataset is 3.4518. After interpolation, we can assess the quality of the model by calculated error prediction error, which is:

![Prediction errors; Mean Error : 0.007746 RMSE : 0.7504](image)

4.2.3. Kriging

Next method to create DEM from elevation points is by Kriging, which is based on statistical models that include autocorrelation. This is the statistical relationships among the measured points. Because of this, not only do geostatistical techniques have the capability of producing a prediction surface, they also provide some measure of the certainty or accuracy of the predictions. In Kriging, the main parameter is a semivariogram, which describe the spatial correlation between points. Original variogram for height point was calculated using R software, but interpolation was performed using ArcGIS. Parameters of the Kriging, the Nugget, Sill, and Range, were calculated in ArcGIS using GeoStatistic analysis, while interpolations were performed using Spatial Analyst’s interpolation method.

When performing a Kriging, a variogram model must be constructed to determine Nugget, Sill, and Range value. Although the original semivariogram already has these values, fitted values of Nugget, Sill and Range will be used in the interpolation. In this research, Ordinary Kriging was used with different variogram models; Gaussian, Spherical, and Circular. Each variogram model will produce different DEMs, and require further DEM quality assessment.
Figure 4-4 Variogram Models

A. GAUSSIAN
The first Kriging interpolation is by using a Gaussian variogram model, which assumes that semivariogram has a low value in short distance, and after certain point, semivariogram increase rapidly until it reaches Sill. Calculated semivariogram model and its parameter can be seen in following figure;

Figure 4-5 Gaussian Variogram Model and Cross-Validations

Nugget : 8.56     Sill : 26.60
Range : 1851.5   Lag : 50

Figure 4.4. Shows that with Gaussian semivariogram, interpolation methods resulted in relatively high RMSE, which shows that this method has a lower accuracy than IDW. Standardized RMSE with this method is 1.12, while IDW has RSME only 0,75. This means that Kriging interpolation with Gaussian variogram model is a less appropriate method to construct a DEM from height points.

B. SPHERICAL
Second Kriging interpolation is by using a spherical variogram model, which describes that semivariance increases rapidly in short distance, and as distance increases, the value of semivariance is slowly decreases until reach the sill value.Variogram model, its parameters and the results can be seen in following figure;
Kriging Interpolation using Spherical Variogram showed a better result than Gaussian Variogram. RMSE with this method is 0.80 which is much lower than Gaussian’s RMSE. But compared to IDW’s RMSE, Spherical RMSE still a little bit higher, which indicate that Spherical Interpolation still has a lower accuracy compared to IDW.

C. CIRCULAR

Final variogram model for Kriging Interpolation is the Circular Variogram Model, which describes that covariance value between nugget and sill has a circular form. This model assumes that there is a geometrically form in the elevation. Thus, generated DEM will have a more regular shape than other semivariogram models.

Figure 4.6 above showed that by using a Circular Variogram for Kriging Interpolation will have RMSE value 0.856. This is lower than Gaussian semivariogram, but still higher than Spherical variogram. Thus, if compared by IDW, this method have a higher RMSE, and therefore, not the most appropriate method to generate DEM. Comparison between different interpolation method can be seen in following figure;
Figure 4-8 Comparison of Interpolation Methods

- **TIN**
- **IDW**
- **Gaussian Kriging**
- **Spherical Kriging**
- **Circular Kriging**

Elevation
- High: 10 Meter
- Low: 0 Meter

Distance: 0 1 2 4 6 8 Kilometers
4.3. DEM Accuracy Assessment

Hydrodynamic modelling urban flood management is a method to develop a digital representation of water movement inside or outside channels within a city. This model can give authorities a better understanding about the extent of flood hazard. Flood modelling and forecasting requires not only rainfall–runoff information, but also requires channel flow routing and forecast updating (Moore, Bell et al. 2005). There are a set of tiered methodologies in hydrodynamic modelling, and each appropriate for different tasks and applications over different scales. The most widely used hydrodynamic model for assessing flood hazard in urban areas are one-dimensional (1D) and two-dimensional (2D) flood modelling (Pender and Neelz 2007).

Root Mean Square Error (RSME)

Previous discussions shows that different interpolation method will resulted in different prediction error. For Kriging Interpolation, different variograms have a significant impact to the error of interpolation. To determine which method can give the best DEM accuracy, the most common way is to use RMSE value. The higher the RMSE, the lower the accuracy of generated DEM. Another useful value to assess the quality of a DEM is Mean Error, which shows the average differences between calculated an observed value. Because Mean Error is not square-rooted, value of Mean Error can be positive or negative. Mean Error and RMSE for DEM construction with different interpolation method can be seen in table 4.1.

Table 4-1 DEM Accuracy for Different Interpolation Methods

<table>
<thead>
<tr>
<th>Interpolation Method</th>
<th>Mean Error</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIN</td>
<td>-0.015051</td>
<td>0.844</td>
</tr>
<tr>
<td>IDW</td>
<td>0.007746</td>
<td>0.7504</td>
</tr>
<tr>
<td>Gaussian Kriging</td>
<td>-0.01063</td>
<td>1.12</td>
</tr>
<tr>
<td>Spherical Kriging</td>
<td>-0.00627</td>
<td>0.8091</td>
</tr>
<tr>
<td>Circular Kriging</td>
<td>-0.001964</td>
<td>0.8567</td>
</tr>
</tbody>
</table>

Table 4.1. Shows that IDW interpolation method and Spherical Kriging Interpolation have a similar quality. RMSE for IDW is slightly smaller than Spherical, while Spherical’s Mean Error is smaller than IDW’s Mean Error. This inconsistency made statistical methods cannot give a definite identification about which method is the most accurate to generate DEM for study area.

Visual Assessment

Because RMSE and Mean Error shows cannot give a decisive definition about which interpolation method has the best accuracy, visual assessment method can be used to decide which DEM is better in representing the study area. Visual assessment is based on general knowledge about study area and common assumptions about topology of urbanized area.
Figure 4-9 Visual Comparison of IDW and Spherical Kriging

DEM generated by IDW interpolation shows a more sharp representation of elevation, while DEM generated by Kriging interpolation shows a smoother surface. For built-up environment, sharper elevation representation is better because elevation in urban area often shows a sudden changes because the presence of man-made features and modifications on the natural terrain. Therefore, IDW interpolation is considered better to generate DEM in the study area.

4.4. DSM Construction

Flood modelling requires a 2D grid as representation of terrain topology. Digital terrain representation of urban areas need further improvement of DEM to accurately represents real terrain in digital format because man-made features, like roads and buildings, have a significant impact to the behaviour of water on a terrain. Thus, those features can play a role to determine the area of interest of the model. This study also use man-made features to delineate study area for flood modelling, which is a toll road that stretches from northern to southern part of Surabaya City. The assumption for this delineation is toll road can block the flow of the water because it usually higher than the natural terrain. Therefore, in this study, toll road in Surabaya City was set as a western boundary of the model’s 2D grid. Northern and eastern boundary of the 2D grid is the sea, and southern boundary is Kali Perbatasan, which also an administrative boundary for Surabaya City and Sidoarjo Regency.

Another man-made features included in DSM construction is buildings and agricultural land uses. For buildings, an additional data was added to the DEM, which is the base of buildings. The main assumption for this method is that water still can penetrate a building, but not building base, which in Surabaya City is around 20 cm – 50 cm higher than natural terrain. Another consideration is basement lower than natural terrain is extremely rare in Surabaya City. Agricultural land use have a different characteristics compared to buildings in term of its relative elevation to the natural terrain. Rice or vegetable fields and fish ponds are agricultural land use can be found in Surabaya City, especially in eastern part. These land use usually inundated by water, and the surface of water is around 20 cm lower than natural terrain.
Roads also an important man made features that should be included in DSM construction. If roads are also included in DSM, maximum pixel size of the DSM is 10 meters (Tennakoon 2004). If DSM for study area was generated with 10 meters pixel resolution, number of pixels is exceeding 1 million pixels, which is exceeding the number of pixels allowed by SOBEK. For 1D2D flood modelling, SOBEK is currently only support up until around 100,000 pixels. Therefore, roads cannot included in DSM generation in this study. DSM construction scheme and its result can be seen in following figure:

**Figure 4-10. DSM Boundary**

![Figure 4-10. DSM Boundary](image1)

**Figure 4-11. DSM Construction Scheme**

![Figure 4-11. DSM Construction Scheme](image2)
5. Flood Management Policies

5.1. Policies of River and Water Management

Regulatory powers of river and water management in Indonesia are vested both in central and local governments. In current system, regulatory power within local government included operation, management, and monitoring function of water resources, are held within one institution, namely Dinas PU Pengairan (water resources agency), which it exercises through its field offices. Therefore, there is no organizational or institutional demarcation between the regulatory and operation and management functions. In the regulatory process, before decisions are made, agreement with concerned agencies, groups, or stakeholders is required. However, this process lacks the independence, fairness, and transparency that regulatory mechanisms should have. It is a common problem that local institutions and operating agencies find it difficult to implement the regulations in river basins (Ramu 2002).

5.1.1. National and Regional Policies

Indonesia has approximately 5,500 rivers, both big and small. Usually, rivers in Indonesia are originated from mountainous areas with distinct characteristics; Upper reaches have a steep slope, middle reaches have a moderate bed slopes, and lower reaches have a relatively flat terrain. Almost major cities in Indonesia is located in the lower reach of a big river, and due to high rainfall intensities and lack of flood retention infrastructures, big cities which located in the low reaches of rivers are very common to heavy and annual flood. A large quantity of sediment transport is also a common phenomenon, which results in river problems in urban areas.

Flooding in urban areas, especially the ones located in low-lying areas, has been a common problem in many of the river basins. Regardless to the size of the river basin, flooding in Indonesia’s major cities usually caused by;

- Increase in flood peaks due to changing land use and severe deforestation,
- Inadequate capacities of the river channel in the middle and lower reaches
- High levels of sedimentation impacting the river morphology and causing river mouth problems
- Lack of flood plain and its encroachment both in rural and urban areas
- Lack of land-use zoning and enforcement of land-use controls
- Inadequate urban drainage and disposal of solid waste into river channels
- Urban land subsidence due to over abstraction of groundwater (Jakarta, Surabaya, Semarang)
- Poor maintenance of flood infrastructure and lack of funding
- Institutional weakness in flood management.

The main issue in Indonesia’s national river and water management is balancing water supply and demand that sometimes can differs greatly, because of the seasonal and annual variation of the river water discharge. Water supply is always lower than demand during dry season, and during rainy
season, lack of reservoirs and storage capacity of the catchment area caused flood on regions along main rivers. Spatial and temporal variation in supply and the high ratio of demand-to-supply on the island of Java and some parts of Sumatra and Sulawesi is a major problem that up until now can not be managed adequately by national and local government. Extreme erosion in the urbanized areas and densely populated watersheds of major river basins also contribute to river management problems.

River and water resources in Indonesia are governed mainly under de-concentrated governmental system, where local governments act as regional representatives and implement central government policies and programs under the supervision of the central government. Local government made initiations and proposals about what and which programs should carried out to manage river and water resources, and then, central government will decide the scope and funding resources for those proposed programs, usually from national budget. At operational level, these programs are carried out by regional sector agencies, which operate under the regional governments and must follow the general outline set out by central government (Ramu 2002).

5.1.2. Brantas River Basin Management

Rivers in Indonesia are grouped into 90 river management boundaries called Satuan Wilayah Sungai (SWS). SWS’s boundaries normally based on regional division for river basin planning, development, and management. The Brantas SWS has 1,555 rivers and is fully located in the East Java province. Because of the importance and strategic role of Brantas River both in regional and national scopes, Brantas River Basin is classified as a national SWS, which means that management of Brantas River Basin still under co-ordination by central government.

