GIS Modelling of River and Tidal Flood Hazards in a Waterfront City

Case study:
Semarang City, Central Java, Indonesia

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February 2003

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By

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Thesis submitted to the International Institute for Geo-Information Science and Earth Observation in partial fulfillment of the requirement for the degree of *Master Science in Geo-Information Science and Earth Observation, Natural Hazard Studies specialization*.

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Abstract

Semarang is a water front city situated on the lowland part of Central Java province in Indonesia. River and tidal floods frequently occur in this area. Local planners and decision makers are in need accurate information on the spatial distribution, magnitude and depth of flooding, and on the landuse affected by it. The integration of GIS and hydrologic models is an active area of research. The present research intends to contribute to this as well. The objectives of this research are: 1) to construct a river flood model in a GIS environment, 2) to construct a tidal flood model in a GIS environment, and 3) to validate and evaluate both models, and to assess flood hazards in a waterfront city.

The applied methodology comprises 5 phases; 1) Preparation 2) Fieldwork and data acquisition 3) Modelling 4) Validation, evaluation, and hazard assessment, and 5) Reporting. Preparation phase comprises of literatures study, ancillary data collection, and fieldwork preparation. Fieldwork and data acquisition phase comprise spatial and hydrological data acquisition e.g. DEM, topographic map, landuse map, river flood map, tidal flood map, river discharge, manning coefficient, river cross sections, and drainage system. Modelling phase consists of the building and running two types of models using hydrological software and GIS environment, i.e.: the river flood model and the tidal flood model. Validation, evaluation, and hazard assessment phase comprises the validation of the models using a confusion matrix of model result against reliable source map to get accuracy and reliability. The hazard assessment has been done by map calculations and table operations to analyze landuse affected by floods. On the reporting phase, whole research process has been translated in a conclusions and recommendations.

The spatial patterns of the river flooding and tidal flooding are depicted in maps. It indicates that the flooded area mostly covers coastal and alluvial landforms. For the tidal flood model, the highest tidal water level (155.43 cm in November 2000) was used in the iteration procedure. Some areas are known to have no flooding, such as the harbor and airport. Also the sea area should be left out of the tidal flood model calculation. Hence, the DEM values on these areas have been replaced with manipulated value. The average accuracy and reliability of the river flood model is 77% and 76% respectively. The average accuracy and reliability for the tidal flood model is 89% and 83% respectively. Total area of river flood is 1245, 78 Hectare, and total area of tidal flood is 1514 Hectare. Landuse types influenced by the river floods are: built up area, fishpond, agriculture and others with the area affected is 510,57; 164,12; 1,34; and 711,68 hectare respectively. Landuse types influenced by the tidal flood are: built up area, fishpond, agriculture and others with the area affected is 814,56; 2,26; 231,94; and 461,86 hectare respectively.

Keywords: *GIS Modelling, hydrological modelling, river and tidal flood, flood hazard assessment.*

Acknowledgement

After an eighteen months struggle, finally here it is! It went slow, but with the help from several people I managed to finish this M.Sc Thesis. Though space is limited here, I would like to express my thanks to the staff and fellow students for their valuable assistance to this study.

Firstly, a big thanks you to my two supervisors, Dr Ir Tjeerd W Hobma and Drs Michiel Damen for their assistance and encouragement. I am deeply indebted to them for their ideas, and methodologies, especially in the field of flood hazards, GIS solutions and hydrological modelling.

I also want to acknowledge Dr Cees Van Westen, Drs Robert Voskuil, and Drs N.C Kingma for their kind cooperation. I am deeply indebted to them for the materials provided during my study in Natural Hazards. And thanks for the field experience in Italy. It has been really precious and worth wile to me.

I am very grateful to the people who gave me suggestions and valuable data. As there are: Ir Rosyid (Semarang Public Work Office), Prof Dr Sudarmadji M.Eng.Sc, Drs Suyono M.S, Dr Junun Sartohadi, M.Sc, and Drs Sudaryatno M.Si (Gadjah Mada University), Drs M Helmi (BIOTROP/WAINDOW SPECTRA Bogor), Ir M Farhan (Bappeda), also Dr Ir Agus Hardoko M.Sc (Fishery Department, Diponegoro University).

I would like express my thanks to the Dean of Geography Faculty in Gadjah Mada University; to the Head of the Environmental and Physical Geography Department; and to other staff in the Geography Faculty, for their encouragement to study in ITC, far away in The Netherlands.

To my colleagues in “hazards”, Njagih (Kenya), Malkem (Ethiopia), Bamutaze (Uganda), Antonio (Mexico), Viera and Edoris (Cuba), Yuan; An; Sung ping; and Gao yan (China), Graciela (Colombia), Prasun and Dr Singh (India): “I am grateful to you!”

My profound gratitude goes to the Indonesian students in ITC 2000; 2001; and 2002, for hospitality in the Malindo café and to Heri for the Semarang data. Special dedication and gratitude goes out to Arindita Dessi, a cheerful lady who streams spirit, and provided not only her notebook to work on my thesis but also accompanied me during hard-pressed time. You were great! Also my sincere thanks to my counterparts for discussion Arif and Arlan. I would also like to thank the Indonesian Student Association in Enschede (PPIE), and IMEA (Indonesian Moslem community in Enschede) for their friendship.

The blessings of my parents and family, as well as my parents in law and their family enabled me to come across all the hurdles. My deepest regards to them. And affectionately, my eternal gratitude goes to my cute wife Vira Ardiati. “The hardest thing was not on defending and writing the thesis,we wish Allahumma Alifbainna Khulubina…”.

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Chapter 1 Introduction

Flood is defined as extremely high flows or levels of rivers, lakes, ponds, reservoirs and any other water bodies, whereby water inundates outside of the water bodies area. Flooding also occurs when the sea level rises extremely or above coastal lands due to tidal sea and sea surges. In many regions and countries floods are the most damaging phenomena that effect to the social and economic of the population (Smith et, al., 1998).

Nowadays computer-modelling techniques have assisted scientists and engineers with determining floods as well as flood assessments. Computer models for the determination of flood effect generally require four parts (Snead, 2000), these are: 1) the hydrologic model which develops rainfall-runoff from a design storm or historic storm event, 2) the hydraulic model which routes the runoff through stream channels to determine water surface profiles at specific locations along the stream network, 3) a tool for floodplain mapping and visualization, and 4) the extraction of geospatial data for use in the model(s).

The key to graphical visualizations on the hydraulic modelling is the inclusion of the series data within a spatial interface, such as a Geographical Information System (GIS). Nowadays, the state of the art technology in the field of Geographic Information System (GIS) allows spatial analysis as well as to generate the modelling for a flood hazard phenomenon. The generally known basic functionality of GIS is input, analysis and presentation of spatial data. With regard to flood hazard studies, GIS is an important tool to do data capture, input, manipulation, transformation, visualization, combination, query, analysis, modelling and output. This study intends to construct models using integration of hydrological software and GIS environment.

1.1. Problem definition

Semarang is a coastal urban area situated on the lowland part/coastal area of Central Java province in Indonesia. As a provincial capital city, Semarang has developed and grown as a big city on Central Java. The residential growth and industrial expanses in Semarang City contribute to the land subsidence and flooding. Land subsidence occurs due to building loads (residential houses and industrial building) and groundwater pumping, particularly on the clayey sediments layer, by then the ground will be lowered from previous elevation. Semarang has three different types of flooding. These are referred to as: *banjir lokal* (locally flood inundation), *banjir kiriman* (river flood) and *banjir rob* (tidal flood). Local flood inundation and river flood occur due to high rainfall intensity combined with insufficient urban drainage system. Local flood inundations in particular places have been identified to be due to the drainage malfunction and stoppage, as well as improper places for waste disposal.

Meanwhile, tidal flood occurs due to high tidal waves overflowing coastal land. The effect of tidal floods increases every year. This is because of the replacement of naturally flooded areas by industrial estates. These are also related to the fact that the lowland areas are subsiding.

Combined river and tidal floods frequently occur, especially in the lowland (coastal urban) area. Therefore, information on the river and tidal flood, such as spatial distribution, magnitude and depth of flood, and the landuse affected by flooding, are needed for the urban decision maker. Several Studies pertaining to the flood hazard problem of Semarang have been done. Nevertheless, research on the integration of GIS and hydrologic modelling has not been done in the area.

1.2. Objectives and practical tasks

The main objectives of this research are:

1. To construct river flood model in a GIS environment.
2. To construct tidal flood model in a GIS environment.
3. To validate and evaluate both models, and to assess flood hazards in a waterfront city.

The main objectives have been elaborated into three sets of practical tasks.

Set 1:

a. Generating the geometric data for river flood modelling.
b. Computation of hydrological data and construction of river flood model.
c. Spatially performing the river flood model.

Set 2.

a. DEM manipulation in order to update DEM, and to define the iterations process.
b. Performing the tidal flood model using the neighbourhood function in ILWIS.

Set 3:

a. Digitising reliable source maps of river and tidal floods for validation.
b. Calculation of the accuracy and reliability of the models.
c. Evaluate the model results.
d. Assessment of the river and tidal flood hazards.

The tasks gave rise to some question on methodology and approach. These are shown in Table 1.1.

Table 1.1 List of research question

No	Task	Questions
1	Generating the geometric data for river flood modelling	• What kind of data is needed to generate the geometry for modelling?
		• How to generate the geometry and what does the result look like?
2	Computation of hydrological data and construction of river flood model	• What kind of data is needed for the hydrological analysis?
		• How is the construction of river flood modelling look like?
3	Spatially performing of river flood model	• How to perform the river flood model as apart of the spatial analysis?
		• How does the spatial pattern of the river flood look like?
		• Which geometric data mostly influence the river flood model?
4	DEM manipulation in order to update DEM, and to define the iterations process	• What data is needed to correctly manipulate the DEM?
		• How to update the DEM?
5	Performing the tidal flood model using the neighbourhood function in ILWIS	• How to define the source as a “start” raster map for the iteration process and what data is needed?
		• How to perform the iteration process and how does the iteration result look like?
		• Which are the most important factors for generating the tidal flood model?
6	Digitising reliable source maps of river and tidal floods for validation	• What kind of reliable source maps area available and what are the characteristics of those maps?
7	Calculation of the accuracy and reliability of the models	• How to perform the calculation to obtain the accuracy and the reliability of the river and tidal flood models?
		• What are the accuracy and reliability of the model results?
8	Evaluate the model results	• What are the advantages and limitations of the river flood model?
		• What are the advantages and limitations of the tidal flood model?
10	Assessment of the river and tidal flood hazards	• How to calculate the distribution of water depth of the river flooded area?
		• How to calculate the distribution of water depth of the tidal flooded area?
		• What is the impact of river flood, especially the correlation with landuse?
		• What is the impact of tidal flood, especially the correlation with landuse?

1.3. Literature review

1.3.1. Flood hazards

Floods are disastrous natural phenomena, which result in numerous losses of life and property. Many factors cause floods. In general, the reasons for increasing flooding in many parts of the world are (Smith et, al., 1998):

1. Climatological events; such as excessively prolonged rainfall cause river floods. Estuarine and coastal floods are usually caused by combination of high tides and the elevated sea level and large waves associated with storm surges, which result from severe cyclonic weather systems.
2. Changes in Landuse and increasing population; changeover from rural area to built up area potentially causes floods. Many of the sites that are subject to flooding, such as coastal plains, estuarine areas, lakes shores, and floodplains are also subject to preferential location by industries, commerce and private housing. Urbanization, building density and population density have on effect to drainage capacity and soil infiltration capacity, and well finally increase overland flow on the volume of runoff. Although urban areas occupy less than 3% of the earth's land surface, the effect of urbanization on flood hazards is disproportionately large.
3. Land subsidence; land subsidence is the process by which the level of the ground is lowered from its previous elevation. When a tidal wave comes from the sea or water overflow from the river, the lower parts of the ground due to the land subsided will be inundated. Land subsidence in coastal and alluvial floodplain areas causes extensive flood inundation.

The dangers of floodwaters are associated with a number of different characteristics of the flood. A summary of the characteristics and related hazards (Kingma, 2002) is given below:

1. Depth of water; building stability against flotation and foundation failures, flood proofing, and vegetation survival, have different degrees of tolerance to inundation.

2. Duration; time of inundation applies to structural safety, the effect of interruption in communication, industrial activity and public services, and the life of plants.
3. Velocity; high velocities of flow create high erosive forces and hydrodynamic pressures. This features often result in complete or partial failure of structures by creating instability or destroying foundation support.
4. Sediment load; high rates of sedimentation can especially in agricultural areas cause high damage depending on the growing season.
5. Rate of rise; the importance of rate of rise of river level and discharge is in its relation to the time available for evacuation and flood fighting arrangements.
6. Frequency of occurrence; cumulative frequency of occurrence of the various hazards is therefore a major factor in the development of Landuse.

1.3.2. GIS modelling flood hazards

Geographic Information System has exhibited two principal advantages for natural hazard mitigation and research. First, the technology allows storage of the information, which may prove invaluable in future situations. Secondly, GIS improves information accessibility. In term of natural hazard studies, GIS give contribution for data display, storage and retrieval, site selection, impact assessment, and modelling. Table 1.2 is shown an example of GIS application for natural hazard management, (DRDE-US, 1991).

Table 1.2. Examples of GIS applications for natural hazards management

Function	Potential Applications
Data display	Aid in the analysis of spatial distribution of socio-economic infrastructure and natural hazard phenomena
	Use of thematic maps to enhance reports and/or presentations
	Link with other databases for more specific information
Land Information Storage and Retrieval	Filing, maintaining, and updating land-related data (land ownership, previous records of natural events, permissible uses, etc.)
Zone and District Management	Maintain and update district maps, such as zoning maps or floodplain maps
	Determine and enforce adequate land-use regulation and building codes
Site Selection	Identification of potential sites for particular uses
Hazard Impact Assessment	Identification of geographically determined hazard impacts
Development/Land Suitability Modelling	Analysis of the suitability of particular parcels for development

Source: Adapted from Levine J., and Landis, J. "Geographic Information Systems for Local Planning" in Journal of the American Planning Association (Spring, 1989), pp. 209-220, cited from DRDE-US, 1991 with modification.

A representation of the real world into a simple form can be considered a model. There are two types of models, namely static models and dynamic models (De By 2001). Static models generally represent a single state of affairs. Dynamic models or process models put emphasis on changes that have taken place, are taking place, or may take place. Models can also be defined according to their form, namely scale, conceptual, and mathematical model. Scale models are representation of real world physical phenomena such as a digital terrain model (DTM). Conceptual models use a quasi-natural language or flowchart to outline the components of the system under investigation and highlight the linkage between them. Mathematical models operationalise the conceptual models, by using scale models to organizing their data, by representing their component and interactions with mathematical formulations (Stayaert, 1993; and Wegener 2000 in Sutanta 2002).

Nowadays the integration between GIS software and hydrological modelling software has been developed for various purposes. One of them is HEC-GeoRAS, which is an arc view GIS extension specially designed to process geospatial data for use with the Hydrological Engineering Center River Analysis System (HEC-RAS). HEC-RAS can be used to perform river flood using floodplain encroachment analysis. (Usage, 2000). The results can be present in a geospatial format using HEC-GeoRAS (Usage, 2001).

1.4. Previous research

In this project, literature and information from previous research has been used as references. An overview has been compiled of previous research work on the basis of area and year of study, methodology and approach, data, and results. The overview gives description diversities in methodology and approach. The resume of relevant flood research and previous research on flooding and land subsidence in Semarang are shown in Table 1.3 and Table 1.4 respectively.

Table 1.3. Resume of relevant flood research in the period 1997-2002

Researcher	Year and location	Methodology/ approach	Data	Result
Kresch, David L. et.al	2002, Olanchito Honduras	Hydrological method using HEC-RAS and HEC-GeoRAS software	DEM, Stream discharge, geometric data, manning's roughness coefficients	Fifty-year flood-inundation maps
Mastin, Mark C. et.al	2002, Santa Rose de Aguan, Honduras	Analytical method using HEC-RAS and HEC-GeoRAS software	DEM (Lidar), Stream discharge, geometric data, manning's roughness coefficients, storm surge data	Fifty-year Storm-Tide Flood-Inundation maps
Pistocchi, A, et al	2002, Romagna River basin	HEC-RAS, and HEC-HMS for hydrological risk	Rainfall, temperature, discharge, hydraulic cross-section, DEM, network water level gauging.	Hydraulic modelling, risk assessment, scenario comparison
Mastin, Mark C.	2002, Honduras	Flood map and constructing a hydraulic model using HEC-GeoRAS and HEC-RAS program	Annual peak discharge, precipitation, and topographic data (DEM)	Flood hazard map and Hydraulic model
Badilla Coto, Elena	2002, Turialba, Costa Rica	Geomorphological mapping, identified element at risk Damage and risk assessment using hypothetic cost value	DEM, Landsat TM, Cadastral map, topographic map, aerial photo, Meteorological data	Flood hazard assessment, Vulnerability analysis, Damage estimation and risk assessment
Snead, Daniel Baldwin	2000, Mill Creek Watershed, Ohio	MIKE 11, HEC-RAS, HEC-HMS, Arc View, HEC-GeoRAS	Stream geometry, streambed resistance factors, time-series flow, spatial data (geometric and terrain data)	Unsteady flood models using GIS (MIKE 11 and HEC-RAS)
Andrysiak Peter B. et al	2000, Mill Creek Watershed, Ohio	Integration HEC-HMS, HEC-RAS with GIS	Hydraulic data (plan, geometric, steady flow, unsteady flow, sediment, and hydraulic design data)	Watershed and Basin model, Hydrological model (peak discharge, water surface profiles and visual floodplain representation
Dasanto Bambang Dwi	2000, Bojonegoro-Tuban-Lamongan, East Java, Indonesia	Field observation, Image processing and interpretation (Tasseled-cap), GIS Technique	Aerial photo panchromatic black and white, and Landsat TM	Geomorphological map, hazard map, risk classification and map.
Islam, Monirul, et.al	2000, Bangladesh	Flood analysis using flood-affected frequency and flood depth	NOAA AVHRR, geologic, physiography, drainage, and population maps.	Flood hazard, Population category map, and Land development priority
Choundhury, Nusha Yamina	1998, DMA and DND polder, Bangladesh	Visual interpretation, GIS technique	Spot XS, IRS-IC, aerial photo, topographic map	Flood risk map for 1/50 year and 1/100 year

Table 1.4. Previous research on flooding and land subsidence in Semarang

Researcher	Year and location	Methodology/ approach	Data	Result
Heri Sutanta	2002, Semarang City	Image Interpretation, collecting Ground Control Point (GCP), GPS measurement.	Aster and Landsat +ETM, DEM data, GCP data.	Land subsidence scenario, spatial modelling of impact of sea level rise
Ferrari Pinem	2002, Part of Semarang, Garang River Catchment	Image interpretation, Hydrological analysis.	Landsat TM 1997, Aerial photo interpretation, Rainfall data.	Flood susceptibility map, Inundation map.
Sudaryatno	2000, Garang River Catchment, Semarang	Image interpretation, Rational Method for peak discharge calculation, GIS approach	Landsat TM 1997, fieldwork, hydrological data analysis	Runoff coefficient, Hydrograph analysis, Peak discharge calculation.
Yasin Yusuf	1999, Part of Semarang, Central Java, Indonesia	Visual interpretation, Pragmatic Geomorphological approach	Panchromatic black and white aerial photo and Infrared aerial photo, Landuse map, contour map, Drainage map, and Flooded area map.	Landform, Flood Susceptibility, Damage, and Hazard map.
Agus Nefo	1997, East Semarang, Babon River Catchment	Hydrological data analysis	Rainfall data, Discharge data.	Peak discharge, flood analysis. Spatial distribution of flood.
Marfai, Muh Aris	2003 (this research) Part of Semarang Central Java, Indonesia	Integration Hydrological software and GIS Environment (HEC-RAS, HEC-GeoRAS, Arc View and ILWIS)	Digital elevation model (DEM) Hydrological and geometrical data	River flood model, Tidal flood model, Validation result, Model evaluation and Hazards assessment

1.5. Thesis structure

The structure of this thesis consists of seven chapters. These chapters are organized as follows:

Chapter 1, this chapter introduces the background, problem definition in the area, and objectives and practical tasks. It also includes a literature review on flood hazards and GIS for flood hazard assessment. An overview is compiled of previous research, which gives the information as a reference for this research.

Chapter 2, deals with the methodology. The applied methodology comprises 5 phases. 1) Preparation, 2) Fieldwork and data acquisition, 3) Modelling, 4) Validation, evaluation, and hazard assessment, and 5) Reporting. Preparation phase comprises of literatures study, ancillary data collection, and fieldwork preparation. Fieldwork and data acquisition phase comprise spatial and hydrological data acquisition. Modelling phase consists of the building and running two types of models using hydrological software and GIS environment, i.e.: the river flood model and the tidal flood model. Validation, evaluation, and hazard assessment phase comprises the validation of the models using a confusion matrix of model result against reliable source map to get accuracy and reliability. The hazard assessment is done by map calculations and table operations to analyze landuse affected by floods.

Chapters 3,deals with the explanation of the physical environment and landscape characteristics of the study area, which includes geographic position, meteorology and hydrology, geology and geomorphology, soil and landuse, and natural hazards. The geographical location of Semarang city makes the city play an important role for regional development, especially in Central Jawa.

Chapter 4, this chapter deals with the first objective, which is the generation of the river flood model in a GIS environment. At first, the geometry for river flood modelling is generated using the HEC-GeoRAS and Arc View software. Then, the hydrology model is computed using HEC-RAS software. Finally, the results of the river flood are processed in the spatial analysis.

Chapters 5, addresses the second objective, namely the generation of the tidal flood model. First, the DEM is manipulated and the iteration process defined. Then, the model is constructed using the neighbourhood function in ILWIS for tidal flood simulation.

Chapters 6, discusses the third objective, to validate and evaluate the river and tidal flood models, and to assess floods hazards in the coastal urban area. Topics discusses are: 1) Digitising reliable source maps of river and tidal floods for validation. 2) Calculation the accuracy and reliability of the models. 3) Evaluate the model results. 4) Assessment of the impact of river and tidal flood hazards using cross map functions and histogram analysis. The assessment involves the calculation of the flooded area for each water depth classes and determines landuse affected by floods.

Chapter 7 Presents the conclusions that have been derived from this research, followed by recommendations.

Chapter 2 Methodology

Different methodologies have been applied to each objective of this research. Hydrological software has been applied in a GIS environment method to generate the river flood model. A Neighborhood operation on raster data is has been applied to generate the tidal flood model. For validation of the model results a confusion matrix and a cross map operation has been applied. The map calculations and table operations are part of a simple flood hazard assessment, which is to describe the distribution of water depth and the impact to landuse.

The methodology of this research comprise of 5 phases, namely; 1) Preparation, 2) Fieldwork and data acquisition, 3) Modelling, 4) Validation, evaluation, and hazard assessment, and 5) Reporting. Preparation phase comprises of literatures study correlate with the topic, ancillary data collection, and fieldwork preparation. Fieldwork and data acquisition phase comprise spatial and hydrological data acquisition e.g. DEM, topographic map, landuse map, river flood map, tidal flood map, river discharge, manning coefficient, river cross sections, and drainage system. Those data have been used to generate the model, validate, evaluate, and assessment also to describe the physical environment and landscape characteristics on the study area. Modelling phase consists of the building and running two types of models using hydrological software and GIS environment, i.e.: the river flood model and the tidal flood model. River flood model has been generated using integration between HEC-RAS software for hydrological analysis, HEC-GeoRAS and Arc View for geometric data and spatial representation of the model. Tidal flood model has been created from neighborhood function (iteration) in ILWIS software. Validation, evaluation, and hazard assessment phase comprises the validation of the models using a confusion matrix of model result against reliable source map to get accuracy and reliability. Evaluation of the model is to determine the advantages and limitations of the models. The hazard assessment has been done by map calculations and table operations to analyze landuse affected by floods. The last phase is reporting whole the research activities and results. The detail methodology is presented in Figure 2.1.

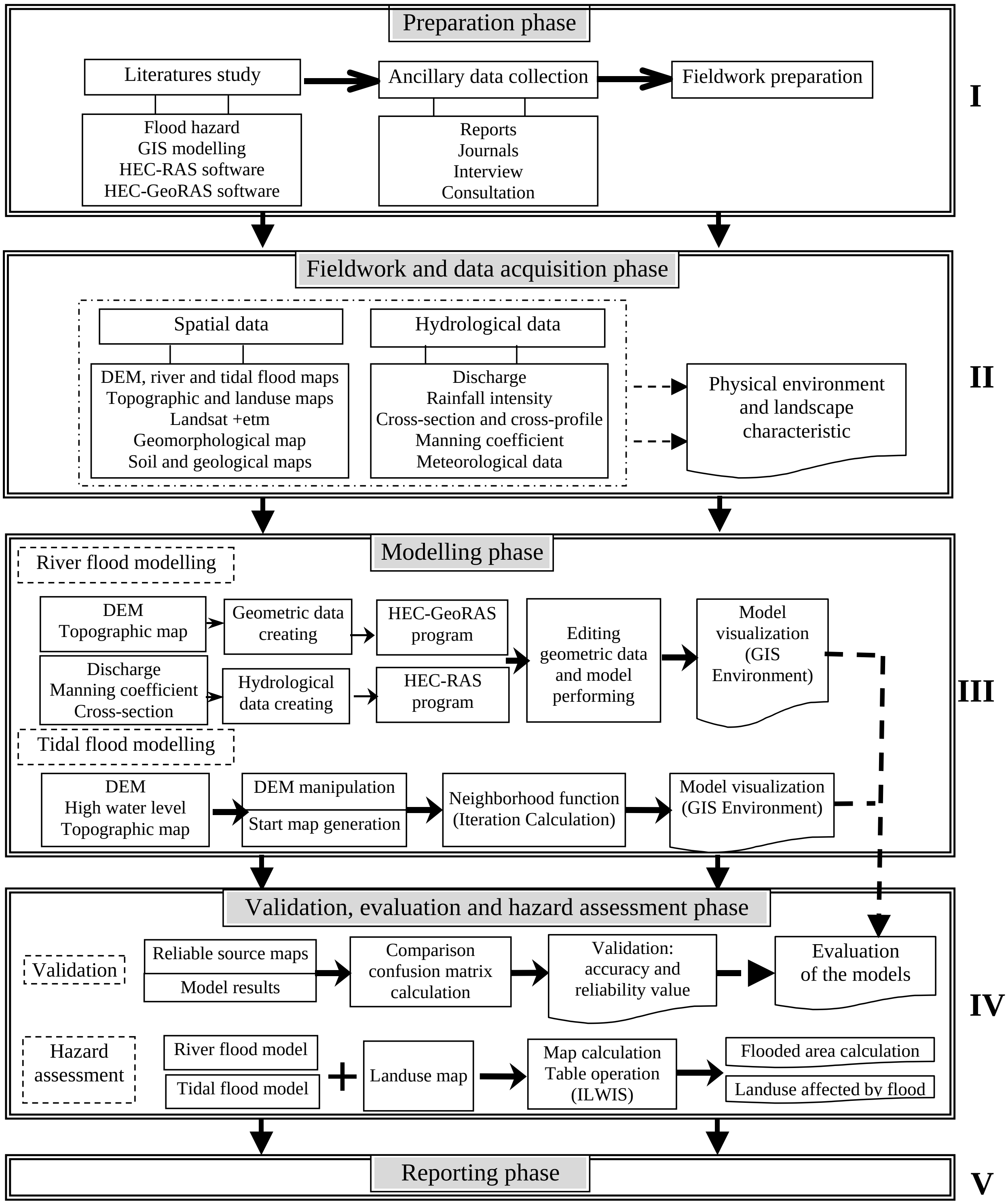


Figure 2.1. Research methodology

2.1. Preparation phase

This phase comprised activities such as literatures study, ancillary data collection, and fieldwork preparation. Literature study was done along the research process. This has been carried out in order to obtain research knowledge and develop the methodology as well. The literature studied mostly deals with flood hazards, GIS modelling, and more specifically HEC-RAS software, and HEC-GeoRAS software. The literature on flood hazard studies includes the causes of flooding, processes, and their impacts. In addition, flood hazard assessment was studied. GIS modelling was studied, especially to obtain knowledge on the use of the hydrological software in a GIS environment. The Hydrologic Engineering Center-River Analysis System (HEC-RAS) was studied and elaborated in order to know how to apply this software to the case study of Semarang with crude and limited data. Also the HEC-GeoRAS software was studied. This software provides facilities to translate the hydrological model result into the GIS environment. Using HEC-GeoRAS and the Arc view software, the spatial analysis would be done. In addition, literature study involved the neighbourhood operation in order to know how to perform this function in the iterative operation of the tidal flood model.

The next step in the preparation phase is ancillary data collection. In this step, reports and journals on the topic of research have been collected. Previous research reports have been collected, especially on the Semarang Area and its problem. Reports from the Public Works office project; thesis reports from Gadjah Mada University (UGM); reports from the board of Regional planning and Development (Bappeda); previous MSc thesis reports (such as Sutanta, 2002); and project documents from the Japan International Cooperation Agency (JICA) have been studied. These and other reports were used as a reference on the study area, and for writing chapter 3 (physical environment and Landscape characteristics), as well as for the model validation. In addition, valuable information has been obtained by undertaking several interviews and consultations. The objective was to develop the researcher’s knowledge in scientific and technical aspects as well as to develop the methodology to do this research. This has been done by visiting, discussion, and electronic mail communication with experts in flood hazards and GIS modelling, Hydrological modelling, and urban planning. Key experts consulted were: Dr. Ir Tjeerd.W. Hobma (ITC Coastal hydrologist) and Drs Michiel Damen (ITC Coastal morphologist), Dr. Chris Mannaerts (ITC Environmental hydrologist), Drs Nanette Kingma (flood hazard), Ir rosyid (Public Work Office), Prof Dr Sudarmadji M.Eng.Sc and Drs Suyono M.S. (UGM, Urban Hydrology), Drs M Helmi (BIOTROP/WAINDOW SPECTRA Bogor), Ir M Farhan (Bappeda), Dr Ir Agus Hardoko M.Sc (Fishery Department, Diponegoro University). The last step on the preparation phase is the fieldwork preparation. This step involves the design route and points of observation, accommodation in the field, obtaining research permits from the local government, and organizing field equipment.

2.2. Fieldwork and data acquisition phase

This phase comprised the fieldwork activities. Spatial data and hydrological data have been collected during the fieldwork from several offices dealing with the topic of study. Observations have been done along the river to check cross-sectional data obtained from Public Works Office and to check landuse surrounding the river and floodplain area as well. This was done to estimate the surface roughness or Manning coefficients as a river flood model requirement. The details of the spatial data and hydrological data, as well as their sources are shown in Table 2.1 and Table 2.2.

Table 2.1 Spatial data for this research

No	Spatial Data	Source
1	Digital Elevation Model (DEM)	Created from photogrammetry high spot, with 100 m interval on the hilly area, and 200 m interval on the lowland area (Sutanta (2002).
2	Topographic Map, scale 1: 50,000	BAKOSURTANAL (Indonesian survey and mapping coordination agency)
3	Detail Topographic map, scale 1:5,000	Public Works Department "Semarang Urban Drainage Master Plan Project 2000"
4	Landuse map, scale 1:5,000	Public Work Department "Semarang Urban Drainage Master Plan Project 2000"
5	Landsat +ETM 2001	BAKOSURTANAL (Indonesian survey and mapping coordination agency) and preveous research (Sutanta 2002)
7	Administration map, scale 1:50,000	Regional planning and development agency (BAPPEDA) Semarang, Indonesia
8	River flood map, 100 year return period on the Garang River	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.
9	Tidal flood map	Public Works Department "Semarang Urban Drainage Master Plan Project 2000"
10	Geological map, scale 1:50,000	Mine and geological office, Semarang, Indonesia
11	Geomorphological map	Research report (Studi Kerentanan dan Bahaya Banjir Sebagian Wilayah Kotamadia Semarang Propinsi Jawa Tengah, Sebuah pendekatan geomorfologi pragmatis, Yusuf 1999)
10	Soil Map	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.

Table 2.2 Hydrological data for this research

No	Hydrological data	Source
1	Climate data (Temperature, wind velocity, and Humidity data)	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.
2	Rainfall Intensity	Public Works Office and Previous research (Sudaryatno 2000)
3	Discharge Normal discharge Peak discharge (100 year return period)	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.
4	River cross-section	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.
5	River cross-profile (upstream to downstream)	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.
6	Manning coefficient	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.
7	Drainage system	Japan International Cooperation Agency (JICA) project "Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans" 1993.

2.3. Modelling phase

This phase consists of the building and running two types of models i.e.; the river flood model and the tidal flood model. The main input and reference data for the river flood model is a DEM and a detailed topographic map. From those data the geometric data has been was created. Other important input data is discharge, Manning coefficients, and cross section data. Those are used for hydrological data pre-processing, which is requested by the hydrological modelling software. The geometric data have been created through the HEC-GeoRAS program. This software is running as an extension in the Arc view GIS software. For generating the geometric data the topographic map is used as a guide for creating several theme files. For creating the hydrological data, the HEC-RAS program has been used. This software is hydrological software that provides the computation of the hydrologic factors for river flood model. This software also provides geometric data correction facilities, which is to edit the geometric data based on the hydrological data, attribute data, and other secondary data. The geometric data editing involved Manning coefficients and cross-sections editing. The geometric data and the hydrological data for the river flood model is shown in Table 2.3.

Table 2.3 Geometric data and hydrological data for river flood model

No	Geometric data creating (Using HEC-GeoRAS and Arc View)	No	Hydrological data creating (Using HEC-RAS)
A	**Creating RAS themes**	**A**	**Steady flow data**
1	Stream centerline theme	1	Normal Discharge
2	Main channel bank theme	2	Peak Discharge (100 year return period)
3	Flow Path centerline theme		Boundary condition
4	Cross-sectional cut lines theme	1	Normal depth
5	Polygon Manning coefficient	2	Water surface elevation
B	**Theme attributing**	**B**	**Geometric data editing**
1	Centerline completion	1	River station
2	XS Attributing	2	Bridge condition
3	XS Elevation	3	River junction
		4	Manning coefficient
		5	Cross-section editing
		6	Channel modification

After generation and editing in the HEC-RAS program, the river flood model can be calculated. The model results have been can be transformed into GIS file by Arc View software.

For the tidal flood model generation, a detailed DEM, high water level data, and a topographic map are needed. For the tidal flood model generation a neighborhood function has been used. A neighborhood function is one of the spatial analyze on the raster format provided by ILWIS software. The iteration operation is one of the neighborhood functions in ILWIS. Iteration is successive repetition of a mathematical operation, using the result of one calculation as input for the next. The calculation stops when the difference of the output compared to the input is negligible or if the number of iterations as defined before is reached (ILWIS user guide 2001). In an iteration operation, a value raster map is needed. In this case, the DEM is the value raster map for iteration. Due to the dynamic character of the sub-surface condition on the study area, especially in the lowland and coastal area, the DEM data has to be modified. The iteration requires pixels source on start map, due to the tidal flood start spreading from the coastline, the start map was located along the coastline.

2.4. Validation, evaluation, and hazard assessment phase

This phase is dealing with the validating, evaluating of the models and assessment of the floods. For validation of the model results, cross maps between model results and reliable source maps have been calculated. The accuracy and reliability values are used to validate the model. Accuracy and reliability value is obtained from confusion matrix method at Table operation in ILWIS. In this case, accuracy is the fraction of correctly classified reliable source map (or as a ground truth) pixels of a certain reliable source class (flooded and not flooded area). For each class of reliable source pixels, the number of correctly classified pixels divided by the total number of reliable source pixels in that class. And the reliability is the fraction of correctly classified reliable source map (or as a ground truth) pixels of a certain class in the model result. For each class in the model result (flooded and not flooded area), the number of correctly classified pixels is divided by the total number of pixels which were classified as this class. The reliable source map for the river flood model validation is the map from the Japan International

Cooperation Agency (JICA), under the project of “Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Sub Urbans”. On the tidal flood model validation, the reliable source map come from the Public Work Office Project, under the name “Semarang Urban Drainage Master Plan Project”. Once the cross map between the tidal flood model and reliable source map was done, the accuracy and reliability value have been calculated.

Evaluations of the river flood model and the tidal flood model have been done by analyzing and evaluating the input data, processes and model results. The analytical approach for the evaluation of the model also determines the advantages and the limitation of the software and operation chosen.

Flood hazard assessment consists of calculation of the distribution of the flooded area for each water depth class, and determines the impact of the flood to the landuse. The assessment has been done using the map calculation and table operation in the ILWIS software. In fact, the distribution of the flooded area each water depth class is important input for the vulnerability and risk assessment. But this study does not going trough to the vulnerability and risk assessment. The Landuse map was obtained from the interpretation of aerial photos on scale 1: 10000, produced by Public Works Office Project in 2001. The detailed landuse map has scale 1:5000. Determination of the impact of the flood to the landuse have been done to know the landuse classes affected by the flood, as well as to describe the spatial pattern of landuse affected by flood.

2.5. Reporting phase

This is the final phase of the thesis research. In this phase the whole research process is translated in conclusions and recommendations. The reporting phase is also important and necessary to communicate the research results to other people as well as to make a good documentation. All data, procedures and documents have been documented in a CD-ROM, and a research paper is in preparation.

Chapter 3 Physical Environment and Landscape Characteristics of the Study Area

Semarang is the main port and capital city of the Central Java Province. It is located at the northern coast of Java and 540 km East of Jakarta at South Latitude $6^0$56'08" to $7^0$06'57" and East Longitude of 110^0 16' 17" to 110^0 30'31". The city covers an area of approximately 400 km^2; the main activities are industrial estate, trade, education, and tourism. Most of the commercial and industrial areas are built on the flat coastal plain with elevations ranging from 0-10 m. Semarang has a population of more than 1.3 million in 1991, and this has been projected to be about 2 million in 2025 (http://www.semarang.go.id, and Sutanta 2002). Semarang consists of 16 sub-districts. Semarang area is shown on Figure 3.1.

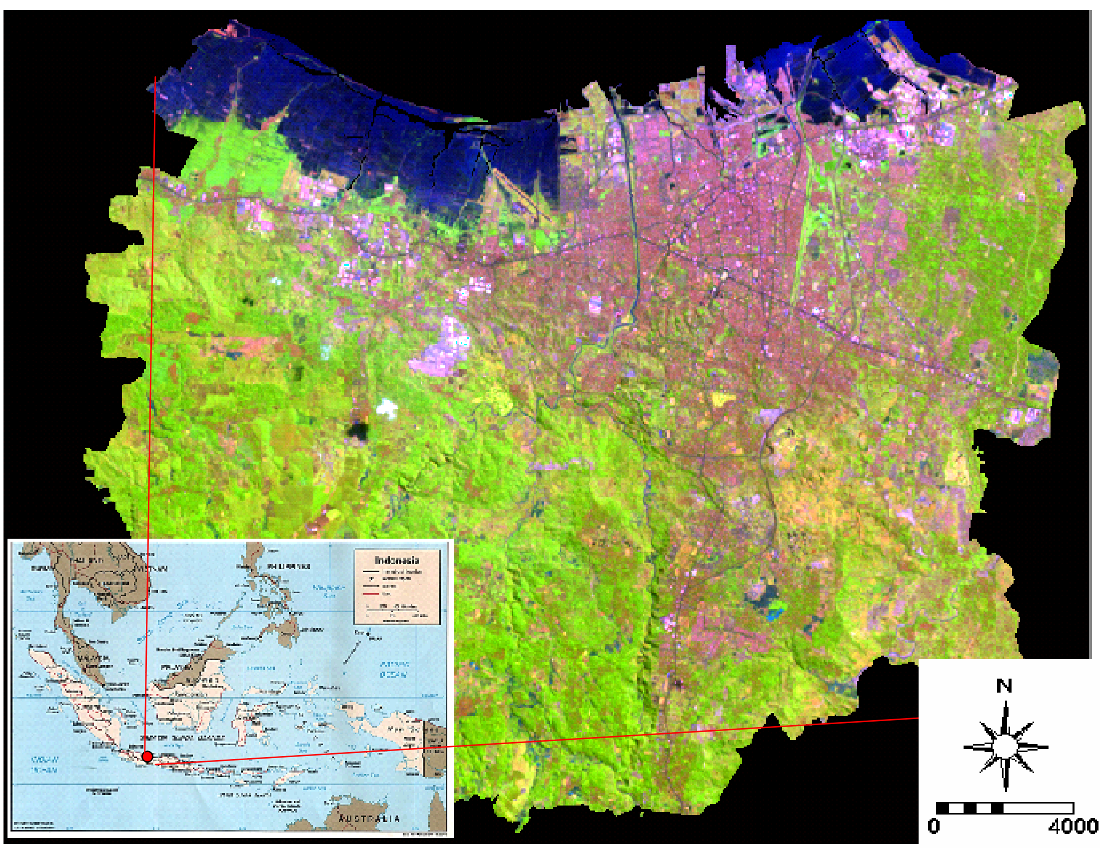


Figure 3.1 Semarang City on composite Landsat ETM data, bands RGB: 542.

3.1. Meteorology and hydrology

The temperature at the Semarang Stations ranges between 25.8^{0}C and 29.3^0 C with an annual humidity of 62% to 84% and a mean annual wind velocity of 5.7 km/hours. At the Ungaran Station, which is located 300 m above mean sea level, temperature ranges between 18^{0}C and 35^{0}C and the average annual temperature is 26.2^{0}C and average annual humidity is 78%.

In the rainy season, rainfall is generally brought about by northwestern humid winds blowing from the Jawa Sea. Rainfall continues in general for approximately 2 to 12 hours, starting in the afternoon until midnight. Annual rainfall amounts to 2,460 mm at Semarang Station and 2,065 mm at Ungaran Station. The maximum rainfall occurs in the months of December and January. (Bappeda Semarang 2000, JICA 1993)

One of the largest river catchments of Semarang and surroundings is the Garang/West Floodway River Catchment. Several rainfall stations record the rainfall data of this catchment, such as Simongan, Gunungpati, Sumurjurang, Pagersari, Ungaran, Mijen, and Limbangan. The average of the monthly rainfall intensity from 1980 to 1994 shows in Table 3.1, Figure 3.2 is shows the thiessen polygon the Garang/West Floodway River Catchment and its river drainage and Figure 3.3 shows the rainfall intensity graph of the Garang/West Floodway River.

Table 3.1 Average of monthly rainfall intensity from 1980 to 1994

Month	Stations						
	Simongan	Gunungpati	Sumurjurang	Pagersari	Ungaran	Mijen	Limbangan
January	462	608	521	535	652	571	627
February	346	458	385	463	475	370	455
March	251	431	336	332	357	325	485
April	206	306	295	294	301	253	344
May	125	135	132	116	138	148	233
June	97	73	92	88	96	85	90
July	77	45	56	47	55	89	81
August	50	41	56	34	48	54	37
September	85	84	81	105	84	82	83
October	145	126	112	134	131	143	170
November	225	198	231	223	246	194	326
December	332	452	407	345	420	305	493

(Source: Semarang Irrigation Office after Sudaryatno 2000)

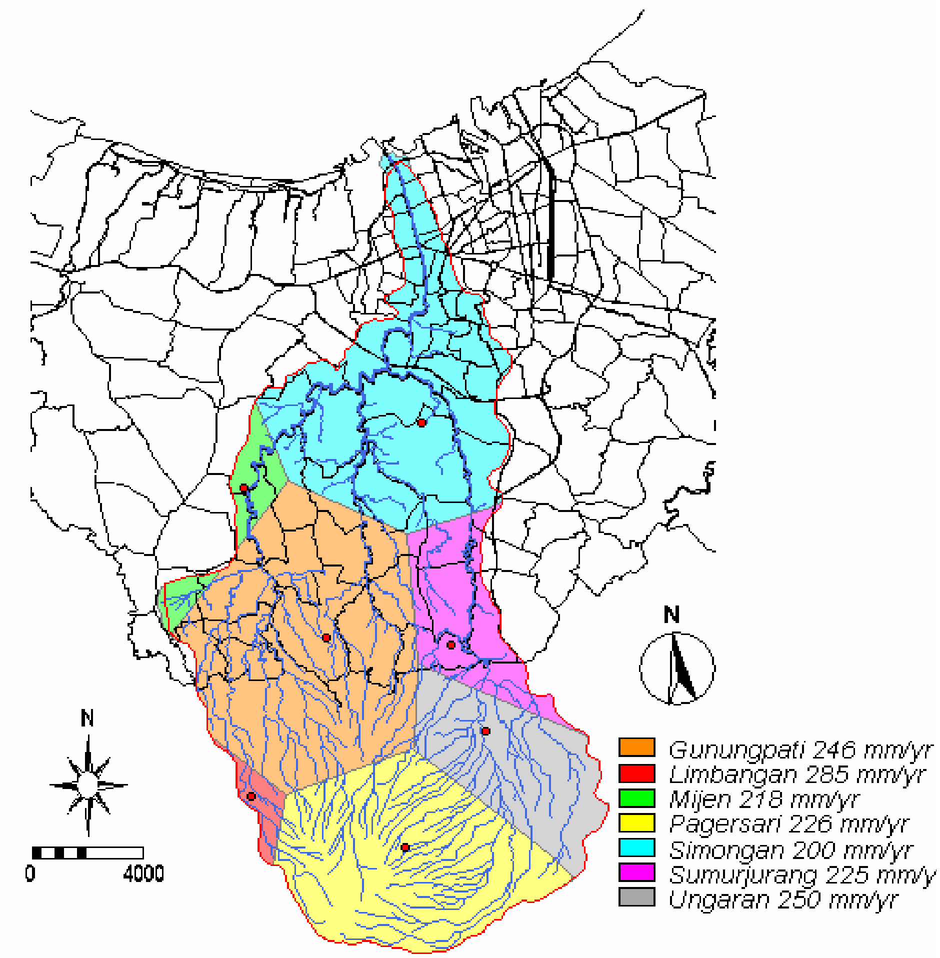


Figure 3.2 Thiessen polygon of
the Garang/West Floodway River catchment and its river drainage

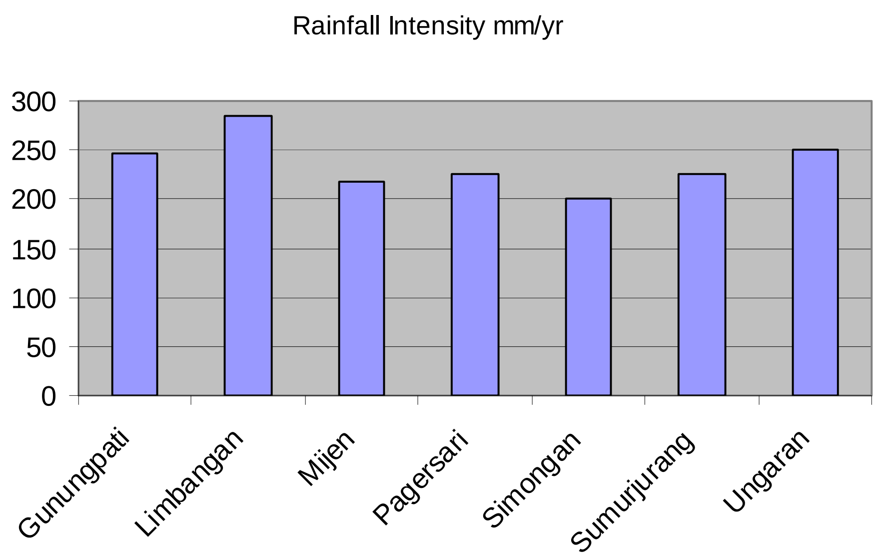


Figure 3.3 Rainfall intensity graph of the Garang/West Floodway River

Semarang has several major rivers; among others are Blorong River, Beringin River, Silandak River, West Floodway/Garang River, East Floodway River, and Babon River. Based on the JICA report (1993), the probability for peak discharge (m^3/s) of the six major rivers is shown on Table 3.2. Figure 3.4 shows the Graph of the Probable Return Period Discharge.

Table 3.2 Probability of peak discharge (m^3/s)

Return Period (Year)	Probable Peak Discharge (m3/s)					
	Garang/West Floodway	Babon	East Floodway	Silandak	Bringin	Blorong
5	520	407	199	68	195	431
10	630	494	240	84	237	549
20	740	552	267	94	264	628
25	770	578	280	99	277	664
50	880	630	306	110	315	739
100	980	710	342	120	342	845

Source: JICA (1993)

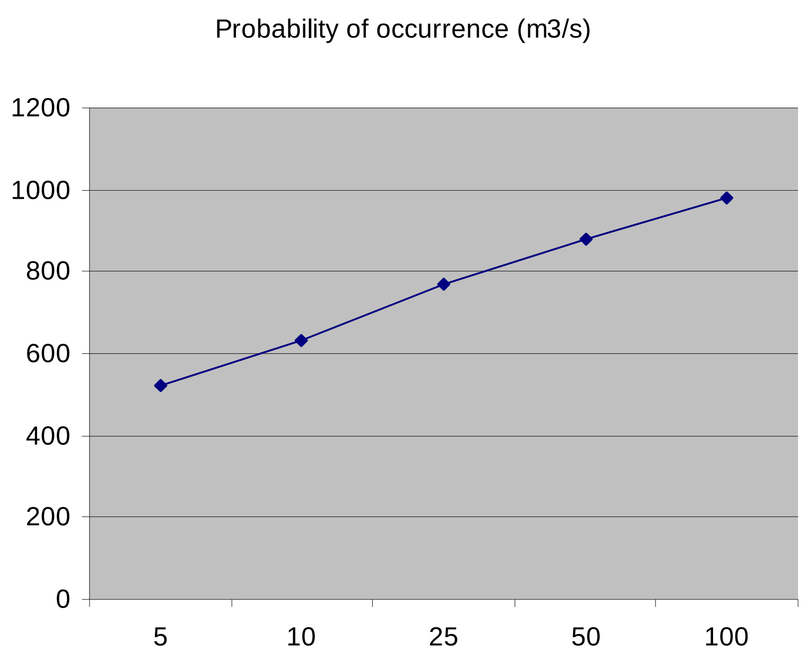


Figure 3.4 Graph of probable return period discharge

The lower part of the Garang/ West Floodway River Catchment is located in the City of Semarang, and upper part is situated within the Kendal and Semarang Districts (kabupaten). The Garang/West Floodway River Catchment, with approximately 205 km^2 of catchment area (Sudaryatno 2000) and 332 km length (JICA 1993), flows north of Mt. Ungaran. It has two major tributaries; the Kreo River and the Kripik River. The Simongan Weir is situated downstream from the confluence with the Kreo River. The Garang River connects with the West Floodway. Hence, in this research called Garang/West Floodway River Catchment. The Simongan Weir is situated about 5.3 km upstream of the river mouth. Annual average discharge observed at the Garang River Gauging station is 10.7 m^2/s (JICA 1993). Figure 3.5 shows the lower part of the Garang/West Floodway River, which is located within Semarang City.

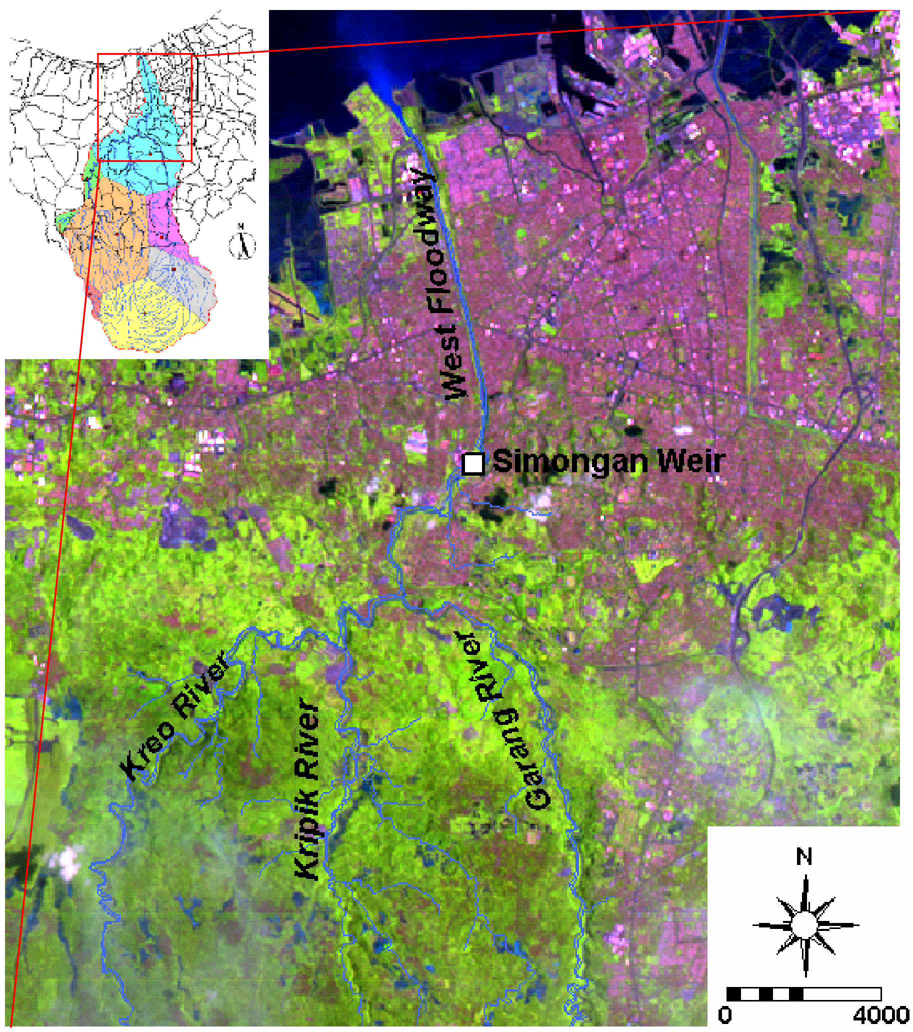


Figure 3.5 Lowland of the Garang/West Floodway River

Semarang has high potency of groundwater hydrology, especially along the alluvial plain, and limited groundwater discharge on the hilly area, especially in the Candi Hilly area, Mijen and Jatingaleh. The groundwater resources of Semarang are used for many purposes, such as for industrial estates and domestic needs. Groundwater extraction is taken place since 1900 and is in line with the population growth. Table 2.3 describes the development of groundwater extraction in Semarang City from 1900 to 1998, and Figure 3.6 shows the Graph of the Groundwater abstraction.

Table 3.3 Development of groundwater in Semarang City since 1900 to 1998

Year	Groundwater abstraction (million m^3/year)
1900	0.4
1910	0.5
1920	0.5
1932	0.6
1982	13.7
1985	16.1
1990	22.5
1995	26.7
1996	29.1
1997	34.9
1998	35.7

Source: Bappeda (2000)

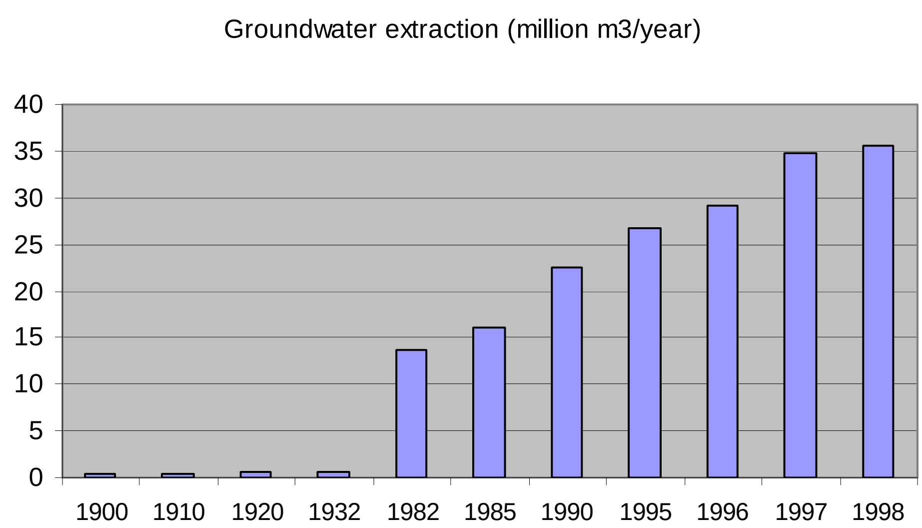


Figure 3.6 Graph of groundwater extraction

There are regulations which restrict and control groundwater within the City of Semarang area. It appears there is low enforcement of these regulations. The uncontrolled groundwater extraction gives contributes to subsidence. Interventions or counter measures are required to reduce the rate of subsidence. In the area of Semarang, extraction rates of more than 30 million m^3/year after 1996 have lowered the groundwater table to more than 20 m below sea level (Sofner,et al 2002).

3.2. Geology and geomorphology

The geology of the area can be roughly divided into three main lithologies; volcanic rock, sedimentary rock, which is marine in origin, and alluvial deposits, which are cover these basement rocks. Volcanic rocks consist of lahars, lava flows of Mt. Ungaran. Alluvial deposits cover these basement rocks. The detailed geological condition described in geological map sheet Semarang and Magelang shows that the area consists of some formation as follows (Thaden, et al 1975, after Sutanta 2002, in appendix 1),

1. Alluvial sediment (Qa)

   This alluvium sediment generally consists of clays and sands, variable in thickness, with 50 m or more are common. Delta of Garang River consists of inter-bedded sand and clay. The thickness of alluvial deposits along the stream is between 1 to 3 m, and consists of gravel with boulders, overlain by sand and silt.
2. Damar Formation

   Consist of tuffaceous sandstone, conglomerates, volcanic breccias and tuff.
3. Volcanic breccias (Qb)

   This formation consists of volcanic breccias, lava flows, tuff, tuffaceous, sandstone, and clay stone. Mostly flow breccias and lahars with inter-bedded small lava flows and coarse-grained tuff.
4. Marin sediment (Tm)

   This formation dominated by clay stone with sandstone and napalm in between.

The geomorphology of the study area is roughly divided into 3 categories; fluvial landforms, structural-denudational landforms, and volcanic landforms. The alluvial landforms of the study area consist of the alluvial-coastal plain and delta, eith intensive erosion and sedimentation. Floodplain area, river terraces, and alluvial plain are the typical landform on the plane area like on the Semarang lowland area. Those landforms briefly can be recognizes from Landsat ETM images color composite RGB: 543. Figure 3.7 shows the example of the interpretation of the alluvial and marine landforms on the study area.

Structural-denudational hills are located in the northern part of Semarang City. Materials in this area consist of clay stone, sand stone, limestone, tuff, massive tuff, conglomerate, and volcanic breccias. Volcanic landforms located in the upper part of the Garang River catchment, among others are volcanic cones, volcanic slopes, and volcanic foot slopes. The materials composition of this landform mostly from the volcanic material, such as volcanic breccias and lahars flows from Mt. Ungaran. Erosion processes occurs intensively in this area, especially rill and gully erosion along the drainage lines. On the volcanic foot slope, dominantly sedimentation processes take place. Some examples of the structural-denudational and volcanic landforms of the study area are shown on the Figure 3.8.

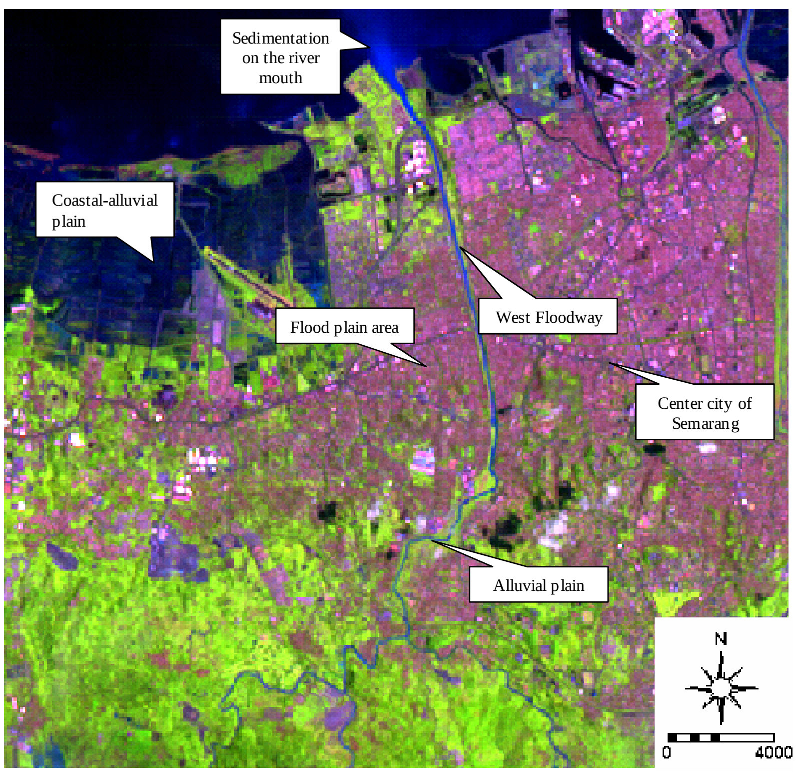


Figure 3.7 Recognition of alluvial and marine landforms

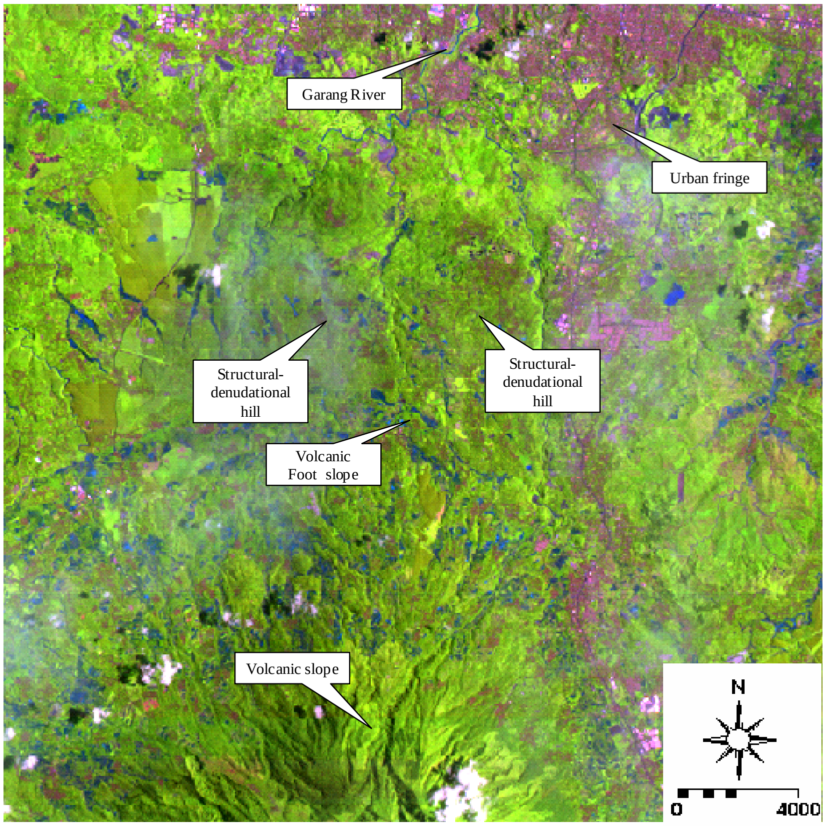


Figure 3.8 Recognition of the
structural-denudational and volcanic landforms

3.3. Soil and landuse

In Semarang City and its surrounding area, the land consists of four soil types. Based on Central Java province Soil Map (Public Work 2000, in appendix 2), they are identified as:

1. Alluvial
2. Regosol
3. Yellowish Red Mediterran and Grumusol
4. Latosol and Andosol

Alluvial

This soil can be found in the lower part of Semarang City. It consists of river deposits. It is either flood plain deposits or deltaic deposits/ alluvial fan deposits, which contain small and large material deposited irregularly. On the hilly area, it has a brown color and it turns to light when it reaches the coast. In East Mangkang, it has brown color formed by flood plain deposits and the local citizens use it for making bricks.

Regosol

This soil type can be found in the hilly area. It is formed by the weathering of lime stone. Regosol consists of horizon A and C, formed in silty clay and sandy clay with colors of brown, light brown, yellowish brown, red, brownish red, white dotted yellow and gray ones.

Yellowish red mediteran and Grumusol

This soil type can be found in the hilly area. It is formed by the weathering of base rock until intermediate igneous stone. Grumusol is part of the vertisol soil type, which is reversed in the dry season by the drying out process when the upper layers collapses due to the drying and cracking processes.

Latosol and Andosol

This soil type can be found in the hilly are up to the mountainous area. It is formed by the weathering of basic until intermediate igneous rock. It has a reddish yellow color as well as brown until reddish brown.

Andosol is the kind of soil, which is newly formed and shows its base formation material, which is mainly clay. Except for the soil in the east of Gunungpati, it consists of very little sand and gravel. It has a reddish brown and yellowish brown color.

The Landuse pattern and physical environment in Semarang has been changing rapidly. The Landuse change of Semarang has been uncontrolled both in the upland and in the lowland areas. The extreme landuse change and mismanagement on the upland area contributes to the hazard floods in the lowland area. Figure 3.9 shows the example of the landuse change on the upland areas. On the other hand the residential growth, industrial expanses and agriculture in the lowland area contributes to the land subsidence leading to increase of the area affected every year. Table 3.4 and Figure 3.10 gives the graph description of landuse in Semarang.

Figure 3.9 Example of landuse change on upland areas

Table 3.4 Description of landuse in Semarang

Nr	Type of Land use	Area (km^2)
1	Residential area	123.6
2	Dry land farming	68.8
3	Agriculture field	43.6
4	Homestead garden	51.4
5	Plantation	8.7
6	Open pit mining	1.4
7	Industry and tourism	10.2
8	Transportation	4.8
9	Forest	13.8
10	Bare land	4.1
11	Fisheries	17.8
12	Miscellaneous	25.5

Source: Bappeda (2000, After Sutanta 2002)

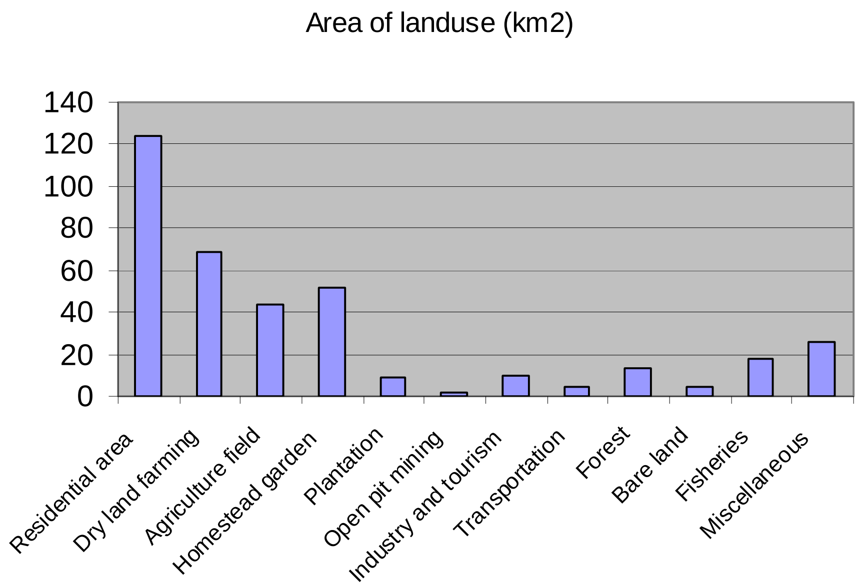


Figure 3.10 Graph of landuse area in Km^2

3.4. Natural hazards

The City of Semarang suffers from many types of natural hazards, such as: flooding, landsliding, and land subsidence. The local name for different floods that are well known in Semarang are *banjir lokal* (locally flood inundation), *banjir kiriman* (river flood) and *banjir rob* (tidal flood). Local inundation combined with river flooding gives rise to frequent inundation in some areas every year. Four areas are inundated frequently, namely:

- Mangunharjo Kampong, Mangkang Wetan Kampong, and Wonosari Kampong located in Tugu Sub district,
- Tambakrejo area, Hanoman street, and Siliwangi Street located in Semarang Barat Sub district,
- Tawang Mas residential area located in Semarang Barat Sub district,
- Genuk area, Kaligawe Street, Ronggowarsito Street, Raden Patah Street, Pasar waru area, and Terboyo bus station located in Semarang Timur Sub district (Kompas 23 May 2001, Kompas 8 February 2002).

In January 1990, flooding took place along Garang/West Floodway River leading to flood damage associated with the destruction of a considerable part of the riverbank.

The serious flood overflow occurred in particular downstream of the Garang River between the confluence with Kreo River and Simongan Weir. The following flood damage were confirmed by the Ministry of Public Work (JICA 1993):

- Death = 47
- Houses collapsed = 25
- House damage = 126
- School building collapsed = 1
- Dormitory collapsed = 1

The total flooded area was around 145 Ha and the maximum water depth was 3 m with 2 to 4.5 hours duration of the inundation.

In January 1993, flooding occurred in the lower part of the Garang/West Floodway River. Several dykes were damaged. Details of the impact due to the flood in January 1993 are shown in the Table 3.5.