According to (Ramu 2002), there is a generic institutional framework for basin management, which is also applicable to the Brantas basin. This framework indicates who and which institutions, whether in central or local level, have significant roles and responsibilities for water and river management in Indonesia. These institutions are as follows;

1. Macro and Program Planning : National, Provincial and Local Planning Boards
2. Supervision & Guidance : Ministry of Public Works represented by Water Resource Directorate and Water Basin Planning and Development Board (IPKPWS)
3. Development : National or Provincial Projects
4. Regulatory : Provincial Water Resources Agency and Basin Water Resources Agency (Dinas PUP, Balai PSDAs)
5. Water Management including Operation and Maintenance: Brantas River Basin Corporation (Jasa Tirta, Inc.) (a national public sector corporation)
6. Irrigation Management :
   a) District Water Resource Agency (Kab. Dinas PU) for irrigation systems inside a district.
   b) Provincial Basin Water Resource Agency (Balai PSAWS) for irrigation systems those are inter-district.
7. Coordination :
   a) Ministerial Coordination Team at the national level.
   b) Provincial Water Resources Committee
Development of the Brantas River basin was started in 1961, with a series of Master Plan had been formulated as development guidance. Basic concept of the development Brantas River basin was to develop a comprehensive and integrated development, which was “one river, one plan, one coordinated management”, because of water is a dynamic resource, that flowing through different administrative boundaries. To avoid conflict of interests between stakeholders, Brantas River must managed under one coordinated management (Ramu 2002).

To improve the management and operational aspects of water resources in Brantas River Basin, in the year 1990, Indonesia’s central government set up a public sector corporation, namely Jasa Tirta, inc., to operate, maintain, and manage all of the major infrastructure and to manage water resources in the Brantas River. Jasa Tirta has no role in developmental activity and acts strictly as a basin manager under the supervision of the Ministry of Public Works.

The three main institutions in the basin that have direct responsibility in Brantas River Basin Water and River Management (WRM) are:

1. The three provincial water agencies
   (a) Balai PSDA, Bango Gedangan
   (b) Balai PSDA Madiun-Kediri
   (c) Balai PSDA, Buntung–Peketigan
2. The Brantas Public Corporation (PJT-I)
3. Basin Coordination Committees
   (a) PPTPA, Malang-Besuki
   (b) PPTPA Madiun-Kediri
   (c) PPTPA Surabaya-Madura.

The primary institutional framework for the Brantas basin is shown diagrammatically in following figure;
The provincial water resources agency acts as the regulator for the Brantas River basin and manages the provincial funded program in water sector in the basin. The Provincial Water Resources Coordination Committee (PPTPA) set up in 1994 provides the policy direction for the Brantas basin water resource development and management. (Usman 2003). There are three main aspects of authority sharing in Delta Brantas River network, which are regarding Licensing for water use and Operation for Dry and Wet Season.

**a. Licensing**

If anyone or any institution wants to take water from Brantas River, it must ask for a license from the local government. Licence issued by the Local Government must be supported by technical recommendation by Jasa Tirta Public Corporation (PJT).

Technical recommendation is important to keep the balance of water supply and demand, because water resources in the Brantas River are used for various purposes. The main consumers are: irrigation (80%), raw water for drinking water, industries, fishpond, city flushing, etc (20%) and electricity (not consume the water). Water allocation from PJT to the users is based on contract basis. Users have to contribute cost of O & M to PJT, except farmers. The rate of tariff is decided by the Government upon pre discussion between PJT and users.

**b. Dry Season Operation Rule**

Water management in the Brantas river is coordinated by a body called East Java Provincial Water Board / EJPWB (Panitia Tata Pengaturan Air), headed by Vice Governor of East Java Province. Water allocation pattern consists of two kinds of Operation Rules that are for the dry season (June-November) and for the rainy season (December-May).
Procedure for preparing operation rule for dry season is as follows. In the month of May (for the dry season) users submitted water demand to PJT. Then by computer simulation and weather forecasting, PJT prepared draft of dry season operation rule. On the end of May the draft of operation rule was discussed in the forum of EJPWB and if all parties agreed, then approved by Vice Governor for implementation. If during the monitoring time, there was deviation of prediction or conflict of interest between users, limited members of EJPWB sitting together to solve the problem or to review it, if needed.

c. Rainy season Operation Rules

Preparation of the rainy season operation rules is the same procedure as for dry season. Focus of rainy season OR is to control flood, because from average annual discharge of 12 billion m³ surface run off, only about 4.5 billion m³ was utilized. The rest is flowing into the ocean, mostly during rainy season. Management of flood control in the Brantas river basin was done by a State Own Company, namely Jasa Tirta Public Corporation. Water management was operated using equipment Flood Forecasting and Warning System, by time interval of 1 hour, on line. A yearly guide line books were prepared as a guide line of flood forecasting, flood warning and flood fighting.

The guide line book mentioned the critical locations of levee along the river (about 600 km length of levees, both sides of river bank), protection methods, numbers of material and equipment available for flood fighting in the warehouse along the river, information of the staff involved (names, addresses, telephone numbers, hierarchy of information to be submitted from the chief of district up to the Governor), etc.

Flood protection scheme at extensive scale has been developed and gradually implemented in the Brantas River Basin. Main features of this flood protection scheme also have been constructed, which are Lahor Dam, Karangkates (Sutami) Dam, Wlingi Dam, and the two retarding basins—Ngrowo and Widas along with the Lengkong flood gates to divert water into the Porong River to reduce flood flows in Surabaya River and protect the town of Surabaya. Construction these structures, coupled with the dike system, have successfully prevented flooding in the mainstream of the Brantas River since 1990. A flood warning system also has been developed, and its implementation provides early warning for operation of the floodgates at the various locations. Flood control scheme of Brantas River Basin can be seen in following figure;
Figure 5-2 Flood Control Scheme of Brantas River Basin

Source: (Ramu 2002)
5.1.3. Brantas Delta Region Management

Lower reach Brantas River Basin is called Brantas Delta area, where Kali Brantas River is divided into two rivers; Kali Surabaya River, a natural river that entering Surabaya City, and Porong River, a man-made river that built as a diversion channel to protect Surabaya City from flooding. Brantas Delta was developed by the construction of Lengkong Barrage in 1857.

Brantas Delta plays a very important role to flood hazard in Surabaya City, because regulations of rivers within Brantas Delta will have a significant impact to the volume of water discharge in Kali Surabaya River, which is the main river in Surabaya City. Until now, Surabaya City is well protected from river flooding because most of water discharge of Brantas River is safely discharged to the sea through Kali Porong. As described in the previous sections, there is a big threat of flooding in Surabaya City due to the mud flood disaster in Sidoarjo, neighbouring municipality of Surabaya, which can reduce the capacity of Kali Porong, and caused increasing water discharge of Kali Surabaya.

Water and river management in Brantas Delta is managed by the three main institutions that have direct responsibility in Delta Brantas;
1. The Provincial water agencies (PSAWS)
   • PSAWS Bango-Gedangan
   • PSAWS Buntung–Peketigan
2. The Brantas Public Corporation (Jasa Tirta, Inc.)

Those three institutions together have the authority to manage river within Brantas Delta, i.e., regulating water discharge, river regulatory structure adjustment, and land use change controls. Layout of Brantas River Basin and Brantas Delta can be seen in next figure.
5.2. Flood Mitigation Measures

To narrow and focus the flood mitigation measures, discussions about existing policies is limited to the Brantas Delta area. Flood mitigation measures in Brantas Delta can be described in four major groups; management boundaries, institutional hierarchy, structural defence measures, and non-structural defence measures.

5.2.1. Management Boundaries

In general, flood management in Surabaya City is divided into 4 drainage area boundaries, which are Eastern, Central, Western, and Southern flood boundaries. Descriptions for each management boundaries are as follows:

1. Eastern Surabaya Drainage Area.
   This area is bounded by Kali Mas River in western part, and sea protection in eastern part. In this area, in flood event, water was discharged to the sea in eastern part using gravity force. This discharge is regulated using several water gates to avoid flood from high sea tide.

2. Central Surabaya Drainage Area.
   This area is confined in central Surabaya area, which has very high density housing, bordered by Gunungsari Channel in western part and Kali Mas River in eastern part. Because this area has a very flat topography, water in flood event must be discharged using water pumps to both Kali Mas River and Gunungsari Channel.
3. Western Surabaya Drainage Area.
   This area located in the western part of Surabaya City, and delimited by catchment area of Gunungsari Channel (13.7 km²) and Kedurus River (67.4 km²). Topography in this area mainly high elevated, so flood is less likely to be occurred in this part of Surabaya City, with exception along Kedurus River.

4. Southern Surabaya Drainage.
   This area is defined as an area south to Kali Surabaya River. Delta Brantas River network system is also included in this management boundary. Regulatory structures in this area are Mlirip Weir, Lengkong Barrage, Jagir Dam, and Gunungsari Dam.

5.2.2. Institutional Hierarchy and Coordination

Flood management in Delta Brantas involving three mayor components; Central Government, Local Government, and Local Communities. At national level, Central government was represented by its two ministries, which are Ministry of Public Works through and Ministry of Home Affairs. Authority for Public Works Ministry is held by its Directorate of Water Resource, while authority for Home Affairs Ministry is held by East Java Province’s Governor.

At local level, Water Basin Planning and Development Board (IPKPWS) and Jasa Tirta held responsibilities of Delta Brantas river and water management under Directorate of Water Resources. The first one is responsible for planning and development process, while the second one is responsible for operational and maintenance of Delta Brantas river network system. In the event of flooding, these two institutions constantly and separately receiving information from community groups and on-duty officer in measurement stations about river and rainfall conditions, and established coordination between each other about proper measures to be taken during flood. Then, together, these two institutions will make a report and informed the latest flood conditions to the Directorate of Water Resource. On the other hand, East Java’s Governor established a provincial and local task force as a coordinator for flood anticipation and mitigation. If flood occurs, local task force will gather information from community group and measurement stations and then report it to provincial taskforce, who finally report it to the governor of East Java Province. The task force also must inform the East Java’s Public Works office to establish coordination between each other.

Final decisions about flood mitigations measurements are held by the Governor of East Java Province, who then gives an order to Provincial Task Force to undertake required actions during flood events. Then, Provincial Task Force gives instructions to Jasa Tirta to adjust river regulatory structures to avoid flood. In case of flood is unavoidable, Local Task Force held the responsibility to undertake required actions during and after flood event.
5.2.3. Structural Defence

There are several regulatory structures located in Delta Brantas that play a role as a structural defence to avoid flood hazard, i.e. Mlirip gates, Gunungsari barrage, Wonokromo gates, Gubeng rubber dam and Jagir barrage. The Surabaya River is a branch of Brantas River starting from Mlirip gates in Mojokerto to the estuary in Surabaya. Along the Surabaya River there are several major flood control structures which are operated in the dry season to guarantee intake flows for water and industry and urban flushing in the rainy season. The major structures must be operated during both the dry and rainy seasons because they have to maintain water levels at fixed elevations, in following figures.
Table 5-1 Main Structural Defense

<table>
<thead>
<tr>
<th>No</th>
<th>Name of structure And (Management Organisation)</th>
<th>Elevation to be kept at</th>
<th>Operation Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lengkong Barrage (Jasa Tirta, inc.)</td>
<td>-</td>
<td>8 gates sized 6.6 x 5m.</td>
</tr>
<tr>
<td>2</td>
<td>Mlirip Weir (Jasa Tirta, inc.)</td>
<td>-</td>
<td>1 gate sized 6 x 9 m and 1 flood gate sized 13 x 9 m</td>
</tr>
<tr>
<td>3</td>
<td>Gunungsari Dam (Jasa Tirta, inc.)</td>
<td>+ 4.60</td>
<td>4 gates sized 14 x 4 m</td>
</tr>
<tr>
<td>4</td>
<td>Jagir Dam (Balai PSAWS – BP)</td>
<td>+2.95</td>
<td>3 gates sized 9 x 4 m</td>
</tr>
<tr>
<td>5</td>
<td>Wonokromo Gates (Jasa Tirta, inc.)</td>
<td>-</td>
<td>2 gates sized 4 x 3.8 m</td>
</tr>
<tr>
<td>6</td>
<td>Gubeng Rubber Dam (Jasa Tirta, inc.)</td>
<td>+2.20 - +2.27</td>
<td>Rubber dam 2 x 12.0 m</td>
</tr>
</tbody>
</table>

Source: Surabaya Drainage Masterplan (SDMP)

Main functions of each structural defence are as follows:

1. Lengkong Barrage.
   Lengkong Barrage’s main function is to regulate Brantas River discharge. In Dry season, this structure plays a role to maintain water quantity for irrigation purpose, while in rainy season, to discharge water directly to the sea through Kali Porong. Irrigation area can be served by Lengkong Barrage is around 40,156 hectares, mainly located south to Sidoarjo. Maximum capacity of Lengkong Barrage in flood event is approximately 1,500 m³/s.

2. Mlirip Weir
   Main function of Mlirip Weir is to regulate water discharge entering Surabaya City through Surabaya River. If flood occurs in Brantas River, to avoid flooding in Surabaya City, Mlirip Weir is closed partially. In dry season, Mlirip Weir completely open to maintain water quantity entering Surabaya City to fill water requirement within Surabaya City.

3. Gunungsari Dam
   Gunungsari Dam plays a role to maintain water elevation at Surabaya River and maintain water quantity for irrigation area (approximately 3,812 hectares) within Surabaya City during dry season. In rainy season, Gunungsari Dam fully opened to discharge water in Kali Surabaya directly to the sea.

4. Jagir Dam
   Jagir Dam’s main function is to regulate downstream of Surabaya River which is divided into two rivers; Kali Mas River and Wonokromo River. During dry season, Jagir Dam plays a role to maintain water elevation of Surabaya River at 2.95 m, maintain intake to Surabaya’s water company (3 m³/s), and to regulate water entering Kali Mas River through Wonokromo Dam as a irrigation supply, industrial use, and urban uses. In rainy season, Jagir Dam fully opened to discharge water directly to the sea through Wonokromo River.

5. Wonokromo Gates
   Wonokromo Gates plays a role to divert water from Surabaya River to Kali Mas River and Surabaya City’s urban area, and during rainy season or flood event, this structure protect excessive water entering Surabaya City that can caused flood in urban area.

6. Gubeng Rubber Dam
   Main functions of Gubeng Dam in dry season are to lift water elevation at Kali Mas River, to protect sea water intrusions into urban areas, and to provide water for irrigation in north-eastern
part of Surabaya City. During rainy season, Gubeng Dam is fully opened to discharge as much as possible water to the sea through Kali Mas River.

**Figure 5-5. Structural Defense Adjustment During Flood Event**

![Map of Surabaya City showing structural defense adjustments during flood event](image)

5.2.4. Non-Structural Measures

Another type of Flood Mitigation Measures is Non-Structural measures, which in general is an effort to maintain or to improve flood retention of the river basin and watershed area. Non-Structural Measures that are applicable to flood management in Delta Brantas is described in Guideline for Spatial Management in Flood-prone areas, issued by ministry of public works of Republic Indonesia. In this guideline non-structural measures in flood-prone areas are;

a. **Watershed management**

   Main purpose of Watershed management is to reduce rainfall-runoff in a river basin to the main river. To support watershed management, regulations about land use conservation must be implemented, to reduce or minimize land use conversions from green and open spaces to built-up areas. Other examples of methods that can be implemented in watershed management to reduce runoff to the main river are;
a. Rehabilitation of forest in catchment areas.
b. Construction of sub-channels.
c. Construction of drainage wells.
d. Regulated agricultural areas.

b. **Floodplain Management and Land Use Zoning Regulation**

Floodplain management is performed by implementation of local policies which regulated spatial plan in floodplain areas, and adjusted with the possibility of flood based on flood risk map and floodplain zoning based on the severity of the flood. By this method, land use conversion in areas that are considered prone to flood can be avoided. Thus, future land use in such areas is projected into open spaces or forestry only. Socio-economics aspects are important factors that must be considered in floodplain management and land use zoning. These factors are:

a. Size of inundated area.
b. Flood duration.
c. Early warning system efficiency.
d. Flood preparedness.
e. Flooding time.
f. Water velocity.
g. Evacuation plan.

C. **Flood Proofings**

Main purpose if flooding is not to prevent or even to reduce flooding, but rather to reduce the impact of flood event by adjusting the physical structure of human settlement. Various methods of flood proofing are:

a. To increase terrain elevation
b. To increase the ground clearance of building structures;
c. To use water-proof materials for building structures.

Flood proofings are implemented by considering following factors:

- Design flood level, both from calculation and from previous flood events.
- Freeboard as a safety factor, which is around 30 – 50 cm above design flood level.
- Flood fringe areas.

Some examples of flood proofing methods can be seen in following figure;
d. **Flood Forecast and Early Warning System.**

Flood forecasting is an effort to give an approximate flooding time and the flood elevation in flood prone areas. On the other hand, Early Warning System gives a warning about flood event or certain water discharge to give enough time to save lives or properties. This method is the cheapest and the most effective way to avoid loss and damage during flood event. This method also proven to be most useful to save lives because people can move or relocated even before the flood struck.

Various mathematical models about hydrology and hydraulic have been used to calculate flood forecast based on hydrological data (rainfall, water discharge, water level) in upstream reach of a river. The result of this model is an approximation of incoming flood event.
To anticipate flood hazard within Delta Brantas River network, Jasa Tirta, inc. equipped with Flood Forecasting and Warning System (FFWS). Monitoring stations for this system is spread along Brantas River, with main monitoring station located at Perning, near Kali Surabaya River upstream.

Through FFWS, hydrological data of the entire Delta Brantas River network can be collected in real time and time-synchronized between monitoring stations. These data included water elevation at main rivers and rainfall. Then, based on this data, Jasa Tirta will produce a flood forecasting report, and then report it to another institutions involved in flood management explained in section 5.2.2. General operational mechanisms of FFWS are as follows;

1. Rainfall, water elevation, and river discharge observations are performed by the on-duty flood observer, and if certain rainfall and/or water discharge or level reaches a point that considered possible to cause flood, he immediately report to Jasa Tirta’s office and then standby for the coming instructions.
2. In case of flood occurs, on-duty flood observer immediately check field conditions and established a continuous coordination with Jasa Tirta’s office to exchange information regarding flood event conditions.
3. On-duty staff in the flood stations will report to Jasa Tirta’s office about;
   - Flood discharge;
   - Flood impact on river structures
   - Flood impact on properties and people.
   - Possible steps to be taken for manage flood and its impacts.
6. Flood Modelling

6.1. Introduction

Prediction about the impact of changes in Delta Brantas River network to flood hazard in Surabaya City requires a computer-based flood modelling which can produce a realistic results. Thus, different scenarios can be developed by this flood modelling to find out what are possible measures to be taken in order to minimize flood impact. For this purpose, SOBEK software developed by Delft Hydraulics provides the best combination of 1D and 2D flood modelling available. SOBEK a valuable instrument for flood forecasting, navigation, optimising drainage systems, controlling irrigation systems, reservoir operation, sewer overflow design, ground water level control, river morphology regulation, and water quality control. SOBEK can combine river systems, urban systems and rural systems for a total water management solution.

The program has been enhanced with facilities to import GIS data into the model and to export computational results to GIS systems for presentation and evaluation. It simulates very well the influence of the existing/planned infrastructure on flooding processes. Advantages of using SOBEK for developing 1D2D flood modelling are (Shaviraach in 2005);

a. Water flow is computed initially on dry land, therefore, doesn’t require any special drying and wetting mechanism.
b. Water flow can be computed in accurate and stable manner, even on very steep slopes and on man made structures.
c. Flood modelling can be developed in a very accurate time scale, up to within minutes.
d. Realistic flood predictions based on given data inputs and boundary conditions.
e. Supporting user-friendly processing and easy interaction with another GIS softwares.

Figure 6-1. 1D2D Combination in SOBEK
6.2. Model Schematisation

Flood schematisation in SOBEK in general consists of Nodes, Reaches, and 2D grid. Descriptions of each element involved in flood modelling can be found in SOBEK Technical Reference, which described below.

1. Up Stream Boundary: Node presentation of a point where water discharge entering the model.
2. Down Stream Boundary: Node presentation of a point where water discharge out from the model.
4. 1D Reach: Line presentation of river network, which only calculated water movement along the river.
5. 2D Reach: Line presentation of river network, which connected to 2D grid to simulate overland flow in the event when water discharge is exceeding the river capacity.
6. 2D Grid: Terrain representation of the study area, which store the information about terrain elevation, both natural and man-made terrain elevation.

For 1D flow, channels were constructed by combination of rivers and primary drainage channels within Surabaya City. The dimension for each channel was determined from Cross-Section data, which is defined as an input element of the SOBEK-Flow-module in which the shape and size of the channel/sewer profile perpendicular to the flow is described. There are different type of cross section, which are; Asymmetrical trapezoidal, Circular, Egg-shaped, Symmetrical Tabulated, and Y-Z River cross section. Cross sections can be open or closed. The asymmetrical trapezoidal cross section, the River cross section and the y-z cross section are always open. The symmetrical tabulated cross section can be open or closed. It is considered closed when the width of the highest level is smaller than 10 mm. The circular and egg-shaped cross sections are closed. In this study, all channels are using Y-Z cross sections to represent its shape. This is a series of Y-Z co-ordinates that form a general profile.

![Figure 6-2 Y-Z Cross Section Profile](source: SOBEK Manual)
Cross sections may be defined at arbitrary locations in the model, provided that for each reach at least one cross section is specified. Depending on the situation, the SOBEK-Flow-module constructs cross sections at the calculation points by way of constant extrapolation or linear interpolation. If there is only one cross section defined at a reach, this cross section and its bed level are applied over the whole reach at all the calculation points. Figures below form an example of the way the cross sections are interpolated and extrapolated. Here, the bed levels are varied, while the cross sectional areas are constant.

The connection between the 2D cells and the 1D network as explained in SOBEK manual reference is done in the following way:
1. The centre of 1D node is internally moved to match with the centre of 2D grid cell, without changing the length of the connecting 1D branch.
2. The 2D Grid Cell is counted as part of 1D Node.
3. The flow in 1D channel below the 2D grid level is treated as 1D flow, while the flow above the 2D Grid level is treated as 2D flow with the area of 2D grid cell.

Technical method for 1D2D connection can be seen in following figure;
One of the first things to do when developing 1D2D flood modeling in SOBEK is to create the schematization of network that represents the water system. Whether it is a river or channel, the principles are the same; it will be a GIS-based network or grid.
6.3. Boundary Conditions

Boundary conditions used in flood modelling for study area are Inflow Discharge as a data source of Up Stream Boundary of the model, Rainfall intensity as a meteorological data, and Sea Tide as a data source for Down Stream Boundary of the model.