Table 3.5 Location of the damage due to the January 30th and 31st 1993 flood event of the Garang/West Floodway River

Location	Flooded area (Ha)	Water depth (m)	Duration	Note
Krobokan, Darat, Lasimin, (West Semarang)	150	0.6	48	Overbank flow on the West Floodway
Bulu lor, Panggung (West Semarang)	160	0.5	60	Overbank flow on the right side of West Floodway
Sampangan (East Semarang)	25	0.6	48	Overbank flow on the right side of the upper part of West Floodway

Source: Semarang Public Work Office (1993 after Yusuf 1999)

Meanwhile, tidal flood occurs due to high tides. The effect of tidal floods increases every year. High tidal waves combined with land subsidence gives rise to inundations at Kemijen, Pengapon, Bandarharjo, Panggung, Kuningan, Purwosari, Rejomulyo, and Mangunharjo Kampong in the Semarang tengah Sub district. These areas are inundated frequently every year (Kompas 23 May 2001, Kompas 12 June 2001). Figure 3.11 shows the Tidal and River Flood phenomena in Semarang City.

Source: Sutanta (2002)

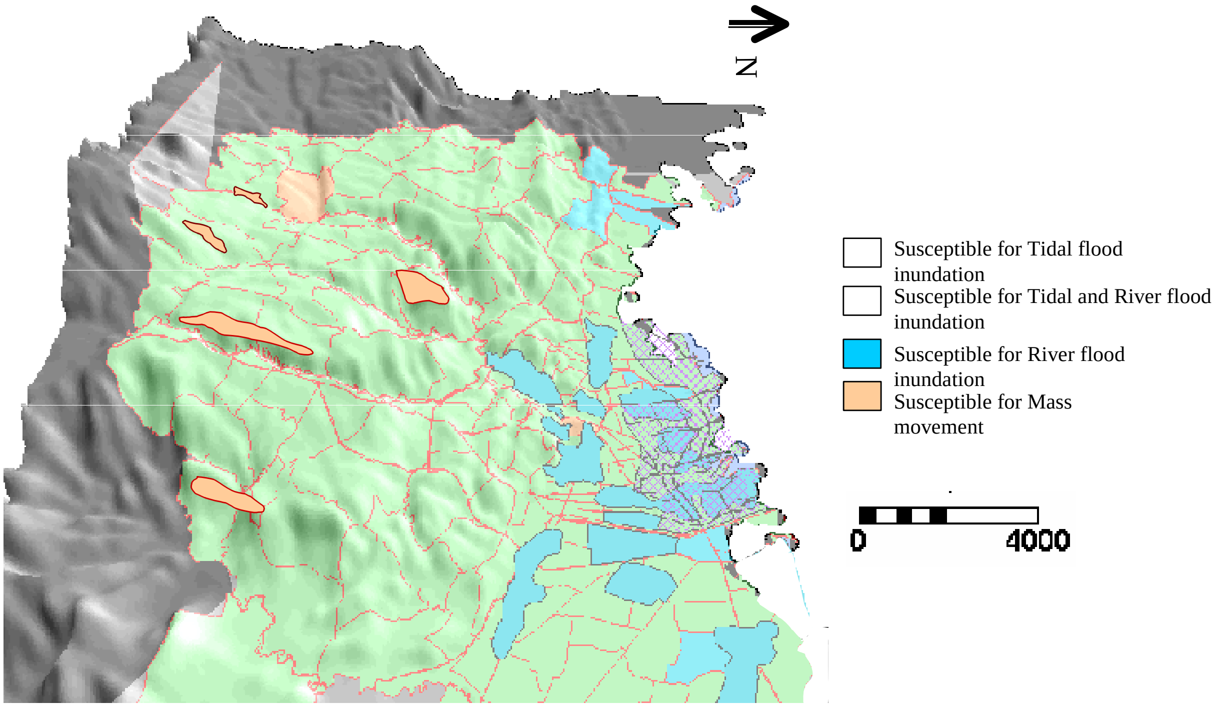
Figure 3.11 Tidal and river flood phenomena in Semarang City

Landsliding is the other hazardous phenomenon that occurs in some areas in the upper part of Semarang City. Landslide susceptibility assessment in Semarang City was determined from the index of occurrence of landsliding in each geological type, slope gradient, and slope stability. Geology, morphology, rainfall, landuse, and seismic activities were used as factors for determine the landslide susceptibility assessment. (Sugalan and Siagaan, 1991, in Bappeda 2000)

The landslide susceptibility assessment in Semarang city can be described as follows:

1. Areas that are susceptible from landslide processes situated in Ngaliyan, Gunungpati, Banyumanik, and Tembalang sub district.
2. Active fault zone, situated along the Mijen and Gunungpati sub district, also situated along Banyjmanik, Gunungpati, and Ngaliyan sub district, and in Ngaliyan Sub district.

Figure 3.12 shows the distribution of susceptible area for Natural hazards in Semarang.



Displayed in 3d view from east, height scale 10.
Source: Yusuf (1999), Bappeda (2000), Sutanta (2002).

Figure 3.12 Distribution of susceptible area of natural hazards in Semarang City

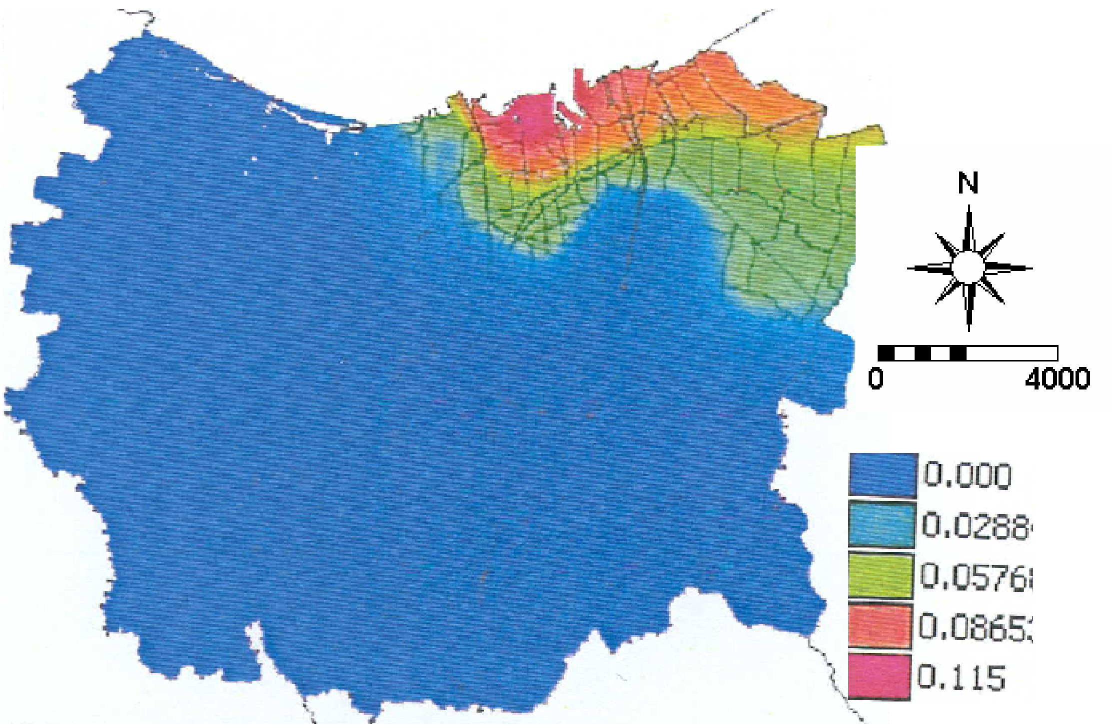
Excess Groundwater extraction combined with increased urbanization in the coastal area triggers the land subsidence in the Semarang city. The rate of subsidence in the Semarang City is varying, 11.5 cm/yr (Sutanta 2002) even more up to 0.2 m/yr (Kompas 23 May 2001). Lowland areas with a high subsidence rate:

- Subsidence more than 0.2 m/yr: Tanjung Emas Harbour and surroundings, Terboyo Kulon Kampung, the southern part of the Genuk sub district, Bandarharjo Kampong in the Semarang Utara sub district, and the Purwawadinatan Kampong in Semarang Tengah sub district.
- Subsidence between 0.15-0.2 m/yr: Tirang area in the western part of the Tugu sub district up to the Kuningan area in Semarang Utara sub district. Plambokan, Jagalan ,Trimulya kampong in the Genuk Sub district.
- Subsidence between 0.1-0.15 m/yr: Tugu Subdistrict, Semarang Barat Subdistrict, Tanah Mas kampong in Semarang Utara Subdistrict, Bulustallan and Burusari

kampong in Semarang Selatan Sub district, and in Wonodri and Trimulyo Kampong in Genuk Sub district.

- Subsidence less than 0.1 m/yr: a small part of the Tugu and Semarang Barat Sub districts extending to Pedurungan and Genuk Sub districts.

A rate subsidence map was created using information about subsidence obtained from levelling measurement by Sutanta (2002) on his thesis. The land subsidence pattern on the Semarang City is shown on Figure 3.13.



Source: Sutanta (2002)

Figure 3.13 Land subsidence pattern in Semarang City

In the present situation, there are more than 8,000 people living in areas up to 0.5 m above sea level. Based on a Sutanta (2002) it has been found that the area below 0.5 m in the year 2010 will be 2,900 ha and it was 1,260 ha in 2001. The fishpond area is the largest to be affected, followed by residential areas, bare land, agriculture fields, and industrial areas (Sutanta 2002). Economic and social consequences of these situations will be enormous.

3.5. Concluding remarks

This chapter describes the physical environment and landscape characteristics of the study area. This includes: geographic position, meteorology and hydrology, geology and geomorphology, soil and landuse, and natural hazards. The location of Semarang city makes the city play an important role for regional development, especially in Central Java.

Meteorological data show that the average minimum temperature is 18^0C and the maximum 35^0C. The minimum humidity is 62% and the maximum is 84%. Minimum rainfall intensity occurs in August (34 mm in Pagersari Station) and the maximum in January (627 mm in Limbangan Station). Intensive groundwater extraction (30 million m^3/year) is done from the aquifers underneath the city.

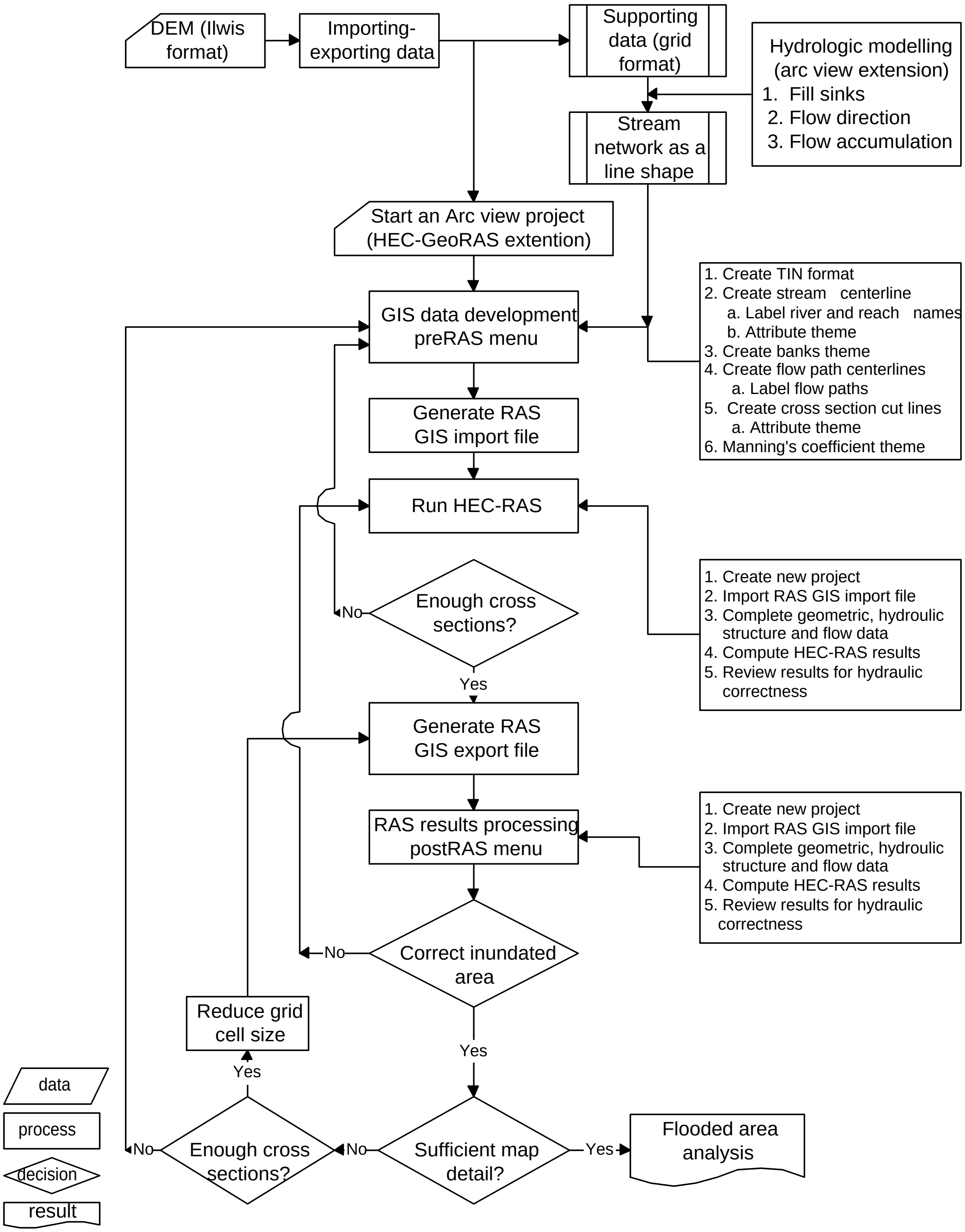
The geological formations encountered consist of alluvial sediments (Damar formation), Volcanic breccias, and Marin sediments. The geomorphologic conditions of the study area can roughly be divided into three categories: Fluvial landforms, Structural-denudational landforms, and Volcanic landforms. Four types of soil have been identified in the study area. These are: (i) Alluvial, (ii) Regosol, (iii) Yellowish Red Mediterran and Grumusol, and (iv) Latosol and Andosol. Semarang city is mostly occupied by residential areas, which cover more than 123 km^2.

Typical natural hazards in the coastal environment of Semarang city are river and tidal floods, landslides and land subsidence. River flooding occurs due to high rainfall intensities in combination with an insufficient drainage system. Tidal flooding occurs due to high tidal waves overflowing the coastal land. The upper part of Semarang consists of two zones with high landslide susceptibility. These zones are characterized as the zone that is susceptible to landslides, and the fault active zone. In the lower parts, land subsidence is becoming the biggest problem in Semarang City. As in many other waterfront cities, this evolving process worsens the impact of other water hazards, such as river and tidal flooding. Estimates of the rate of subsidence in Semarang range from 0.1 m/yr to 0.2 m/yr.

Chapter 4 River Flood Modelling

An integrated approach using hydraulic modelling software and GIS software has been used to generate the river flood model. The HEC-RAS (Hydrologic engineering center river analysis system) software has been used to perform, calculate and do analysis of the hydrological factors, as well as to generate the encroachment scenario and a 3d perspective for floodplain analysis. For geometric data, which is data to perform the spatial analysis, the HEC-GeoRAS software has been applied. HEC-GeoRAS software is an extension of Arc view GIS. In this section, a number of issues regarding to the generation of the river flood model will be elaborated, namely digital elevation model, geometric data input, hydrological data input, editing geometric data, and performing of the river flood model. The conceptual and detailed technical approach for generating the river flood model are describe as a flowchart in Figure 4.1 and Figure 4.2 respectively.

Figure 4.1 Conceptual flowchart for generating river flood model



Source: (Modified from Usage, 2000)

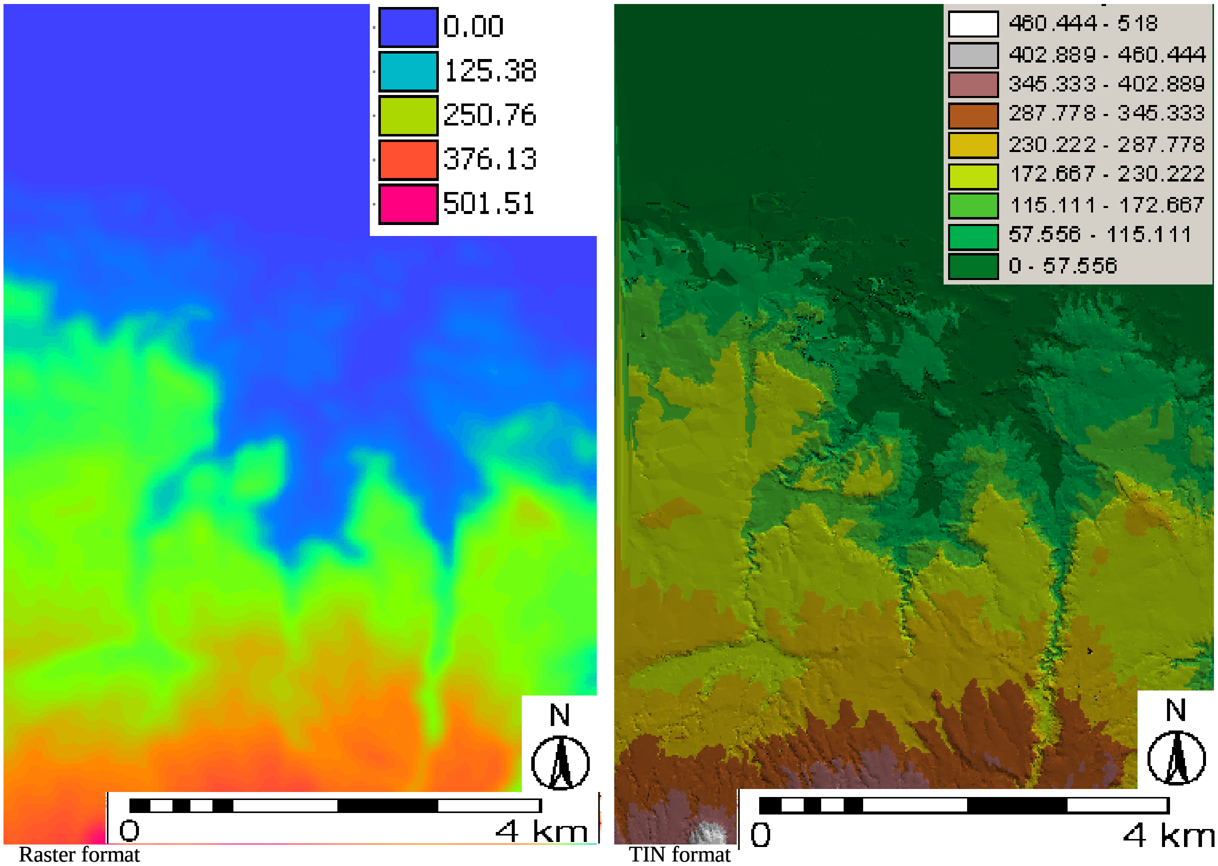
Figure 4.2 Technical flowchart of river flood model

4.1. DEM generation

The available digital elevation model of the study area is a photogrammetrically DEM. It has spot heights at 100 m distance in the undulating and hilly area, and 200 m intervals on the lowland and flat area. The DEM have been field checked and have been added some values on the basis of ground survey by Sutanta (2002). Most additions have been made in the area near the coastline. The observed GPS points have been superimposed on the DEM and the elevation of the DEM was recorded.

In this study, the digital elevation model has been created using point interpolation in the ILWIS software. Point interpolation performs an interpolation on randomly distributed point values and returns regularly distributed point values. In ILWIS, the output values are raster values. The input map on this research is a point map in which the points themselves are values (point map with a value domain). The output of a point interpolation is a raster map. For each pixel in the output map, a value is calculated by an interpolation on input point values. Moving average methods have been used in interpolation process. Moving average assigns to pixels weighted averaged point values.

In this project, two types of DEM structure have been used. Firstly, a regular grid, which is grid defined as a square cell with constant size and an elevation value associated to it. Secondly the TIN format is a vector format of DEM, which consists of a series of polygons in the form of a triangle. Each triangle represents a uniform slope steepness and direction. The TIN format has been used for HEC-GeoRAS files generation. Figure 4.3 is shows the DEM formats.



Raster format

TIN format

Figure 4.3 DEM formats on ILWIS and Arc view

4.2. Geometric data input

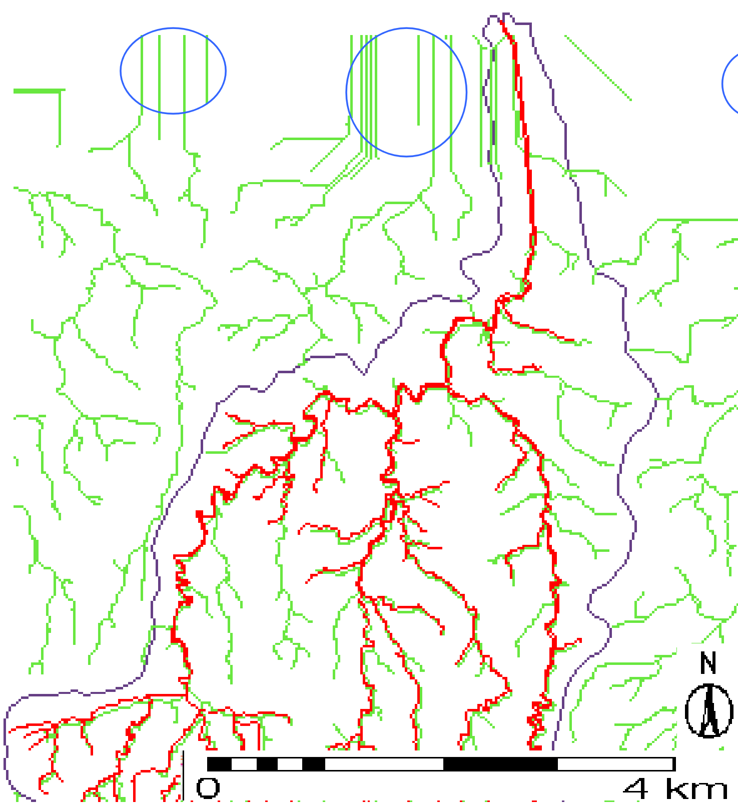
4.2.1. HEC-GeoRAS application

HEC-GeoRAS is an extension used with Arc View GIS. It is specially designed to process geospatial data for use with the Hydrological Engineering Center River Analysis System (HEC-RAS). It allows the creation of a HEC-RAS import file containing geometric attribute data from an existing digital elevation model (DEM) and complimentary data sets. The results exported from HEC-RAS will be further processed in the GIS environment. By means of HEC-GeoRAS an import file have been created describing the geometry of the discharging watersheds into the West Floodway in Semarang. The geometric includes; river, reach, cross sectional cut lines, cross sectional surface lines, cross sectional bank stations, downstream reach lengths for the left overbank, main channel, and right overbank, and cross sectional roughness coefficients.

4.2.2. Creating RAS themes

RAS themes are file data formats in HEC-GeoRAS, which have been used for geometric data development and extraction of the Garang/West floodway river catchment. These are organized as line and polygon themes. Line themes that have been created for the study area are: 1 stream centerline, 2 main channel banks, 3 flow path centerlines, and 11 identify cross section cut lines. One polygon theme has been created. It contains Manning's n values based on the land cover. The following section provides an overview of the created geometrical input data:

- <u>Stream centerline</u>, the river is represented by the stream centerline theme. It has been used for assigning the 11 cross-sections and to define the main channel flow path. To make as accurate as possible the line of the stream, the contour map, topographic map, and stream network map have been used as a guide in downstream direction. The stream network of the Garang river resulting from hydrological modelling has been compared with a stream network from manual delineation and combined with the contour map. The detail stream centerline theme and stream network for the study area are shown in Figure 4.4.



= Some errors on the development of the streamline using hydrological modelling due to the insufficient or less detail DEM on the lowland area

= Stream network from manual delineation

= Stream network from hydrological modelling extension

= Lower part of catchment boundary

Figure 4.4 Stream centerline theme and stream network

- Main channel banks. The separation of the main channel from the overbank areas is defined by the main channel banks theme. The topographic map has been used as a guide to situate the channel banks in the model.
- Flow path centerlines. The flow path centerlines have been used to identify the hydraulic flow path in the left overbank, main channel, and right overbank. The flow path has been created in the direction of flow (upstream to downstream).
- Cross-sectional cut lines. The location, position, and expanse of the cross-sections have been represented by the cross section cut lines defined here. The cross sections have been dog-legged perpendicular to the direction of flow. While the cut lines represent the planar location of the cross sections, the station elevation data has been extracted along the cut line from the DEM. Figure 4.5 shows the geometric data, which contains stream centerline (orchid), main channel banks (green), flow path centerlines (baby blue) and cross-sectional cut lines themes (purple).

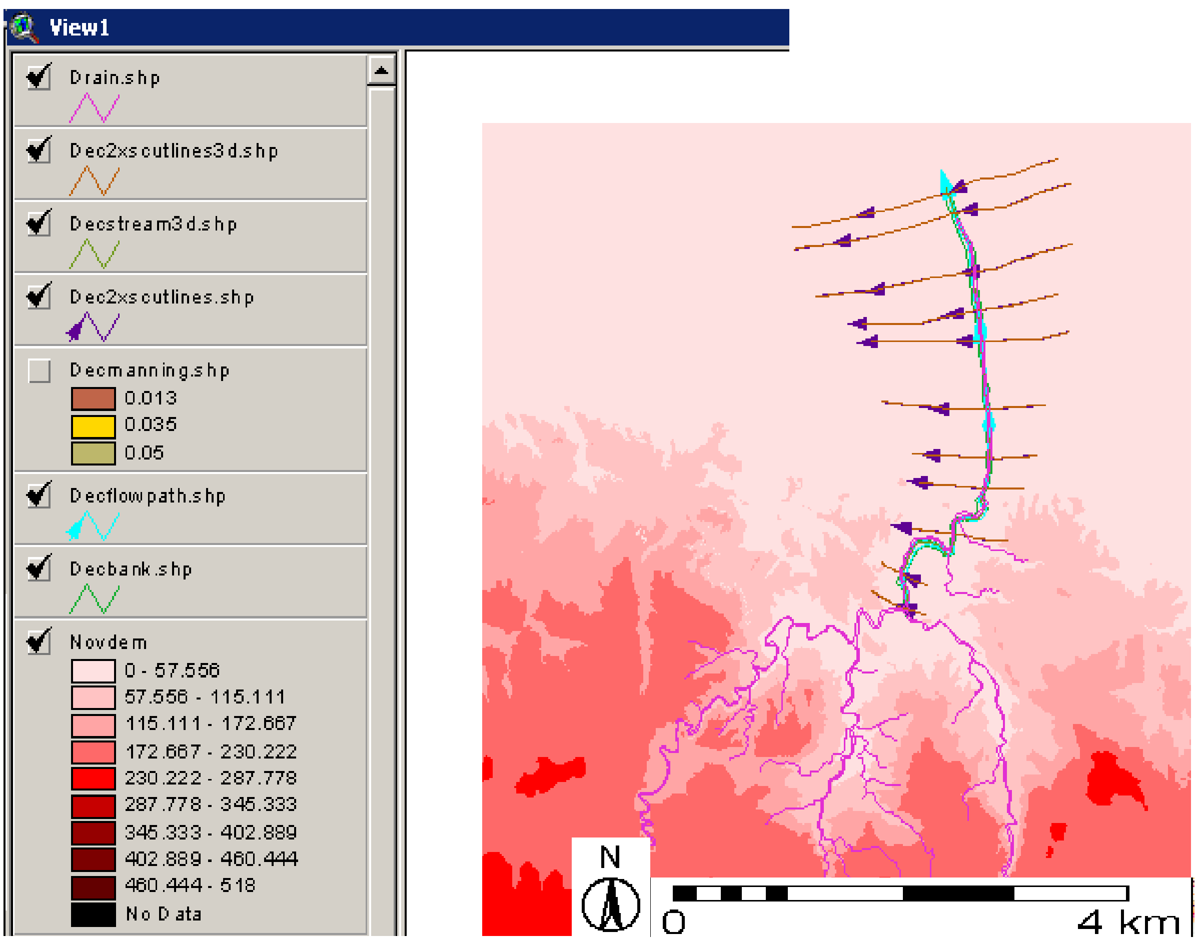


Figure 4.5 Geometric data

- Manning's coefficient values. To estimate Manning's values a polygon map has been aggregated from the land cover map. A look-up table of simplified land cover and specific n-values has been compiled. The table of n-values has been joined to the land cover data tables. The Manning's values on the study area have been adapted from Chow (1959 after Chow, et al 1988) and the JICA report (1993). Table 4.1 and 4.2 shown these Manning roughness coefficients.

Table 4.1 Manning roughness coefficients from literature

Material		Typical Manning roughness coefficient (n)
Concrete		0.012
Gravel bottom with sides	- Concrete	0.020
	- Mortared stone	0.023
	- Riprap	0.033
Natural stream channels	Clean, straight stream	0.030
	Clean, winding stream	0.040
	Winding with weeds and pools	0.050
	With heavy brush and timber	0.100
Flood plains	Pasture	0.035
	Field crops	0.040
	Light brush and weeds	0.050
	Dense brush	0.070
	Dense trees	0.100

Source: Chow (1959) after Chow, et al (1988)

Table 4.2 Manning roughness coefficients applied to the Garang/West Floodway River

Location		Typical Manning roughness coefficient (n)
River	River channel	0.035
	Riverbank	0.05
Flood plains	Light brushes	0.05
	Build-up area	0.013
	Agriculture	0.05

Source: adapted from Chow (1959) and JICA (1993).

4.2.3. Themes Attributing

After completion of the geometric data, several attributes required in the model have been created and linked. These involve centerline completion, XS attributing, and XS elevations. The centerline completion process establishes the connectivity and orientation, and extracts the elevation profile. There are three processes that take place during the centerline completion, namely the lengths/stations item computes the river reach lengths, centerline topology to establishes the connectivity and orientation (upstream and downstream ends) of the river, and centerline Z extract, which have been created a 3D shape file from the stream centerline theme.

To add the cross-section attributes to the cross section cut line theme is called XS attributing. This involves stream/reach names, stationing, manning's n value, bank stations, and reach lengths. A Stream/reach name has been used to add the stream_ID and reach_ID to the cross section cut lines. The stationing function adds the cross-sectional based on the intersection of the cross-sectional cut lines and the stream centerline. Manning's values have been reported at each change along the polygon data set as a percent along the cross section cut line. The data extraction process is shown in Figure-4.6.

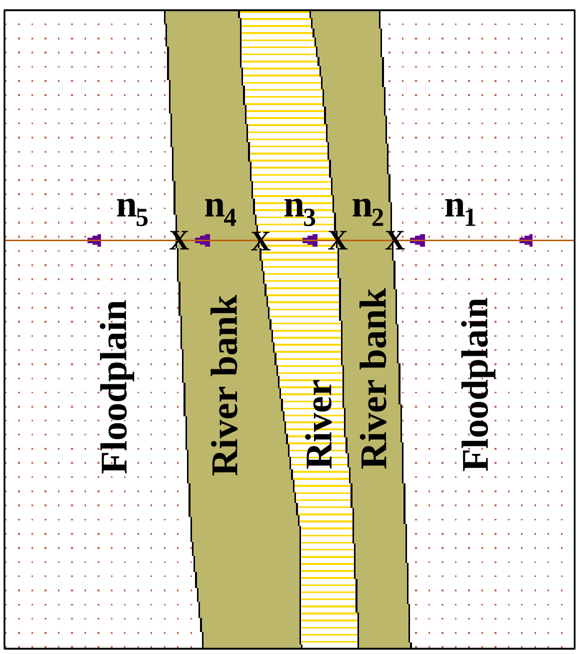


Figure 4.6 Data extraction process on the Manning's values

Bank station positions have been calculated as the percent distance along the cut line from its start in the left overbank. The method of bank station calculation is shown in Figure 4.7.

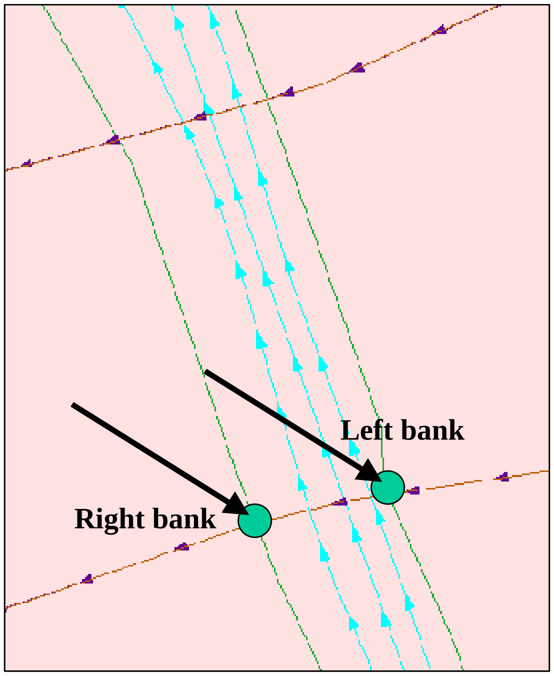


Figure 4.7 Calculations of bank station locations from bank lines and cross section cut lines

Reach lengths, which are left, center, and right reach lengths have been added to the cross section cut line theme for the downstream reach lengths in the left overbank, main channel, and right overbank, respectively. The method for calculating downstream reach lengths is shown in Figure 4.8.

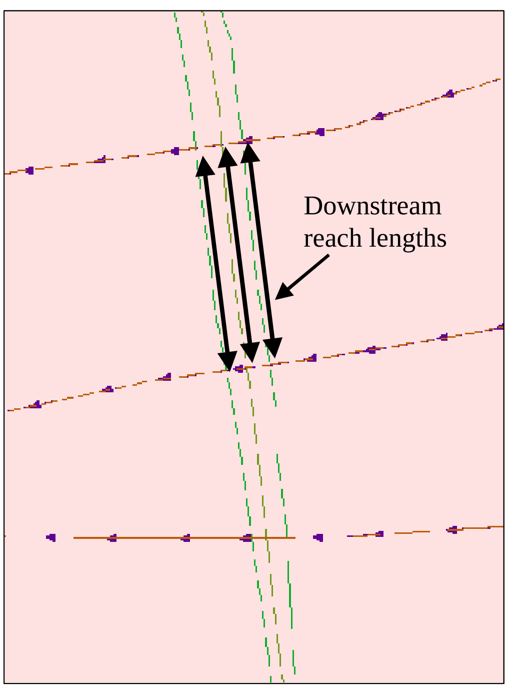


Figure 4.8 Calculations of downstream reach lengths from the flow path centerlines and cross section cut lines

The XS elevation function creates a 3d shape file from the cross section cut line theme. Station-elevation data has been extracted from the terrain TIN at the edge of each triangle along a cut line. The cross section cut line (2d) theme should be completely processes before converting it to a 3d shape file. A visualization extraction process is shown in Figure 4.9.