6.3.1. Inflow Discharge

Available data for inflow discharge is the Brantas River Down Stream for 2, 5, and 10 years return period. This data is collected from the measurement station located at intersection of Brantas River, Surabaya River, and Porong River. The hydrograph for Brantas River down stream is calculated for 5 days period, and the in the flood modelling, this data was entered with 1 hours time steps. Brantas River Downstream discharge was collected from Jasa Tirta, and Hydrograph for 5 days flood discharge data can be seen in following figure;

Figure 6-6. Hydrograph for Brantas River Downstream

From figure above, maximum water discharge of Brantas River is around 1,500 m$^3$/second for 10 years return period. In current condition, most of water Brantas River discharge is entering Porong River, and then can be safely discharge into river. From the 5 years time-synchronized data collected between year 2000 – 2005, average percentage of Brantas River discharge entering Porong River is around 98%, while discharge entering Kali Surabaya River is only around 2% of the Brantas River discharge.
6.3.2. Rainfall Intensity

There are ten daily rainfall stations in Surabaya City, but from observations during development of Surabaya Drainage Master Plan (SDMP), there is relatively little variation across the study area, with the highest and lowest values within approximately +/-10% of the average. Thus, the results of the daily analysis do not indicate any clear geographic pattern, and it is considered appropriate to average the results for all stations. According to Surabaya Drainage Master Plan (SDMP), severe storms in Surabaya almost always occur in the afternoon or early evening. Analysis of hourly data for the peak months of the 1998/99 wet season (December and January) shows that 45% of the total rainfall occurred between 15:00 and 17:00, and 87% between 1500 and 21:00. For design purposes in SDMP, the short duration observations from Perak Station were factored by the ratio (average of 10 stations/Perak from the 31-year period) from the daily analysis for each return period, and then divided by the duration to give rainfall intensities. This gives design rainfall intensities which are going to be used in the flood modelling.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Rainfall Station</th>
<th>Return Period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>Larangan</td>
<td>95</td>
</tr>
<tr>
<td>2</td>
<td>Kebon Agung</td>
<td>84</td>
</tr>
<tr>
<td>3</td>
<td>Gubeng</td>
<td>96</td>
</tr>
<tr>
<td>4</td>
<td>Wonorejo</td>
<td>84</td>
</tr>
<tr>
<td>5</td>
<td>Keputih</td>
<td>91</td>
</tr>
<tr>
<td>6</td>
<td>Kedung Cowek</td>
<td>104</td>
</tr>
<tr>
<td>7</td>
<td>Sememi</td>
<td>96</td>
</tr>
<tr>
<td>8</td>
<td>Banyu Urip</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>Gunung Sari</td>
<td>95</td>
</tr>
<tr>
<td>10</td>
<td>Perak</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>94</td>
</tr>
</tbody>
</table>

Source: SDMP

<table>
<thead>
<tr>
<th>Duration</th>
<th>Return Period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>5 minutes</td>
<td>172</td>
</tr>
<tr>
<td>10 minutes</td>
<td>138</td>
</tr>
<tr>
<td>15 minutes</td>
<td>125</td>
</tr>
<tr>
<td>30 minutes</td>
<td>95</td>
</tr>
<tr>
<td>45 minutes</td>
<td>75</td>
</tr>
<tr>
<td>1 hour</td>
<td>66</td>
</tr>
<tr>
<td>2 hours</td>
<td>40</td>
</tr>
<tr>
<td>3 hours</td>
<td>27</td>
</tr>
<tr>
<td>6 hours</td>
<td>13</td>
</tr>
</tbody>
</table>

Source: SDMP
Hydrograph for rainfall data then derived by using rainfall intensity data. Then, the hydrograph was synchronized with discharge of Brantas River discharge hydrograph. This is requirement in flood modelling so that simulation runs as close as possible to real conditions. Hydrograph for rainfall data used in this study is:

![Table 6-3 Rainfall Hydrograph](image)

### 6.3.3. Sea Tide

Because Surabaya is a coastal city, sea tide level plays an important role in flood modelling because water discharge from rivers within Surabaya is greatly influenced by sea tide level. Therefore, sea tide level data must be also included in flood modelling. One important consideration is that it is unjustified to combine sea tide return period with return period of river discharge and rainfall intensity. Sea tide has a different time frame with river discharge and rainfall intensity, i.e., both has increasing values during rainy season, while sea tide doesn’t shown similar increases.

To define the design value of sea tide level, at least three key factors are involved:

a) The state of the tide within the daily tidal cycle, i.e. does the high tide coincide with the flood runoff.

b) The state of the tide within the monthly tidal cycle, i.e. is it a spring or neap tide.

c) Variations from one monthly cycle to another, or from theoretical tide levels, for example storm surge.
SDMP already taking account of all the above points in its calculation, where it is considered that the design downstream boundary condition should have a peak equal to the average high tide in the peak wet season months plus allowance for sea level rise (i.e. 2.5 + 0.1 = 2.6m). Design sea tide level used in SDMP can be seen in following figure;

**Table 6-4. Design Sea Tide Level (m)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Design Tide (m)</th>
<th>Time</th>
<th>Design Tide (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:00</td>
<td>1.8</td>
<td>09:00</td>
<td>1</td>
</tr>
<tr>
<td>17:00</td>
<td>1.9</td>
<td>10:00</td>
<td>1.3</td>
</tr>
<tr>
<td>18:00</td>
<td>2.1</td>
<td>11:00</td>
<td>1.5</td>
</tr>
<tr>
<td>19:00</td>
<td>2.3</td>
<td>12:00</td>
<td>1.7</td>
</tr>
<tr>
<td>20:00</td>
<td>2.4</td>
<td>13:00</td>
<td>1.8</td>
</tr>
<tr>
<td>21:00</td>
<td>2.5</td>
<td>14:00</td>
<td>1.8</td>
</tr>
<tr>
<td>22:00</td>
<td>2.6</td>
<td>15:00</td>
<td>1.8</td>
</tr>
<tr>
<td>23:00</td>
<td>2.4</td>
<td>16:00</td>
<td>1.8</td>
</tr>
<tr>
<td>24:00</td>
<td>2.1</td>
<td>01:00</td>
<td>1.8</td>
</tr>
<tr>
<td>02:00</td>
<td>1.4</td>
<td>03:00</td>
<td>1</td>
</tr>
<tr>
<td>04:00</td>
<td>0.7</td>
<td>05:00</td>
<td>0.5</td>
</tr>
<tr>
<td>06:00</td>
<td>0.4</td>
<td>07:00</td>
<td>0.5</td>
</tr>
<tr>
<td>08:00</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: SDMP

**6.3.4. Surface Roughness**

Overland water flow in urban area is influenced greatly by the land use. Surface water is moving relatively more freely in open space and agricultural areas compare than built-up areas. Description about how difficult water movement on certain surface characteristics is called Surface Roughness, with the Manning Coefficient as the most commonly used parameter.

**Table 6-5. Manning Coefficient for Urban Areas**

<table>
<thead>
<tr>
<th>Land use</th>
<th>Manning’s Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
<td>1.00</td>
</tr>
<tr>
<td>Agricultural</td>
<td>0.04</td>
</tr>
<tr>
<td>Open Space</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Source: (Tennakoon 2004)

Surface roughness input for flood modelling is derived from land use map of Surabaya City. Generated raster map with manning value then used as an input for Bottom Friction Coefficient in SOBEK flood model.
6.4. Model Calibration

To improve the quality of the flood model, model calibration is performed by comparing the original modelling result with observations from previous flood events. The main principle of model calibration is that some parameters used in flood model may require tuning due to the possibility of data error or different benchmarking between parameters (i.e., 0 value of terrain elevation and sea tide). By calibrating the model, difference between model results and observed flood extents can be reduced.

Most commonly used parameters in model calibration are flood depth and flood extent. Available observations from previous flood event are flood extent, which can be found in Surabaya Drainage Master Plan document, which shows the flood extent during 2002 flood. In this study, model calibration was done by comparing flood extents from results of the model’s initial (1st) run and from 2002 flood events. Parameters used in initial run of the model are;

a. Upper boundary condition: 2% discharge of Brantas River downstream.
b. Rainfall Intensity : Design rainfall from Surabaya Drainage Master plan (SDMP)
c. Sea Tide : Design sea tide from SDMP
d. Surface roughness : Bottom friction map based on Manning’s Coefficient

By using above parameters, the model produced an unrealistic result, because flood extent is far too big compared to the observed 2002 flood event. A main concern of this result is the difference of benchmark between two values; Digital Elevation Model (DEM) and Sea Tide data. Minimum value of DEM is 0 m above sea level, while median value of Sea Tide data is 1.8 m. Therefore, for 2nd run of the model, sea tide data was adjusted so that median value of sea tide is corresponded with 0 value DEM.

**Figure 6-7. Sea Tide Adjustment**
The result of 2\textsuperscript{nd} run of the model, by using adjusted Sea Tide level shows a more realistic result because flood extent from the model is quite similar with the observed 2002 flood event. Although other parameters can also be adjusted to improve the result of the model, model calibration phase facing following difficulties;

- Hydrograph of Brantas River downstream is not tested, and there is no other data can be used as a reference to improve it.
- The model did not incorporate small rivers flowing into Surabaya City from eastward and southward directions.
- Computation time restricted number of simulations that can be run. Each simulation requires approximately 8 hours to complete.

Result of model calibration in this study can be seen in following figure;

### Figure 6-8 Model Calibration

6.5. Model Sensitivity

Analysis of model sensitivity was done by changing upper boundary condition, which is Brantas River downstream reach. As previously described, main source of river discharge entering Surabaya city is came from Brantas River, which on its downstream divided into two rivers, Kali Surabaya and Kali Porong. Relationship between these three rivers can be described by using a time-synchronized water discharge from different measurement stations. Observed monthly discharge between January 2002 and November 2006 and the relationship formula are;
Figure 6.9 shown that almost all water discharge from Brantas River is entering Porong River, and only small proportion is entering Surabaya River. Because of the presence Mud flood disaster, this proportion is threatened to be changed. Therefore, model sensitivity is developed by raising the percentage of water discharge entering Kali Surabaya.

Although discharge data for Brantas River Downstream is available for different return period, due to time constraints, only discharge for 2 years return period is going to be used in flood sensitivity analysis. Other consideration is that in urban areas, it is usual to design storm water drains for a return period of around 2 years. It is almost invariably found that designing for a more severe event cannot be economically justified because the increased costs outweigh the benefits arising from less frequent flooding. The effect of upper boundary condition adjustment to the results of the model, in term of flood depth, can be seen in the next figure;
Figure 6-10. Model Sensitivity Analysis (Flood Depth)

2% Brantas Discharge 10% Brantas Discharge
20% Brantas Discharge 30% Brantas Discharge
40% Brantas Discharge 50% Brantas Discharge

Depth

Kilometers

High : 2
Low : 0
Previous figures shown that there is no significant change in flood depth if upper boundary was set between existing condition (2%) and 30% Kali Brantas discharge. After 40% Brantas Discharge, the model showed a significant increase of flood depth. Model sensitivity in flood depth and flood velocity can be seen in following figure;

**Figure 6-11 Depth and Flood Extent Sensitivity**

Figure 6.7 shows that flood depth and flood extent have similar behaviour; if upper boundary condition of the flood model was set between 2% until 20% of Kali Brantas Discharge, there was no distinct behaviour of both parameters. If upper boundary of the model increased above 20% of the Brantas Discharge, there was a significant increase in average flood depth and inundated area. This model behaviour means that the present system of rivers within Surabaya City is sufficient enough to handle an increase of water discharge up until 20% of Brantas River discharge.

One important point that can be drawn from model sensitivity analysis is that current flood problem in Surabaya City is not caused by water discharge of rivers and primary channels within Surabaya City, but rather caused meteorological phenomenon, which are precipitation and sea tide changes. Storm is rarely seen in Surabaya City, and its presence usually influenced by global weather condition, such as observed during 2002 El Nino storm.
7. Flood Risk Analysis

7.1. Introduction

Flood Risk is a combination of different factors that together determine how big the loss to property and human life caused by flood is. Spatial extent of flood risk is the most popular parameter used in flood risk mapping. By this parameter, scale of flood is easily understood, and gives sufficient information about possible flood event. The most important information given by spatial extent of flood is where is the location of flood, and how big the size of inundated area. These to information are sometime enough for decision makers and people in affected area to prepare flood mitigation measures. However, combination of spatial extent of flood with other parameters can be very useful to improve flood mitigation measures. Risk is defined as the expected number or lives lost, persons injured, damage to property and disruption of economic activity due to flood event. Risk refers to the consequences of an event. The Risk Research Group uses a simple expression to define risk:

\[
\text{Risk} = \text{Hazard} \times \text{Elements at Risk} \times \text{Vulnerability}' \quad \text{(Dwyer 2004)}.
\]

This expression of risk is represented by the three-dimensional pyramid in Figure 7.1. The pyramid figure shows that risk is depend on three elements, hazard, vulnerability and exposure of elements at risk. If any of these three elements in risk increases or decreases, then risk increases or decreases respectively. The risk pyramid also shown that the three elements of risk can be visualized in three dimensions, with the volume of the pyramid representing risk. Each edge of the pyramid is proportional to the three factors; hazard, vulnerability and elements exposed. The greater the contribution of one of the factors, the greater the volume and therefore risk also increases.

![Figure 7-1 Flood Risk Parameters](Source: www.ga.gov.au)

Assessment of flood event cannot be calculated by the flood event itself, but must be combined by other parameters influenced by flood. For example, flood in urban area and flood in forest can have a totally different impact although both have similar characteristics (depth, duration, and velocity). To
analyse the impact of changes in Brantas River system to Surabaya City, various parameters must be combined together to produce a flood risk assessment that can give an information not only the extent of flood, but also the scale of its impacts.

Flood risk analysis phase in this study consists of three sections. First, analysis of flood hazard based on results from flood modelling. Then, flood hazard maps were developed to identify possible impacts of changes of Brantas River System to flood problems in Surabaya City. Second, vulnerability analysis of elements at risk to assess the impact of flood hazard to physical features in Surabaya City such as building and agricultural areas. Last, risk analysis was performed by combining flood hazard maps and vulnerability map. In this study, flood hazard, vulnerability, and flood risk were calculated in ArcGIS environment, by using one of its features, which is spatial analyst. There are two spatial analyst methods that implemented in this study; Conditional Method and Weighted Sum method. General overview of flood risk analysis in ArcGIS environment using Spatial Analysis can be seen in following figure;

Figure 7-2 Overview of Risk Analysis
7.2. Flood Hazard

Definition of Hazard is any phenomenon, either natural or human-induced, which has a potential to cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. However, hazard can be characterized in many ways based on the specific purposes. The impact of the natural hazard can be recognized in several aspects as listed below (Zulkarnain 2006):
1. Hazard to people – Death, injury, disease, stress
2. Hazard to goods – Property damage, economic loss
3. Hazard to environment – loss of flora and fauna, pollution, loss of amenity

Factors influencing flood hazard can be generalized into two components; human and natural component. Flood hazard maybe caused only by climate, but human activities, for instance deforestation and modification of river, has a significant impact on flood hazard. In more specific term, actors that affect hazard and the disruption caused by a flood could be grouped into four broad categories as follows:

- Flood behavior (severity of flood, response time, rate of rise, depth, flow velocity, duration, water quality and etc.)
- Evacuation issues (evacuation routes and time for evacuation).
- Population at risk (number and vulnerability of people, flood awareness).
- Emergency management (flood forecasting, flood warning, flood response, evacuation and recovery)

Flood hazard definitions traditionally were derived only from the flood extent, or inundated area. Recent development in flood modelling, like 1D2D in SOBEK, made it possible to analyze another parameters, such as flood event; flood depth, flood velocity, and flood duration, etc. Thus, output maps from 2D flood model provide a better way to develop more meaningful and user-friendly flood hazard maps with some additional flood parameters.

7.2.1. Factors Influencing Flood Hazard

Flood hazard can be described in various terms, either physical, social, or economical. The most widely used definition of flood hazard is in physical term, which consists of various parameters, like flood extent, flood depth, flood velocity, etc. Social and economical aspects of flood hazard usually derived from its physical aspects overlayed with other spatial characteristics. The reason for this phenomenon is that flood hazard assessment and mapping is much easier if based on spatial distribution or flood extent. Another physical characteristics can be easily added to improve assessment and mapping of flood hazard.

Flood depth is the most important factor to be added in the spatial extent of the flood hazard. Water depth in inundated area immediately has the impact to the damage caused by flooding. Overland flow module in SOBEK can easily produce flood depth information attached to the spatial extent of the flood. Based on these considerations, flood depth is used as the first parameter to be used in the calculation of flood hazard. Duration of flood also important factor to be included in flood hazard assessment, because damage to property and live can be greatly influenced by the length of inundation.
period. Flood duration can also give an information about the scale of flood hazard. Unlike flood hazard, SOBEK cannot automatically produced duration of flood as an output. This parameter must be derived from other output produced by SOBEK.

Another commonly used parameter in flood hazard assessment is kinetic energy of the flood, which derived from water velocity during the flood. Surabaya City has a very flat terrain, which means that water velocity during flood is relatively low, and kinetic energy of the flood is not strong enough to cause any damaged to property or human live. Therefore, those two parameters, flood depth and flood duration are considered sufficient to calculate flood hazard in the study area. Hence, the formula to defining flood hazard in this study is;

\[ Flood\ Hazard = f(Flood\ Depth,\ Flood\ Duration) \]

Where:
Flood Depth is the maximum depth of flood for each pixel within the simulation period,
Flood Duration is the inundation time for each pixel during simulation period.

7.2.2. Flood Depth
Flood depth information usually presented as maximum depth for each cell within simulation period. This way, the presence of flood hazard is clearly explained in both aspects, the size and the severity of the flood. Flood depth is described as distance between water level and bed level. Water level itself described as the level of the water surface relative to the model datum (terrain elevation). Bed level is defined as the lowest value of the cross sections for channel, and the terrain elevation for overland flow. Definition of flood depth can be seen in following figure;

**Figure 7-3 Flood Depth Definition**

\[ Flood\ Depth = Water\ Level – Bed\ Level \]

SOBEK can generates flood depth map file for each simulation time step, and at the end of simulation, SOBEK generates two files related to depth;
- Maximum water depth.
  In each cell the maximum water depth of all calculated time steps is written.
- Time of maximum water depth.
  In each cell is written after what period this maximum water depth has been reached.
- Rate of change of water depth.
  In each cell the difference in water depth is written between two depth map files divided by specified time step for simulation.

SOBEK generates maximum water depth value for the whole simulation written in ASCII file format, while the corresponding time step when the maximum water depth occurs also written in the same format. These files are generated if the option of water depth map generation is selected during settings of the model. Output files generated by SOBEK can be reclassified into flood depth classes for further analysis of the results. In this study, flood depth is reclassified using Quantile method, where the range of possible values is divided into unequal-sized intervals so that the number of values is the same in each class. Classes at the extremes and middle have the same number of values. Because the intervals are generally wider at the extremes, this option is useful to highlight changes in the middle values of the distribution.

By using Quantile reclassification method, flood depth below 0.17 meter is considered as a shallow flood, between 0.17 – 0.5 meter is considered medium flood, and 0.5 – 2 meter is considered a deep flood. An example of flood depth map, using 20% Brantas River Discharge as an upper boundary and its classified values can be seen in figure 7.7.

7.2.3. Flood Duration

Time scale of flood event also plays an important role in flood hazard analysis, because the duration of flood can influence the extent of damage and loss to properties. Although the relation between flood duration and threat to human live is not as strong as flood depth, prolonged inundation of flood can caused another threat to human live, such as diseases and lack of drinking water. Flood duration also has an effect to the evaluation of possible damage to infrastructures and access to emergency facilities. Until recently, flood duration is rarely included in flood hazard assessment because the difficulties to produce or to calculate flood duration. Unlike flood depth, which can be gathered from physical evidence of previous flood event, flood duration calculation requires a good flood modelling.

1D2D modelling in SOBEK cannot generate flood duration automatically. This information must be derived using integration of 120 flood depth created for each calculated time step (2 hours). First, all of 120 flood depth maps were reclassified into binary raster map with value 0 for cells without flood and value 1 for inundated cells. Then, all reclassified flood depth maps were summed up to get the flood duration map. The final flood duration map has a value between 0 and 120. Flood duration maps also need to be reclassified to be useful for flood hazard analysis. In this study, flood duration maps were reclassified with following values; < 1 day was classified as Short Flood, between 1 and 2 days was classified as Medium Flood, and longer than 2 days was classified as Long Flood. An example of
flood duration map, calculated by using 20% Brantas River Discharge as an upper boundary and its classified values can be seen in figure 7.8.

Flood duration classification map showed that almost all flooded areas have a long duration flood, which is longer than 2 days. The reason for this result is that upper boundary condition (Brantas River discharge) and rainfall data used an input in the model are based on 2 years return period data, and the flood duration map generated is also shown 2 years return period map. This value is considered acceptable, because in present condition, several parts of Surabaya City, especially along river banks, are annually inundated by flood. Another important remark is upper boundary condition used in model was 20% of Brantas River discharge, which is never happened after Brantas River was divided into Surabaya River and Porong River. As described before, in present condition, only around 2% of Brantas River discharge is entering Surabaya City through Surabaya River.

Both conditions, return period of input data and upper boundary condition made flood duration maps generated by the flood model show a larger value than existing condition. This difference is considered acceptable, since the objective of this study is to analyze the impact of changes in Brantas River System, not existing flood problems.

7.3. Flood Hazard Mapping

In this study, flood hazard map was derived from flood depth map and flood duration map. Two methods for flood hazard mapping were explored in this study; By Flood Hazard Zoning and Multi Criteria Evaluation (MCE). Both were calculated in GIS environment, where Conditional method was used for Flood Hazard Zoning, while Weighted Sum method was used for MCE. By using Conditional method, the resulted flood hazard maps have an ordinal scale, which each value represents its hazard level (for example, 1 = low, 2 = medium, 3 = high). On the other hand, calculation using Weighted Sum produced flood hazard maps that have a ratio scale, between 0 – 1. These value also represents the hazard level i.e., 0 means no hazard, and 1 means very hazardous.

7.3.1. Conditional Method

Conditional Method is a function available in ArcGIS Spatial Analyst that allows user to control the output value for each cell based on whether the cell value fulfil a certain specified conditional statement. If the cell value is fall within the specified value, it will receive designated value, and if the value of the cell fall outside the specified value. Based on conditional method, different flood hazard zones can be generated using the value of flood hazard parameters, which in this study are flood depth and flood duration.

Flood Hazard Zones is an area of land that is prone to flooding, and defined by its hazard level, which is for each cell, determined by location if its parameters inside hazard zones. Flood hazard zoning is the most widely used flood hazard mapping method because it can give a clear information about spatial distribution of flood problems. Some examples of flood hazard zoning method can be seen in following figure;
In this study, flood zoning method was used to generate flood hazard maps based on two parameters: flood depth and flood duration. As described before, both flood depth map and flood duration map are reclassified with certain cut-off values. Flood depth below 0.17 meter is considered a shallow flood, between 0.17 – 0.5 meter as a medium flood, and 0.5 – 2 meter is considered a deep flood. On the other hand, flood duration under 1 day is considered a short duration flood, between 1 – 2 days is considered a medium flood, and longer than 2 days is considered a long duration flood. Flood duration and flood depth were plotted in 2D Cartesian space, and two regression lines were drawn to connect each pair of cut-off values; 1 day duration connected to 0.17 flood depth, and 2 days flood duration connected to 0.5 flood depth. Flood hazard zoning then assigned to the zones bounded by the Cartesian coordinates and the regression lines.
Delineation of each hazard zone is:

Low Hazard Zone = \{ T_{(i,j)} < 1 - (5.88 \times D_{(i,j)}) \}

Medium Hazard Zone = \{ T_{(i,j)} < 2 - (4.00 \times D_{(i,j)}) \}

High Hazard Zone = \{ T_{(i,j)} < 2 - (4.00 \times D_{(i,j)}) \}

Where:
\[ T_{(i,j)} = \text{Duration of flood for each cell} \]
\[ D_{(i,j)} = \text{Maximum flood depth for each cell} \]

Flood hazard map then generated based by using combination of flood depth map and flood duration map in ArcGIS Raster Calculator environment with an equation described in (Tennakoon 2004):

\[ H_{(i,j)} = \text{CON}(T_{(i,j)} > (2 - [D_{(i,j)}], 3, [T_{(i,j)}] > (1 - [D_{(i,j)}], 2, [T_{(i,j)}] > 0 \& [T_{(i,j)}] < (1 - [D_{(i,j)}]), 1.0) \]

Where:
\[ H_{(i,j)} = \] Hazard level for each cell (1=Low, 2=Medium, 3=High)
\[ D_{(i,j)} = \] Maximum flood depth for each cell
\[ T_{(i,j)} = \] Duration of flood for each cell

Flood hazard map generated by this method can be seen in figure 7.9.
7.3.2. Weighted Sum

Flood hazard mapping can also be done by using another type of spatial analysis available in ArcGIS environment, which is Weighted Sum. In spatial analysis, Weighted Sum provides the ability to weight and combine multiple raster maps to create an integrated analysis. The general method of Weighted Sum is Overlays several rasters multiplying each by their given weight and summing them together. One important note regarding Weighted Sum tool is that maps generated using Weighted Sum method have a value in an interval-ratio scale. General overview of this method can be seen in following figure.

![Figure 7-6 Weighted Sum Method](source: ArcGIS Help)

Weighted Sum method can be improved by combining it with Multi Criteria Evaluation (MCE) method. In MCE, parameters are combined using Weighted Summation (WS) method, which is calculation of flood hazard based on weight and standardized value of the parameters. First step in WS is standardization of parameters used in calculation. There are different methods of standardization in WS, and for this study, maximum standardization was used.