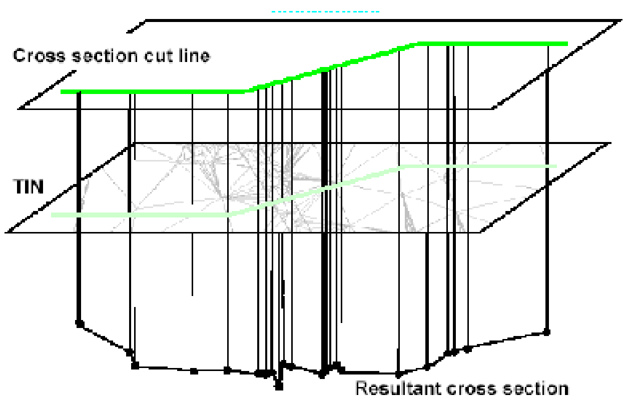


Figure 4.9 Extraction of station-elevation data from TIN (Adapted from Usage 2000).

The RAS GIS import file has been generated after completion the geometric data, includes the 3d stream centerline and cross section surface line (3d) shape file. This import file has been generated in order to edit the geometric data and hydrological data input on the HEC-RAS software.

4.3. Hydrological data input

4.3.1. HEC-RAS application

Hydrological data required after all of geometric data entered. Hydrological data of the Garang/West Floodway River have been processed in HEC-RAS software. This software is comprised of graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics, and reporting facilities. One of the hydraulic analysis components on the HEC-RAS is steady flow water surface profile. This component of the modelling system is intended for calculating water surface profiles for steady gradually varied flow. The steady flow system also designed for application in floodplain management and to evaluate floodway encroachments and flooded area.

4.3.2. Flow data and boundary conditions

A selected number of profiles, the peak flow data, and boundary conditions are needed in order to perform the flow analysis in HEC-RAS. To perform the flood scenario, two different conditions are required. One is the condition of the normal discharge and the other is the 100-year return period of flood discharge. Discharge data have been obtained from the Semarang Public Works Office (2001) and JICA (1993). The annual average discharge observed at the Garang/ West Floodway River gauging station is 10.7 m^3/s. Measurements are taken at the Simongan Weir situated downstream of the junction of tributaries of the Garang River (Figure 3.5). Water is accumulation from the Kreo, Kripik and Garang River tributaries. This is the only reliable measurement station available for analysis on the Garang/West Floodway River. The probable peak discharge from the study area, which is based on the Simongan weir, has been estimated using Gumbel Method from the annual maximum discharge data for 1961 to 1990. The probable peak discharge estimation of the 100-year return period is included in Appendix III. The estimated amounts of probable peak discharge are shown in Table 4.3. A 100-year return period, as a biggest return period of the estimation of the Garang/West Floodway River, has been chosen the scenario for flood encroachment analysis.

Table 4.3 Probable peak discharge at Simongan Weir

Return period (year)	Probable peak discharge (m3/s)
5	520
10	630
25	770
50	880
100	980

Source: JICA Report (1993).

High water surface elevation data as boundary conditions are needed in order for the program to begin the calculations. Probable high water surface elevation for the existing river channel on the West Floodway River has been estimated. The condition is presented in Table 4.4.

Table 4.4 Present channel condition

Return period (year)	Probable discharge (m3/s)	Water level*		Manning's roughness coefficient
		River mouth elevation (m)**	Simongan Weir elevation (m)***	
100	980	0.6	9.77	0.035
25	770	0.6	9.11	0.035
10	630	0.6	8.63	0.035

* All elevations are based on the datum of mean sea level at Tanjung Priok in Jakarta
** Mean high water level (MHWL) observed at Semarang Harbour
*** Watershed of overflow discharge at the weir. (Source: JICA 1993)

4.4. Geometric data editing

Geometric data editing involves cross sections, and Manning coefficients. Due to limited data availability, the small tributaries along the West Floodway River have not taken into consideration in the computation process. Therefore junction and reach editing of these tributaries to the main channel has not be done. Checking for cross sections has been done based on the surveyed cross-section profile along the West Floodway River (JICA 1993). These have been validated and updated on the basis of the fieldwork (2002). The 6 cross section profiles from JICA are included in App. IV.

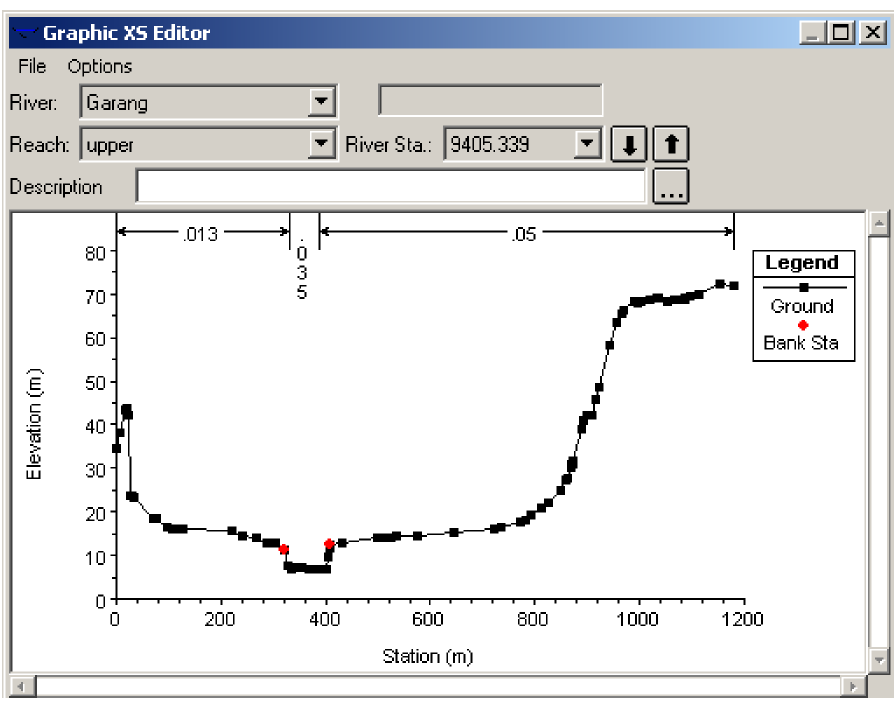
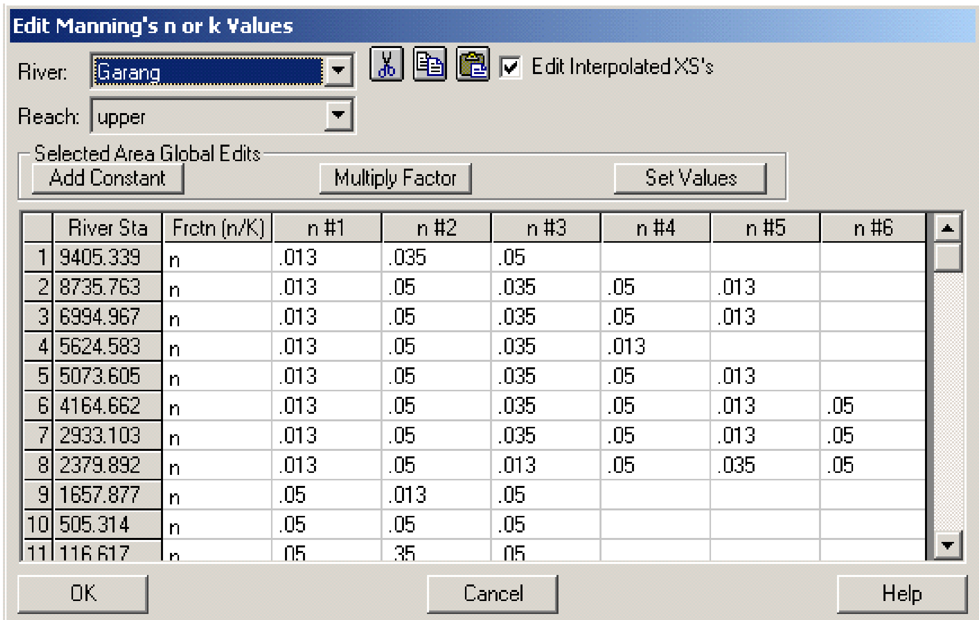


Figure 4.10 Edited West-East cross section no 1 situated on the upstream.

One example of the edited cross sections by means of HEC-RAS is shown in Figure 4.10. The fullest of 11 cross-sections is included in Appendix V.

Manning coefficients have been edited for overlapping surface covers. An example of the storage and editing of the Manning values in HEC-RAS is shown in the Figure 4.11.



	River Sta	Frctn (n/K)	n #1	n #2	n #3	n #4	n #5	n #6
1	9405.339	n	.013	.035	.05			
2	8735.763	n	.013	.05	.035	.05	.013	
3	6994.967	n	.013	.05	.035	.05	.013	
4	5624.583	n	.013	.05	.035	.013		
5	5073.605	n	.013	.05	.035	.05	.013	
6	4164.662	n	.013	.05	.035	.05	.013	.05
7	2933.103	n	.013	.05	.035	.05	.013	.05
8	2379.892	n	.013	.05	.013	.05	.035	.05
9	1657.877	n	.05	.013	.05			
10	505.314	n	.05	.05	.05			
11	116.617	n	.05	.35	.05			

Figure 4.11 Storage and editing the Manning value in HEC-RAS

4.5. Performing the river flood model

4.5.1. Steady flow analysis

The simulation has been performed based on the geometric data, flow data and boundary conditions in a steady flow analysis. Steady flow describes condition in which depth and velocity at a given channel location do not change with time. Gradually varied flow is characterized by minor changes in water depth and velocity from cross-section to cross-section. The primary procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario and is called the direct step method. The basic computational procedure is based on an iterative solution of the energy equation as follow:

$$H = Z + Y + \frac{\alpha V^2}{2g} \qquad \text{where,}$$

(H) = total energy at any given location along the stream
(Z+Y) = potential energy
$\left(\frac{\alpha V^2}{2g}\right)$ = kinetic energy (Tate., 1998; in Andrysiak., et al, 2000)

The energy equation parameters are illustrated in Figure 4.12. Given the flow and water surface elevation at one cross-section, the goal of the direct step method is to compute the water surface elevation at the adjacent cross-section.

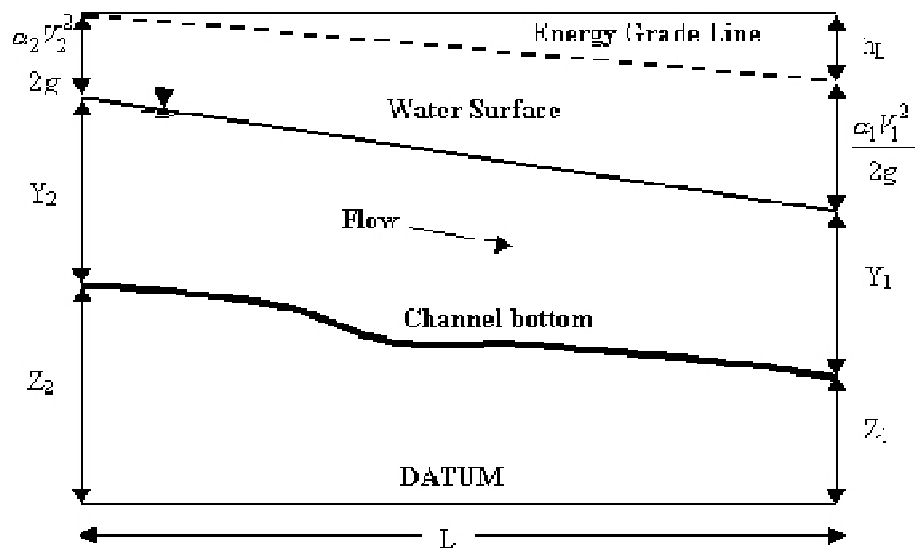


Figure 4.12 Energy equation parameters for gradually varied flow (Source: Tate 1998, in Andrysiak 2000).

Plan data and encroachment option have been decided on the steady flow analysis computation. The plan defines which Geometric and hydrological data of the Garang / West Floodway River has been used to define a plan data. The 5th method of encroachment has been chosen, which is to obtain the target different in water surface elevation between natural and encroached condition based on the 100-year return period. The result is shown in Figure 4.13, Figure 4.14, and Figure 4.15.

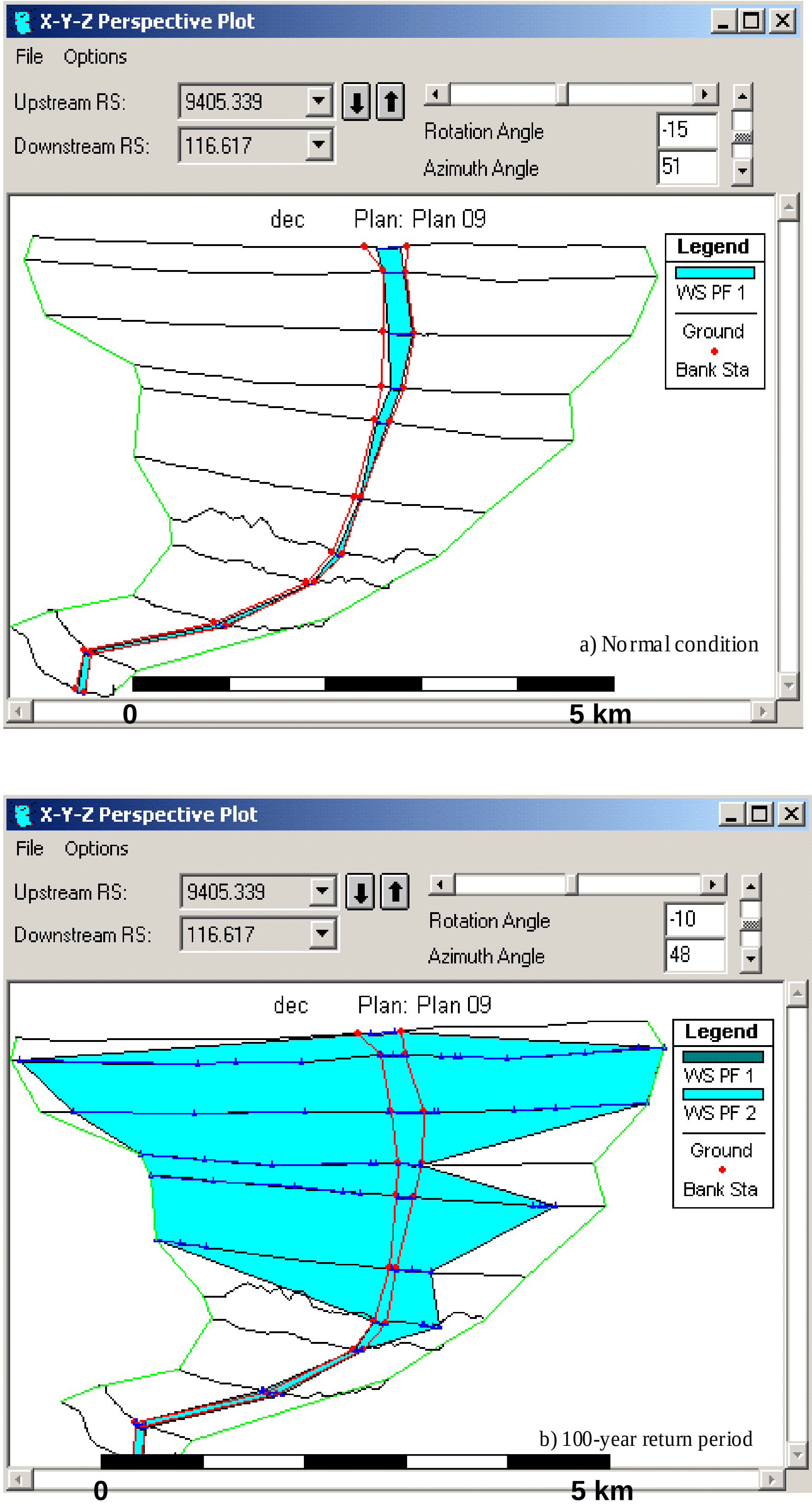
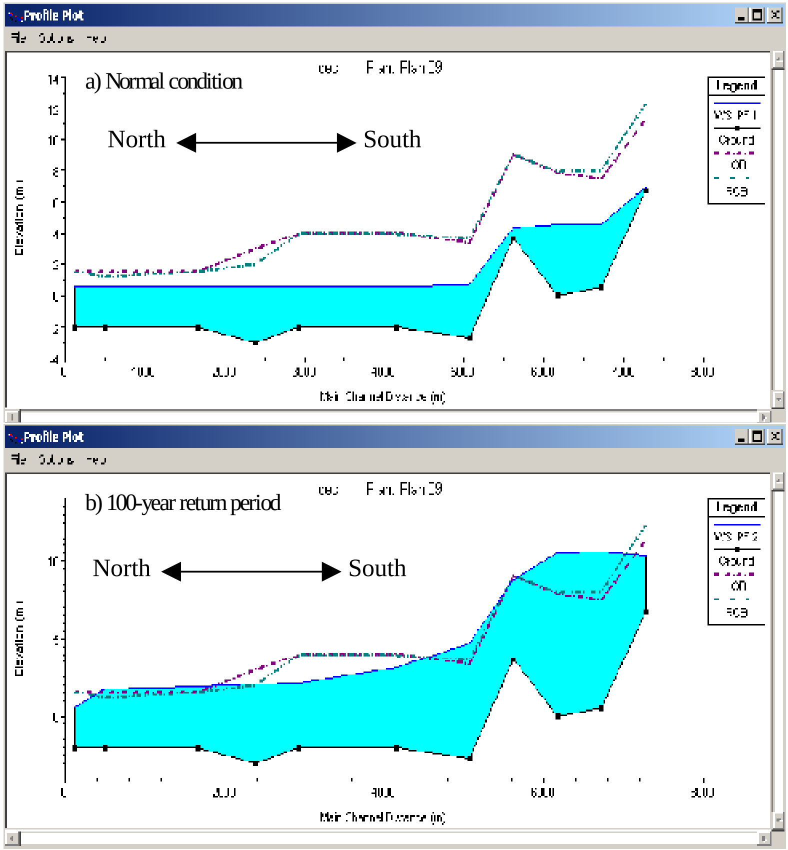


Figure 4.13. X-Y-Z Perspective for flood spreading



WS PF= water surface profile

LOB = left overbank

ROB= right overbank

Figure 4.14 Water surface profiles

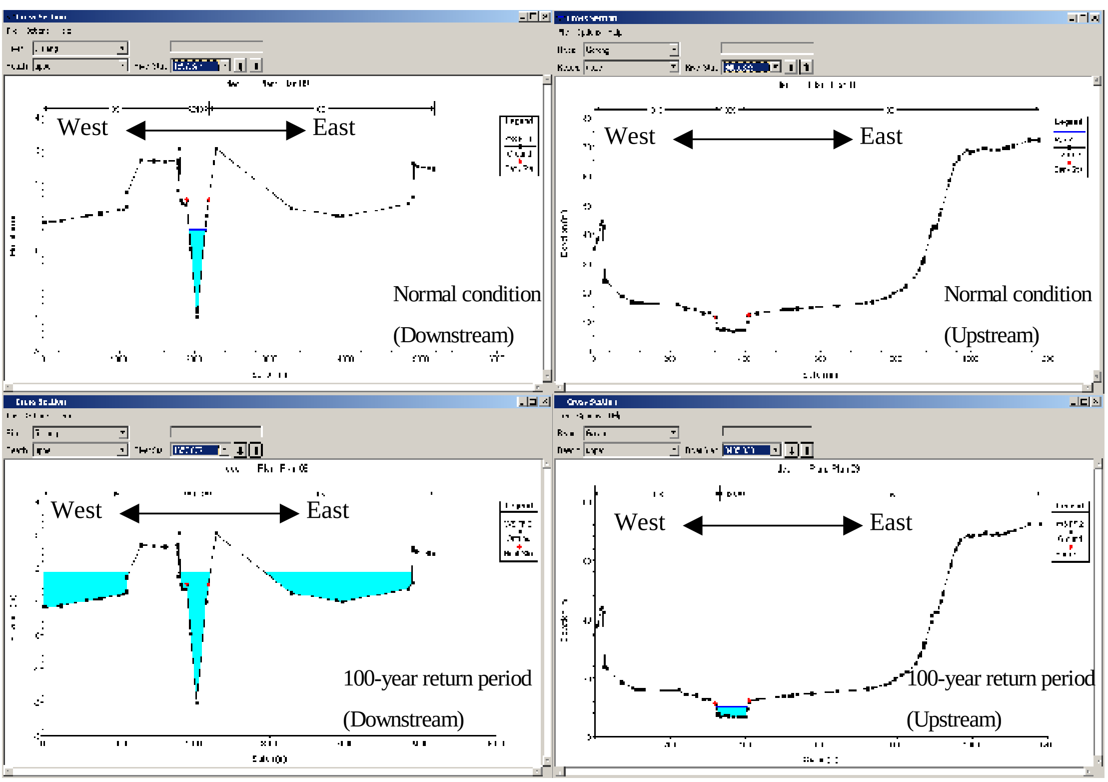


Figure 4.15 Example of cross-sections

4.5.2. Flooded Area Delineation

The flooded area has been delineated using water surface data in conjunction with the terrain elevation data. A water surface TIN has been created irrespective of the terrain TIN. It has then been clipped by the bounding polygon, limiting the water surface to the part of the city modeled by HEC-RAS. The water surface TIN is shown in Figure 4.16.

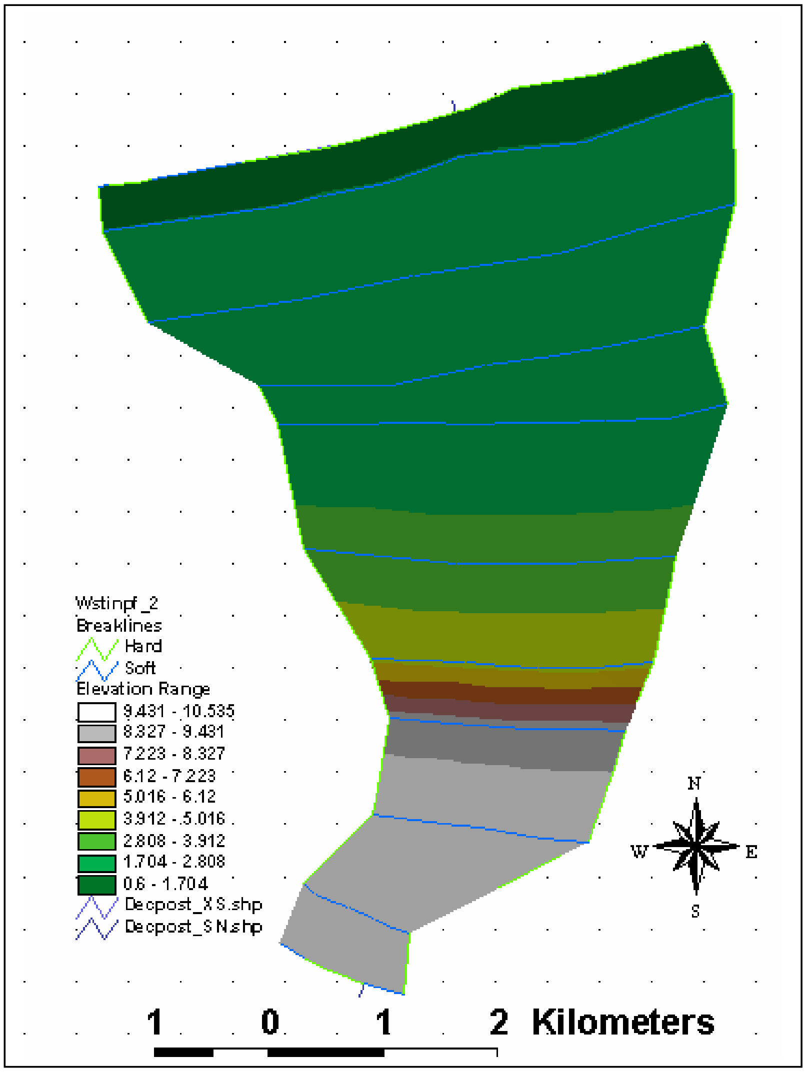


Figure 4.16 Water surface TIN generations

The Flooded area has been delineated where the water surface grid and the terrain grid at 100 year return period flood have the same elevation or the edge of the water surface grid is limited by model boundary. The river flood area delineation result is shown in Figure 4.17.

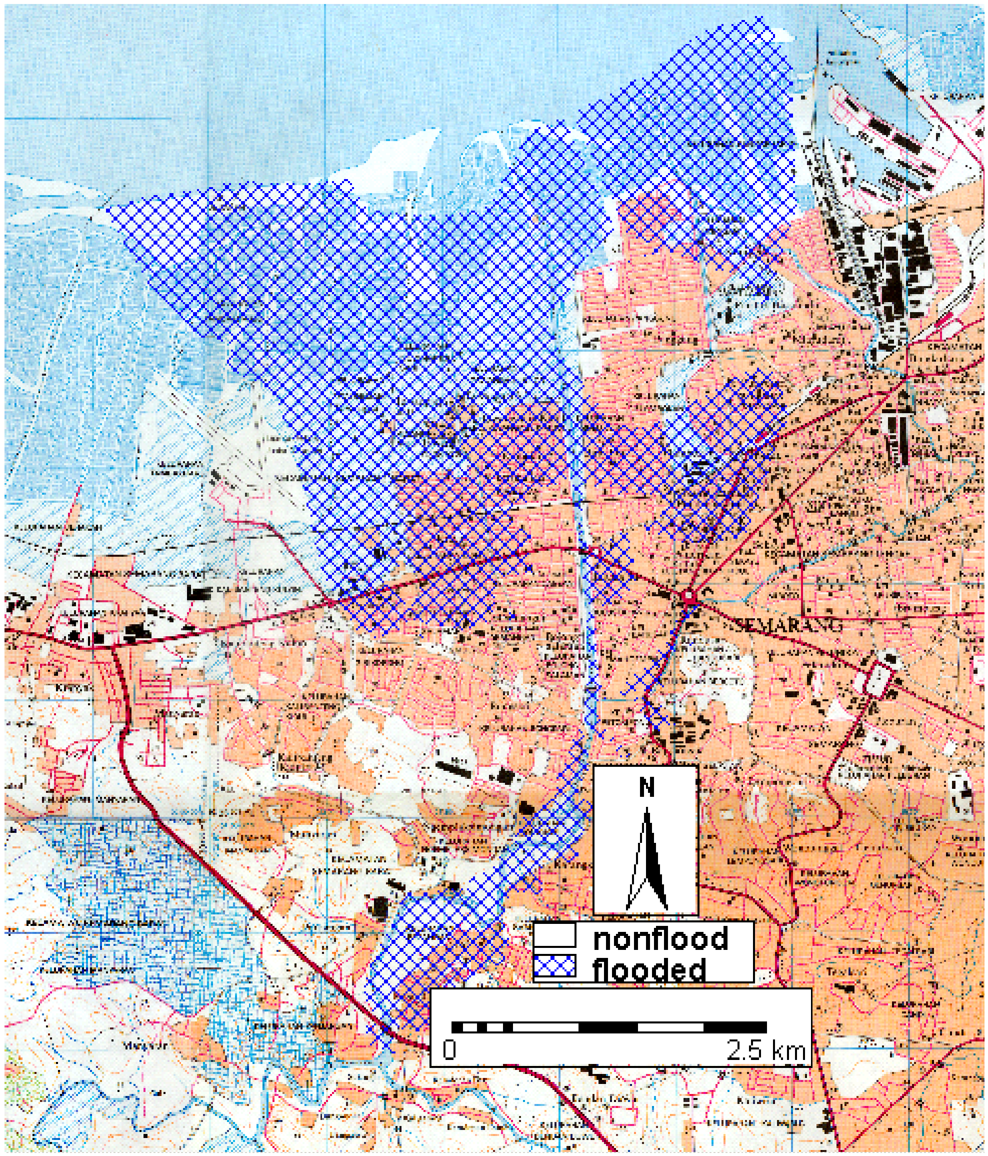


Figure 4.17 River flood area delineation with topographical map

The spatial distribution of the flooded area is mostly located in the lower parts (< 10 m high from mean sea level) or situated in coastal and alluvial landform, and a few parts in the higher area (> 50 m high from mean sea level). The flooded area delineation results should be carefully examined. The topographic map and flood maps from other sources have been used for model validation. The validity of the model will be explained on Chapter 6.

4.6. Concluding remarks

In this chapter, a river flood model has been created using hydrological and GIS software. Several types of input data have been prepared, namely a DEM, geometric data, and hydrological data. A high quality DEM is required for this type of modelling. The topographic map on scale 1:5000 has been used as a guide to generate the geometric data. Crude hydrological data on the Garang/West Floodway River have been used in the hydrological analysis and in the model simulation. Annual average discharge and probable peak discharge for a 100-year return period have been used to perform the hydraulic calculations. In order to obtain the associated water levels and the spatial distribution of the floods under these two different conditions, the model used the so-called encroachment method. The flood model has been constructed on the basis of cross-sectional data. Whereas the computations have been done on these vector data describing boundary conditions and driving forces for water runoff, model output of flood extension and water depth has been converted to raster maps in the GIS environment. These will be validated by comparison with flood maps from other resources (Chapter 6).

The applied flood modelling approach has appeared to be a powerful tool as an input to flood hazard assessment (Chapter 6) in the coastal environment, when only under scarce hydrological data are available. It should, however, be mentioned that the analysis is largely based on measured discharges at one location in the river catchment (Simongan Weir). It has been assumed that the annual average discharge and the probable peak discharge for a 100-year return period are equal in all (11) cross-sections used in the model. In reality this is not true. In between the cross-sections, small watercourses contribute to an increasing discharge in downstream direction. Because of the scarcity and unreliability of these drainage data, this accumulating effect has been left out of the analysis. In order to obtain more accurate results, especially for the downstream built-up area, far more detailed geometric (hydraulic) data from the urban drainage system is required. This also applies to small-scale measures in water management that have been taken by the local government and the citizens of Semarang. For further research, it is therefore recommended to obtain accurate and up to date information on the status of the urban drainage system in Semarang.

Chapter 5 Tidal Flood Modelling

A raster based tidal flood model has been constructed in the ILWIS GIS environment in order to calculate the flooded area using a neighborhood operation. The neighborhood function for spatial data analyses enables the evaluation of the characteristics of a specific location and its surrounding area. The outcome of a calculation depends directly on the values of the neighboring pixels. These calculations make use of a small calculation window (e.g. 3x3 cells) that repeats a specified calculation on every pixel in the map, taking into account the values of its neighbors (ILWIS user guide 2001).

The neighborhood function for tidal flood spreading calculation is an iterative procedure. Iteration is a successive repetition of a mathematical operation, using the result of one calculation as input for the next. The calculation stops when the difference of the output compared to the input is negligible, or if the number of iterations as defined before is reached (ILWIS user guide 2001). For the iteration operation, the value raster map is needed, i.e. surface elevation map. Every pixel on the map is representative of the surface elevation at that location. The different steps in the tidal flood modelling are shown in Figure 5.1. The tidal flood phenomenon and each step of the procedure are discussed in the following sections.

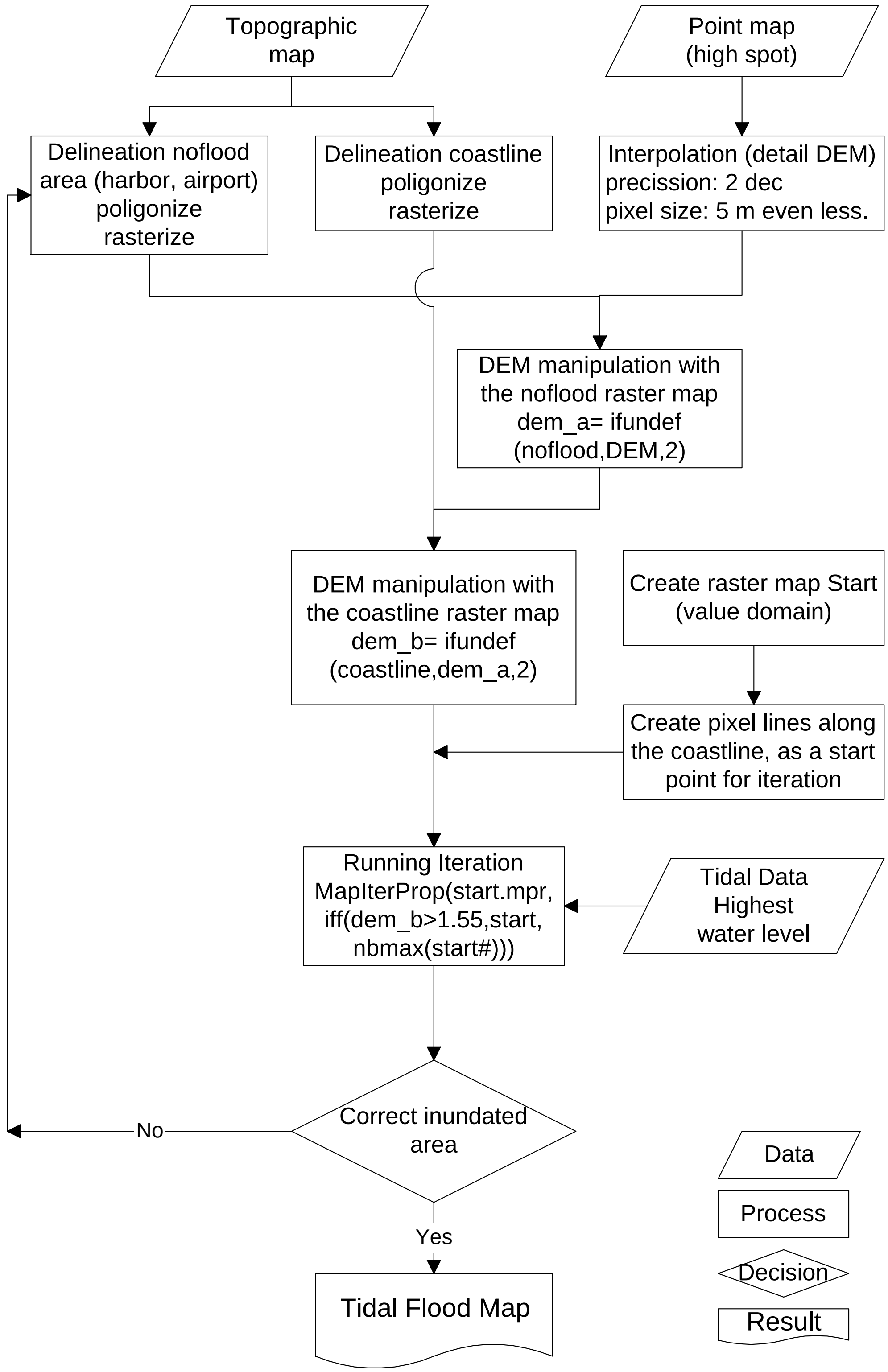


Figure 5.1 Flow chart of tidal flood model

5.1. Tidal flood in Semarang

Tidal flooding is one of the major environmental problems of Semarang City. Unlike the river floods, which occur only during the rainy season, tidal flooding occurs daily with variation depending on the tidal highs. Nowadays, the tidal flood extent in land direction is seen in combination with the land subsidence phenomenon and conversion by industry and residential estate. Land subsidence is expected to have been accelerating dramatically since 1983 by uncontrolled groundwater abstraction (Table 3.3.) for industrial and residential need.