In maximum standardization method, the scores for each cell are standardized with a linear function by using its own value and the highest value of the dataset. For benefit effect, highest score is indicated with 1, while for cost effect, lowest score is indicated with 1. Therefore, the result of this standardization method is a value between 0 and 1. Maximum standardization is recommended when...
the parameters used are measured in a ratio scale, and since all output of 1D2D flood modeling is also written in a ratio scale, this method is considered appropriate to use. The main advantage of maximum standardization is that the standardized values are proportional to the original values. Flood Depth and Flood Duration are considered a cost parameter, and the formula for parameter standardization is;

\[
D_{s(i,j)} = 1 - \frac{D_{(i,j)}}{2}, \quad T_{s(i,j)} = 1 - \frac{T_{(i,j)}}{120}
\]

Where;
\(D_{s(i,j)}\) = Standardized flood depth for each cell
\(D_{(i,j)}\) = Flood depth for each cell
\(T_{s(i,j)}\) = Standardized flood duration for each cell
\(T_{(i,j)}\) = Flood duration for each cell

The next step is an appraisal of the importance for each parameter. A weight value then given to each parameter indicates its importance. Weight for each parameter can be obtained by various ways, and the most commonly used is by direct ranking, which is assigning weight to a parameter by using the range of the criterion scores. Value range of the weights for each parameter is standardized values between 0 – 1 and the maximum added value of weights is 1. These range, however, depend on the standardization method and the original value. IF these range changes, for example due to a change in the standardization method or to an additional parameter, the assigned weights are no longer valid. In that case, the weighting must be done again.

In this study, flood depth and flood duration are considered equally important, and hence, both are given weight value of 0.5. Last step of WS is summation of the weighted and standardized values of all parameters. The formula of Weighted Summation for Flood Hazard mapping is;

\[
H_{(i,j)} = 0.5 * D_{s(i,j)} + 0.5 * T_{s(i,j)}
\]

Where;
\(H_{(i,j)}\) = Hazard level for each cell
\(D_{s(i,j)}\) = Standardized flood duration for each cell
\(T_{s(i,j)}\) = Standardized flood duration for each cell

From figure 7.6, we can see that flood hazard mapping using MCE is better than using Hazard Zoning, because the first can shown more variability than the latter. This is an important advantage because with higher variability, flood mitigation measures can be more effective. Another advantage of flood hazard mapping using Multi Criteria Evaluation is that the hazard value still written in a ratio scale, which is very useful for further use of generated flood hazard map. This is a contrast to a flood hazard map produced by hazard zoning method, which generalized flood hazard value into several classes.
Figure 7-7 Flood Depth Classification

Figure 7-8 Flood Duration Classification

Figure 7-9 Flood Hazard Classification

Based on Multi Criteria Evaluation

Based on Flood Hazard Zoning
By using changing upper boundary condition, different flood hazard maps can be generated by flood model to simulate the impact of changes of Brantas River System to flood problems in Surabaya City. In this study, different flood hazard maps were generated by gradually increasing water discharge entering Surabaya City, ranged between 2% - 50% of Brantas River discharge. The results of these upper boundary changes to flood hazard for 2 years return period in Surabaya City are;

**Figure 7-10 Flood Hazard Analysis (2 Years Return Period)**

From figure above, we can see that both average hazard value and flood hazard area are influenced by increasing water discharge entering Surabaya City. For average hazard value, its increase is constant, corresponds to increase of upper boundary condition values. On the other hand, the area of flood hazard shows a significant jump if water discharge entering Surabaya City is exceeding 20% of Brantas River discharge.

### 7.4. Vulnerability Analysis

Flood hazard map cannot completely fulfil the information requirement in urban flood management. Information about the extent of damage and loss in flooded areas is important. The extent of the damage cannot be predicted from the severity of the hazard alone, but depends also on the condition of the building stock. Predicting the risk of future damage needs a closer examination of the causes of damage and this is assisted by consideration of the three elements exposure, hazard, and vulnerability.

Therefore, there is a need to combine flood hazard with another parameters to develop more useful information for urban flood management. For this purpose, Risk Analysis was developed to analyze the impact of flood event to properties and human live in urban areas. Definitions of risk used in research vary with the applications for which they are used. Their basis lies in a common-sense understanding of the concept of risk, such as the notion that the risk associated with some particular hazard lies in the consequences of that hazard, and increases with both the probability and severity of the hazard.
The probability and severity of the hazard is not the only factor that affects risk. The risk also depends on how much building is exposed to the hazard and how vulnerable it is to damage. Further to this, risk can be seen graphically as a function of these three elements, hazard, exposure and vulnerability. If any of the three elements hazard, vulnerability or exposure, is absent there is no risk present, as can be demonstrated (Fedeski and Gwilliam 2007):

- Where buildings are located on a flood plain, both hazard and exposure are present in the event of a flood. However, if the buildings have been designed to be resilient to flood, vulnerability is absent, so there is no risk.
- Where a piece of flooded land contains no buildings, the hazard is present but exposure is absent, so again there is no risk.

Vulnerability refers to the capacity of an element exposed during the impact of a hazard event. Definitions of vulnerability to natural hazards generally refer to the characteristics of an element exposed to a hazard - road, building, person, economy – that contributes to the capacity of that element to resist, cope with and recover from the impact of a natural hazard(Dwyer 2004). The basic method to evaluate urban losses is dependent upon the development and use of stage-damage curves, alternatively called loss functions or vulnerability functions. A stage-damage curve normally relates to a specific class of buildings or another type of element at risk that can give information about the relationship between flood damage and depth flood depth. In this study, available data is not sufficient to conduct this kind of vulnerability analysis, because there is no information about stage-damage curve for building or building classes.

Another method to analysis the vulnerability in study area is by using information about and element at risk and its function. The function of element at risk can also used as parameter, because it can indicate how vulnerable the element is. For example, different building use (residential, commercial, public, etc.) can have different flood vulnerability.

Vulnerability value is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (high damage). There are different types of damage that can be caused by flood. The separation between damage types is based on several factors. The most common separation between types of damage is to distinguish between tangible and intangible damages based on whether or not monetary values can be assigned to the consequences of flooding. Examples of intangible losses include anxiety, inconvenience and ill-health. Tangible damages can be divided into the direct and the indirect. Direct damages result from the physical contact of flood water with damageable property.

Direct damages are a function of many variables. Some of these are controlled by the physical make-up of the flood prone area, which are the land use and its susceptibility to flood damage. Others are related to the characteristics of the flood event, including the area covered, the depth and duration of flooding, the velocity of flood water and its sediment and effluent content. Indirect damages are losses caused by disruption of physical and economic linkages of the economy. Examples include interruption of traffic flows, loss of industrial production, loss of personal income and business profit. It is further possible to conceive of secondary direct damages, such as damage due to gas explosion.
The basis for this reclassification is general assumption and local experience about different for each type of element at risk. Reclassification maps can be seen in figure 7.11, and vulnerability values for element at risk can be seen in following table:

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Element at Risk</th>
<th>Vulnerability Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Industrial, Chemical, Hospital</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Housing, Office, School, Market, Public, and Other Buildings.</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>Fishery, Agricultural</td>
<td>0.6</td>
</tr>
<tr>
<td>4</td>
<td>Open Space, Vacant</td>
<td>0.1</td>
</tr>
<tr>
<td>5</td>
<td>Water</td>
<td>0</td>
</tr>
</tbody>
</table>

7.4.1. Flood Risk Analysis

Flood risk then calculated by using parameters from previous step, which are hazard level and vulnerability. The result of this calculation if risk value, ranged between 0 – 1 that shows the level of possible damage inflicted by a flood event. However, due to some limitations, this study is not calculating the risk value in term of financial or social damage, but rather the scale of the damage caused by flooding. Previous phase of this study shown that there are different ways to generate flood-related map. An example of these methods is Flood Hazard Zoning and Weighted Sum. However, for risk mapping, these two methods are not valid anymore, because risk mapping is a function using two unrelated parameters, hazard and vulnerability.

This is contrast to hazard analysis which using different parameters, but still related each other (i.e., flood depth and flood duration). Another reason why Flood Zoning and Multi Criteria analysis cannot be use for calculating flood risk map is that flood risk is a function with a rule that both parameters must exist to have a risk value. Therefore, if any of the two parameter does not exist or have a value 0, flood risk also not exists. The most straightforward calculation method is by multiplication of Flood Risk parameters. The risk value for each cell is determined using following formula;

\[ R_{(i,j)} = H_{(i,j)} \times V_{(i,j)} \]

Where:

\( R_{(i,j)} \) = Risk value for each cell

\( H_{(i,j)} \) = Hazard level for each cell

\( V_{(i,j)} \) = Element at Risk Vulnerability
An example of risk map is shown in figure 7.12, which was calculated by combination of hazard level map for 20% Brantas River discharge generated using Multi Criteria Analysis method, and vulnerability of element at risk within Surabaya City.

**Figure 7-11 Element at Risk Vulnerability**

By using different boundary conditions, different flood risk maps can be generated. In this study, flood risk maps were generated using different upper boundary condition, simulating the gradual increase of water discharge entering Surabaya City due to changes in Brantas River System. Spatial distribution of flood risk in Surabaya City caused by increasing water discharge can be seen in following figure;
Figure 7-12 Flood Risk Maps (2 Years Return Period)

- 2% Brantas River discharge
- 10% Brantas River discharge
- 20% Brantas River discharge
- 30% Brantas River discharge
- 40% Brantas River discharge
- 50% Brantas River discharge
Beside spatial variation of flood risk visualized in previous page, flood risk can also draw in Cartesian coordinates, which shows the relationship between upper boundary condition and flood risk value. By using comparison of two parameters, Average Risk Value and Area of Risk with upper boundary conditions, their relationship is better visualized, as shown in following figure;

**Figure 7-13 Flood Risk Variation**
8. Flood Mitigation Scenarios

8.1. Introduction

Previous phases was try to model and explore the possible hydrological changes in Surabaya City due to changes in Brantas River System. Results of the model shown that changes in Brantas River System clearly can cause flood hazard in Surabaya City. Recent development in flood modelling, especially with introduction of 1D2D flood modelling in SOBEK, made it easy to change the settings and parameters of the model. In this study, different flood hazard and risk were developed by changing the value of parameters used in the model to simulate the different possibilities of changes in Brantas River System and its impact to flood problems in Surabaya City.

To develop Flood Mitigation Scenarios, different flood Scenarios was simulated by adjusting Surabaya River upstream boundary. These adjustments are done incrementally, between 2% and 50% of Brantas River Discharge to analyze the impact of each increase of water discharge entering Surabaya. 2% value was selected because this is the current percentage of Brantas River discharge that entering Surabaya River, while 50% of Brantas River discharge entering Surabaya River was selected because this value is considered the worst scenario. Main consideration about how many flood scenarios can be developed was time constraint, because each flood scenario requires a considerable amount of time (about 6 hours each).

Flood hazard and risk were generated by using different values of parameter, and different flood hazards and flood risk conditions are generated. Therefore, it is important to develop at least one flood mitigation measure for each condition. This is why this study was not only exploring one possible flood mitigation measure, but developing various flood mitigation measures scenarios, where each mitigation measures corresponds to one or more flood hazard and risk conditions.

Flood mitigation scenarios developed in this study are divided into two groups; Structural measures and Non-structural Measures. Structural measures scenarios described the possibility of adjusting the existing river regulatory structures and channel improvement to reduce flood hazard caused by changes in Brantas River System. Non-structural measure scenarios explore the possibility to develop policies and regulations to reduce flood hazard. Another aspect explored in Non-structural scenarios is previous changes in Brantas River System, and since the flood retardation capacity of Brantas River is constantly decrease, this study explores the possible efforts to restoring or increasing it.

8.2. Structural Measures Scenario

First group of flood mitigation scenarios is Structural Measures, which means changing the properties of the river system within Surabaya City. This scenario can be developed into two ways; by adjusting existing river system and by river and channel improvement. Regulatory structures adjustment clearly is the easiest and cheapest way to reduce flood hazard. The main problem of this scenario is that there
will be limitations in a sense that for a certain flood extent, regulatory structures adjustment will have no any significance to flood mitigation measures. Another important issue is that changes in regulatory structures must be done very carefully, because the wrong adjustment is not only useless to reduce flood hazard, but also can even increase the flood problems.