Tidal inundation has a severe impact on economic activity and living condition in Semarang City. In the permanently inundated area several buildings have been abandoned and the road to reach the location has been blocked by the inundation. Only big trucks can pass over the road. Several measures have been taken to minimize the impact of the tidal flood by the local government and citizens. Among these are; creation of the small dykes along the drainage system in residential areas, excavations to take out sedimentations from the drainage channel, reconstruct houses and rise floors, and build a small barriers in front of the houses to prevent the water from flowing in.

Sea level observations are being done at the Tanjung Emas Harbor in Semarang (Bappeda 2000, in Sutanta 2002). Tidal data obtained from the harbor of Semarang has been used for tidal flood model (Table 5.1).

Table 5.1 Sea level observations in Semarang
from November 1998 to November 2000

Type of elevation	Observation (cm)		
	Nov-1998	Nov -1999	Nov-2000
Highest high water level	126.4	155.43	145.1
High water level	120.0	131.37	141.4
Mean sea level	60.0	83.37	81.6
Low water surface	0.0	23.37	21.6
Lowest low water surface	-6.4	13.80	15.5

Source: Bappeda (2000, after Sutanta 2002)

Highest observed high water level (1.55 m + msl) has been selected for the iteration operation. The highest high water level has been used in order to get the maximum condition of the tidal flood spreading.

5.2. DEM value modification

A high quality DEM is an essential input for the tidal model generation. The DEM with 2 decimal precisions and 5-meter pixel resolution has been used. In particular areas known not to be flooded, such as main harbor and airport, additional values have been put on the DEM data. This is referred to here as controlled DEM manipulation. The non-flooded areas have received values higher than the highest water level for the flooding (+1.55 m). In the iteration process, these areas are not inundated. Therefore, the non flooded areas have been delineated from the topographic map; polygonized; rasterized; and assigned the value of 2 m, as follow;

The detail formula for the DEM modification with the no flooded area is written down as follow:

$$dem\_a = ifundef\ (noflood\ , dem\ , 2)$$

Where:

Dem_a = map result from the ifundef formula calculation.

If condition *noflood* is undefined value, then return to outcome of expression *dem*, else return/replace with 2 value.

noflood = the raster map which contain the area should be no flooded.

Dem = original DEM data.

2 = value to put on the *noflood* map,

(The idea is the value has to be more than 1.55 /highest water level) and now the *dem* is already modified and it called *dem_a*.

To avoid unnecessary calculation during the iteration process, pixel values within the sea area have not been taken into account in the calculation. Therefore, the coastline has been delineated; polygonized; rasterized and also assigned a value higher than the highest water level for iteration, (1.55 m) i.e. 2 m +msl.

The detail formula for the DEM modification with the coastline delineation is written down as follow:

$$dem\_b = ifundef\,(coastline, dem\_a, 2)$$

Where:

Dem_b = map result from the ifundef formula calculation.

If condition *coastline* is undefined value, then return to outcome of expression *dem_a*, else return/replace with 2 value.

coastline = the raster map which contain the coastline delineation area.

Dem_a = DEM modified with no flood map.

2 = value to put on the *coastline* map,

(The idea is the value has to be more than 1.55 /highest water level) and now the *dem_a* is already modified and it called *dem_b*.

In the further calculations, the manipulated *dem_b* have been used instead of the original DEM.

5.3. Iteration operation

Iterative calculations are performed line-by-line, pixel-by-pixel and take place in all directions. When a calculation in one direction is finished (for instance from top to bottom) a rotation takes place for the calculation in the next direction. Iteration has been used here in combination with a neighborhood operation. This involves the selection of an item or area, which fits a certain condition, starting from pixels, or in this case a series of pixels situated on one (coast) line.

The input map for iteration is called a start map and contains pixels, which act as the starting point of the calculation. The iteration expression defines a certain condition or defines a calculation to be performed. Figure 5.2 shows the coastline and start map.

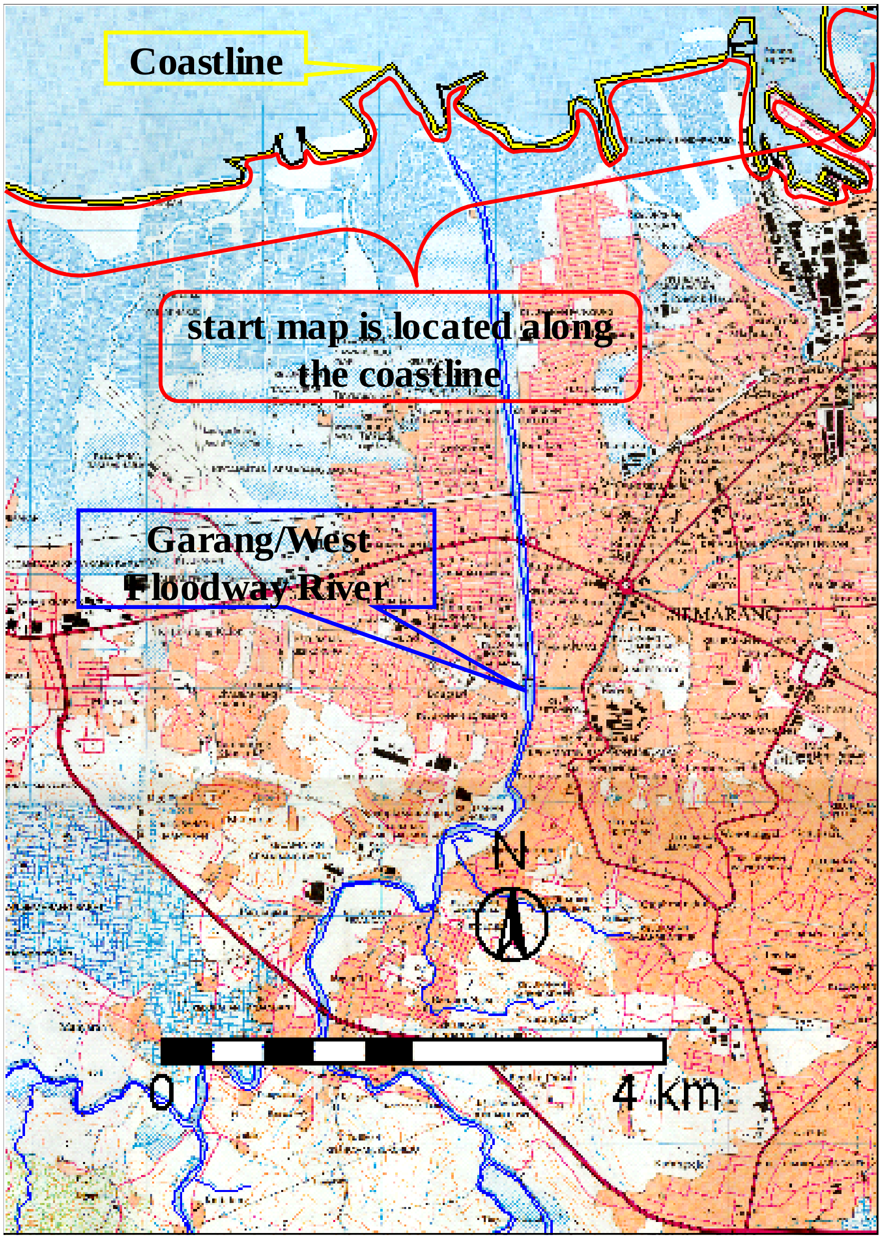


Figure 5.2. Pixels of start map is located

5.4. Performing the tidal flood model

Once the start map has been created, the iteration operation can be done. In ILWIS format, the iteration formula is written down as follow:

Iteration result = MapIterProp (startmap, *iterexpr*, *nr of iterations*).

This formula performs a specified number of iterations with propagation on a start map; the newly calculated value for a pixel is used in calculating the next line instead of in the next iteration. To obtain the tidal flood area of Semarang, the operation has been applied as follows:

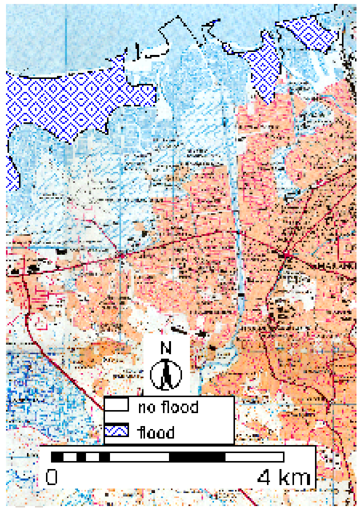
Tidal155 = MapIterProp(start.mpr, iff(dem_b>1.55,start,nbmax(start#)))

Where:

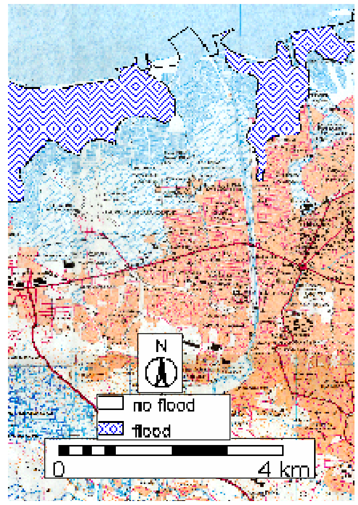
Tidal155	= result map
MapIterProp	= iteration operation with propagation
Start.mpr	= the start map for start the iteration
Dem_b	= DEM modified data
1.55	= the highest water tide
nbmax	= returns the largest value of the values found by a neighborhood matrix.

This means: if the altitude in the dem modified (dem_b) is more than 1.55 meter, then return the pixel values of raster map start (which are undefined). Otherwise, assign the maximum value of the neighboring pixels found in raster map start (which is a value of 1). In the first iteration there is only one pixel that has value 1 (the starting pixel). In every iteration, the neighboring pixels that satisfy the condition (altitude<1.55 meter) will get the same value as that starting pixel. This will continue until the next neighboring pixels have an altitude of more than 1.55 meter. The program will calculate in a downward, upward, left, and right direction. When no changes occur after a full iteration, the final map is generated. After each iteration ILWIS shows the number of changed pixels. This number is the total of changes after performing one iteration in all directions (up, down, right and left).

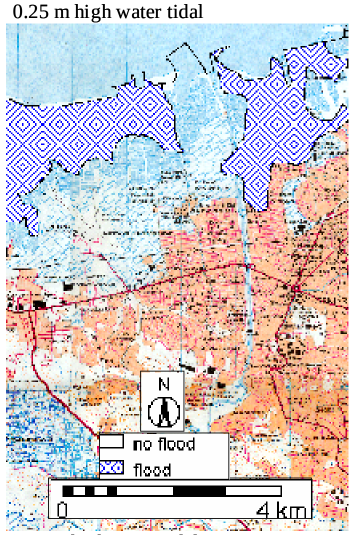
The gradual step of the spreading of the tidal flood describe on the simulations of the model. Model simulations have been performed using 0.25 m; 0.55 m; 0.75 m; 1.0 m; 1.25 m; and finally 1.55 m values. Model simulations are shown in Figure 5.3.



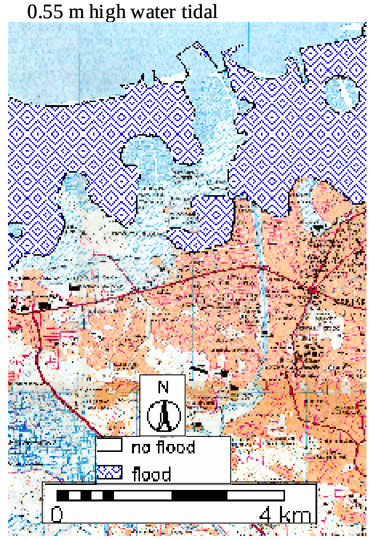
0.25 m high water tidal



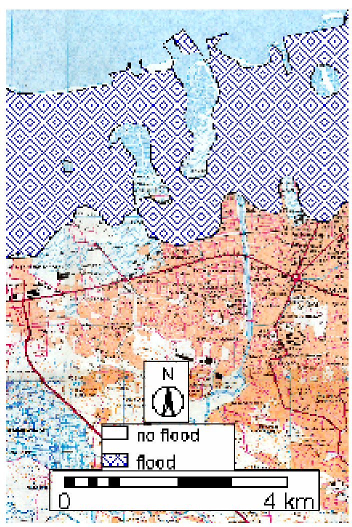
0.55 m high water tidal



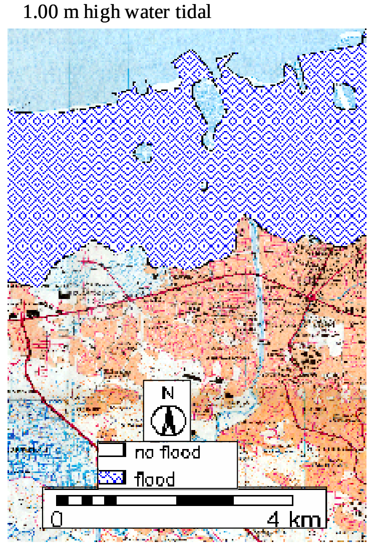
0.75 m high water tidal



1.00 m high water tidal



1.25 m high water tidal



1.55 m high water tidal

Figure 5.3 Model simulations of the tidal flood spreading

The iteration result is a raster map, which contains pixel values for the flooded area and undefined for the non-flooded area. In the further analysis, the flood map has been overlaid with a landuse map, as well as with the tidal flood from a different source. This has been done to calculate the reliability of a model in order to calculate the reliability of this model (chapter 6).

5.5. Concluding remarks

This chapter dealt with the tidal flood modelling. This included: a description of the tidal flooding phenomenon in Semarang, the digital elevation model (DEM) modification, the iterative modelling operation, and the performance of the tidal flood model.

As for the river flood model, a high quality DEM is an essential input to the tidal model as well. The most recent, photogrammetrically derived, DEM of Semarang, with 2 decimals and 5-meter pixel resolution has been used in this study. The DEM has been manipulated in order to correct for real world conditions of the surface and sub-surface, and to restrict the iteration operation. These manipulations have mostly been based on experience gained from the fieldwork. This DEM manipulation is regarded as the modeller's last resort to steer the tidal flood encroachment in the iteration procedure.

The iteration requires one or more pixels as a source in the start map. In accordance to real-world tidal flooding, the high water gradually spreads from the coastline land inward. Therefore, a series of pixels situated on the coastline have been assigned as start pixels. It is obvious that the accuracy of the DEM entirely determines the sequence of flooding, and to a lesser extent the total flooded area. This has been illustrated by producing intermediate tidal flood extension maps at .25 m water level intervals.

It should be noted that no drainage infrastructure has been taken into account in the tidal flood model. This is the weakest point in the analysis. Then again, the iterative modeling approach has been selected while bearing in mind that detailed drainage information was not available. Acquiring such information was beyond the scope of this study. As for the river flood model, this is recommended for future research.

Chapter 6 Validation and Evaluation of River and Tidal Flood Models and Flood Hazards Assessment

This chapter is dealing with the model validation, evaluation, and flood hazards assessment. Model validation has been done both for the river flood model and for the tidal flood model. A simple validation method has been applied used through reliability and accuracy calculation. Reliable source maps have been obtained and processed to enable comparison and validation on a pixel-by-pixel basis. The source maps are used by the Local Government to make decisions on urban planning. These have been produces by the Board of Regional Planning and Development (Bappeda). In the evaluation of the river and tidal floods model is also discussed the advantages and the limitations of the respective approaches.

The assessment of the flood hazards has been done using both models. The distribution of water depth and the impact of the flood hazards on landuse have been analysed. The landuse map has been extracted from the detailed landuse map, which has been created in 2001 based on the aerial photos scale 1: 10,000 by Public Works Office.

6.1. Model validation

Accuracy and reliability calculations have been used to validate the models. The model results have been compared to reliable source maps. The source map for the river flood with 100-year return period has been obtained from the JICA (1993). The source map for the tidal flood has been obtained from Semarang Public Works Office (2001).

The confusion matrix concept has been applied in order to get the accuracy and reliability values. Confusion matrix has been obtained by crossing maps and generating table containing areas of different combination of classes. Accuracy is the fraction of correctly classified ground truth (or source map) pixels of a certain source class. For each class of source pixels, the number of correctly classified pixels is divided by the total number of source pixels in that class. Reliability is the fraction of correctly classified ground truth (or source map) pixels of a certain class in the model. For each class in the model class, the number of correctly classified pixels is divided by the total number of pixels which were classified as this class. The detail task to access the validation of the models is shown in Figure 6.1.

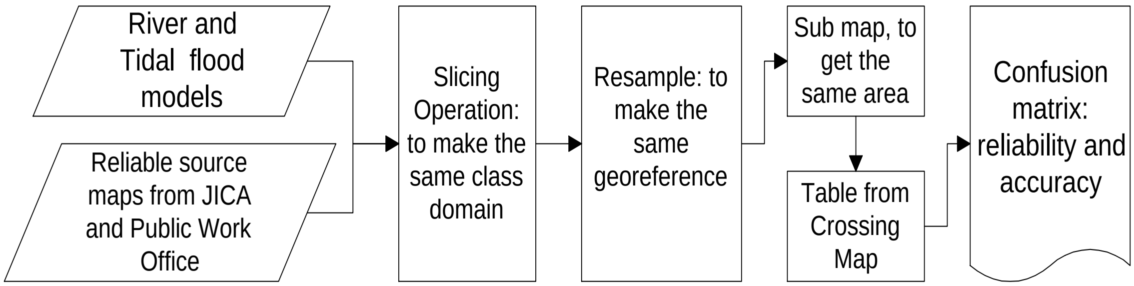


Figure 6.1 Flowchart of validation method of the models

All maps for validation have been sliced in order to get a same class domain. Resample operation to get same a same georeference have been done to enable cross map operation. Finally, the table generated from cross map operation have been used for confusion matrix.

6.1.1. River flood model

A comparison between river model and source map refer to the area of the source map, due to the source map has smaller area than the model, therefore only the pixels within the source map boundary have been compared. Comparison between the numbers of pixel in every class ("non-flood" and "flooded") from the source map and the river flood model has been made. The result is shown in the Table 6.1.

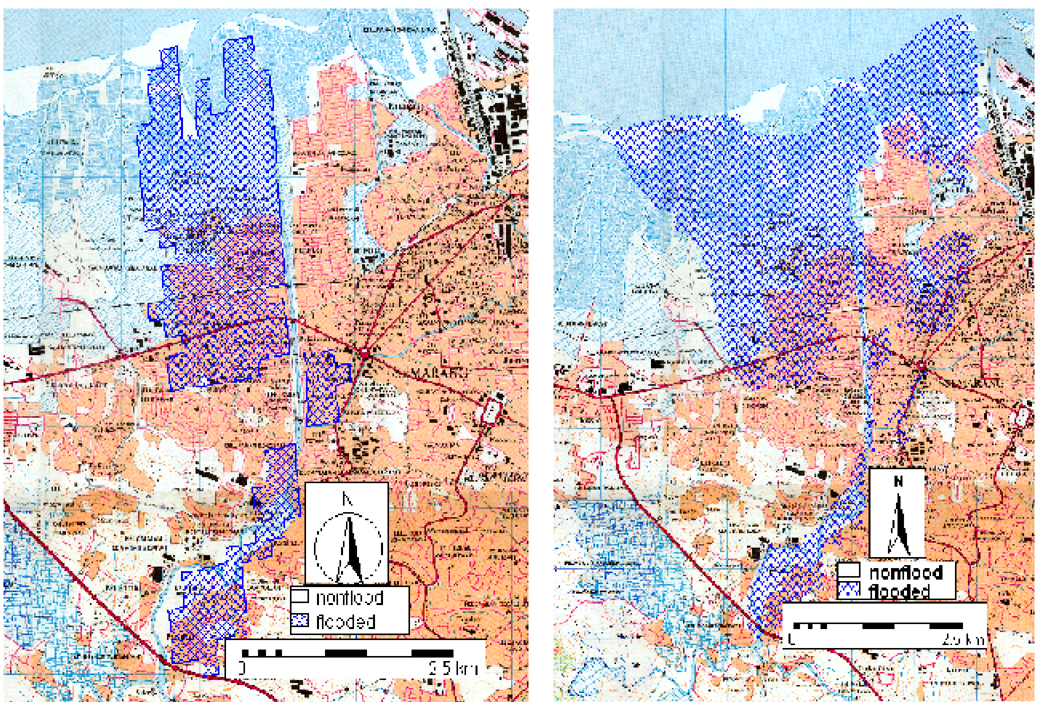
Table 6.1 Confusion matrix of source map of the river flood and river flood model

		River flood model		Accuracy
		non-flood	flooded	
Source map	non-flood	1222434	445156	0.73
	flooded	202923	837127	0.80
Reliability		0.86	0.65	

Average Accuracy = 77 %
Average Reliability = 76 %

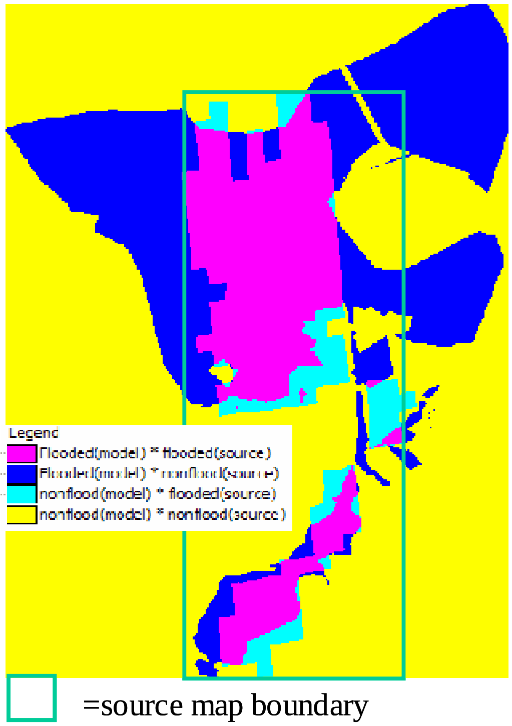
According to table 6.1 for the flooded class, the accuracy is 837127/(202923+837127) = 0.80 meaning that approximately 80% of the flooded source map pixels also appear as flooded pixels in the model. Reliability for the flooded class is 837127/(445156+837127) = 0.65 meaning that probably 65% if the flooded pixels in the model are correct compared to the source pixels. The average accuracy is calculated as the sum of the accuracy figures in column accuracy divided by the number of classes in the source map, the result is 77%. The average reliability is calculated as the sum of the reliability figures in column reliability divided by the number of classes in the source map, the result is 76%.

The comparison between the source map and the model is shown on the Figure 6.2 and the overlaid between them is shown on the Figure 6.3.



River source map River model

Figure 6.2 Comparison between river source map and river model



=source map boundary

Figure 6.3 Overlaid between river source map and river model

In Figure 6.3 the differences of the area in area between non-flooded and flooded in the source map and in the river flood model area quit large. This causes the difference in accuracy and reliability of the maps. In general, the pattern of both two maps is giving the same impression on the flooded area. The larger part flooded area for the 100 year return period appears on the left side of the river. Graph on Figure 6.4 shows the area each class on source map and river flood model.

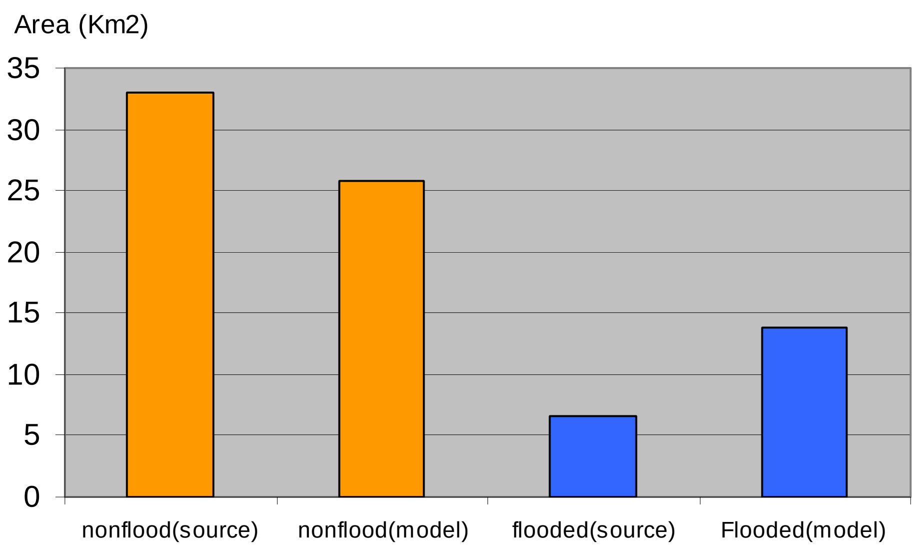


Figure 6.4 Area each class on source map and river flood model

1. The model validation is influenced by factors, these are: 1) Different spatial resolutions of the surface elevation data (DEM) of source map and modelled map. Source map has larger pixel size (200 m), (JICA 1993) than the modelled (5 m). 2) Different sources of the DEM data and time lag. . In the modelling process, the updated DEM also included the rate of land subsidence (11.5 cm/year) (Chapter 3).

6.1.2. Tidal flood model

The Semarang Urban Drainage Master Plan has been completed by Public Works Office. The map is used for urban regional planning in Semarang. Therefore, to validate the tidal flood model the map from Public Works Office would be used. The accuracy and reliability calculation have been done using the number of pixel in every class of the source map and tidal flood model. The comparison between the number of pixels in every class (“non-flood” and “flooded”) from the source map and the tidal flood model is shown in the Table 6.2.

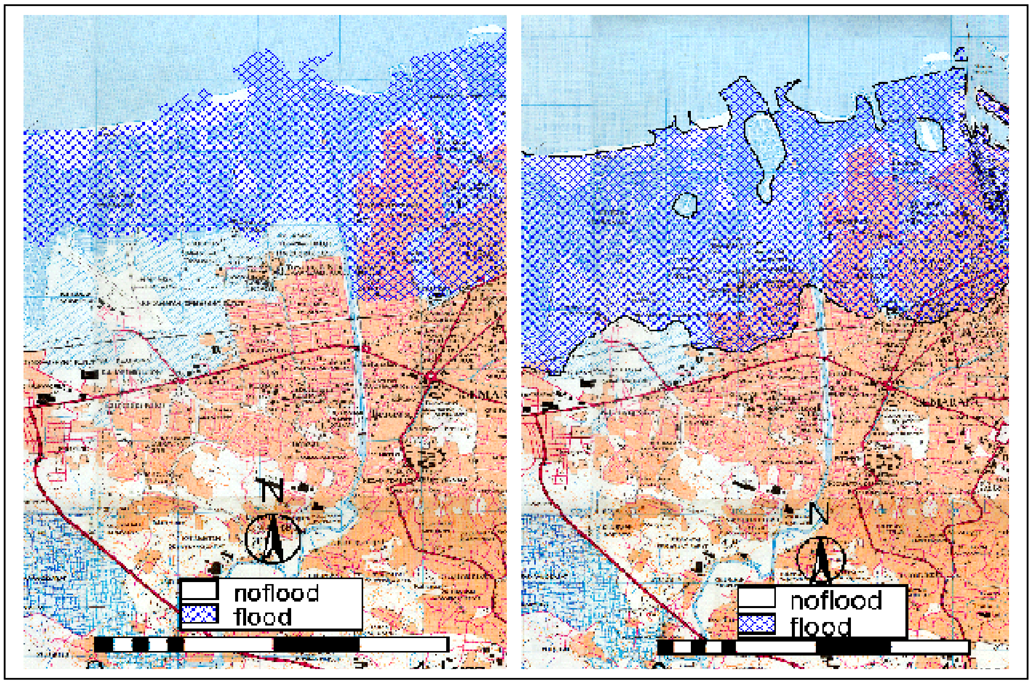
Table 6.2 Confusion matrix of source map of the tidal flood
and tidal flood model

		Tidal flood model		Accuracy
		non-flood	flooded	
Source map	non-flood	4625620	740270	0.86
	flooded	158884	1682522	0.91
Reliability		0.97	0.69	

Average Accuracy = 89 %
Average Reliability = 83 %

According to table 6.2 for the flooded class, the accuracy is 1682522/ (158884+1682522) = 0.91 meaning that approximately 91% of the flooded source map pixels also appear as flooded pixels in the model. Reliability for the flooded class is 1682522/ (740270+1682522) = 0.69 meaning that probably 69% if the flooded pixels in the model are correct compared to the source pixels. The average accuracy is calculated as the sum of the accuracy figures in column accuracy divided by the number of classes in the source map, the result is 89%. The average reliability is calculated as the sum of the reliability figures in column reliability divided by the number of classes in the source map, the result is 83%.

The comparison between the source map of the tidal flood and the model is shown on the Figure 6.5, and the overlaid between them is shown on Figure 6.6.



Tidal source map Tidal model

Figure 6.5 Comparison between source map of tidal flood and model

Figure 6.6. Overlaid between tidal source map and tidal model

Figure 6.6 gives the impression that the differences between classes (non flooded and flooded classes) in the source map and in the tidal flood model are small area. The Graph in Figure 6.7 shows the area classes in source map and tidal flood model.

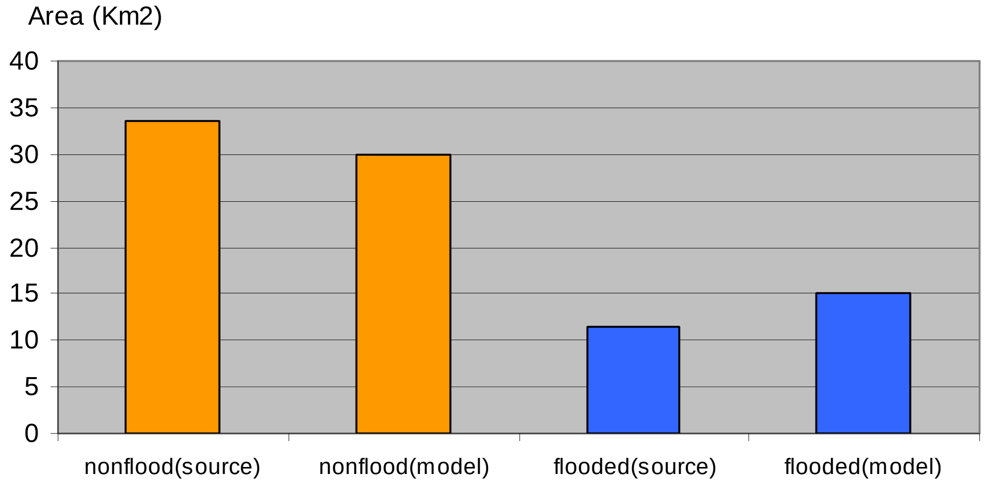


Figure 6.7 Area each class on source map and tidal flood model

The result from the confusion matrix lead to the conclusion that, the tidal flood model is fairly accurate compared to the Public Works source map.

6.2. Model evaluation

The GIS modelling of river and tidal flood hazards have been done in this study using various methods in the GIS environment and in the hydrological modelling environment. In the GIS environment the generation of river and tidal flood models has been based on the vector and raster data. River flood modelling was largely done using vector data with the final spatial analysis and validation in GIS raster format. Tidal flood model has entirely been done using raster maps with the ILWIS software.

On the performing of the river flood model, an integration method has been used, namely hydrological software and GIS environment. Several matters concerning the methodology has been found and written down as follows:

1. Detail DEM is needed in order to get more detail terrain surface for spreading flooded area. Detail cross-sections, path of the river, riverbank delineation, floodplain delineation, and tributaries delineation are important regarding to the detail geometric data. The hydrological data are also important, not only about the peak discharge and average discharge data, but also sedimentation data, slope gradient, manning coefficient, and the hydraulic condition of the river, such as the weir location, bridge location, and the channel condition. In this research coarse data have been used, and obviously the result would be different if the detail and complete hydrological data are used.
2. Processing using hydrological software (HEC-RAS) has to be done in every cross-section, its mean the detail data every cross-section is very important. Since the coarse data used, it is assumed that every cross-section has a same condition.
3. The compatibility of the hydrological and GIS software makes it easily to operate both of them, especially for data up dating, performing different scenario, and data sharing.
4. Complicated surface elevation on the urban area make harder on the cross sections generation and editing, since the detail surface information cannot be obtained. Therefore, the field observation is still needed, especially along the floodplain area in the urban environment.

On the performing of the tidal flood model, a neighbourhood function in ILWIS software has been used. Several matters concerning the methodology has been found and written down as follows:

1. Determination of the flooded area in ILWIS can be done either using the iteration process, map calculation, or slicing method. The different between the iteration and other method is in iteration all the pixels will connect each other. In term of the tidal flood, which is water come from the sea, only if the water has a path to reach some places then the places will be inundate, if there is no path to reach a place, than the area will not inundate. Therefore, to make more logic on tidal inundation, the iteration process has been used.

2. However, tidal flood measured on the cm high, and to do calculation on it, the detail DEM is needed. It is difficult to get the detail DEM, particularly on the coastal urban area on Semarang, where is the city on the coastal growing very fast, and surface elevation also may changes. Hence, the accuracy of the model depends fully on the detail DEM data.
3. The detail data of the highest water tidal is needed, because not on the entire area has the same high of tidal water elevation, and than the iteration calculation has to be made separately each region.

6.3. Flood hazards assessment

Flood hazard assessment is the evaluation of potential damage due to flood. Flood hazards in Semarang, either from river or sea are considered as a potential hazardous phenomenon having and give the negative impact on economy and population. In this section, the assessment of the flood hazards is done. Firstly, the flooded area has been calculated for different water depth classes using river and tidal flood model results. Secondly, the impact of the floods on landuse has been determined. Different water depths on different landuse have a different impact in term of damage and cost.

6.3.1. Water depth distribution of river flood

The distribution of water depth can be calculated by subtracting grid maps of water surface and Terrain. The calculation of flooded area per water depth class is the done by histogram calculation. Figure 6.8 shows the flowchart of calculation of water depth distribution by the river flood model. Figure 6.9 shows the map with the distribution of water depth.

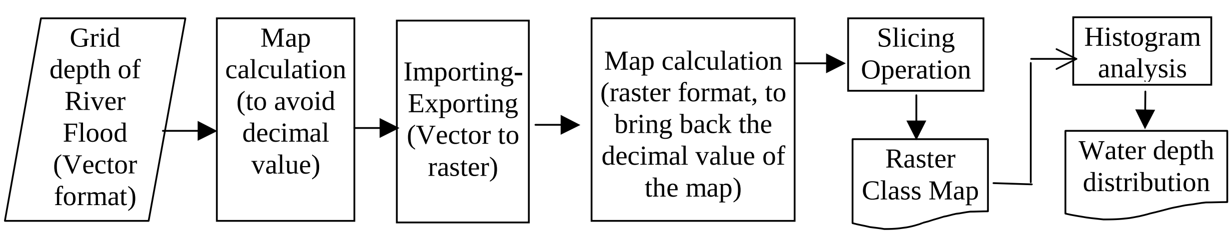
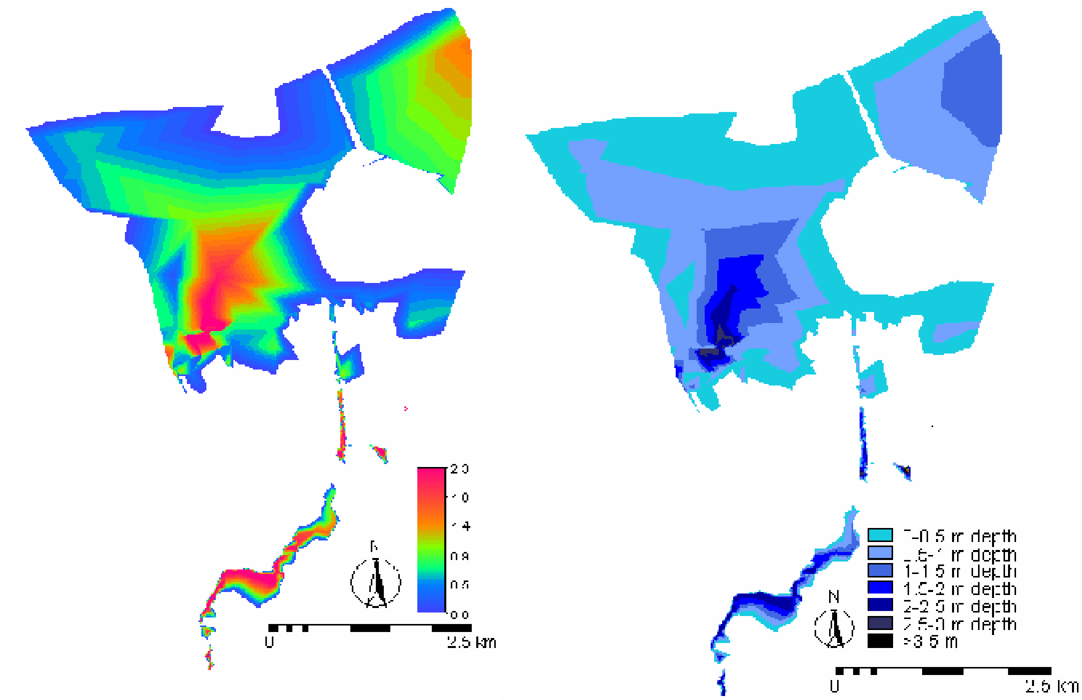


Figure 6.8 Flowchart of calculation of water depth distribution on river flood model



Raster map of water depth　　　　Slicing operation of water depth

Figure 6.9 Distribution of river flood depth

The water depth map has been classified using a slicing operation in order to get the flooded area for every depth class. The river flood area per depth class is shown in Table 6.3 and in Figure 6.10 as a graph.

Table 6.3 Area per class of river flood depth

Depth Class (m)	Number of Pixels	Area (Ha)
0.0 - 0.5	54845	548.45
0.5 – 1.0	44852	448.52
1.0 – 1.5	16569	165.69
1.5 – 2.0	5333	53.33
2.0 – 2.5	2556	25.56
2.5 – 3.0	397	3.97
> 3.5	26	0.26
Total	124578	1245.78

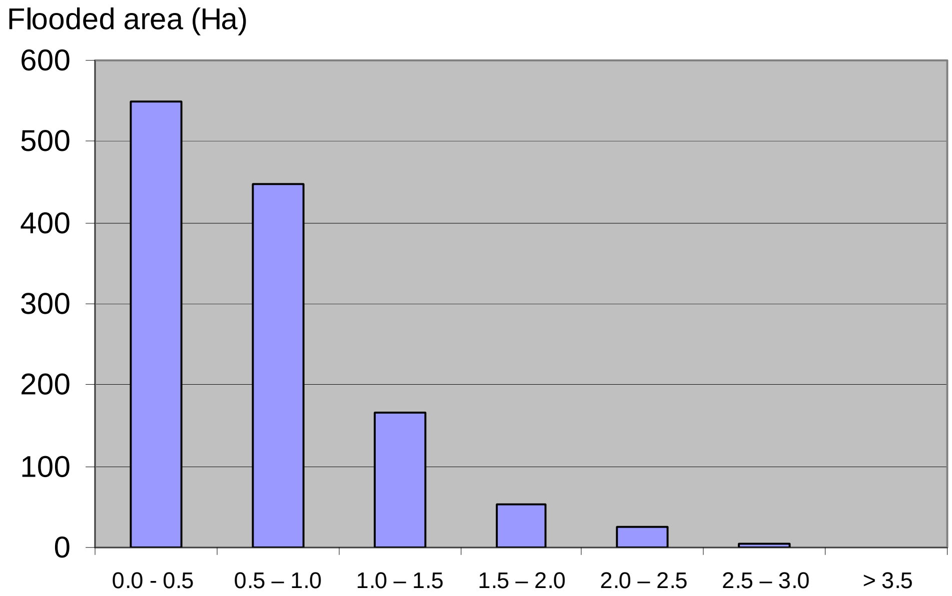


Figure 6.10 Graph of river flood area per depth class

6.3.2. Water depth distribution of tidal flood

Using the cross map between tidal flood and digital elevation model the distribution of the water depth can be calculated, Figure 6.11 shows the flowchart of the calculation of the water depth distribution on the tidal flood model. The cross map operation produced a table, which contains the elevation value enclosed by the highest water level value (+ 1.55 m). The water depth is the difference between the DEM value and the highest water level, and written down as follows:

Waterdepth = 1.55-DEM

Where

Waterdepth = new column for creating the attribute map of water depth.
1.55 = the highest water level
DEM = surface elevation map

Using slicing operation, the flooded area per water depth class has been calculated as well. Figure 6.12 shows the water depth map of the tidal flood and Table 6.4 and Figure 6.13 are shows the area per water class depth.

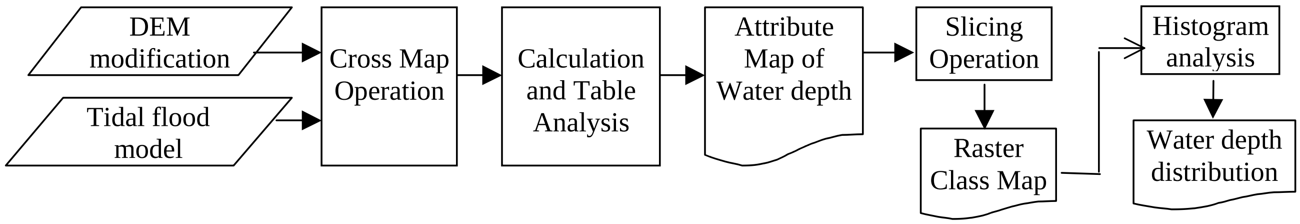


Figure 6.11 Flowchart of calculation of water depth distribution on tidal flood model

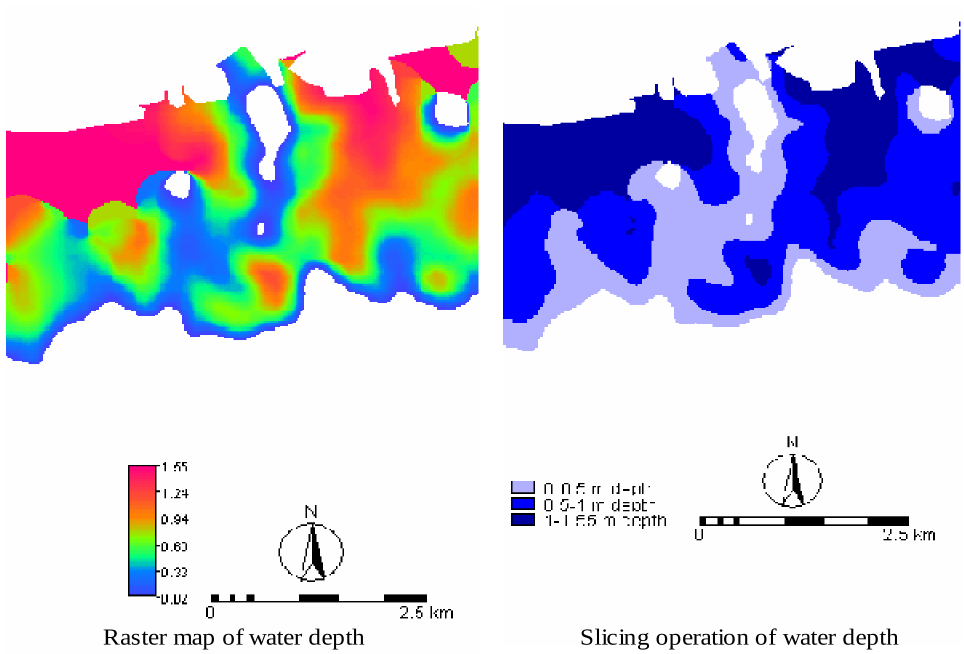


Figure 6.12 Distribution tidal flood depth

Table 6.4 Area per class of tidal flood depth

Depth classes (m)	Number of pixels	Area (Ha)
0.0 - 0.5	756802	473
0.5 - 1.0	976297	610
1.0 – 1.55	689693	431
Total	2422792	1514

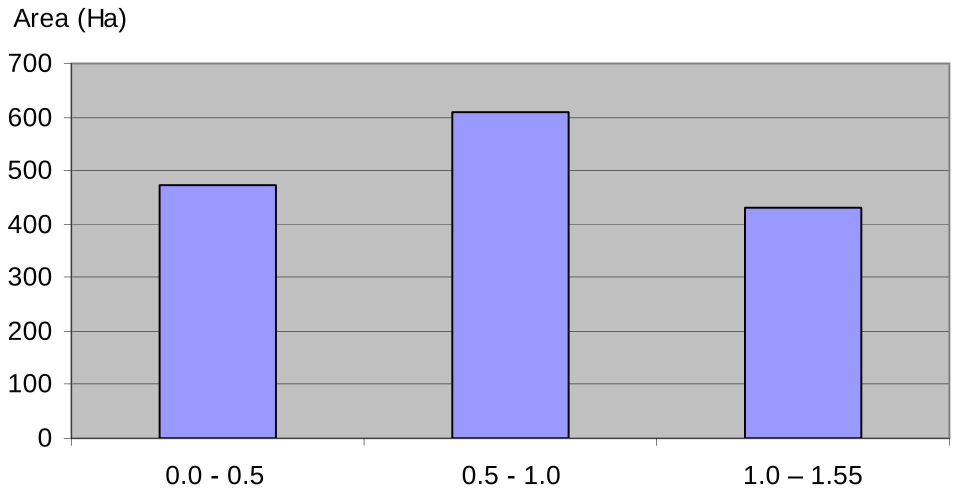


Figure 6.13 Graph of tidal flood area per depth class

6.3.3. Impact of river flood on landuse

The impact of river flood on landuse has also been determined by crossing both maps and table calculation. The landuse map (scale 1:5000) that has been obtained from the Public Works Office contains 12 classes of landuse. This map has been aggregated into 4 classes of landuse, namely build up area, agriculture area, fishpond area and other. The process of grouping has been based on the similar impact of flooding on those types. The grouping of the landuse classes is shown in the Table 6.5.

Table 6.5 Grouping of landuse classes

Classes of landuse map	Classes of aggregate landuse map
Paddy field	Agriculture
Dry farming	
Fishpond	Fishpond
Swampy area	
Residential	Build area
Office buildings	
Public buildings	
Road	Others
Open space	
Grass land	
Coast area	
Yard	

After the grouping of the landuse classes in a new aggregated landuse map, calculations have been performed by crossing the river flood map and the landuse map. From the table calculation the respective areas of landuse class affected by river flood have been determined. The aggregated landuse map is shown in Figure 6.14. The crossed map between river and landuse is shown in Figure 6.15. The associated numbers of pixels per class, and the areas in hectares are shown in Table 6.6.

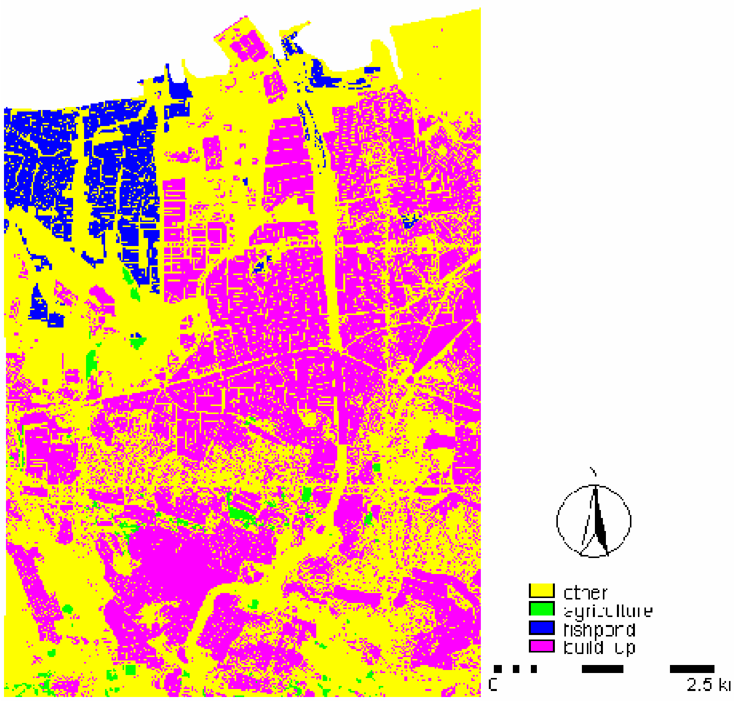


Figure 6.14 Landuse map

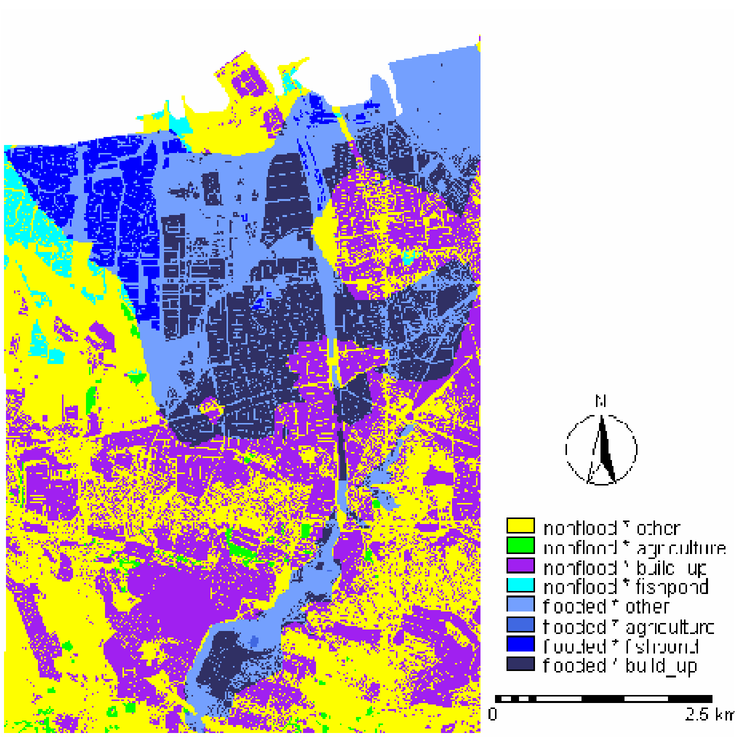


Figure 6.15 Crossing map between river flood and landuse map

Table 6.6 River flooded and non-flood areas per landuse class

Classes	npix	Area (m^2)	Percentage
nonflood * other	2227467	13921668.8	35.06
nonflood * agriculture	59296	370600	0.93
nonflood * fishpond	113979	712368.8	1.79
nonflood * build_up	1732987	10831168.8	27.27
flooded * other	1138696	7116850	17.92
flooded * agriculture	2147	13418.8	0.03
flooded * fishpond	262603	1641268.8	4.13
flooded * build_up	816927	5105793.8	12.86

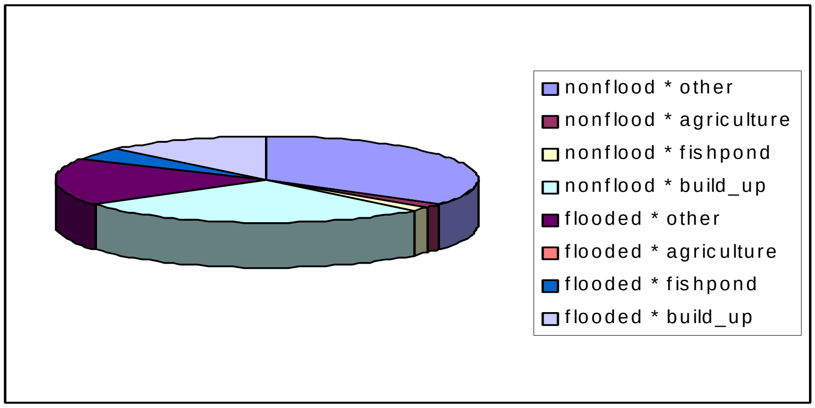


Figure 6.16 Graph of distribution of river flooded and non-flood areas per landuse class

6.3.4. Impact of tidal flood on landuse

Using the same aggregated landuse map and same map crossing procedure as for the river flood; the impact of tidal flood on landuse has been determined. The resulting map is shown in Figure 6.17. From the table produced by the map crossing, the calculation of the flooded area per landuse class has been made. The result is shown in Table 6.7, with the graph in Figure 6.18.

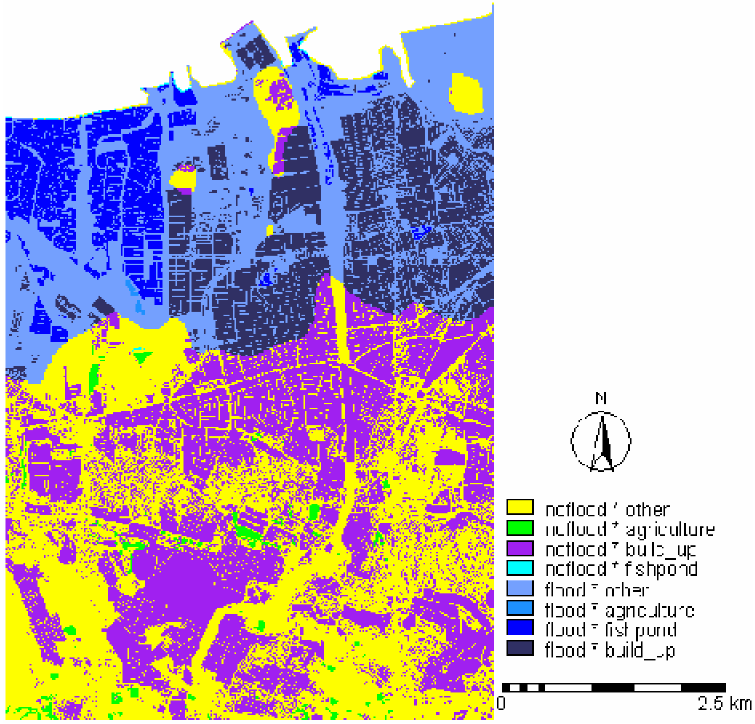


Figure 6.17 Crossing map between tidal flood and landuse map

Table 6.7 Tidal flooded and non-flood areas per landuse class

Classes	npix	Area (m^2)	percentage
noflood * other	2062855	12892843.8	32.46
noflood * agriculture	57827	361418.8	0.91
noflood * fishpond	5476	34225	0.09
noflood * build_up	1810938	11318362.5	28.5
flood * other	1303308	8145675	20.51
flood * agriculture	3616	22600	0.06
flood * fishpond	371106	2319412.5	5.84
flood * build_up	738976	4618600	11.63

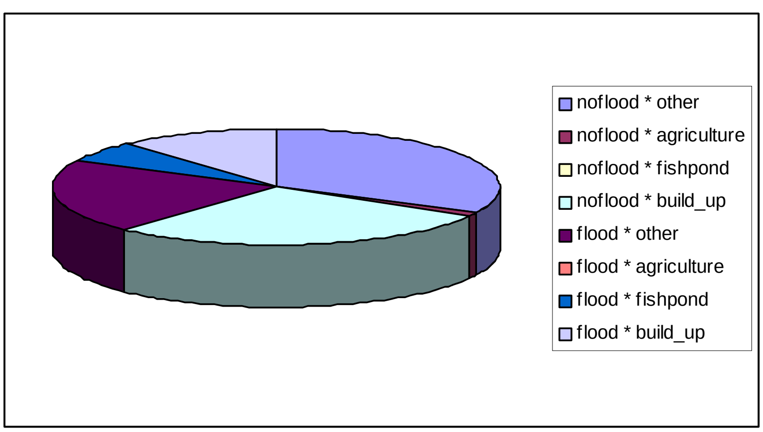


Figure 6.18 Graph of distribution of tidal flooded and non-flood areas per landuse class

6.4. Concluding Remarks

This chapter dealt with the validation and evaluation of the model results and the flood hazard assessment. A simple validation methodology has been applied, using reliable source maps from the JICA project (1993) and Public Works Office Project (2001). A confusion matrix has been produced to validate each model. Every pixel in the resulting flood extension maps from the two models has been compared to the source maps in order to calculate the accuracy and the reliability.

Accuracy has been defined as the fraction of correctly flooded or non-flooded ground truth (or source map) pixels. For each of the two classes, the number of correctly classified pixels has been divided by the total number of source pixels in that class. In the opposite way, reliability has been defined as the fraction of correctly classified flooded or non-flooded ground truth (or source map) pixels of a certain class in the model. For each class in the model, the number of correctly classified pixels is divided by the total number of pixels which were classified as this class.

In this study, the applied geographic validation method, on the basis of pixel by pixel comparison, has appeared to be a fairly reliable accuracy test. ‘Geographic’ relates to the fact that not the calculated water depth maps (in m + MSL) but the flood zonation maps (flooded vs. non-flooded) have been compared. For future research it is recommended to observe the process of flood encroachment in the field or by a time series of airborne image data, in combination with in-situ observations of water levels. This would not only enable a more accurate model validation, but calibration as well.

Flood hazard assessment involves the calculation of water depth and landuse affected by floods. Water depth calculations have been calculated using a slicing operation and table analysis in raster format, for both river and tidal flood model. Land use affected by floods has also been analyzed using a cross map operation and table analysis in raster format. To improve the accuracy of the analysis and the added value of the derived maps and tables, it is recommended to redo the entire approach on the basis of high accuracy airborne multi-spectrally scanned image data (for land use classification) and laser-scanned altimetry data (for DEM generation; flood assessment).

Chapter 7 Conclusions and Recommendations

This chapter deals with the conclusions and recommendations based on the research process and results.

7.1. Conclusions

Methodology; the applied methodology comprises 5 phases, namely; 1) Preparation phase; comprises of literatures study, ancillary data collection, and fieldwork preparation. 2) Fieldwork and data acquisition phase; comprise spatial and hydrological data acquisition e.g. DEM, topographic map, landuse map, river flood map, tidal flood map, river discharge, manning coefficient, river cross section, and drainage system. 3) Modelling phase; consists of the building and running two types of models using hydrological software and GIS environment, i.e.: the river flood model and the tidal flood model. 4) Validation, evaluation, and hazard assessment phase; comprises the validation of the models using a confusion matrix of model result against reliable source map to get accuracy and reliability. The hazard assessment has been done by map calculations and table operations to analyze landuse affected by floods. 5) Reporting phase; on the reporting phase, whole research process is translated in a conclusions and recommendations.

Physical environment and landscape characteristics; Semarang is the provincial capital of Central Java. The geographical location of Semarang makes the city play an important role for regional development, especially in Central Java. Industrial estate and residential areas are growing rapidly, covering more than 3 km^2. It has an impact on groundwater extraction, which is intensively done at a rate of 30 million m^3/year.

The natural hazards occurring in Semarang city are river and tidal flooding, landsliding and land subsidence. River flood occurs due to the high rainfall intensity combined with insufficient drainage system, and Tidal flood occurs due to high tidal wave overflowing on the coastal land The upper part of Semarang consists of two zones with high landslide susceptibility, namely susceptible to landslide process and fault active zone.

Meanwhile, land subsidence is becoming the biggest problem of Semarang City. The rate of subsidence is varying 11.5 cm/yr even more up to 0.2 m/yr.

River flood modelling; A high quality DEM is required for this type of modelling. Topographic map on scale 1:5000 has been used as a guide to generate geometric data. Crude hydrological data on the Garang/West Floodway River have been used on the hydrological analysis. Annual average discharge and probable peak discharge of 100-year return period, and water level on the normal condition and on the probable peak discharge 100 year return period have been used to perform the hydraulic calculation. To obtain the different of the water level on the model between a normal condition and a 100-year return period condition, encroachment method has been used.

Tidal flood modelling; the detail DEM is the important factor for generation this model, the DEM with 2 decimal precisions and 5-meter pixel resolution have been used on this study. The DEM has been manipulated in order to correct for real world condition of sub surface and to restrict during the iteration operation. The iteration requires pixels source on start map, due to the tidal flood start spreading from the coastline, the start map has been located along the coastline.

Validation and evaluation of models, and flood hazard assessment; A simple validation methodology has been applied in this study, using reliable source maps from the JICA project (1993) and Public Works Office Project (2001). A confusion matrix has been produced to validate models. Every pixel on the models has been compared to the source maps to calculate accuracy and reliability. Average accuracy for river flood model is 77% and for tidal flood model is 89%. Average reliability for river flood model is 76% and for tidal flood model is 83%.

Evaluation concerning of the generation of models have been done. Several factors influence on the generation of the river flood models, namely; the detail cross-sections, path of the river, riverbank delineation, floodplain delineation, and tributaries delineation. The hydrological data are also important, not only about the peak discharge and average discharge data, but also sedimentation data, slope gradient, manning coefficient, and the hydraulic condition of the river, such as the weir location, bridge location, and the channel condition. Determination of the tidal flood model has been done using the iteration process. Tidal flood measured on the cm high, therefore detail data of the highest water tidal and DEM data are needed. The accuracy of the model depends fully on them.

Flood hazard assessment; involves the calculation of water depth and landuse affected by floods. Water depth calculations have been calculated using slicing operation and table analysis in raster format. Landuse affected by floods have been analyzed using cross maps operation and table analysis, also in raster format. Landuse types influenced by the river floods are: built up area, fishpond, agriculture and others with the area affected is 510,57; 164,12; 1,34; and 711,68 hectare respectively. Landuse types influenced by the tidal flood are: built up area, fishpond, agriculture and others with the area affected is 814,56; 2,26; 231,94; and 461,86 hectare respectively.

7.2. Recommendations

The results of this study have led to the following recommendations for future research by UGM and ITC on the issue of land subsidence and flooding in Semarang City.

Integrated hazard assessment is regarded as a necessary input to the development of a management and spatial planning strategy for the City of Semarang. This would involve not only an assessment as the present-one. But it would also include aspects of vulnerability and risk assessment. Local planning authorities (Bappeda) would benefit from such an integrated approach in which a prototype of a spatial planning support system would be developed. Such a SPSS would be capable of weighing different measures and strategies to adapt to and mitigate the relevant coastal hazards, such as land subsidence, flooding, sea level rise, and groundwater abstraction.

In this study, river and tidal floods have been treated separately. They do occur at the same time during the wet season. The combined effect of the two floods has an even larger impact on the city and it’s population than follows from the present hazard assessment. Therefore, it is recommended for future research to develop an integrated model capable of dealing with both types of floods in an integrated way. It is, however, realized that such a dynamic modeling approach also involves intensive fieldwork on hydrological data collection.

Summary

Background and objectives; Semarang is a water front city situated on the lowland part of Central Java province in Indonesia. River and tidal floods frequently occur in this area. Local planners and decision makers are in need accurate information on the spatial distribution, magnitude and depth of flooding, and on the landuse affected by it. The integration of GIS and hydrologic models is an active area of research. The present research intends to contribute to this as well. The objectives of this research are: 1) to construct a river flood model in a GIS environment, 2) to construct a tidal flood model in a GIS environment, and 3) to validate and evaluate both models, and to assess flood hazards in a waterfront city.

Methodology; Different methodologies have been applied to each objective of this research. Hydrological software has been applied in a GIS environment method to generate the river flood model. A Neighborhood operation on raster data has been applied to generate the tidal flood model. For validation of the model results a confusion matrix and a cross map operation has been applied. The map calculations and table operations are part of a simple flood hazard assessment, which is to describe the distribution of water depth and the impact to landuse.

The methodology of this research comprise of 5 phases, namely; 1) Preparation, 2) Fieldwork and data acquisition, 3) Modelling, 4) Validation, evaluation, and hazard assessment, and 5) Reporting. Preparation phase comprises of literatures study correlate with the topic, ancillary data collection, and fieldwork preparation. Fieldwork and data acquisition phase comprise spatial and hydrological data acquisition e.g. DEM, topographic map, landuse map, river flood map, tidal flood map, river discharge, manning coefficient, river cross sections, and drainage system. Those data have been used to generate the model, validate, evaluate, and assessment also to describe the physical environment and landscape characteristics on the study area. Modelling phase consists of the building and running two types of models using hydrological software and GIS environment, i.e.: the river flood model and the tidal flood model. River flood model has been generated using integration between HEC-RAS software for hydrological analysis, HEC-GeoRAS and Arc View for geometric data and spatial

representation of the model. Tidal flood model has been created from neighborhood function (iteration) in ILWIS software. Validation, evaluation, and hazard assessment phase comprises the validation of the models using a confusion matrix of model result against reliable source map to get accuracy and reliability. Evaluation of the model is to determine the advantages and limitations of the models. The hazard assessment has been done by map calculations and table operations to analyze landuse affected by floods. The last phase is reporting whole the research activities and results.

Physical environment and landscape characteristics; Semarang is the main port and Capital of the Central Java Province. It is located on the north coast of Java and lies 540 km East of Jakarta at South Latitude of $6^0$56’08” to $7^0$06’57” and the East Longitude of 110^0 16’ 17” to 110^0 30’31”. The City of Semarang covers an area of approximately 400 km^2 which main activities are industrial estate, trade, education, and tourism. The geographical position of Semarang city makes the city play an important role for regional development, especially on the Central Java.

The minimum temperature is about 18^0C and the maximum is about 35^0C, and the minimum humidity is 62% and the maximum is 84%. Rainfall intensity on the Garang/West floodway river catchments recorded from several rainfall stations, which the minimum rainfall intensity occurs on August (34 mm in Pagersari Station) and the maximum on January (627 mm in Limbangan Station). Geology formation consists of alluvial sediment, Damar formation, Volcanic breccias, and Marin sediment. Geomorphology condition on the study area roughly divided into three categories: Fluvial landforms, Structural-denudational landforms, and Volcanic landforms. Soil types on the study area identified as Alluvial, Regosol, Yellowish Red Mediterran and Grumusol, and Latosol and Andosol.

The natural hazards occurring in Semarang city are river and tidal flooding, landsliding and land subsidence. River flood occurs due to the high rainfall intensity combined with insufficient drainage system, and Tidal flood occurs due to high tidal wave overflowing on the coastal land. The upper part of Semarang consists of two zones with high landslide susceptibility, namely susceptible to landslide process and fault active zone.

Meanwhile, land subsidence is becoming the biggest problem of Semarang City. The rate of subsidence is varying 11.5 cm/yr even more up to 0.2 m/yr.

River flood modelling; an integrated approach using hydraulic modelling software and GIS software has been used to generate the river flood model. The HEC-RAS (Hydrologic engineering center river analysis system) software has been used to perform, calculate and do analysis of the hydrological factors, as well as to generate the encroachment scenario and a 3d perspective for floodplain analysis. For geometric data, which is data to perform the spatial analysis, the HEC-GeoRAS software has been applied. HEC-GeoRAS software is an extension of Arc view GIS. In this section, a number of issues regarding to the generation of the river flood model has been elaborated, namely digital elevation model, geometric data input, hydrological data input, editing geometric data, and performing of the river flood model.

The detail DEM is required in this model; the DEM data on the study area was typically photogrammetry data. The DEM data formatted into the spot height with 100 m interval on the undulating and hilly area and 200 m interval on the lowland and coastal area. The DEM raster map has been created using point interpolation using the moving average method. Two types of the DEM structure for this research are regular grid on raster format and TIN in vector format.

The geometric data of Garang/West Floodway River have been used to generate model. Geometric data consist of Themes stream centerline, main channel banks, flow path centerlines, cross section cut lines, and polygon theme, which contains Manning's values. Crude hydrological data on Garang/West Floodway River have been used on the hydrological analysis. Annual average discharge observed at the Garang/ West Floodway River gauging has been used. The annual discharge on the Simongan Weir is 10.7 m^3/s, and the probable peak discharge for 100-year return period is 980 m^3/s. The water level on the normal condition is 0.6 m and 6.25 m on the river mouth and Simongan Weir respectively. The water level on the probable peak discharge 100-year return period is 0.6 m and 9.77 m measured at river mouth and Simongan Weir respectively. Those conditions have been applied to perform the hydrological analysis in HEC-RAS software. The geometric data have been edited. The editing consists of cross section and manning coefficient. Cross section extracted from DEM data has been corrected, particularly surrounding the river. Meanwhile, the manning editing has been done to make proper condition.

Steady flow analysis with the 5th encroachment method has been used to perform the flood spreading area. For the spatial visualization and analysis, the model result has to be converted to the RAS GIS form. The spatial pattern of the model has been displayed on the river flood map, and it is indicate that the flooded area mostly situated on the lower part (coastal and alluvial landform) and other flooded area situated on the upper part of the West Floodway River.