Adjustments of river regulatory structures can have a significant impact on flood hazard. By using this method, flood can be avoided by re-directing water discharge to channels with bigger capacity, or in case of flood is unavoidable, because different land use can have different flood vulnerability, water inundation in areas with high hazard proneness can be avoided in exchange of more flood in areas with less hazard proneness.

On the other hand, river system improvement by making the channels wider or deeper, or even by constructing new channels surely at some extents can reduce flood hazard. The main problem for this scenario is that in urban areas, widening the river or creating new channels are very difficult things to do. It is also possible that an urban area already reaches its maximum flood retardation and river system improvement is not efficient anymore because the cost required is much higher compared to its usefulness in flood hazard mitigation.

Structural measures scenario in this study was developed in following way; First, for lower value of upper boundary condition, river regulatory changes simulated with flood modelling to see its impact on flood hazard in Surabaya City. The model shown that until a certain cut-off value, regulatory structure adjustment is useful to reduce flood hazard and flood risk. Second, river and channel improvements were simulated using upper boundary condition above the cut-off value to simulate how efficient channel improvement scenario in reducing flood hazard caused changes in Brantas River System.

8.2.1. Regulatory Structures Adjustment

There are two structures inside Surabaya City that can be utilized to re-directing flood discharge; Jagir Dam, and Wonokromo Gate. In current Operation Rule (OR), Jagir Dam and Gunungsari Dam are fully opened, while Wonokromo Gate is opened at 50% capacity to avoid flood in Surabaya City. Up until now, this mechanism can well protecting Surabaya City because each time water discharge of Brantas River increases, excessive water can safely discharge to the sea through Porong River. Flood simulation using these settings produced extensive flooding in eastern part of Surabaya City. Therefore, regulatory structures are adjusted to redirecting water to northern part of the city, where flood extent is relatively low. Adjusted regulatory structures are Jagir Dam, which capacity was reduced to 20 %, and Wonokromo Gate, which is fully opened, against flood operation rule. Adjusted regulatory structures and its impact on inundated area and the size of area at risk can be seen in following figures;
Table 8-1 Regulatory Structure Adjustment

<table>
<thead>
<tr>
<th>Regulatory Structure Name</th>
<th>Current Adjustment (Operation Rule during Flood)</th>
<th>Proposed Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jagir DAM</td>
<td>Fully Open</td>
<td>25 % Capacity</td>
</tr>
<tr>
<td>Wonokromo Gate</td>
<td>50 % Capacity</td>
<td>Full Capacity</td>
</tr>
</tbody>
</table>

Figure 8-1 Adjusted Regulatory Structures

Figure 8-2 Impact of Structure Adjustment
Results of implementation of regulatory structure adjustment in the flood modelling show that by using this measure, average flood depth was reduced significantly and the size of area in risk also reduced. However, the reduction of area in risk is not as obvious as reduction of flood depth. The model also indicate that this mitigation measures only effective to reduce flood hazard if water discharge entering Surabaya City is only a small fraction of the whole Brantas River Discharge. In term of reducing average flood depth, adjustment or regulatory structures is only effective if water discharge entering Surabaya City is not exceeding 15% of Brantas River discharge, while in term of reducing the size the cut-off value is 3%.

8.2.2. Channel and Flow Improvement

Another possible structural measure that can be implemented to reduce flood hazard in Surabaya City is by improvement of rivers and water channels within Surabaya City. To explore the possibility of structural mitigation measures by channel improvement as anticipation to increasing water discharge entering Surabaya City caused by changes in Brantas River System, channel improvement method was simulated in 1D2D flood modelling environment. Although the cost to implement this method is much higher compared to regulatory structure adjustment, channel and flow improvement can cope with bigger flood problems. There are several factors that made channel and flow improvement is considered important to be implemented in Surabaya City, which are;

1. Model sensitivity phase in chapter 6 shown that flooding problems in Surabaya City have a significant increase if water discharge entering Surabaya City is bigger than 30 % of Brantas River Discharge. Therefore, it is logical to assume that current river system in Surabaya City only sufficient if water discharge entering Kali Surabaya is not higher than 30% of Brantas River discharge.
2. Adjustment of river regulatory structures can only cope with 20 % Brantas River discharge. This mitigation measure is only effective for only small increase of water discharge entering Surabaya. Thus, for higher water discharge, this method made the flood problems even worse.

One important aspect to be considered is which channels are going to give the best impact for flood hazard mitigation if they were improved. Improvement for every single river segment and primary drainage channel is not only too costly, but also improvement for some channels might not have an impact on flood hazard mitigation. Therefore, decision about which channels should be improved as an anticipation of changes in Brantas River System must be done with through consideration and also try to looking at the historical development of river and drainage system in Surabaya.

In this study, flood channel and flow improvement by creating a new diversion channel is considered as one of flood mitigation scenarios based on the fact that there is only one man-made diversion channel in Surabaya City, namely Wonokromo Channel. This channel was constructed in the year 1920, as anticipation for urban development in Surabaya City. Back then, Surabaya was only a small city, and built-up areas are only located in northern part of Wonokromo Channel. Land use plan that developed in the year 1950 also indicate that government of Surabaya City didn’t anticipating urban development at southern part of Surabaya, as can be seen in following figure.
Compared to existing to the present conditions (described in chapter 2), Surabaya was only a small city back in the year 1950. It is possible that Wonokromo Channel was not constructed as a diversion channel to cope with present Surabaya City development. It also possible that Surabaya City was not suppose to be developed as far as its present condition, but lack of development control and urbanization made Surabaya City grew until its current stage of development. Based on this consideration, it is important to develop a new diversion channel to cope with current flooding problems and also anticipation to the changes of Brantas River System.

There are two possibility of development of new diversion channel. First, a totally new diversion channel can be built. Second, a new diversion channel can be developed by improving the dimension of an existing channel. One river that has a big potential to be developed into diversion channel is Perbatasan River, located at southern part of Surabaya City. Compared to another channel, this river has advantages as follows;

1. Land cover around Perbatasan River is not fully built-up areas. Therefore, river improvement such as river widening is still possible.
2. Perbatasan River is located at the point where Surabaya River is entering Surabaya City, which means any excess water discharge can immediately discharged to the sea before entering the city. Despite its strategic location, this river has a very small dimension that made only a small volume of water can get through it.
3. Perbatasan River plays a role as a boundary between Surabaya City and Sidoarjo Municipality. Improvement of Perbatasan River as a diversion channel made this river can also play a role as a buffer zone between those two regions. Existing and proposed diversion channel can be seen in following figure.

![Figure 8-4 Existing and Proposed Channel](image)

To act as a new diversion channel, the dimensions of Perbatasan River must be improved. Due to time constraints, optimum dimension for channel improvement was not calculated to give a brief overview about how development of diversion channel can reduce flood hazard, cross section values of Surabaya River were assigned to Perbatasan River, and then 1D2D flood simulations were run using the new dimension of Perbatasan River. The result of simulations show that improvement of Perbatasan River as a new diversion channel can reduce the amount of water entering Surabaya City. If the dimension of Perbatasan River was improved at least similar to the dimension of Surabaya River, water discharge from upper reach of Surabaya River will be divided equally. Thus, flood hazard in Surabaya City can be reduced because any excess water can directly discharge to the sea through improved Perbatasan River. Surabaya River and Perbatasan River discharge without and with channel improvement can be seen in Appendix 2.
8.3. Non-Structural Measure Scenario

Previous analysis shows that structural measures have a high possibility to be useful in reducing flood hazard caused by changes in Brantas River System. However, flood mitigation measures can be improved by combining structural and non-structural mitigation measures. Although structural mitigation measures can give a direct impact on reducing flood hazard, in many situations, especially where the risk of flooding is very high, that structural measures can not cope anymore, non-structural measures are important measures to reduce the risk and damage caused by flooding. The key aspect of non-structural mitigation measures is reducing flood hazard without physical intervention of the existing hydraulics network (Parkinson 2005). In this chapter, two non-structural flood mitigation measures are discussed; First, by improvement of catchment area along Brantas River basin. This scenario explores previous changes in Brantas River system, and possible interventions that can be implemented to increase flood retardation capacity of Brantas River. Second, by development control on areas with high flood hazard, and possible policies and regulations to prevent extensive urban development on such areas.

8.3.1. Catchment Area Improvement

The possibility of increasing Water discharge entering Surabaya City is not only caused by the presence of mud flood disaster in Sidoarjo, but also by the fact that water discharge of Brantas River has a tendency to increase annually. Therefore, even without the presence of mud flood disaster, Surabaya still facing flood hazard due to the increasing amount of water discharge entering the city. Thus, there is still a requirement to develop flood hazard mitigation measures based on the possible increase of water discharge.

The changes of Brantas River discharge has been studied by Toshikatsu Omachi, and the result indicate that in the recent three decades, due to check of sediment by reservoirs and excessive extraction of the riverbed materials, violent degradation of riverbed has occurred and this trend is ongoing. These changes resulted in the runoff mechanism of floods in the basin. This study also indicates that the basin storage capacity of the Brantas River basin has almost halved in the past 30 years, which resulted in a faster and higher runoff peak.

Since 1980’s, the riverbed of Brantas River gradually lower due to the sediment deposition along upper reach and sand extraction in the middle and lower reaches. Extensive deforestation in Brantas and gradual increase of cultivation areas in mountain hillside plays a major role in sediment deposition and sand extraction along Brantas River Basin. Natural forests are very limited, and if any exist, high economic value of trees such as mahogany and teak caused them threatened by illegal logging. Forest cover on the Brantas River basin made up only 25% of the whole area, and decrease of flood retardation capacity of catchment area in Brantas River basin can related to the lack of forest cover.

Another factor that plays a significant role on changes in Brantas River system sedimentation, that predominantly produced by volcanic activities of mountains such as Mount Semeru, Mount Arjuno, and Mount Kelud, which are still active volcanoes, and their activities, combine with extensive land use changes in Brantas River’s catchment areas, made sedimentation problems worsen every year.
Sediment deposition and sand extraction have opposite effect to the Brantas River; sediment deposition caused decrease of discharge capacity, while sand extraction leads to increase capacity of Brantas River. Because sand extraction has a higher rate than sediment deposition, there is a constant increase of discharge capacity in Brantas River while on the other hand, retarding capacity of Brantas River significantly decrease. These changes in Brantas River caused constant increase of flood hazard problem in Brantas River basin and its affected areas, including Surabaya City.

Based on previous changes of Brantas River system, improvement of catchment area can also be promoted as a part of flood mitigation measures to reduce flood hazard in Surabaya City. Although catchment area of Brantas River covers a big area, where Surabaya City is a just a small part of it, the strategic role of Surabaya City as the capital of East Java Province made implementation of catchment improvement of Brantas River is considered important. The most important aspect of catchment area improvement is to increase or restore its storage capacity by reforestation. With adequate forest on catchment area, the runoff rate can be reduced, and sudden increase of water discharge in Brantas River can be minimized.

**8.3.2. Development Control**

Urban development control is a considerably more cost-effective flood mitigation measure compared to other methods. To reduce and minimize exposure to elements at risk of flooding, land use controls can be implemented. Intervention in form of development control are strongly connected to the land management and urban planning, especially development controls over flood-prone areas. One most widely used development control for flood hazard mitigation is development restrictions, either partial or full, on flood-prone areas. This method is facing some challenges, especially ones caused by high demand of land in cities, which made development restrictions are very difficult to implement. It is up to local government to implement development control which involves alternative uses for the land in order to insure that urban development does not occurs on flood-prone areas.

Development control measures explored in this study is Flood Zoning, which is widely used as a basis for land use control. Development control by zoning involves the designation of the proper mitigation measures for each mitigation categories, and can be used by urban authorities control the type of allowed development or redevelopment on such areas. Flood zoning is a planning tool which may be used to assist flood mitigation strategies by identifying the most appropriate action to reduce flood hazard and this approach can be used as the basis for development of legal measures for land development.