Tidal flood modelling; A raster based tidal flood model has been constructed in the ILWIS GIS environment in order to calculate the flooded area using a neighborhood operation. The neighborhood function for spatial data analyses enables the evaluation of the characteristics of a specific location and its surrounding area. The outcome of a calculation depends directly on the values of the neighboring pixels. These calculations make use of a small calculation window (e.g. 3x3 cells) that repeats a specified calculation on every pixel in the map, taking into account the values of its neighbors (ILWIS user guide 2001). The neighborhood function for tidal flood spreading calculation is an iterative procedure. Iteration is a successive repetition of a mathematical operation, using the result of one calculation as input for the next. The calculation stops when the difference of the output compared to the input is negligible, or if the number of iterations as defined before is reached (ILWIS user guide 2001). For the iteration operation, the value raster map is needed, i.e. surface elevation map. Every pixel on the map is representative of the surface elevation at that location.

The tidal flood on the study area is considered as a big environmental problem. Tidal flood extent to landward due to several reasons, namely 1) the land surface already situated lower than the high water tidal, 2) land subsidence phenomenon, 3) replacing the water parking area by the industrial and residential area. Based on the observation data by Tanjung Emas Harbor office, the highest water level was 155.43 cm or 1.55 m in November 2000.

The detail DEM is the important factor for the tidal model generation; the DEM with 2 decimal precisions and 5-meter pixel resolution have been used on this study. The DEM data have been manipulated with the additional value for non-flood area. Some areas known no flood occur, such as at harbor and airport. Therefore, the DEM value on those areas has been replaced with the manipulation value. The sea area should be not taking into account on the tidal flood model calculation, because the tidal flood occurs from the sea goes forward to the land. Therefore, the DEM data also has been manipulated with the coastline area in order to restrict during the iteration operation. The input map of iteration is called a start map and contains pixels which act as the starting point of the calculation. The iteration requires pixels source on start map, due to the tidal flood start spreading from the coastline, the start map has been located along the coastline.

Validation and evaluation of models, and flood hazard assessment; Accuracy and reliability calculations have been used to validate the models. The model results have been compared to reliable source maps. The river flood with 100-year return period has been obtained from the JICA (1993). The source map for the tidal flood has been obtained from Semarang Public Works Office (2001). In the evaluation of the river and tidal floods model is also discussed the advantages and the limitations of the respective approaches. The assessment of the flood hazards has been done using both models. The distribution of water depth and the impact of the flood hazards on landuse have been analysed. The landuse map has been extracted from the detailed landuse map, which has been created in 2001 based on the aerial photos scale 1: 10,000 by Public Works Office.

The confusion matrix concept has been applied in order to get the accuracy and reliability values. Confusion matrix has been obtained by crossing maps and generating table containing areas of different combination of classes. Accuracy is the fraction of correctly classified ground truth (or source map) pixels of a certain source class. For each class of source pixels, the number of correctly classified pixels is divided by the total number of source pixels in that class. Reliability is the fraction of correctly classified ground truth (or source map) pixels of a certain class in the model. For each class in the model class, the number of correctly classified pixels is divided by the total number of pixels which were classified as this class. Average accuracy for river flood model is 77% and for tidal flood model is 89%. Average reliability for river flood model is 76% and for tidal flood model is 83%.

Evaluation concerning of the generation of models have been done. Several factors influence on the generation of the river flood models, namely; the detail cross-sections, path of the river, riverbank delineation, floodplain delineation, and tributaries delineation. The hydrological data are also important, not only about the peak discharge and average discharge data, but also sedimentation data, slope gradient, manning coefficient, and the hydraulic condition of the river, such as the weir location, bridge location, and the channel condition.

Flood hazard assessment on the study area is concerning about the calculation of the water depth of models and the impact of the floods to the landuse. The total of river flood area is 1245, 78 Hectare. The total of tidal flood area is 1514 Hectare. The landuse influenced by the river flood are build up area, fish pond, agriculture and others with the area affected is 510,57; 164,12; 1,34; and 711,68 hectare respectively. The landuse influenced by the tidal flood are build up area, fish pond, agriculture and others with the area affected is 814,56; 2,26; 231,94; and 461,86 respectively.

Recommendations; Integrated hazard assessment is regarded as a necessary input to the development of a management and spatial planning strategy for the City of Semarang. This would involve not only an assessment as the present-one. But it would also include aspects of vulnerability and risk assessment. Local planning authorities (Bappeda) would benefit from such an integrated approach in which a prototype of a spatial planning support system would be developed. Such a SPSS would be capable of weighing different measures and strategies to adapt to and mitigate the relevant coastal hazards, such as land subsidence, flooding, sea level rise, and groundwater abstraction.

In this study, river and tidal floods have been treated separately. The combined effect of the two floods has an even larger impact on the city and it’s population than follows from the present hazard assessment. Therefore, it is recommended for future research to develop an integrated model capable of dealing with both types of floods in an integrated way. It is, however, realized that such a dynamic modeling approach also involves intensive fieldwork on hydrological data collection.

Ringkasan (Indonesian summary)

<u>Latar belakang dan tujuan;</u> Semarang merupakan *water front city* yang terletak di Popinsi Jawa Tengah, Indonesia. Banjir sungai dan banjir rob merupakan fenomena yang sering terjadi. Data dan informasi tentang distribusi spasial, besaran dan kedalaman banjir serta pengaruh banjir terhadap penggunaan lahan sangat diperlukan oleh perencana dan pemerintah daerah Kota Semarang. Penelitian dengan menggunakan integrasi Sistem Informasi Geografis (SIG) dan model hidrologi merupakan kajian yang sedang berkembang, dan penelitian ini merupakan salah satu aplikasinya. Tujuan dari penelitian ini adalah; 1) untuk membangun model banjir sungai dengan menggunakan SIG, 2) untuk membangun model banjir rob dengan menggunakan SIG, 3) untuk melakukan validasi, dan evaluasi terhadap kedua model, dan melakukan penilaian terhadap bahaya banjir sungai dan rob.

<u>Metodologi;</u> Beberapa metode yang berbeda diterapkan untuk mencapai setiap tujuan dari penelitian ini. Software hidrologi diterapkan bersama dengan metode SIG untuk membangun model banjir sungai. Operasi "*neighborhood*" dilakukan dengan menggunakan data raster untuk membangun model banjir rob. Untuk validasi model, digunakan *confusion matrix* dari operasi *crossing map*. Penilaian bahaya banjir dilakukan dengan menggunakan *map calculations* dan *table operations* dalam software ILWIS untuk menggambarkan dan menghitung kedalaman air serta dampak banjir terhadap penggunaan lahan.

Metodologi dalam penelitian ini meliputi 5 tahap, yaitu; 1) Persiapan, 2) kerja lapangan dan pencarian data, 3) Pembuatan model, 4) Validasi, evaluasi dan penilaian bahaya banjir, dan 5) Penulisan laporan. Tahap persiapan meliputi studi literatur yang berhubungan dengan topic penelitian, pengumpulan data sekunder, dan persiapan kerja lapangan. Tahap kerja lapangan dan pengumpulan data meliputi pengumpulan data hidrologi dan data spasial, antara lain model medan digital (DEM), peta topografi, peta penggunaan lahan, peta banjir sungai, peta banjir rob, debit sungai, kekasaran koefisien (Manning), penampang melintang sungai (*cross-sections*), dan system drainase. Semua data tersebut digunakan untuk membangun model, evaluasi, validasi, dan penilaian bahaya banjir, serta untuk deskripsi kondisi lingkungan fisik dan karakteristik bentang

lahan di daerah penelitian. Tahap pemodelan meliputi pembangunan dan proses pembuatan dua tipe model dengan menggunakan software hidrologi dan SIG, yaitu model banjir sungai dan model banjir rob. Model banjir sungai dibangun dari integrasi software HEC-RAS untuk analisis hidrologi, HEC-GeoRAS dan Arc View untuk pembuatan data geometri dan pemaparan hasil model dalam format spasial. Model banjir rob dibangun dengan menggunakan iterasi atau fungsi "*neighborhood*" dalam software ILWIS. Tahap validasi, evaluasi, dan penilaian bahaya meliputi validasi kedua model dengan menggunakan *confusion matrix*. *Confusion matrix* dilakukan antara peta sumber yang dapat dipercaya dengan peta hasil model untuk memperoleh nilai akurasi dan reliabilitas. Evaluasi terhadap model dilakukan untuk mengetahui kelebihan dan kekurangan dari kedua model yang telah dibuat. Penilaian bahaya dilakukan dengan menggunakan *map calculations* dan *table operations* untuk menganalisis dampak banjir terhadap penggunaan lahan. Tahap terakhir adalah penulisan laporan dari semua aktivitas dan hasil penelitian.

Lingkungan fisik dan karakteristik bentang lahan; Semarang adalah ibukota propinsi Jawa Tengah dan merupakan salah kota pelabuhan laut di Jawa Tengah. Daerah ini terletak di pantai utara Jawa yang berjarak 540 Km ke arah timur dari Jakarta. Semarang terletak pada garis $6^0$56'08" - $7^0$06'57" lintang selatan dan garis 110^0 16' 17" - 110^0 30'31" bujur timur. Kota Semarang mempunyai luas areal sebesar lebih kurang 400 Km^2 dengan aktivitas utama sebagai daerah industri, perdagangan, pendidikan dan turis. Posisi geografis Semarang menjadikan Semarang merupakan kota strategis yang berpengaruh terhadap pembangunan regional terutama untuk Jawa Tengah.

Temperatur minimum di Kota Semarang berkisar 18^0C dan temperatur maksimum berkisar 35^0C. Kelembaban minimum adalah 62% dan kelembaban maksimum adalah 84%. Intensitas hujan di Daerah Aliran Sungai Garang/ Sungai Banjir Kanal Barat diukur dari beberapa stasiun pengukur hujan, dengan minimum intensitas hujan terjadi pada Bulan Agustus sebesar 34 mm di Staisun Pagersari dan maksimum pada Bulan Januari sebesar 627 mm di Stasiun Limbangan. Formasi geologi di daerah Semarang dan sekitarnya terdiri dari Alluvial sedimen, Formasi Damar, breksi vulkanik, dan sedimen pantai. Kondisi geomorfologi di daerah penelitian secara umum dapat dibagi menjadi tiga katagori, yaitu bentuklahan fluvial, bentuk lahan struktural-denudasional, dan bentuk lahan vulkanik. Tipe tanah di daerah penelitian terdiri dari Alluvial, Regosol, Yellowish Red Mediterran-Grumusol, dan Latosol-Andosol.

Berbagai potensi bencana yang terdapat di Kota Semarang adalah banjir sungai, banjir rob, tanah longsor, dan *land subsidence*. Banjir sungai terjadi disebabkan intensitas hujan yang tinggi dibarengi dengan sistem drainase yang kurang memadai. Banjir rob terjadi disebabkan air pasang yang melampaui daerah pantai. Sebagian daerah perbukitan Kota Semarang merupakan daerah yang rawan terhadap bahaya longsor, yang meliputi dua tipe longsor, yaitu kerawanan terhadap proses longosoran dan daerah patahan aktif. Sementara itu, *land subsidence* merupakan masalah bahaya alam yang semakin besar di Kota Semarang. Perkembangan *land subsidence* di Kota Semarang sangat bervariasi dengan rata-rata 11.5 cm/yr dan bahkan lebih sampai dengan 0.2 m/yr.

Model banjir sungai; Pendekatan terintegrasi dengan menggunakan software modelling hidrologi dan software SIG dilakukan untuk membangun model banjir sungai. Software HEC-RAS digunakan untuk menampilkan, melakukan perhitungan dan analisis faktor-faktor hidrologi dan juga untuk membangun skenario pelimpahan (*encroachment*) dan prespektif 3 dimensi untuk analisis dataran banjir. Untuk data geometri, yaitu data untuk menampilkan analisis spasial, digunakan software HEC-GeoRAS. Di bagian ini dibahas tentang pembangunan model banjir sungai yang meliputi pembuatan DEM, input data geometri, input data hidrologi, edit data geometri, dan penampilan model banjir sungai.

DEM detil diperlukan untuk membangun model banjir sungai; data DEM yang digunakan untuk penelitian ini merupakan jenis DEM fotogrametri. Data DEM dalam format spot ketinggian (*spot height*) dengan interval 100 m di daerah yang bergelombang dan daerah perbukitan, serta interval 200 m untuk dataran rendah dan daerah pantai. Peta raster DEM dibuat dengan menggunakan interpolasi titik-titik ketinggian menggunakan metode *moving average*. Penelitian ini menggunakan dua macam struktur DEM, yaitu format raster dan format vektor (TIN).

Data geometri untuk model banjir sungai merupakan geometri Sungai Garang/Banjir Kanal Barat. Data geometri meliputi; *stream centerline*, *main channel banks*, *flow path centerlines*, *cross section cut lines*, dan *polygon theme* sebagai representasi dari nilai

Manning. Analisis hidrologi menggunakan data hidrologi daerah Sungai Garang/Banjir Kanal Barat. Debit rata-rata tahunan dari hasil pengamatan di Sungai Garang/Banjir Kanal Barat digunakan untuk pembuatan model banjir sungai. Berbagai data hidrologi digunakan dalam pembuatan model ini sebagai persyaratan input data dari software HEC-RAS. Berbagai data tersebut meliputi; debit sungai dalam kondisi normal dan dalam kondisi periode ualng banjir 100 tahunan, ketinggian muka air dalam kondisi normal dan kondisi banjir dengan periode ulang 100 tahunan yang terukur di muara sungai dan Bendung Simongan. Debit tahunan di Bendung Simongan sebesar 10.7 m^3/s, dan debit puncak untuk periode ulang 100 tahun sebesar 980 m^3/s. Ketinggian muka air pada kondisi normal yaitu sebesar 0.6 m di bagian hilir atau muara sungai dan 6.25 m di Bendung Simongan. Ketinggian muka air pada kondisi banjir dengan periode ualng 100 tahunan di muara sungai terukur sebesar 0.6 m dan di Bendung Simongan terukur sebesar 9.77 m. Koreksi data geometri perlu dilakukan yang meliputi data *cross-sections* dan koefisien kekasaran (Manning). Data *cross-sections* diperoleh dari DEM yang telah dikoreksi, sementara koefeisien Manning diedit untuk menyesuaikan kondisi nyata di lapangan.

Analisis *Steady flow* dilakukan dengan menggunakan metode *encroachment* dalam software HEC-RAS untuk memperoleh luasan genangan banjir. Untuk visualisasi dan analisis secara spasial hasil model yang diperoleh di konversikan ke format RAS-GIS dalam bentuk peta banjir sungai. Dari peta yang diperoleh terlihat bahwa sebagian besar banjir terdapat di daerah pantai dan bentuk lahan alluvial, serta sebagian kecil di daerah atas dari Sungai Banjir Kanal Barat.

Model banjir rob; Model banjir rob dibuat dengan berdasarkan raster format dalam SIG. Dalam hal ini software ILWIS digunakan untuk melakukan operasi *neighbourhood.* Fungsi *neighbourhood* dalam analisis data spasial adalah untuk melakukan evaluasi terhadap daerah-daerah tertentu yang diinginkan dalam format data raster. Hasil akhir dari perhitungan dengan menggunakan *neighbourhood* sangat tergantung dari nilai-nilai piksel di sekitarnya. Perhitungan-perhitungan dalam *neighbourhood* menggunakan *small calculation window* (misal; sel 3x3) dengan pengulangan perhitungan-perhitungan tertentu dalam setiap piksel di dalam peta raster. Dengan mempertimbangkan nilai-nilai disekitarnya. (ILWIS user guide 2001). Fungsi *neighbourhood* yang digunakan untuk membuat model banjir rob adalah prosedur iterasi. Iterasi adalah operasi matematika secara pengulangan dan berturut-turut dengan menggunakan hasil perhitungan sebelumnya sebagai input untuk perhitungan selanjutnya. Perhitungan berhenti jika perbedaan antara hasil perhitungan dan input hampir sama, atau tidak mempunyai pengaruh untuk perhitungan selanjutnya. Perhitungan iterasi juga dapat berhenti sesuai dengan jumlah iterasi yang diinginkan. (ILWIS user guide 2001). Operasi iterasi membutuhkan peta raster yang mempunyai *domain value*, sebagai contoh adalah peta ketinggian. Dalam peta ketinggian setiap piksel dalam peta mewakili nilai ketinggian dari lokasi yang bersangkutan.

Banjir rob di daerah penelitian merupakan salah satu masalah besar dalam bidang lingkungan. Banjir rob melampau dan meluas ke daratan disebabkan oleh beberapa faktor, yaitu; 1) daerah daratan sudah terletak lebih rendah dari air pasang laut, 2) adanya fenomena *land subsidence*, 3) Perubahan daerah kantong banjir menjadi daerah industri dan perumahan. Berdasarkan pengamatan yang dilakukan oleh kantor pelabuhan Tanjung Emas, pasang tertinggi adalah 155.43 cm atau 1.55 m terjadi pada Bulan November 2000.

Pembuatan model banjir rob memerlukan data detil DEM. Dalam penelitian ini digunakan DEM dengan presisi 2 desimal dan ukuran resolusi piksel 5 meter. Untuk daerah yang seharusnya tidak terkena banjir, seperti pelabuhan dan bandara, maka dilakukan manipulasi nilai DEM untuk daerah-daerah tersebut. Areal lautan dalam peta DEM tidak diperhitungkan dalam perhitungan iterasi, karena banjir rob melanda dari sepanjang garis pantai ke arah dataran. Untuk itu diperlukan pembatasan terhadap daerah lautan dengan melakukan modifikasi data DEM. Peta input untuk melakukan iterasi diperlukan, dalam hal ini disebut *start map*. *Start map* merupakan peta dengan *domain value*, dalam hal ini *start map* merupakan pixel-pixel yang terletak sepanjang garis pantai. Berdasarkan nilai-nilai pixel tersebut iterasi dilakukan.

Validasi dan evaluasi model, serta penilaian bahaya banjir; Validasi diperoleh dengan melakukan perhitungan akurasi dan reliabilitas. Peta-peta model dibandingkan dengan peta-peta acuan dari sumber yang dapat dipercaya untuk memperoleh akurasi dan reliabilitas dari model yang telah dibuat. Peta acuan dari sumber yang dapat dipercaya untuk banjir sungai dengan periode ulang 100 tahunan diperoleh dari JICA (1993), dan untuk peta banjir rob diperoleh dari kantor Pekerjaan Umum Semarang (2001). Dalam evaluasi model didiskusikan tentang keunggulan dan kelemahan dari metode yang digunakan. Penilaian bahaya banjir dilakukan dengan menggunakan peta-peta hasil model, yang meliputi perhitungan persebaran kedalaman banjir dan analisa dampak banjir terhadap penggunaan lahan. Peta penggunaan lahan yang digunakan diperoleh dari foto udara skala 1:10.000 dari kantor Dinas Pekerjaan Umum.

Perhitungan akurasi dan reliabilitas dilakukan dengan menggunakan konsep *confusion matrix*. *Confusion matrix* diperoleh dari metode *crossing maps* dan *generating table* yang meliputi daerah dengan kombinasi kelas yang berbeda-beda. Akurasi dalam hal ini diartikan sebagai bagian-bagian yang diklasifikasikan benar terhadap piksel-piksel acuan (*ground truth* /peta acuan) dari kelas tertentu dalam peta acuan. Jumlah piksel yang diklasifikasikan benar dibagi dengan jumlah total piksel dari peta acuan dalam kelas yang sama. Reliabilitas dalam hal ini diartikan sebagai bagian yang diklasifikasikan benar dari piksel-piksel acuan (*ground truth*/peta acuan) dalam kelas tertentu dari peta model. Jumlah piksel yang diklasifikasikan benar dibagi dengan total piksel dalam kelas yang bersangkutan dalam peta model. Rata-rata akurasi dari model banjir sungai adalah sebesar 77% dan model banjir rob sebesar 89%. Rata-rata reliabilitas dari model banjir sungai adalah 76% dan banjir rob sebesar 83%.

Evaluasi dilakukan terhadap kedua model yang telah diperoleh. Beberapa hal yang berpengaruh dalam pembuatan model banjir sungai adalah; detil *cross-sections, path of the river, riverbank delineation, floodplain delineation*, dan *tributaries delineation*. Detil data hidrologi juga penting, tidak hanya tentang debit puncak dan rata-rata debit, melainkan juga data sedimentasi, kemiringan lereng, koefisien Manning, dan kondisi hidrolik sungai seperti letak bendung, letak jembatan, dan kondisi saluran. Banjir rob dibuat dengan menggunakan operasi iterasi, dalam hal ini air pasang laut diukur dalam centimeter, sehingga data DEM yang detil dibutuhkan, dan keakuratan hasil model sangat tergantung terhadap kedetilan data tersebut.

Penilaian bahaya banjir dilakukan dengan mengadakan perhitungan kedalaman banjir dan analisa dampak banjir terhadap penggunaan lahan. Total areal yang terkena banjir sungai adalah sebesar 1245, 78 Hectare. Total areal yang terkena banjir rob adalah sebesar 1514 Hectare. Penggunaan lahan yang terkena dampak banjir sungai meliputi daerah terbangun, tambak, pertanian, dan penggunaan lahan lainnya, yang masing-masing secara berturut-turut sebesar 510,57; 164,12; 1,34; dan 711,68 hectare. Penggunaan lahan yang terkena dampak banjir rob meliputi daerah terbangun, tambak, pertanian, dan penggunaan lahan lainnya, yang masing-masing secara berturut-turut sebesar 814,56; 2,26; 231,94; dan 461,86.

Recomendasi; Penilaian bahaya alam secara terintegrasi merupakan masukan penting untuk strategi pengelolaan, pengembangan dan perencanaan keruangan Kota Semarang. Dengan demikian tidak hanya penilaian bahaya seperti yang telah dilakukan, akan tetapi juga melibatkan aspek *vulnerability* dan penilaian resiko (*risk*). Dengan menggunakan pendekatan terintegrasi, seperti *spatial planning support system* (SPSS) akan memberikan keuntungan kepada badan perencana pembangun di daerah (Bappeda), karena pendekatan SPSS dapat digunakan untuk melakukan perencanaan mitigasi dan analisis terhadap bencana di daerah pantai seperti *land subsidence*, banjir, *sea level rise*, dan eksploitasi air tanah.

Di dalam penelitian ini analisa terhadap bahaya banjir sungai dan banjir rob dilakukan secara terpisah. Bahaya banjir sungai dan rob yang terjadi secara bersamaan dapat menimbulkan akibat yang lebih besar terhadap Kota Semarang dan penduduk di dalamnya, Sehingga penelitian berupa pengembangan model terintegrasi dari banjir sungai dan banjir rob dapat dilakukan untuk masa yang akan datang, dengan pendekatan model dinamik dan kerja lapangan dan data detil hidrologi.

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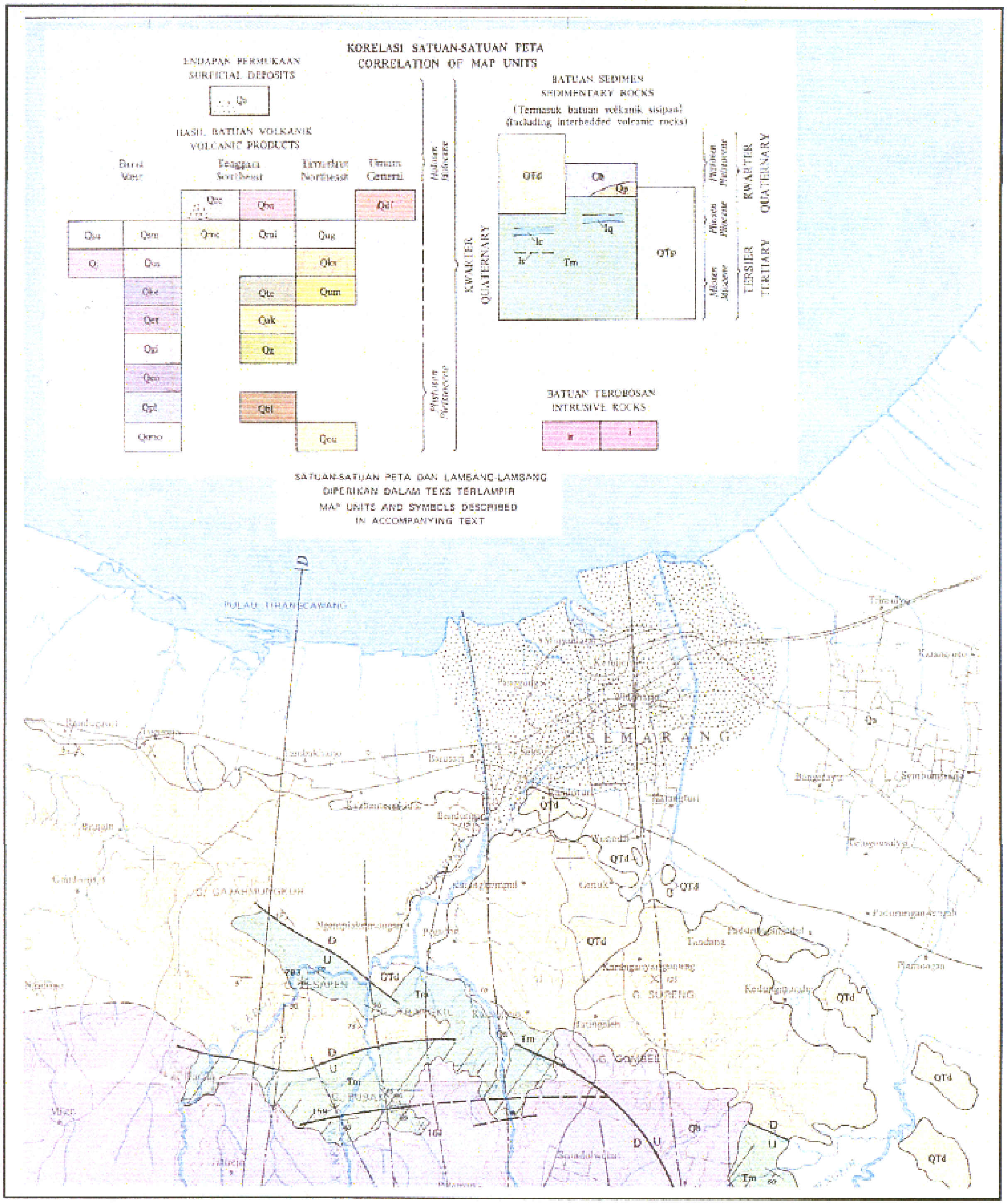
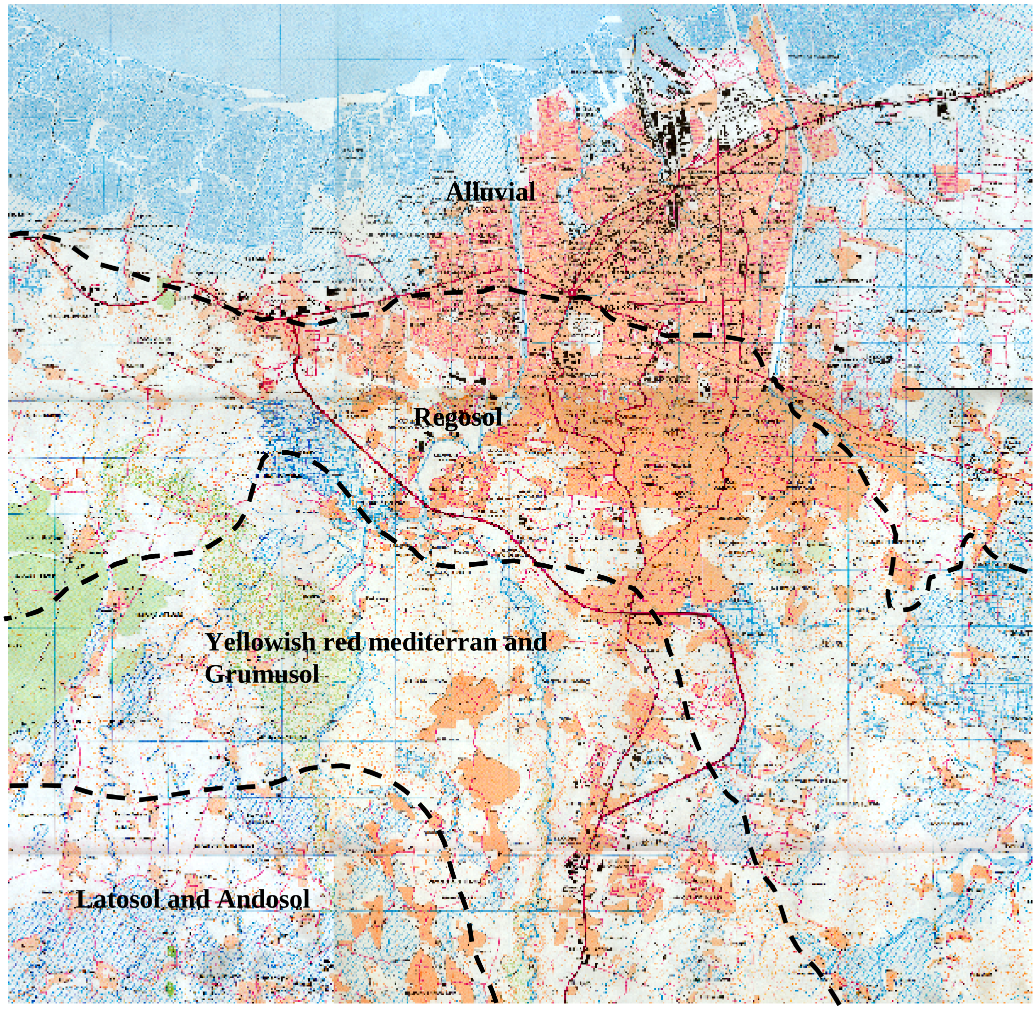
Appendix

Appendix I. Geological Map of Semarang



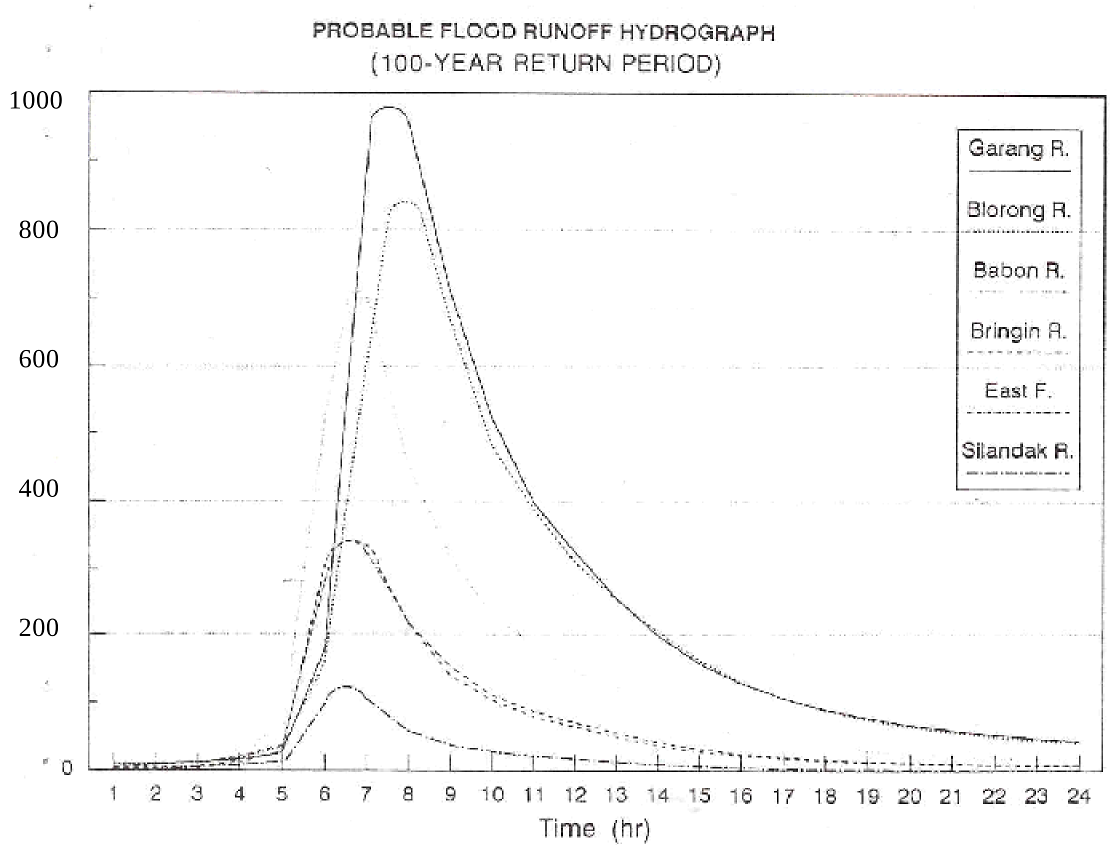
Source: Thaden, et al (1975) after Sutanta (2002)