Development control of flood-prone areas are based on two parameters; First, Flood Scenario Class, which is based on different upper boundary conditions to simulate different possible scenario of flooding in Surabaya City caused by changes in Brantas River System. One important assumption related to this parameter is that the higher the percentage of Brantas River entering Surabaya City, the lower the chance it occurs. Therefore, a new value can be assigned to flood scenario map, where smaller values are assigned to higher percentage of water entering Surabaya City, and vice versa.

Second parameter used in the construction of development control zones is land use, because main features of development control scenario are how often it is likely to flood and its impact on land use.
This scenario requires a set of legal mechanism to prevent urban development, and also needs to be supported by financial and economic measures to discourage development in such areas (Parkinson 2005). Development control classification can be seen in following figure.

**Figure 8-5 Development Control Zones**

In Figure 8.6, both parameters are reclassified into classes based on its characteristics related to flood hazard. For Flood Scenario, higher percentage of water entering Surabaya City is less likely to occurs, and therefore, lower class value was assigned. For land use, type of land uses that are more tolerable to flood hazard are assigned lower class value, while higher class values were assigned for land uses which is vulnerable to flood. Maps of both parameters and the result of this construction of development control zones can be seen in following figure.
9. Conclusion and Recommendation

9.1. Delta Brantas River System

Lower reach of Brantas River, or often called Delta Brantas, is a complex river system which consists of several rivers and regulatory structures. This system is covering a large area, including Surabaya City and Sidoarjo Municipality. There are three main rivers in Delta Brantas River System, which are Brantas River as the main river, Surabaya River, and Porong River, a man-made diversion channel which was constructed to protect Surabaya City from flooding. These three rivers are connected to each other, and changes in each river will have an impact to another.

Water flow through rivers in Delta Brantas is regulated by two main regulatory structures; Lengkong Barrage, a regulatory structure that constructed to regulate water flow through Porong River, and Mlirip Weir, which regulate water intake of Surabaya River. Maximum water discharge of Brantas System is around 1,500 m$^3$/s, which most of it is was discharged to sea through Porong River. Only 2% of Brantas River discharge was entering Surabaya City through Surabaya River.

Main institution that has the biggest role in Delta Brantas River management is Jasa Tirta, Inc. (PJT), a public corporation which was set up in the year 1990 to improve the management and operational aspects of water resources in Brantas River Basin. Adjustment of regulatory structures within Delta Brantas River System is PJT’s responsibility, and the main purpose of regulatory structure adjustment is to balance water supply and demand in both dry season and rainy season. During flood events, there are some Operation Rule (OR) regarding adjustment of regulatory structures that must be followed by PJT. If adjustment of regulatory structure can not cope with water discharge and flood occurs, PJT must establish a coordination line with Government of East Java Province, and together, deciding what are the best mitigation measures to reduce damage caused by flood.

Current Operation Rule of regulatory structures within Surabaya City is proven to be effective against any increase of Brantas River discharge, and flooding caused by increasing river discharge is very rare. The established flow regulations in Delta Brantas River System is threatened by the presence of mud flood in Sidoarjo, nearby municipality from Surabaya. Presently, mud from this disaster is discharged to the sea through Porong River, and caused some sedimentation problems in lower reach of Porong River. This sedimentation caused discharge capacity of Porong River is decreased, and therefore, its function as a diversion channel to protect Surabaya City is also reduced.
9.2. Flood Risk Analysis

Analysis about how changes of Brantas River System can caused flood problems in Surabaya City consists of three parts; Flood Hazard Mapping, Vulnerability Analysis, and Risk Mapping. Flood hazard mapping is a process to generate maps that can give information about physical characteristics of the flood. The most common parameters used in flood hazard mapping are flood depth, flood duration, and kinetic energy. Because Surabaya City has a very flat topography, kinetic energy analysis will be irrelevant because flow velocity is considerably low. Combination of flood depth and flood duration proven to be sufficient enough to produce a good flood hazard map.

For flood hazard mapping, this study explores the implementation of two spatial analysis methods available in ArcGIS environment; Conditional Method and Weighted Sum method. The use of conditional method in flood hazard mapping is very common, and the result of this method is flood hazard zoning. On the other hand, Weighted Sum method is rarely used to produce flood-related maps. Each method has its own advantages and drawbacks, and the choice about which one should be implemented is strongly related to the purpose of flood hazard mapping.

If the objective of flood hazard mapping is only to analyze flood hazard, not extended to risk analysis, then flood hazard zoning method is a better way to develop flood hazard maps. This method will have information about the scale of the flood, i.e. high, medium, and low, which in some cases is very useful to support local authorities when dealing with flood problems. The main drawback of flood zoning method is that the information stored in Ordinal scale, which is not suitable to be used in mathematical function (i.e. addition and multiplication). Therefore, flood hazard maps developed by using flood zoning method are not suitable to be use for further risk analysis.

In contrast to flood zoning method, Weighted Sum method is proven to be very useful for further development of flood hazard maps. This study combined Weighted Sum method with Multi Criteria Evaluation (MCE) and the result shown that implementation of MCE in flood hazard analysis proven to be useful for further analysis of flood problems. With MCE method, information about flood hazard is stored in Interval-Ratio Scale, which is very suitable for mathematical calculations required in flood risk analysis. One drawback of flood hazard mapping using MCE method is that there is no classification of flood hazard, which is sometimes required in flood mitigation measures.

Flood hazard mapping is not enough to explain the extent of flood problems in urban area, because urban settlement has various object that can be influenced differently by flood. Therefore, vulnerability analysis is an important step to improve flood hazard analysis by adding urban entities into account. Combination of Flood Hazard and vulnerability is called Flood Risk, which is defined as the presence of two aspects; flood hazard and element at risk. This study was tried to perform vulnerability analysis of element at risk from flooding, and due to some limitations, especially time constraints, vulnerability analysis was based on assumptions and local experiences, not by actual vulnerability of elements at risk. Still, the results of risk analysis are most likely very useful for the anticipation of changes of Brantas River system.
Results from 1D2D hydrological modelling developed in this study show that changes in Brantas River system caused by the presence of mud flood in Sidoarjo has a significant impact to both flood hazard and flood risk in Surabaya City. If this mud flood keeps on continuing, capacity of Porong River will be reduced, and bigger percentage of Kali Brantas discharge will entering Surabaya City. Increase of flood hazard in Surabaya City is not significant if water volume of Surabaya River does not exceeding 30% of Brantas River discharge. This is an indication that existing rivers and channels within Surabaya City can cope with certain increase of water discharge.

9.3. Flood Mitigation Measures

Both mitigation measures, structural and non-structural measures were explored in this study, and the possibilities of implementation for each measure were also analyzed. Different flood scenarios were developed, and each impact to flood hazard problems was assessed. For structural measures mitigation scenarios were developed by using river regulatory structures and channel improvement. For non-structural measures, catchment area improvement and development regulations to reduce flood hazard were developed.

Structural measures are easy to assessed, because it can simply be simulated using flood model to analyze its impact on flood problems. Regulatory structures adjustment and channel improvement can be simulated by changing cross sections of channels within possible range. On the other hand, non-structural measures is difficult to assessed because it developed in form of policies and regulations not related to the physical characteristics of river system.

The flood modelling results shows that regulatory structures adjustment is only effective if changes of Brantas River system do not caused water discharge entering Kali Surabaya River more than 20% or Brantas River discharge. If discharge of Kali Surabaya River exceeding 20% Brantas River discharge, regulatory structures adjustment made the flood problems even bigger. Therefore, implementation of this mitigation measures must be done with a great cautions, to avoid unnecessary flood problems caused by the wrong adjustment of regulatory structures.

Beside structural measures, non-structural measures is also important to be implemented. Direct impact of non-structural measures in reducing flood problems cannot observed immediately, but rather can be expected at long term. By improving catchment area of Brantas River, its flood retardation capacity can be increased and subsequently reducing flood threats to Surabaya City. Thus, catchment area improvement can also prevent future changes on Brantas River Basin that can have a negative effect on its water storage and flood retardation capacity. Development controls are required to be implemented to regulate development in flood prone areas according to its flood hazard level. Development control zones are constructed based on two parameters; the probability of occurrence and existing land use. Based on these parameters, development controls for flood prone areas can be categorized as high, medium, and low development control zones. For certain areas, where flood hazard is very high, development should not be allowed at all.
9.4. Recommendation to Surabaya City’s Government

Results of this study clearly indicate that changes of Brantas River System can caused a significant increase of flood problems within Surabaya City. Efforts to minimize flood hazard can only effective at certain level. For example, regulatory structures adjustment can only effective if water entering Surabaya not exceeding 10% of Brantas River discharge. Channel improvement by creating a new diversion channel also a mitigation measure that should be considered by Government of Surabaya City, because currently there is only one diversion channel exists in Surabaya City, the Wonokromo Channel, which was built in the year 1922. Current development of Surabaya City is already far beyond its condition when Wonokromo Channel was constructed. Therefore, a new diversion channel is required in Surabaya City to cope with current flood problems, to anticipate changes in Brantas River System, and also to cope with future development of Surabaya City.

Government of Surabaya City must should decide at what extent flood hazard caused by changes of Brantas River System is still acceptable, and then develop regulations to prevent flood hazard exceeding acceptable level. If it was decided that water discharge entering Surabaya River must not higher than 30% of Brantas River discharge, Mlirip Weir must be adjusted to prevent higher discharge of Surabaya River, and then implementing regulatory structures adjustment to reduce flood hazard. This adjustment might protect Surabaya from flood, but can caused flooding in other areas along Delta Brantas River System.

On the other hand, if Government of Surabaya decided to construct a new diversion channel, river system within Surabaya City can cope with much higher water discharge. This mitigation measure not only protect Surabaya from flooding, but also can protect agricultural areas along Delta Brantas River System. Although construction of new diversion channel by improvement of an existing channel is far more costly than other mitigation measures, but its impact will be very significant to reduction of flood problems in Surabaya City, and can cope with future flood problems caused by the constant development of Surabaya City.

A broader flood mitigation measures which involves governments along Brantas River basin will be very useful to reduce flood problems in Surabaya City. Improvement of catchment area requires involvement of all authorities of local governments and institutions related to water and river management to be effective in reducing flood hazard. A special flood mitigation measures must be developed between government of Surabaya City and Sidoarjo Regency, because mud flood disaster in Porong has a direct impact on both regions.
9.5. **Recommendation for Future Studies**

This study was only analyzing the possible impact of changes of Brantas River System to flood problems in Surabaya City and its possible flood mitigation measures. To improve flood management in Surabaya City, various flood modelling using recent development in hydrological simulation such as 1D2D in SOBEK can be developed. Some recommended future studies are;

1. 1D flood model developed in Surabaya Drainage Master Plan can be transformed to an advanced 1D2D flood modelling. 1D flood model can not give information about flood extent if water discharge is exceeding channel capacity. Data availability in SDMP for development of 1D flow is considered very complete, and it only required an additional 2D data models such as Digital Surface Model (DSM) to develop an appropriate 1D2D model.

2. Flood modelling can be developed for broader area, even for the whole Brantas River Basin, and because there are some cities along Brantas River, a general flood mitigation measures for each city can be developed.

3. Apart from flood hazard caused by changes of Brantas River System, 1D2D model can be developed to simulate the comprehensive hydrological system in Surabaya City that can be very useful in flood hazard management in Surabaya, not only the one caused by changes of Brantas River System, but also problems caused by natural events, such as storm, constant increase of sea tide, and even tsunami threat.

4. This study shown which areas has a higher hazard level than others. A detailed 2D flood modelling can be developed in such areas or other areas that are considered critical, such as hospital, chemical storage, and industrial area, to develop a local flood mitigation measures that can protect flood prone and critical areas.
REFERENCES


Ramu, K., P.E., Dr (2002). "Brantas River Basin Case Study Indonesia." *Agriculture and Rural Development Department, World Bank.*


APPENDICES

Appendix 1. Regulatory Structures of Delta Brantas River System

Mlirip Weir

Lengkong Barrage
Appendix 2. Impact of Channel and Flow Improvement

<table>
<thead>
<tr>
<th>Without Channel Improvement</th>
<th>With Channel Improvement</th>
</tr>
</thead>
</table>

- **Kali Surabaya Discharge (m3/s)**
- **Kali Perbatasan Discharge (m3/s)**
Appendix 3. Model Schematization in SOBEK