Appendix II Soil Map of Semarang

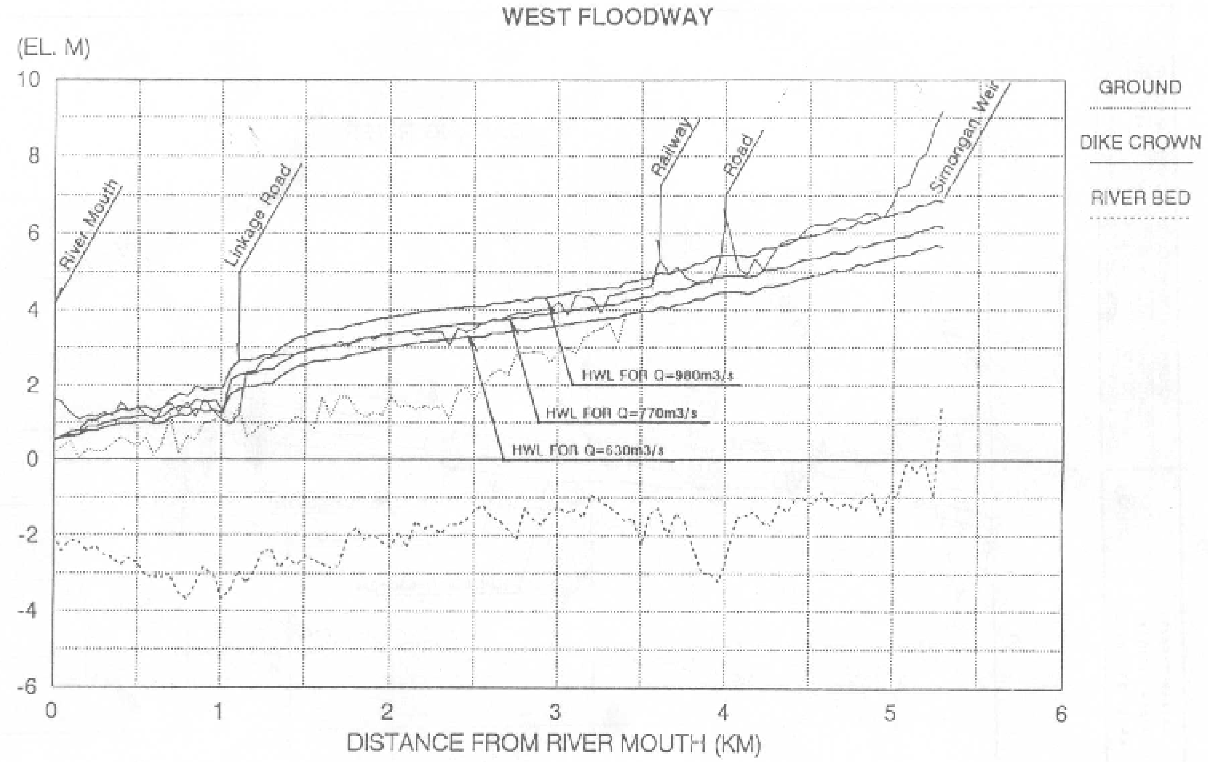


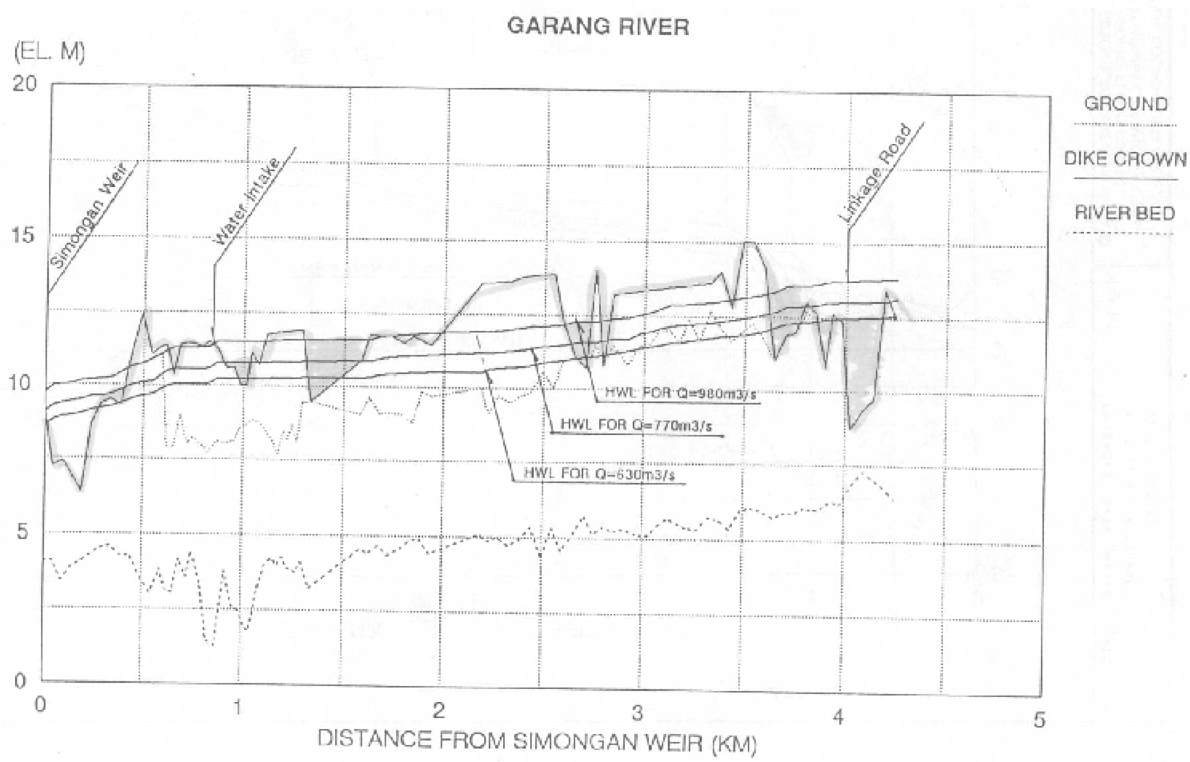
Source: Balai Penyelidikan Tanah in Public Work Office Project 2000 (Semarang Urban Drainage Master Plan)

Appendix III Probable peak discharge of the 100 year return period



Appendix IV. Cross-section Profile of Garang/West Floodway River





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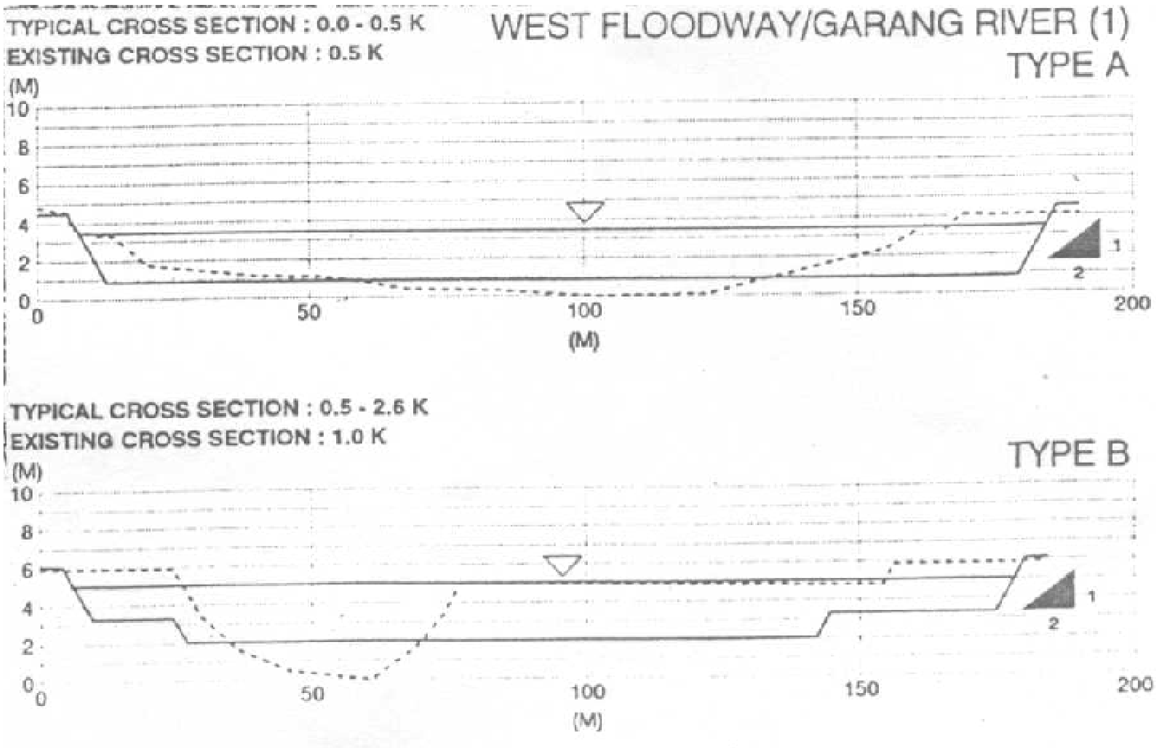
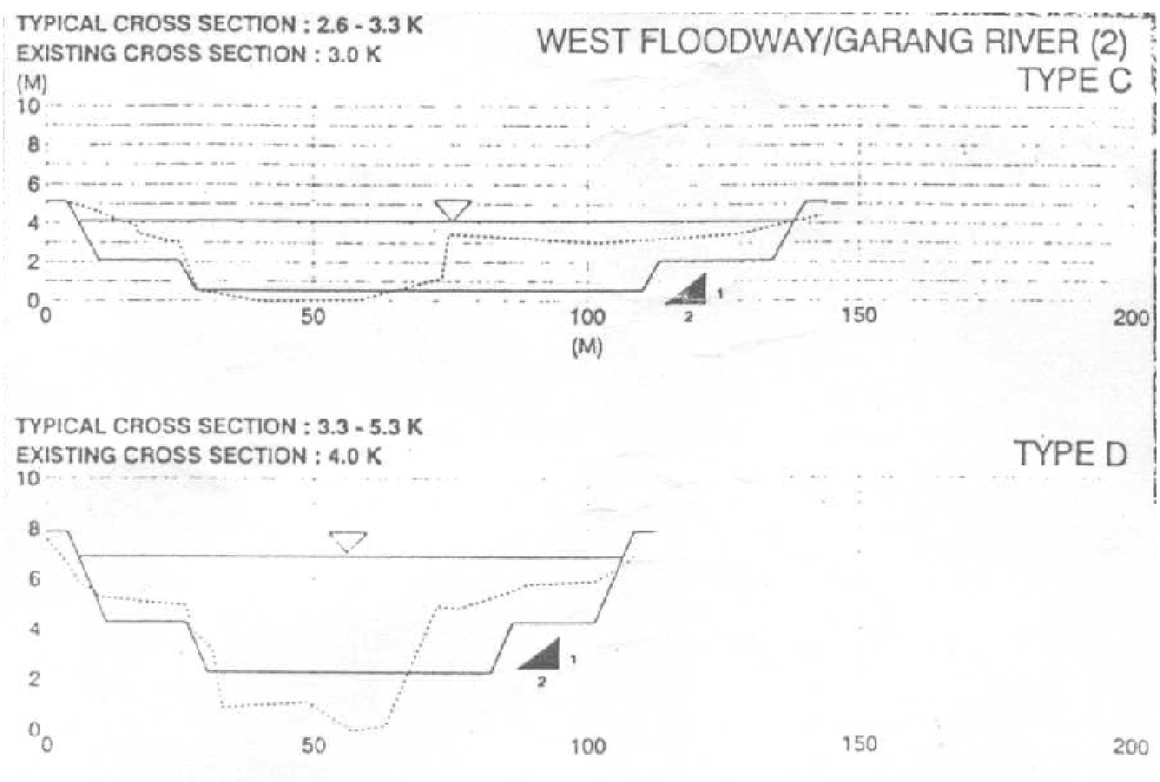
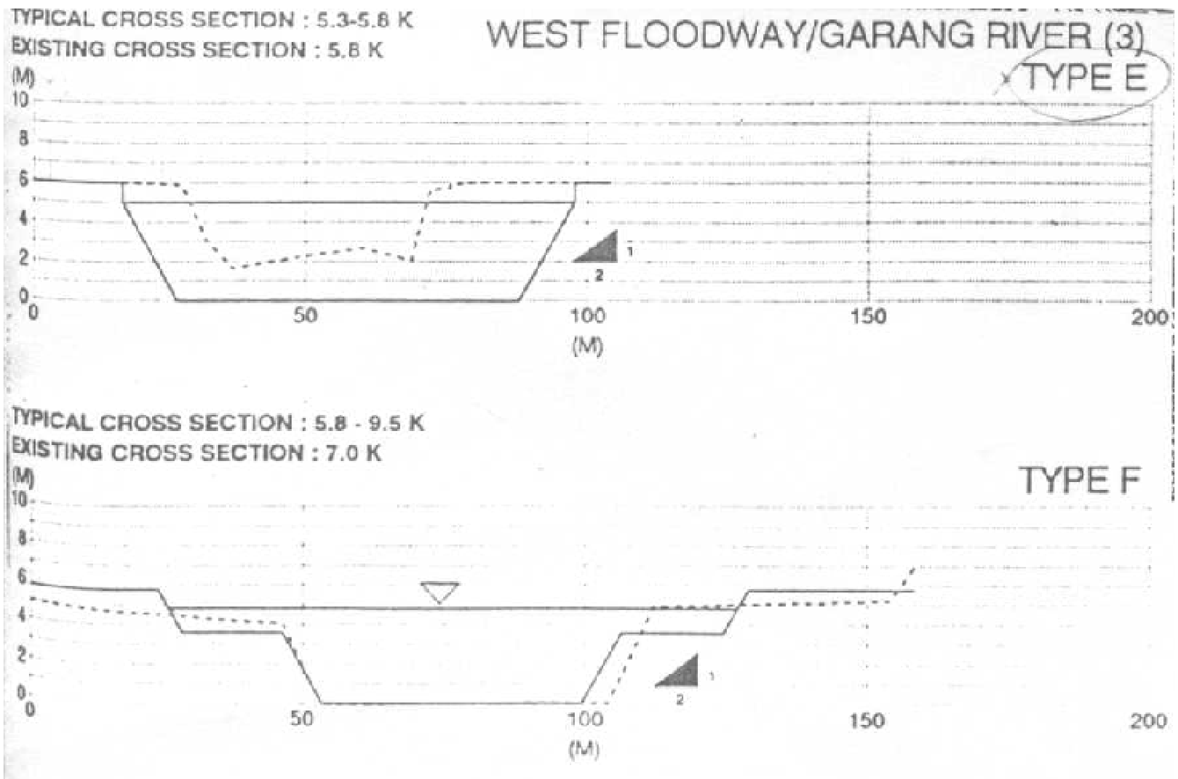


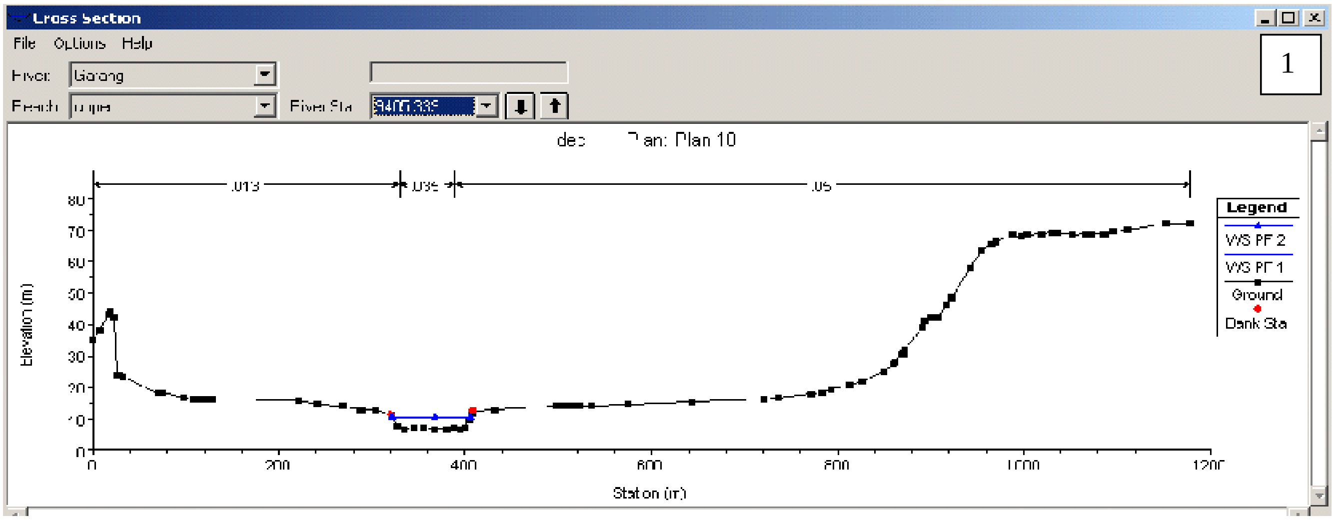


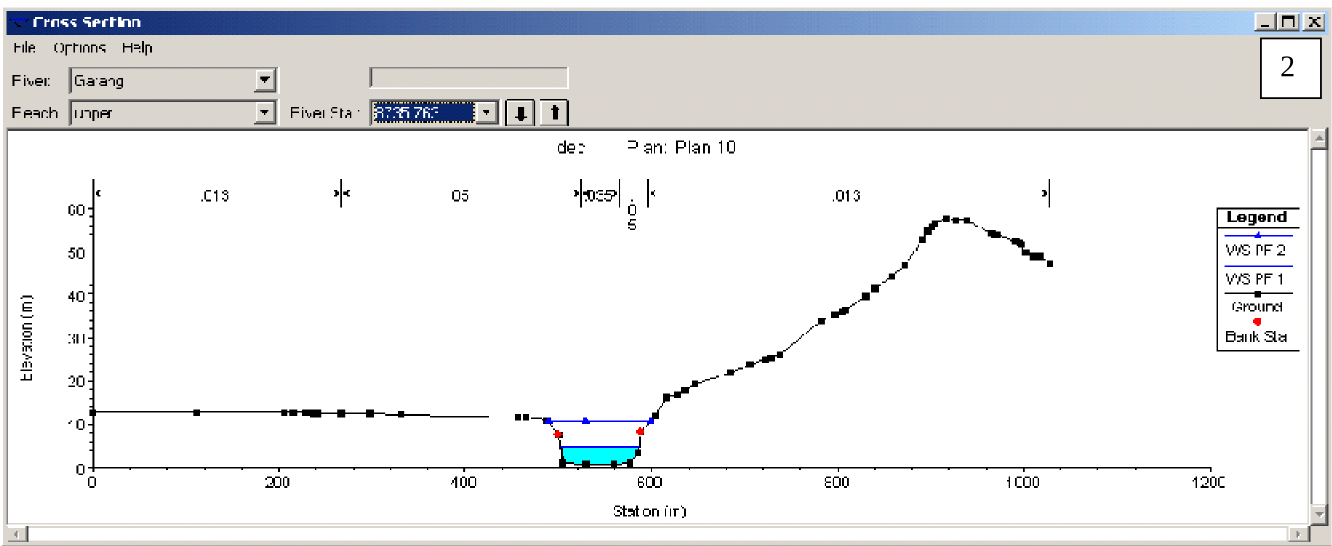
Appendix IV. Cross-section Profile of Garang/West Floodway River

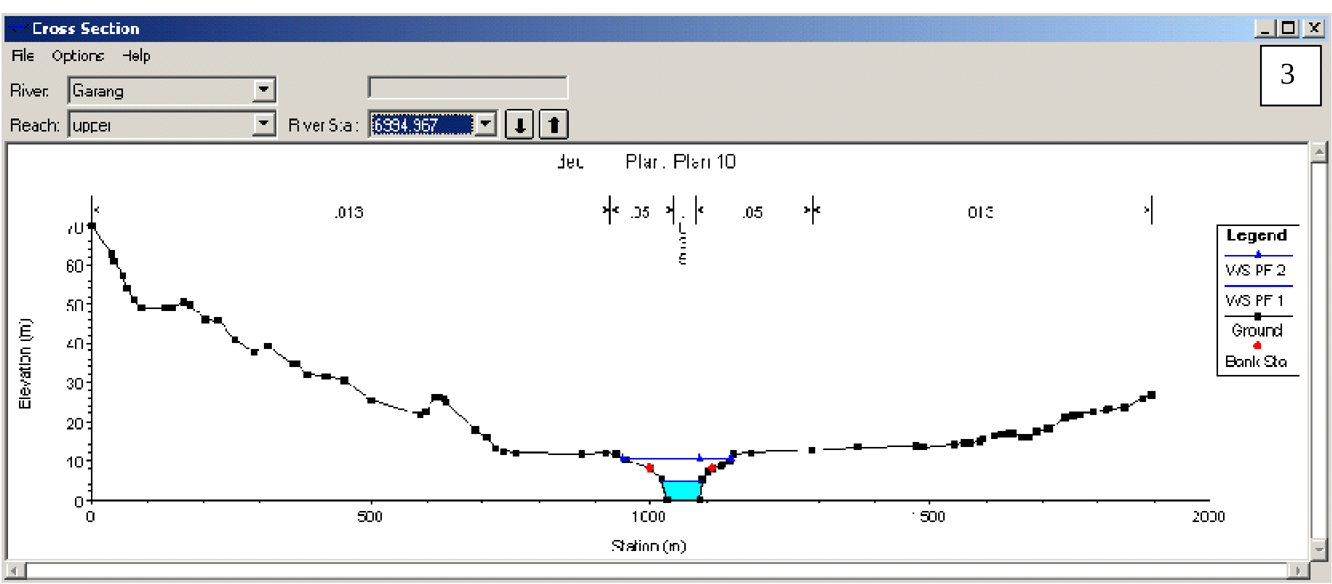


Source: JICA Project (1993)

Appendix V. Cross-sections geometric data from HEC-RAS (Upstream-Downstream)







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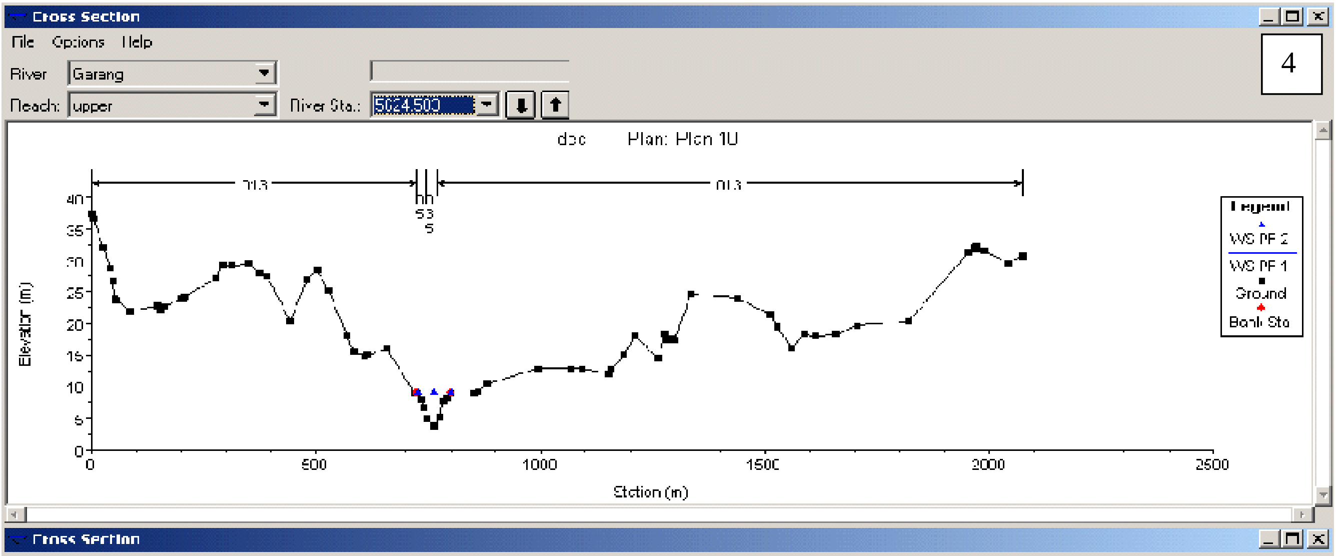
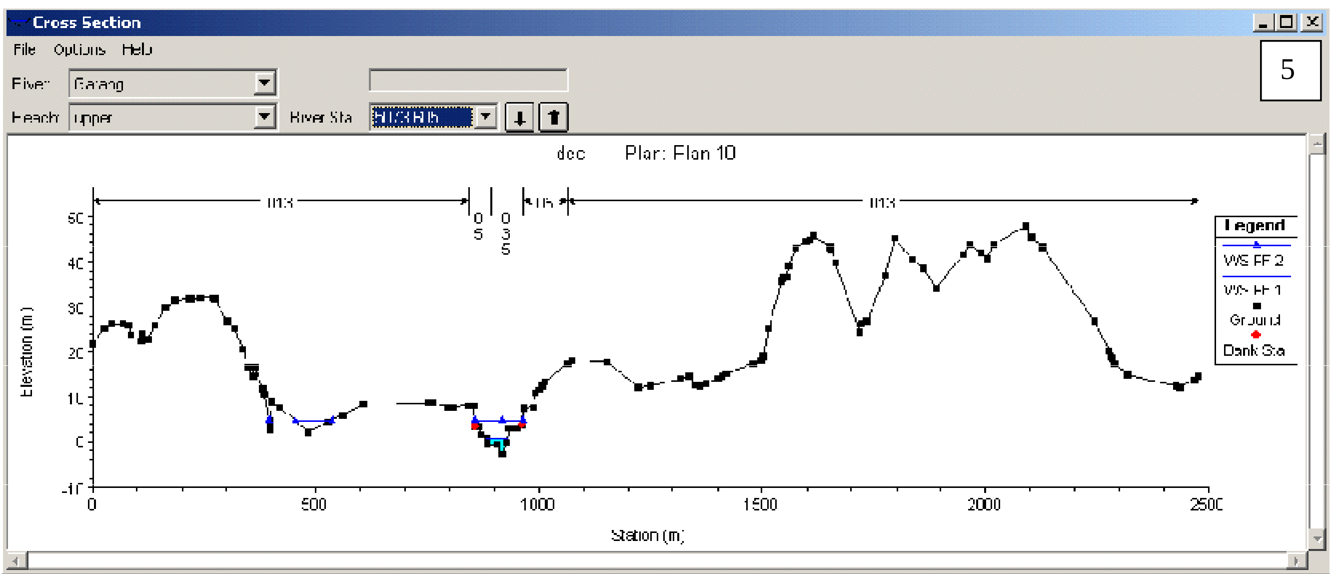
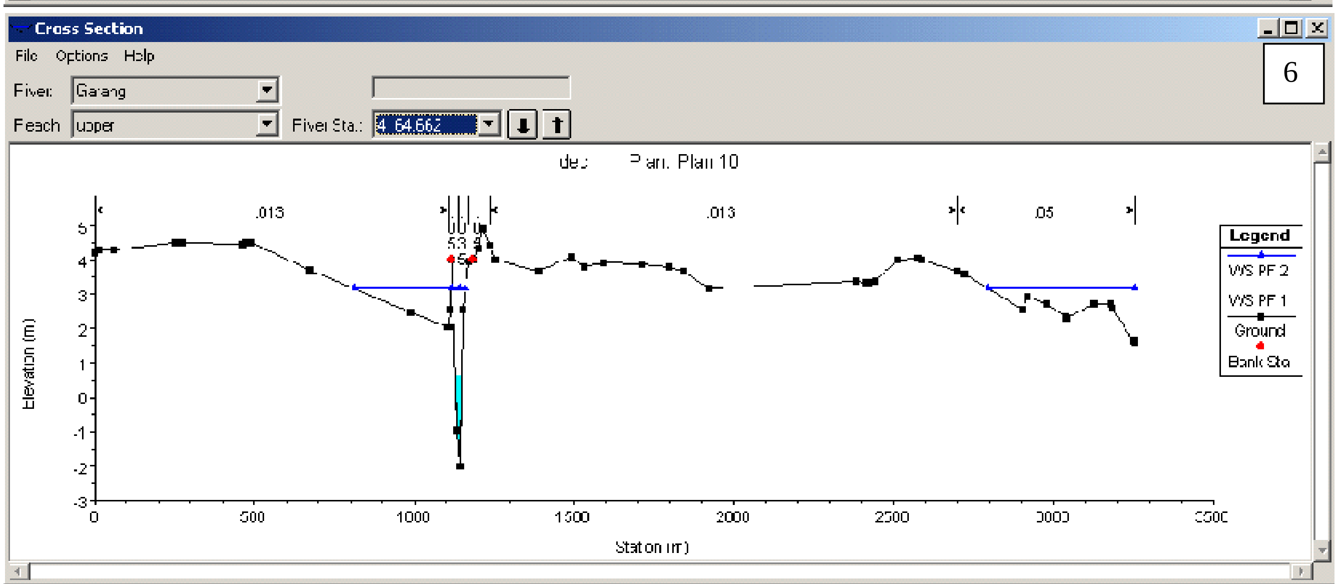
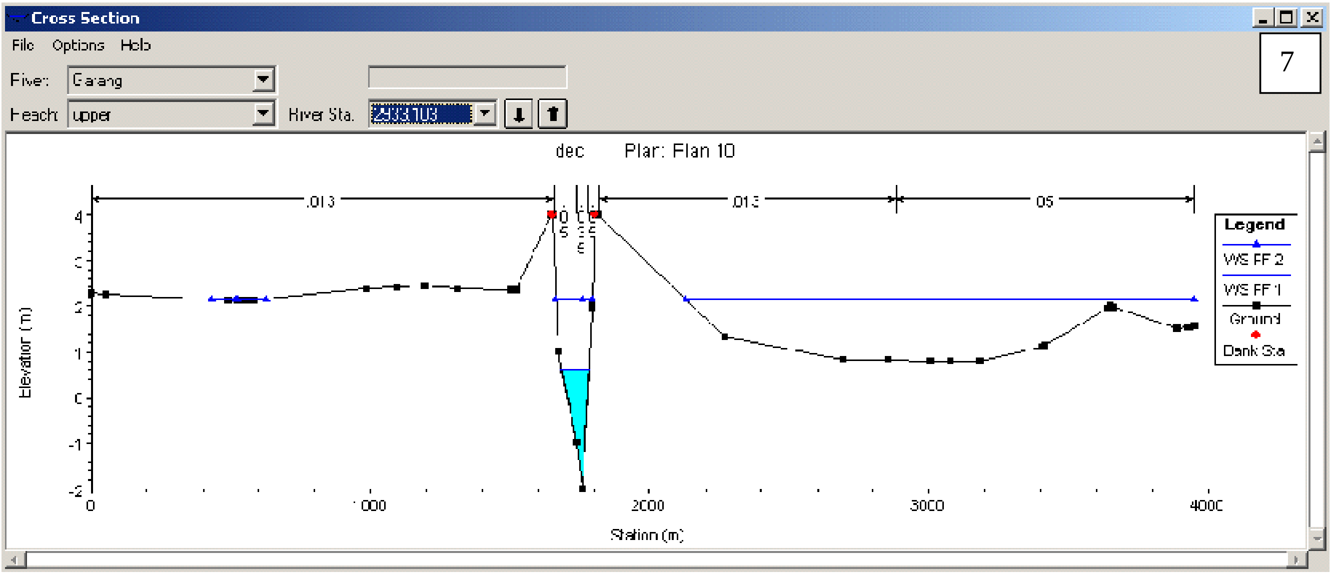
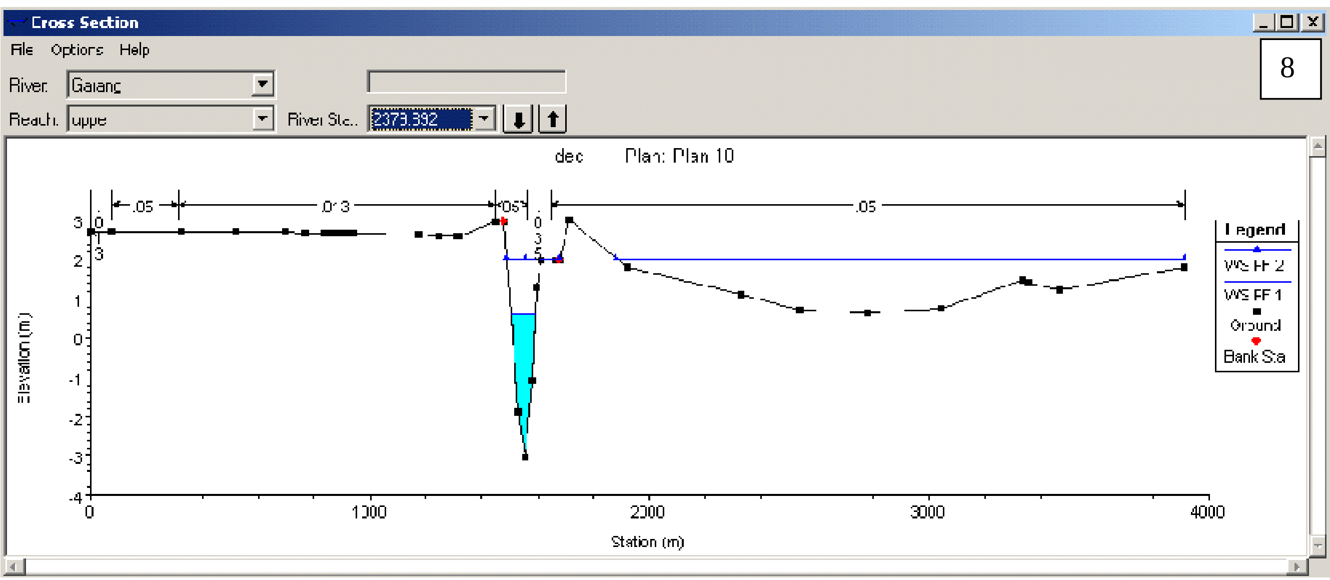


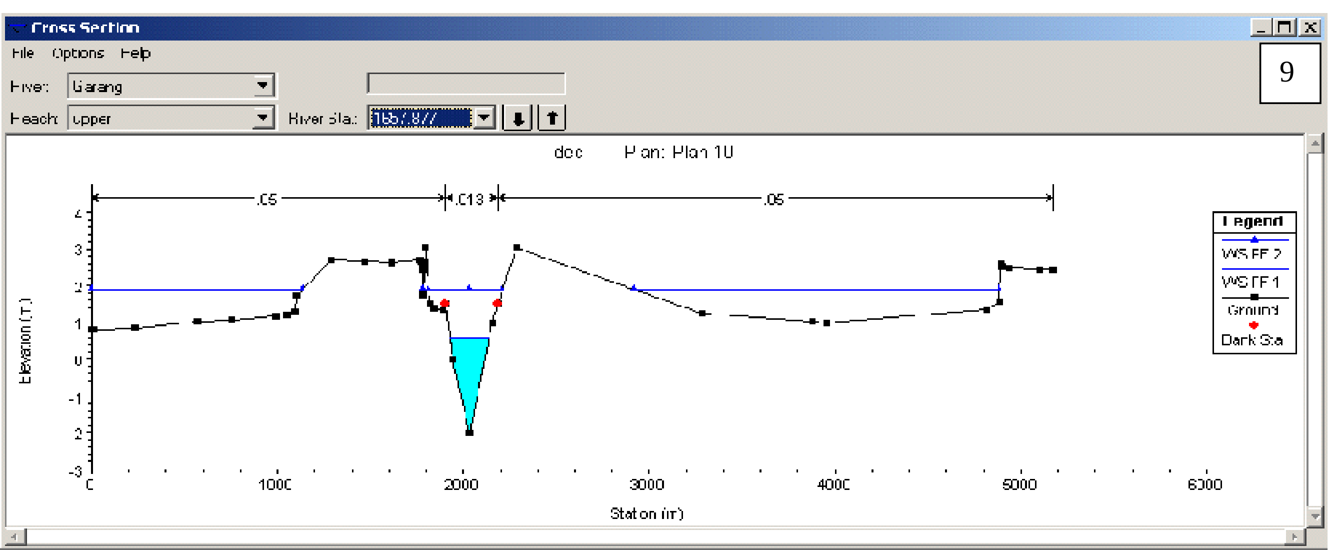




Appendix V. Cross-sections geometric data from HEC-RAS (Upstream-Downstream)







Appendix V. Cross-sections geometric data from HEC-RAS (Upstream-Downstream)